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

BULLETIN 130

GEOLOGY OF THE BOWEN BASIN, QUEENSLAND

J. M. DICKINS AND E. J. MALONE

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA 1973

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS
Director: N.H. Fisher

ASSISTANT DIRECTOR GEOLOGICAL BRANCH: J. N. CASEY

Published for the Minister for Minerals & Energy, the Hon. R.F.X. Connor, M.P., by the Australian Government Publishing Service

ISBN 0 642 00228 2

Manuscript received: April 1970
Issued: April 1973

Printed by Waite & Bull Pty. Ltd., Sydney

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SUMMARY

The Bowen Basin, comprising essentially Permian and Triassic rocks, is situated in central and southern Queensland and beneath the surface of the Great Artesian Basin, is possibly continuous with the Sydney Basin. This Bulletin is concerned mainly with the northern exposed part of the basin, its eastern, northern, and western margins, and the eastern extension of the Great Artesian Basin, the Surat Basin, which covers the southern part of the Bowen Basin.

Lower Palaeozoic rocks are found along the western margin and possibly along the eastern margin. The Anakie Metamorphics in the west comprise schist and gneiss with widespread quartz veins and reefs. An isotopic age of 450 m.y. has been determined. Granite associated with the metamorphics in the Telemon Anticline has been found to have a similar age. The metamorphics near Marlborough have been assigned a Lower Palaeozoic age because of their degree of alteration and the Mount Windsor Volcanics in the northwestern corner of the map area are also regarded as Lower Palaeozoic.

In the east, Lower Silurian to Middle Devonian rocks are found south of Marlborough, and in the west they consist of the Ukalunda Beds, Dunstable Volcanics, and Douglas Creek Limestone. Basic to intermediate volcanics, chert, and limestone are prominent. Corals are important in the rather meagre marine faunas and some reefs may have been formed around volcanic islands or submarine mountains. The beds are separated by an angular discordance from the Lower Palaeozoic rocks.

In Devonian to Carboniferous times, sediments were deposited in three large basins: the Drummond Basin, a basin in which the Mount Rankin Beds (with the Mount Wyatt Beds at the base) were laid down, and the Yarrol Basin. Outside these basins the Theresa Creek Volcanics were deposited on the Anakie Inlier. The Campwyn Beds were formed in what may be the northern extension of the Yarrol Basin, and the Connors Volcanics west of the Yarrol Basin. The Camboon Andesite as mapped appears to contain equivalents of the Connors Volcanics. Volcanics and sediments are found in all areas, but marine conditions have been identified only in the Mount Wyatt Beds and in the Yarrol Basin and its possible extension occupied by the Campwyn Beds.

In Upper Carboniferous to Permian times the Bulgonunna Volcanics, Joe Joe Formation, and Torsdale Beds were deposited in widely separated areas around the margin of the Bowen Basin. The Bulgonunna Volcanics are terrestrial and predominantly acid. They are intruded by granite with an isotopic age of 285 m.y. The granite is overlain by the Lizzie Creek Volcanics (previously called the Lower Bowen Volcanics) which contain a *Glossopteris* flora and near the top a marine fauna (Fauna 1 of Dickins, *in* Malone, Corbett, & Jensen, 1964) which is not older than late Sakmarian and may be early Artinskian. The Joe Joe Formation is partly glacial in origin and contains a *Rhacopteris* flora.

The Camboon Andesite and the Rannes Beds appear to contain rock units of different ages. The Camboon Andesite includes Lower Permian rocks as well as a suite older than Upper Carboniferous. The Rannes Beds are affected by low-grade regional metamorphism in a structurally complex area; they contain strata of Permian age as well as, apparently, older rocks. The Boomer Formation of the Back Creek Group is separated from part of the Rannes Beds by an angular unconformity.

The history of the Permian-Triassic sequence is complex. In the Permian the basinwide threefold subdivision corresponds to the Lower, Middle, and Upper Series of Jack (1879a), which were later referred to as Lower, Middle, and Upper Bowen Formations. Early in the Permian four units were formed in largely separate areas: the Reids Dome Beds in the Denison Trough, the Camboon Andesite in the Auburn Arch area, and the Lizzie Creek Volcanics (previously Lower Bowen Volcanics) and the Carmila Beds in the northern part of the Bowen Basin. Accumulation was apparently non-marine until the sea entered the area during late Lizzie Creek Volcanics time. The Reids Dome Beds contain numerous beds of coal, and consist of a thick sequence of entirely or predominantly non-volcanic rocks. The Camboon Andesite and Lizzie Creek Volcanics are largely intermediate volcanics with some sediments, whereas the volcanics of the Carmila Beds, farther east, are mainly acid.

The middle part of the Permian sequence, the Back Creek Group (previously Middle Bowen Beds), is more widespread and has been subdivided into three subgroups which can be recognized throughout the basin. The predominantly marine Tiverton Subgroup is thickest in the Denison Trough and on the Connors Arch and Nebo Synclinorium, and thinnest over the Comet Ridge and to the southeast. In the Gebbie Subgroup quartz sandstone is widespread. In the north the Gebbie Subgroup overlaps the Tiverton Subgroup and rests directly on the Lizzie Creek Volcanics. In the west, it is represented by the relatively thin Colinlea Sandstone, which rests directly on the Reids Dome Beds, Joe Joe Formation, or older rocks. The Gebbie Subgroup was apparently not deposited in the Cracow area in the southwest. The environment of deposition ranged from non-marine, including coal measures in places, to offshore marine. The isolated Blair Athol Coal Measures, and probably also the Calen Coal Measures, are of this age. The youngest part of the Back Creek Group, the Blenheim Subgroup, began with a major marine transgression in late Lower Permian or early Upper Permian. In the north, west, southwest, and southeast, the Blenheim subgroup overlaps the older parts of the Back Creek Group. It is largely marine, but lateral variation is considerable and coal measures were formed in the west and north. In the east, where the basin was less stable, the subgroup is represented by the flysch-like Boomer Formation with spilitic pillow lavas (Rookwood Volcanics) at the base. Each of the sequences

is characterized by a distinctive marine fauna Faunas II III, and IV of Dickins (*in* Malone et al., 1964; Malone, Jensen, Gregory & Forbes, 1966).

In the Upper Permian, the Bowen Basin was cut off from the sea by uplift along the eastern margin, and the Blackwater Group (previously Upper Bowen Coal Measures) was deposited in the trough. The granites on the eastern margin, which have an isotopic age of about 240 m.y., were probably emplaced during the uplift and are of the same age as the volcanics within the Blackwater Group. The sedimentary cycle was complex and numerous formations have been recognized. Coal is known at several levels. The coal measures at the top of the group, which have been given different names in different areas, are almost continuous throughout the basin. These measures and the Upper Coal Measures in the Hunter River Valley of New South Wales are among the most important sources of black coal in the southern hemisphere. The Blackwater Group contains a rich *Glossopteris* flora from which *Taeniopteris* has been recorded. The spore assemblage is distinct from that of the overlying Rewan Formation.

The Triassic sequence (Mimosa Group) comprises three non-marine formations of basinwide extent: the Rewan Formation, Clematis Sandstone, and Moolayember Formation. The Rewan Formation, the lower part of which may be Permian, consists of lithic sandstone and green and red-brown mudstone, which indicates a change in climate. On the margins of the basin the boundary with the Blackwater Group is disconformable, but in the centre it is possibly transitional. The Clematis Sandstone is predominantly quartzose; minor red-brown mudstone has been recorded. The Moolayember Formation consists mainly of mudstone and lithic sandstone laid down under less stable conditions than the Clematis Sandstone. Uplift, folding, and erosion took place in the Upper Triassic, and in the Lower Jurassic the Great Artesian Basin and its eastern lobe, the Surat Basin, were developed as separate structures. The Jurassic formations are mainly terrestrial, except for possible ephemeral marine incursions. The terrestrial environment persisted into the Lower Cretaceous until the sea entered the margins of the area from the north and west in Aptian-Albian time. The Styx Coal Measures were laid down unconformably on Permian rocks in the Strathmuir Synclinorium in the Lower Cretaceous.

Terrestrial Tertiary deposits are widespread. The thickest sequence is in the Duaringa Basin, where a thickness of 1050 m has been suggested. Basalt and associated intermediate and acid rocks, with isotopic ages ranging from 20 to 30 m.y., are found over large areas. In Tertiary and Quaternary times, the whole area was subjected to a long period of deep weathering during which lateritic profiles were strongly developed.

The ages of the granitic intrusions along the western and eastern margins of the basin are Ordovician(?), Silurian to Lower Devonian, Middle to Upper Devonian, Upper Devonian to Carboniferous, Carboniferous, Permian, and Triassic to Cretaceous. The Auburn Complex in the southeast appears to contain Carboniferous and Permian granitic rocks, and the Urannah Complex, in the northeast, Carboniferous, Permian, and Cretaceous. The contacts of the serpentinite intruding the Lower Permian strata in the Marlborough area are generally faulted.

The structure of the Bowen Basin and adjoining areas reflects the complex tectonic history. Strong pre-Lower Devonian movement is indicated and there is a marked discordance between the Middle and Upper Devonian rocks; the movements can be correlated with strong movements elsewhere in the Tasman Geosyncline. On the eastern and western margins the Carboniferous and Permian sequences are separated by discordance, particularly apparent in the west, where strongly folded and faulted Carboniferous beds are overlain by relatively flat-lying Permian formations. The structures within the Bowen Basin (Denison Trough, Comet Ridge, Collinsville Shelf, Mimosa Syncline, etc.) and the strong igneous activity in the eastern hinterland reflect developments during the Permian and Triassic. Mobility was particularly marked at the beginning of the Upper Permian in the Eungella-Cracow Mobile Belt. Uplift and folding took place in the late Triassic, and sedimentation in the Great Artesian Basin began in the Jurassic. Considerable movement occurred in the Tertiary, but little is known of the detailed geological history.

The main mineral resource of the Bowen Basin is black coal, which has been formed at many stratigraphic levels in Permian, Jurassic, and Cretaceous rocks. Most production has come from the Upper Permian Blackwater Group. Coal has also been produced from the Jurassic Injune Group and the Cretaceous Styx Coal Measures.

Although source and reservoir rocks and structure appear suitable for accumulation, particularly in the Denison Trough, so far only traces of petroleum have been found in any of the wells drilled.

Metalliferous minerals are found mainly on the margin of the basin. Gold has been mined in the Clermont and other areas; the Golden Plateau mine near Cracow is the largest producer, as it is also of silver. Copper was mined at Peak Downs in the middle 19th Century, and the area has recently been the site of considerable exploratory activity

The Anakie Field has yielded nearly one and a half million dollars' worth of sapphire, and chrysoprase is mined near Marlborough.

INTRODUCTION

The Bowen Basin is a Permian to Triassic basin extending from Collinsville in the north to Goondiwindi in the south, where it is overlapped by Mesozoic rocks of the Surat Basin (the easternmost extension of the Great Artesian Basin). Beneath the cover the Bowen Basin may be continuous with the Sydney Basin.

The northwestern boundary is the pre-Permian Clermont Stable Block, that in the east is formed by the Strathmuir Synclinorium and the Eungella-Cracow Mobile Belt, where pre-Permian rocks are faulted against or overlain by steeply dipping Permian sediments, through which they penetrate as inliers. The western boundary is the Birkhead axis, which separates the Bowen Basin from the Galilee Basin. Between these boundaries lies the structural basin that Derrington (1962) called the Bowen Synclinorium: we prefer the more general term Bowen Basin.

Most of the stratigraphy of the basin has been described in detail in published reports, to which reference is made, and descriptive material is therefore kept to a minimum in this Bulletin; only rock units not adequately described elsewhere, or re-interpreted in the light of more recent work, are described here. Figure 1 lists all the main rock units in the order in which they will be discussed.

The map area (Pl. 1; 1:500,000 geological map) is largely contained within the Fitzroy and Burdekin-Townsville Regions. The physical and cultural geography of these regions is set out in a series of maps and booklets issued by the Commonwealth Department of National Development, which have been freely drawn on for the data that follow. The towns, culture, and physiographic features of the area are shown in Figure 2. The mapped area is about 150,000 km^2. The coastline extends some 250 km north and south of Mackay. Rockhampton, the largest town in central Queensland, lies 55 km east of the mapped area.

The regional survey was a joint project by the Commonwealth Bureau of Mineral Resources and the Geological Survey of Queensland. The field parties engaged in the survey are listed below.

Year	*Sheet Area*	*Composition of Field Party*
1960	Clermont	J.J. Veevers (party leader), R.G. Mollan, and M.A. Randal (BMR); R.G. Paten (GSQ)
1960	Mt Coolon	E.J. Malone (party leader), D.W.P. Corbett, and A.R. Jensen (BMR); P.E. Bock and L.G. Cutler (GSQ)
1961	S. part of Bowen, & Mackay	E.J. Malone (party leader), C.M. Gregory, and A.R. Jensen (BMR); V.R. Forbes (GSQ)
1961	Emerald	J.J. Veevers (party leader), R.G. Mollan, and F. Olgers (BMR); A.G. Kirkegaard (GSQ)
1962	Duaringa & S. part of St Lawrence	E.J. Malone (party leader), R.G. Mollan, and F. Olgers (BMR); A.G. Kirkegaard (GSQ)
1962	Mackay, S. part of Proserpine, & N. part of St Lawrence	A.R. Jensen (party leader) and C.M. Gregory (BMR); V.R. Forbes (GSQ)
1963	Baralaba & Gogango Range	F. Olgers (party leader), J.A.J. Smit, and A.W. Webb (BMR); B.A. Coxhead (GSQ)
1963	Duaringa	L.V. Bastian and E.J. Malone (BMR)
1963	W. part of Mundubbera, & Taroom	A.R. Jensen (party leader) and C.M. Gregory (BMR); V.R. Forbes (GSQ)

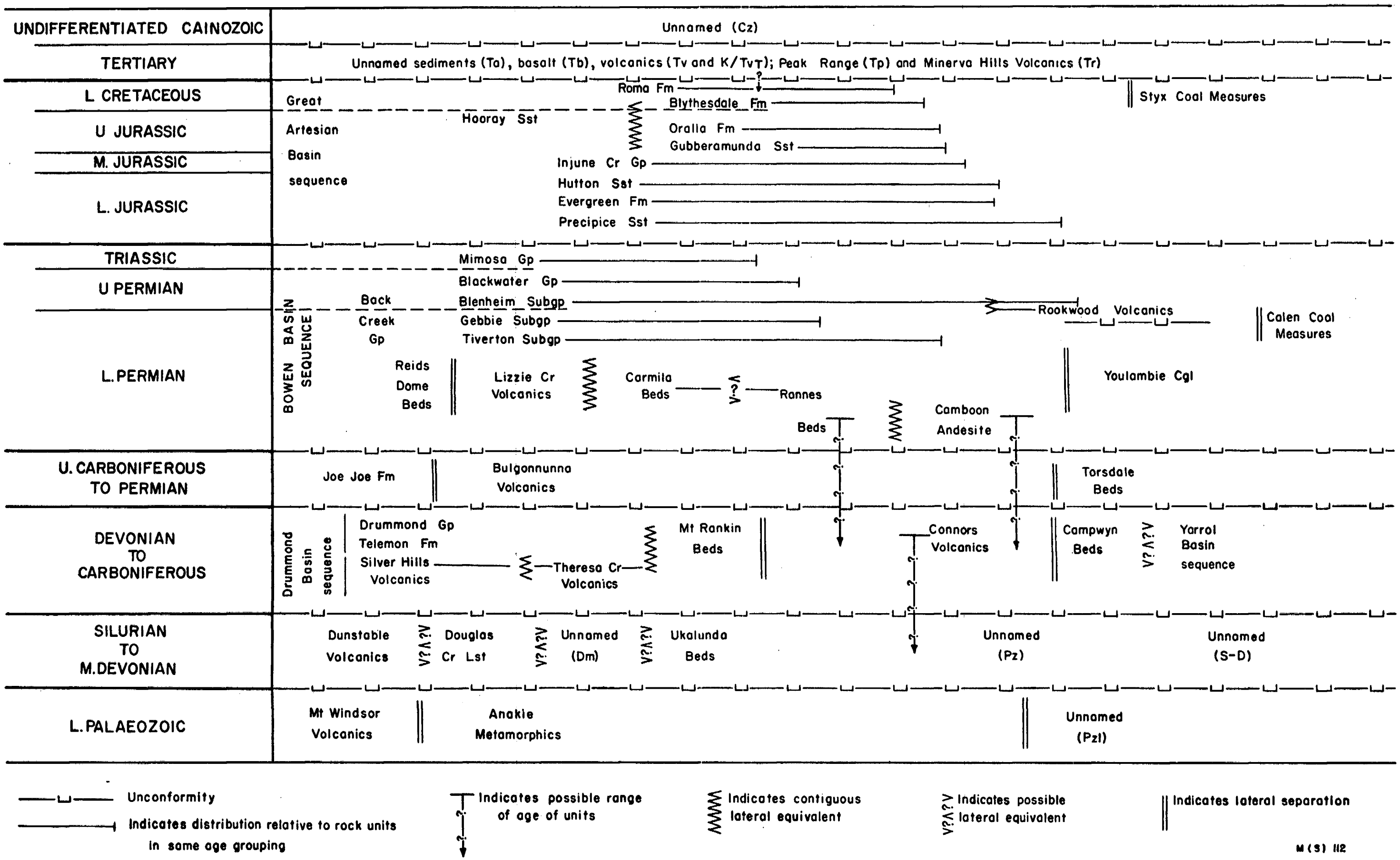

Figure 1. Age groupings of main rock units.

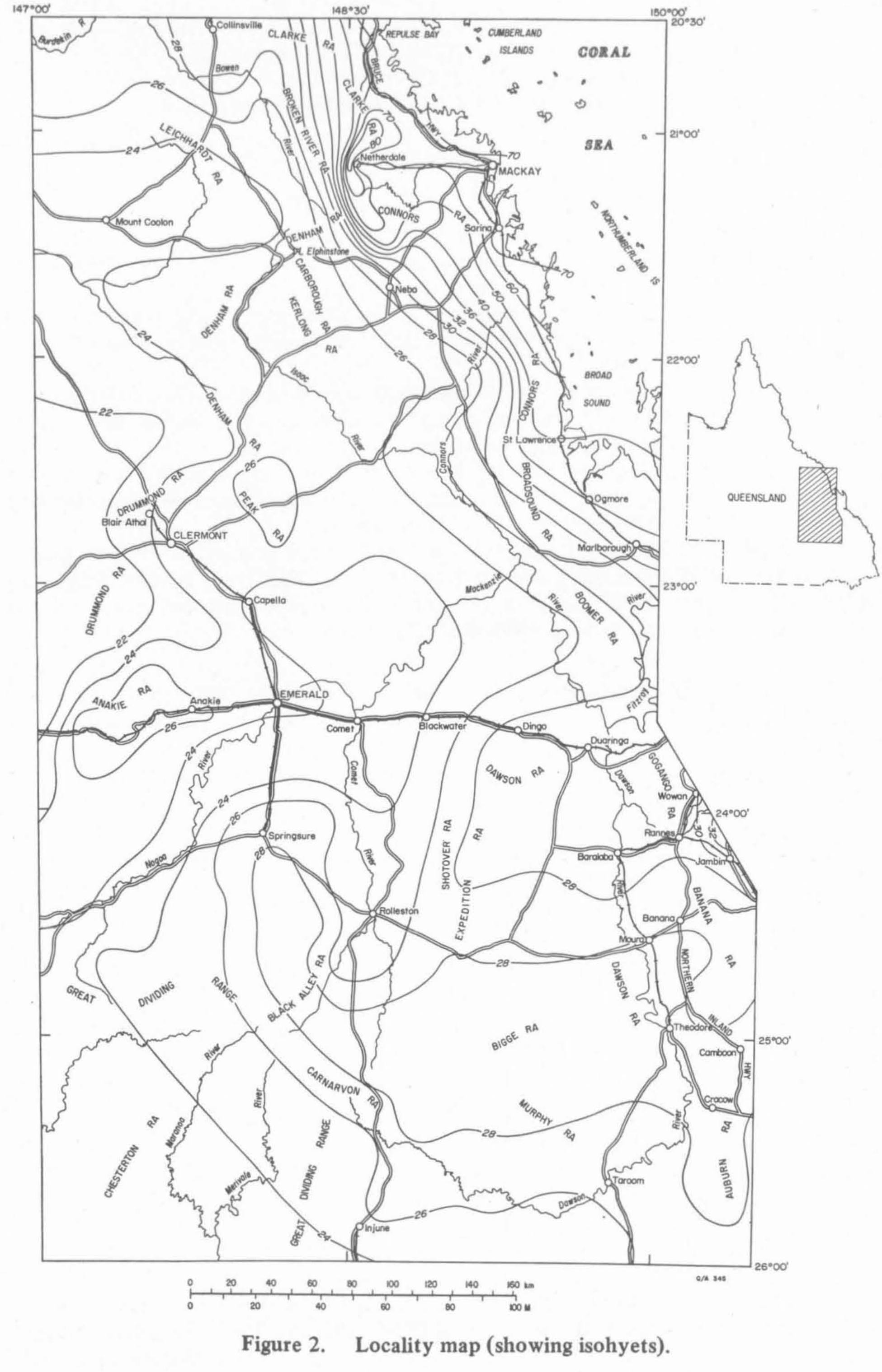

Figure 2. Locality map (showing isohyets).

1963	Springsure	R.G. Mollan (party leader) and N.F. Exon (BMR); A.G. Kirkegaard (GSQ)
1964	N.E. part of Duaringa & E. part of St Lawrence	F. Olgers (party leader) and E.J. Malone (BMR); A.G. Kirkegaard (GSQ)
1964	Eddystone	R.G. Mollan (party leader) and N.F. Exon (BMR); V.R. Forbes (GSQ)

Others who visited the field area or were associated with the regional survey were M. Armin, J.M. Dickins, P.R. Evans, A. Fehr, W.J. Perry, J.A. Talent (Geol. Surv. Victoria), Professor Dorothy Hill (Qld Univ.), Beverley Houston (GSQ), A.G. McKellar (GSQ), J.E. Thompson, and Mary E. White.

Fifty-one shallow core holes were drilled for stratigraphic and palaeontological information in 1963 and 1964, and a helicopter was used in 1964 to map otherwise inaccessible parts of the area.

Authorship of this Bulletin is as follows – Malone: geology, tables, plates, figures; Dickins: introduction, Permian palaeontology, economic geology; Dickins also collated the volume and has been responsible for bringing it to publication.

The results of the regional mapping have been or are being published in a series of reports (see Fig. 3). Coloured editions of the ten 1:250,000 Sheet areas within the map area, together with explanatory notes, have been published.

Much geological and geophysical work and drilling has been carried out by private companies engaged in the search for petroleum and coal. The survey has benefited greatly from collaboration with many organizations and individuals, and their help is acknowledged in the reports on individual Sheets.

Access

The area, especially near the coast, is fairly accessible (see DND, 1965). Scheduled flights serve several communities, and all are linked by a network of public and private roads. All-weather roads have been constructed near the coast, but inland many of the roads are impassable after heavy rain. Part of the area is rugged and is difficult to reach by motor vehicle.

Three railways extend from Rockhampton into or across the area; one runs south to Theodore with a spur line from Rannes to near Biloela; one west through Emerald and the third north parallel to the coast. A fourth line links Collinsville to Bowen on the coast to the north, and a fifth links Moura to Gladstone on the coast to the east.

Population and Industry

Mackay, with a population of more than 21,000, is the largest town in the area. Emerald (3050), Clermont (1750), and Collinsville (about 2000), all inland, are the only towns with populations greater than 1000. The rural population is very sparse, except near Mackay, where sugar-cane farming supports a fairly dense population.

Cattle raising is the main industry and most of the towns exist to supply goods and services to the surrounding homesteads. Coal mining at Moura, Baralaba, Blackwater, Blair Athol, and Collinsville is contributing an increasing part of the primary production. Agriculture is mainly confined to sugar-cane farming near Mackay, and to the growing of various crops near Theodore and Baralaba. Supplemental cattle feed is grown in many small areas. Timber cutting and milling are locally important, and many of the population are employed in road and railway maintenance work.

Climate, Vegetation, and Drainage

The climate in the main is subtropical and subhumid, with a variable rainfall which falls mostly in the warmer half of the year (DND, Climate, 1965). In general, rainfall decreases to the west away from the coast: west of Mackay the annual average rainfall is about 2000 mm, whereas at Emerald and Clermont it is about 625 mm.

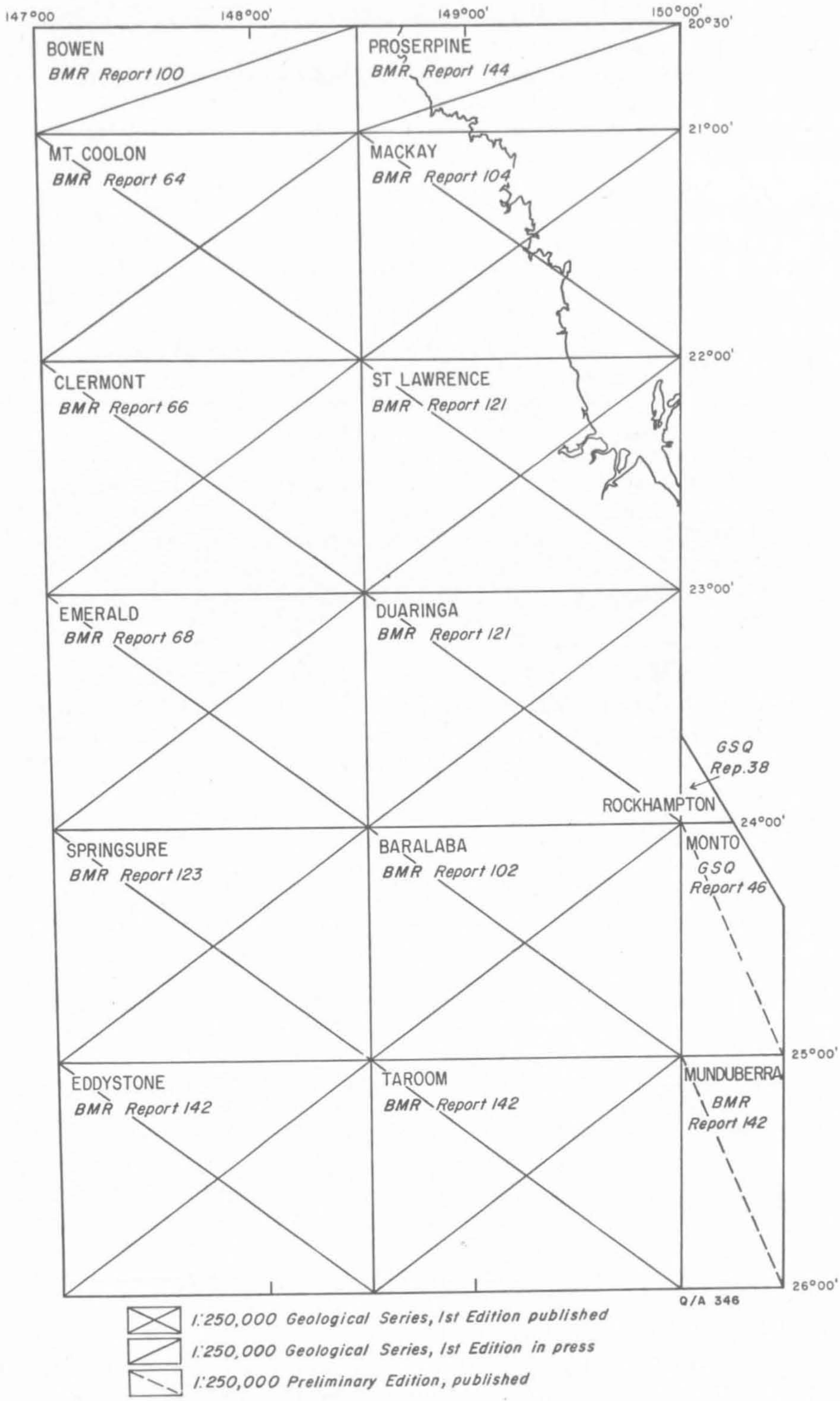

Figure 3. Areas covered by BMR maps and reports.

Day temperatures range from about 25°C to 35°C during most of the year, although they are rather more extreme inland.

Average annual evaporation ranges from about 1.5 m in coastal regions to about 2.4 m inland.

The vegetation varies according to the climate and soil, and ranges from dense rain forest and lush grassland near the coast to open park and grassland inland.

Drainage is mainly towards the coast into a few large and many small rivers. Most of the area is drained by the Fitzroy River system, which includes the Mackenzie and Dawson Rivers. Some streams drain into the Burnett River in the south and the Bowen River, which joins the Burdekin, in the north. Rivers in the southwest enter the Warrego River.

Physiography

The physiographic units range from coastal plains in the northeast to inland plains, in the southwest, which merge into the Lake Eyre drainage basin (see DND, 1967a).

The coastal plains between the Eastern Highlands and the east are nowhere extensive. The highlands form an almost continuous belt of resistant rocks with summits generally between 360 and 750 m above sea level; in the Clarke Range west of Mackay they rise to 1200 m. The extensive Central Plains and Lowlands correspond closely to the Bowen Basin as a geological structural entity. Resistant Mesozoic rocks form extensive tablelands in the central part of the basin (Redcliffe and Carborough Tablelands), and particularly in the south-central part (bounded by the Dawson and Expedition Ranges). The South-central Tableland slopes gradually to the south, in accordance with the structure of the Mesozoic rocks.

Previous Investigations

Geological. Before World War I, geological investigations were mainly concerned with the search for coal, gold, sapphires, and groundwater. Daintree, Dunstan, Jack, and Rands, of the Geological Survey of Queensland, were the principal investigators. Jack, with R. Etheridge of the Australian Museum, Sydney, also wrote a comprehensive account (1892) of the geology and palaeontology of the whole Colony, in which the threefold division of the Permian of the Bowen Basin was first proposed. Later work, including our own, has confirmed the value of this subdivision in understanding the development of the basin.

Between the wars, the search for petroleum, stimulated by the discovery of gas at Roma in 1900, assumed considerable importance, and the work of officers of the Survey, notably Ball, Jensen, Morton, and Reid, was supplemented by that of petroleum exploration companies. Shell (Qld) Development Pty Ltd, in particular, undertook some detailed surface mapping, and followed it with drilling – unfortunately unsuccessful. Indeed, despite present production of gas in the Roma district, the early promise of the area has yet to be fulfilled.

Since World War II, the search for both petroleum and coal has been intensified. Geophysical surveys were made by both the Bureau of Mineral Resources and private companies; companies have undertaken much geological work; and on the initiative of Professor Dorothy Hill, the University of Queensland, and later the Geological Survey of Queensland, undertook many geological and palaeontological studies. Finally, in 1960, a survey of the entire region was begun by the Bureau of Mineral Resources and the Geological Survey of Queensland. It is this survey that is mainly reported in this volume

There has been no commercial production of petroleum in the area covered by this Bulletin, but the coal resources, particularly of coking coal, are among the most important in Oceania and Southeast Asia.

Aeromagnetic. The results of the 1961-63 BMR aeromagnetic survey have been summarized by Wells & Milsom (1966). They plotted the magnetic profiles on a geological base map at 1:250,000 and drew estimated depth to magnetic basement contours at a scale of 1:1,000,000. The depth to magnetic basement contours and Bouguer anomalies are shown in Plate 3.

The magnetic basement contours agree reasonably well with structural units, such as the Nebo Synclinorium, Mimosa Syncline, and the Styx Basin and Strathmuir Synclinorium. In the Nebo Synclinorium, where the calculated magnetic basement is 9600 m, pre-Permian structure may be indicated. Similarly, the deep magnetic basement in the southwest may reflect pre-Permian, that is, pre-Bowen Basin, structure.

Gravity. Previous gravity surveys are summarized in Lonsdale (1965) and Darby (1966), and the results are shown in Plate 3, compiled from published BMR 1:500,000 maps and from preliminary 1:250,000 maps (Springsure and Eddystone). The Strathmuir and Nebo Synclinoriums, the Mimosa Syncline, and the Denison Trough are outlined by negative gravity anomalies, whereas the Connors Arch, Gogango Overfolded Zone, and Auburn Arch in the Eungella-Cracow Mobile Belt are defined by positive anomalies. The Comet Ridge and Anakie Inlier are also marked by positive anomalies. The Bouguer gravity map, however, suggests that the boundary between the Collinsville Shelf and the Nebo Synclinorium possibly lies to the west of the boundary shown in Plate 3. The Clermont Block and its assumed continuation under the western part of the Bowen Basin and Great Artesian Basin shows a complex pattern of positive and negative anomalies, which apparently reflect pre-Permian structure.

Seismic. Numerous seismic surveys have been completed, particularly in the southwest and south. Much of the seismic work was carried out after 1960, but most of the results have not been published. The first surveys to be carried out were those by Shell (Qld) Development (1952) and the BMR (Smith, 1951). The BMR reconnaissance survey (Robertson, 1961, 1965) was particularly useful in outlining the structure within the basin along an east-west line between Emerald and Duaringa.

The seismic surveys have been particularly useful in delineating structure, but few are sufficiently detailed to delineate more than one or two horizons. The coal measures of the Blackwater Group are a major reflecting horizon and, while this reflection has tended to mask lower horizons, it has offered good control for determining the overall structure of the basin.

LOWER PALAEOZOIC

Rock units assigned to the Lower Palaeozoic are the Anakie Metamorphics in the Anakie Inlier in the west, the Mount Windsor Volcanics in the northwest, and metamorphics cropping out around Marlborough in the east.

Anakie Metamorphics

Jensen (1921c) used the term Anakie Series for the granite, porphyry, schist, and slate near Anakie. Later, the name Anakie Metamorphics was applied to Lower Palaeozoic rocks extending from Anakie to southwest of Collinsville (Geological Map of Queensland, Hill, ed., 1953; Hill & Denmead, eds., 1960).

The Anakie Metamorphics crop out in a belt extending north-northwest from Anakie to Rosetta Creek, and in the core of the Telemon Anticline, west of Springsure. The largest area of outcrop is west of Clermont, where the metamorphics form high gently rounded closely spaced hills with a deeply incised dendritic drainage. Near Anakie, they crop out in prominent strike ridges south of the contact with the Retreat Granite. The topography is more subdued east of Clermont and north of Miclere Creek, where low rubble-covered hills rise about 15 m above the surrounding alluvial and black-soil plains. In the north the metamorphics are lateritized in places. The laterite profile has been dissected into scattered low mesas.

Mapping of the Anakie Metamorphics was confined to locating the main boundaries, mainly by photogeological interpretation. Few outcrops were examined in detail and few specimens were examined in thin section. The main rock types include mica schist, quartz-mica schist, knotted schist, phyllite, banded phyllite, slate, and quartzite. Lenses of unfossiliferous crystalline limestone, 6 m thick and up to 150 m long, are interbedded with slate northwest of Anakie, and what appears to be metamorphosed pillow lava crops out about 19 km north of Anakie. The widespread quartz veins and reefs in the metamorphics are the source of the abundant quartz rubble covering areas of poor outcrop. The inlier in the core of the Telemon Anticline consists of strongly foliated coarse quartz-feldspar-mica gneiss interbedded with garnetiferous muscovite schist, biotite-quartz phyllite, schist, and sheared diorite and other igneous rocks.

Most of the lutites in the Anakie Metamorphics are closely foliated. Two foliation directions, 080° and 340° (Veevers, Mollan, Olgers, & Kirkegaard, 1964a) were noted west of Clermont, but other foliation directions are dominant elsewhere. The quartz veins are concordant with the foliation in places (Veevers, Randal, Mollan, & Paten, 1964b). Foliation in the Telemon Anticline inlier strikes northeast and dips southeast.

Little is known of the structure of the Anakie Metamorphics. The formation is exposed in the elongate Anakie Inlier separating the Drummond Basin to the west from the sequence of thick Devonian-Carboniferous sedimentary rocks to the east. At times during the Devonian-Carboniferous, sedimentation probably extended across the inlier, particularly near Miclere Creek; farther south, the inlier supplied detritus to the Drummond Basin.

At the northern end of the inlier the Anakie Metamorphics are separated by a narrow strip of alluvium from lower Middle Devonian Ukalunda Beds. The boundary is arbitrary; scattered trends indicate that the Ukalunda Beds trend south into the Anakie Metamorphics, but the two units cannot be distinguished because of poor outcrop. Blocks of fossiliferous lower Middle Devonian rocks were mapped south of Clermont and in the Nogoa Anticline; their relationships to the Anakie Metamorphics are obscure, but presumably they rest unconformably on the metamorphics. However, the Anakie Metamorphics, as mapped, probably included some Middle Devonian rocks. The Anakie Metamorphics are unconformably overlain by the Drummond Basin sequence and are intruded by the Retreat Granite.

No fossils have been found in the Anakie Metamorphics. An age of 458 m.y. was determined on muscovite from a mica schist about 22 km southwest of Clermont (see Webb & McDougall, 1968). This was probably the age of metamorphism. A similar age was determined (A.W. Webb, pers. comm.) for the granite in the core of the Telemon Anticline. These results indicate that the Anakie Metamorphics are Ordovician or older.

Lower Palaeozoic Metamorphics (Pzl)

Metamorphic rocks crop out around Marlborough and extend east into the adjacent Rockhampton and Port Clinton Sheet areas. The outcrops within the map area are described by Malone, Olgers, & Kirkegaard (1969) and those to the east by Kirkegaard, Shaw, & Murray (1970). The metamorphics include sediments and interbedded volcanics or minor intrusives which have been regionally, and later thermally and dynamically, metamorphosed. They include quartz-mica schist, talc schist, quartzite, hornfelsed quartz-mica schist, pyroxenite, and garnetiferous quartz-mica schist interbedded with uralitized metagabbro and schistose altered andesite or basalt.

The structure of the metamorphics is unknown. In many outcrops, they have a prominent steeply dipping foliation trending east or northeast. The metamorphics were intruded by serpentinite, though most of the contacts are faulted; two form a block which is faulted against Lower Permian rocks to the west and is intruded by Permian gabbro and granite.

The age of the metamorphics is unknown. They are thought to be Lower Palaeozoic because their grade of metamorphism is much higher than that of fossiliferous Upper Silurian sediments and volcanics cropping out 48 km south of Marlborough.

Mount Windsor Volcanics

The Mount Windsor Volcanics occupy a small area in the northwest corner of the map area. They are much more extensive to the north and west, and are described in Wyatt, Paine, Clarke, Gregory, & Harding (1967) and Paine, Gregory, & Clarke (1970). They consist of fine-grained porphyritic rhyolite and rhyolite breccia, rhyodacite, dacite, andesite, and minor sediments, and are strongly jointed and cut by numerous northeasterly trending faults. The volcanics are sheared and mylonitized in fault zones and are strongly contact metamorphosed by the Ravenswood Granodiorite. They are unconformably overlain by the Bulgonunna Volcanics.

The Mount Windsor Volcanics are regarded as Lower Palaeozoic because they are older than the Ravenswood Granodiorite, which has been dated isotopically at about 420 m.y., that is, probably Silurian (A.W. Webb, pers. comm.).

SILURIAN TO MIDDLE DEVONIAN

The rock units deposited in Silurian to Middle Devonian times comprise the unnamed Upper Silurian to Lower Devonian rocks (S-D) south of Marlborough in the east; the lower Middle Devonian Ukalunda Beds in the northwest; the Lower or Middle Devonian Dunstable Volcanics in the Nogoa Anticline, west of Springsure; the Middle Devonian Douglas Creek Limestone and unnamed equivalents (Dm) south and southeast of Clermont; and a small block of unnamed metamorphics (Pz) 40 km southeast of Theodore.

Silurian-Devonian (S-D)

The oldest fossiliferous rocks in the area are unnamed volcanics, chert, limestone, and minor clastics cropping out about 40 km south of Marlborough. They are described in Malone et al. (1969), and their extension to the east is described in Kirkegaard et al. (1970). They crop out over about 150 km^2 in the core of the Craigilee Anticline and in smaller inliers to the west and southwest. Volcanics predominate; they include keratophyre, altered trachyte and spilite, andesite, andesitic and spilitic crystal and lithic tuffs, and volcanic conglomerate. Light green chert predominates in some areas, and in places it is associated with purple mudstone and conglomerate. Thick beds or lenses of limestone are interbedded with the volcanics in three localities. About 50 km south of Marlborough, lenses of thin to thick-bedded fossiliferous limestone, up to 30 m thick, are interbedded with flows, tuffs, and fossiliferous calcareous tuffaceous sandstone. The fossils from this locality are Upper Silurian (Mackellar, appendix 7 *in* Malone et al., 1969). In the other two localities the limestone is recrystallized and metamorphosed to marble in places, but contains some very fossiliferous bands; the fossils indicate a Silurian to Lower Devonian age (Hill, appendix 4 *in* Malone et al., 1969).

No fossils have been found in the small inliers west and southwest of the main area of outcrop. The rocks in the inliers are regarded as Silurian-Devonian because they consist mainly of volcanics, including abundant keratophyre, which are lithologically similar to the volcanics associated with the fossiliferous beds.

As the sequence consists largely of massive volcanics, the structure of the Silurian-Devonian rocks is difficult to elucidate, though gross changes of lithology suggest a regional easterly dip in places. The limestone beds near the northeast corner of the main area of outcrop are closely jointed and sheared, and tightly folded. The style of folding is apparently related to the thickness of the beds: the thick-bedded limestone is folded into very steep almost symmetrical folds; while the thin-bedded limestone is folded and cross-folded into disharmonic structures involving about 30 m of section, complicated by small-scale folds with an amplitude of about 30 cm. Elsewhere the limestone beds are steeply dipping. The Silurian-Devonian rocks were folded before the Upper Devonian to

Lower Carboniferous sediments were laid down on them. The magnitude of the unconformity is clearly visible east of the Upper Silurian fossil locality, where the Silurian-Devonian rocks dip vertically and strike northeast, and the overlying sediments dip east at about 70°.

The Silurian-Devonian rocks were partly emergent during the Devonian-Carboniferous sedimentation. Clasts of Silurian-Devonian limestone are contained in a conglomerate, locally basal to the Devonian-Carboniferous sequence, about 1.5 km east of the folded limestone outcrops. The succeeding sediments and volcanics onlapped the Silurian-Devonian rocks so that Lower Carboniferous, Upper Carboniferous, and Lower Permian rocks are in contact with the Silurian-Devonian rocks in places. The inliers of Silurian-Devonian rocks to the west are faulted against the Lower Permian or older Rannes Beds and are unconformably overlain by the late Lower Permian Rookwood Volcanics and the Upper Permian Boomer Formation.

The thickness of the Silurian-Devonian rocks is not known, but they are obviously thick and are more extensive than their area of outcrop. They are regarded as Upper Silurian to Lower Devonian in age.

Ukalunda Beds

The Ukalunda Beds occupy the northern end of the Anakie Inlier. They were distinguished from the Anakie Metamorphics during the mapping of the southern half of the Bowen Sheet area (Malone et al., 1966) when the fossils collected from many localities in the Ukalunda Beds indicated that they were of lower Middle Devonian age, much younger than the Ordovician or older Anakie Metamorphics. The southerly extension of the Ukalunda Beds into the Mount Coolon Sheet area was earlier described as part of the Anakie Metamorphics (Malone et al., 1964). The name Ukalunda Beds (Jack, 1889) was revived by Malone et al. (1966), who described the unit and discussed its stratigraphic position.

The boundary between the Ukalunda Beds and the Anakie Metamorphics as shown on the 1:500,000 geological map is arbitrary as both units are poorly exposed in the western part of the Mount Coolon Sheet area.

Five rock associations can be recognized in the Ukalunda Beds, but as the beds are poorly exposed it is not known whether they have any stratigraphic significance. The approximate distribution of the five units, A, B, C, D, and E, is shown in Figure 4.

Unit A

Unit A is the most widespread and possibly the youngest unit. It consists mainly of siltstone and arenite. The siltstone is closely jointed or cleaved, deeply weathered, and commonly ferruginized; it ranges from grey to buff, pink, and red, or mottled red and white, according to the degree of weathering. The arenite is lithic or sublabile and commonly feldspathic; it is generally fine to medium-grained and in most places has a calcite and chlorite cement. The fine arenite is generally closely jointed. Unit A includes thinly interbedded siltstone and arenite and interlaminated and varicoloured siltstone and claystone. The siltstone contains thin beds of fossiliferous silicified limestone in a few places; the fossils are poorly preserved, but are similar to some in other collections from the Ukalunda Beds.

Unit A has been contact metamorphosed to quartz-muscovite schist, hornfels, and spotted and lineated siltstone, and in places it has been silicified, epidotized, and locally mineralized.

Unit B

Unit B consists of jointed quartz-veined and silicified quartz sandstone grading in places into quartz-pebble conglomerate. The sandstone is metamorphosed to quartzite in one place; in general, the quartz grains are cracked, broken, strained, and re-oriented, and in places the sericite flakes in the matrix are aligned.

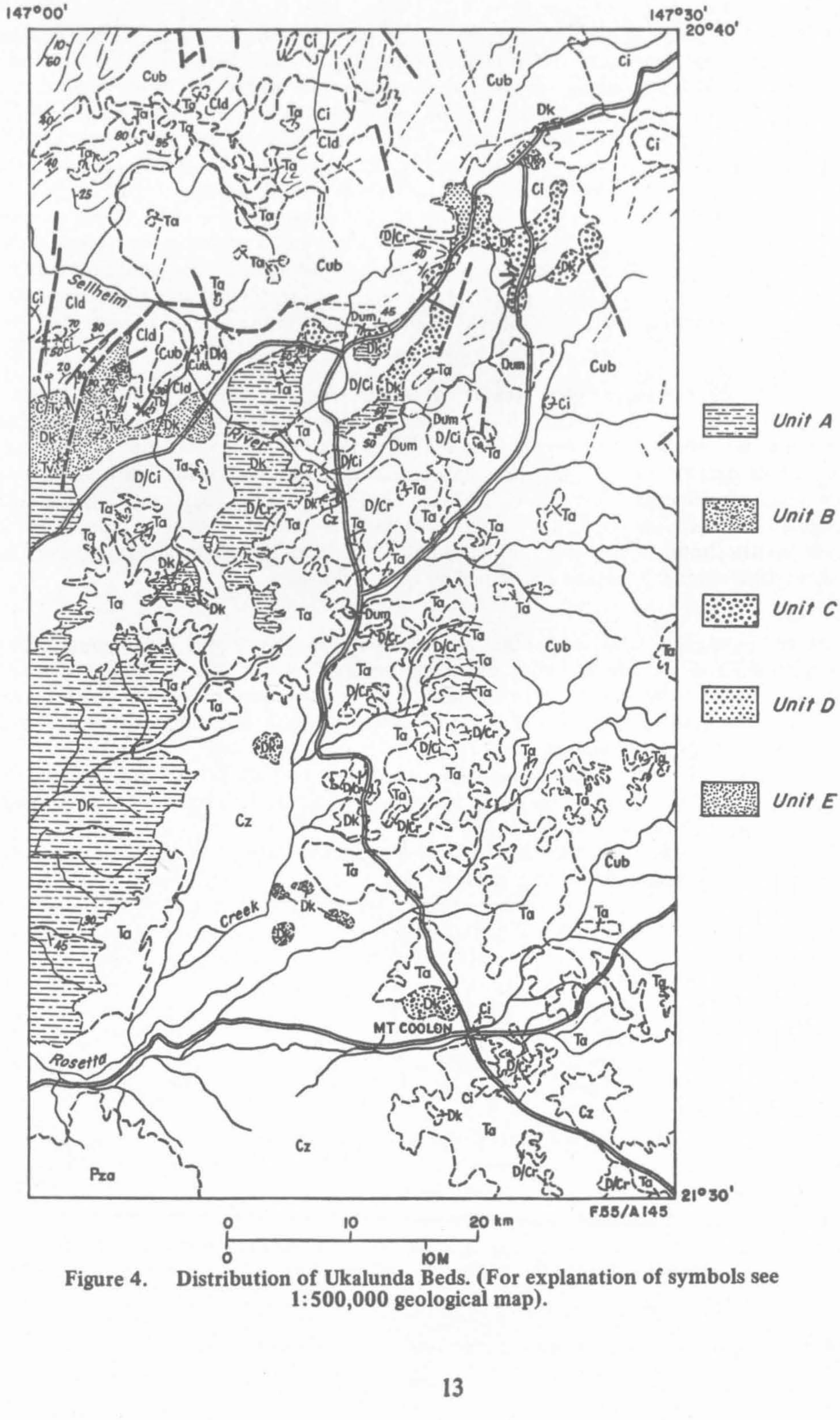

Figure 4. Distribution of Ukalunda Beds. (For explanation of symbols see 1:500,000 geological map).

Unit C

Unit C consists of (i) alternating and generally well bedded fine to coarse hard calcareous labile greywacke and thin-bedded grey, green, and brown siltstone and dark shale, slump folded in places; (ii) thick lenses of blue-grey pebble to cobble conglomerate interbedded with lithic arenite; (iii) banded grey-green thick-bedded silicified limestone, biostromal in part; and (iv) a sequence of green medium-grained tuff, coarse crystal tuff, grey-green siltstone, tuffaceous arenite, thin rhyolite flows, volcanic agglomerate, and thick beds of partly volcanolithic* pebble to cobble conglomerate interbedded with thin-bedded fine and coarse tuff. (Subunit 'iv' was referred to Devonian-Carboniferous volcanics *in* Malone et al., 1966). The calcareous labile greywacke of subunit (i) contains feldspar grains and lithic fragments which include devitrified glass and flow-banded volcanics. Flow-banded rhyolite porphyry and uralitized trachyandesite flows or sills are interbedded in unit C in places. Unit A overlies unit C where they are in contact.

Unit D

Unit D occupies the smallest area. It consists of (i) closely jointed khaki to dark grey siltstone, which is calcareous and fossiliferous in places and commonly contains rounded non-jointed cobbles of siltstone; (ii) beds and lenses up to 15 cm thick of grey fossiliferous limestone and small blocks of compound corals which are interbedded with calcareous siltstone or calcareous lithic arenite; (iii) thin-bedded micaceous coarse siltstone and fine arenite; (iv) soft olive-grey thin-bedded siltstone interbedded with dense grey to dark grey pyritic impure chert, which in places encloses pods of limestone; and (v) medium to coarse lithic arenite, hardened and veined by quartz in places.

Unit E

Unit E consists of siltstone, lithic arenite, quartz sandstone, and conglomerate. The conglomerate is a distinctive rock consisting mainly of white quartz pebbles in a red siliceous matrix. The conglomerate and associated quartz sandstone resemble unit B. The siltstone is closely jointed, khaki or grey, generally calcareous and fossiliferous, and contains pods of foetid limestone.

The best preserved and most abundant fossil faunas were collected from similar rock types in units D and E; but only one species is present in both units. Both faunas are Eifelian (lower Middle Devonian).

The Ukalunda Beds are intruded by large granodiorite intrusions and are extensively contact metamorphosed; minor gold, bismuth, arsenic, silver, lead, and copper mineralization occurs in the contact zones in places. They have undergone low-grade regional metamorphism which has produced the common jointing and shearing, and in places a schistose alignment of secondary sericite flakes in the argillaceous laminae. A zone of shearing in units A and E strikes north to northeast along the western margin of the Ukalunda Beds, parallel to the Drummond Basin. The shearing has produced phyllite, sheared siltstone, and interbedded unaltered fine arenite and sheared siltstone containing aligned sericite flakes. The shear cleavage is approximately parallel to the axial planes of folds in the Drummond Basin and possibly developed in response to the stress which folded the Drummond Basin sequence.

The Ukalunda Beds are moderately tightly folded into structures with a fairly large amplitude; few tight minor folds were noted. Dips are mainly between 30° and 70°. The Ukalunda Beds are unconformably overlain by the Drummond Basin sequence to the west, by the Mount Rankin Beds to the east, and by the Bulgonunna Volcanics to the northeast. The unconformity at the base of the Bulgonunna Volcanics is exposed at several places. The unconformities at the base of the Drummond Basin sequence and at

*The term 'volcanolithic' is used for rocks composed mainly of fragments of volcanic rocks.

the base of the Mount Rankin Beds are not exposed, but can be reliably inferred from the regional structure and from the difference in the degree of metamorphism and difference in age between the Ukalunda Beds and the younger units.

Dunstable Volcanics

The name Dunstable Volcanics (Hill, 1957) was revised in Mollan, Dickins, Exon, & Kirkegaard (1969). The volcanics are exposed in a small northeasterly trending fault-bounded inlier in the northern culmination of the Nogoa Anticline. Their area of outcrop and relationships to the overlying units are illustrated in Figure 5. The Dunstable Volcanics consist of tough green andesitic lavas and pyroclastics which contain lenses of partly recrystallized coralline limestone and splintery black and olive-green cherty shale. The Dunstable Volcanics are resistant to weathering, and this serves to distinguish them from the overlying, generally deeply weathered, Silver Hills Volcanics. Fossils from the limestone lenses are probably lower Middle Devonian (Hill, appendix 3 *in* Veevers et al., 1964a); as the fossiliferous lenses are near the top of the exposed section, the age of the lower part of the volcanics is not known. A thickness of about 450 m of Dunstable Volcanics is exposed in the Nogoa Anticline, but neither the top nor the bottom is exposed.

Douglas Creek Limestone and Equivalents(?)

The Douglas Creek Limestone is reviewed in Veevers et al. (1964b). It consists of blue-grey fine-grained massive and well jointed richly fossiliferous limestone cropping out in a small area 8 km south of Clermont. The fossils indicate a late Lower Devonian or early Middle Devonian age (Jell & Hill, 1970).

The unnamed Middle Devonian sediments south of the Douglas Creek Limestone outcrop include three small outcrops of well bedded thin-bedded grey to brown micaceous siltstone and one small area of limestone rubble. About 30 m of siltstone is exposed in the largest outcrop; it contains fossils of lower Middle Devonian or possibly Lower Devonian age (Veevers et al., 1964b).

Middle Devonian sediments (the 'undifferentiated Palaeozoic sandstone and siltstone' of Veevers et al., 1964b) crop out in a narrow strip 24 km southwest of Clermont. They are thrust-faulted against the Anakie Metamorphics, faulted against the Theresa Creek Volcanics, and intruded by monzonite. The sequence consists mainly of fine to medium-grained cross-bedded mauve calcareous arkosic sandstone and laminated red-brown micaceous siltstone; the sediments contain angular detritus up to 15 cm across derived from the Anakie Metamorphics. Also present are tuff, coarse recrystallized limestone, and a coarse basic flow or intrusive. These rocks are tentatively regarded as Middle Devonian; they could be part of the Theresa Creek Volcanics.

The Douglas Creek Limestone and Middle Devonian sediments rest unconformably on the Anakie Metamorphics. The unconformity is not exposed, but is clearly indicated by the difference in metamorphic grade and by the absence of quartz veins in the Middle Devonian sediments and their abundance in the Anakie Metamorphics. The Middle Devonian sediments are overlain, apparently conformably, by the Theresa Creek Volcanics.

Middle Devonian sediments also crop out 29 km west-southwest of Emerald (Veevers et al., 1964a). The rocks exposed are siltstone, pebbly quartz grit, tuff, shale, limestone, and rhyolite. The limestone contains corals which indicate a Middle Devonian age (Hill, appendix 3 *in* Veevers et al., 1964a). The base of the sequence is not exposed; it is unconformably overlain by subhorizontal Permian sediments.

The Middle Devonian rocks crop out at the northern and southern ends of the Anakie Inlier and near the eastern margin of the inlier. All the sediments are of about the same age and were possibly deposited in a sea which was bounded to the west by the Anakie Metamorphics. Volcanism was dominant in the south (Dunstable Volcanics) and was relatively rare in the north

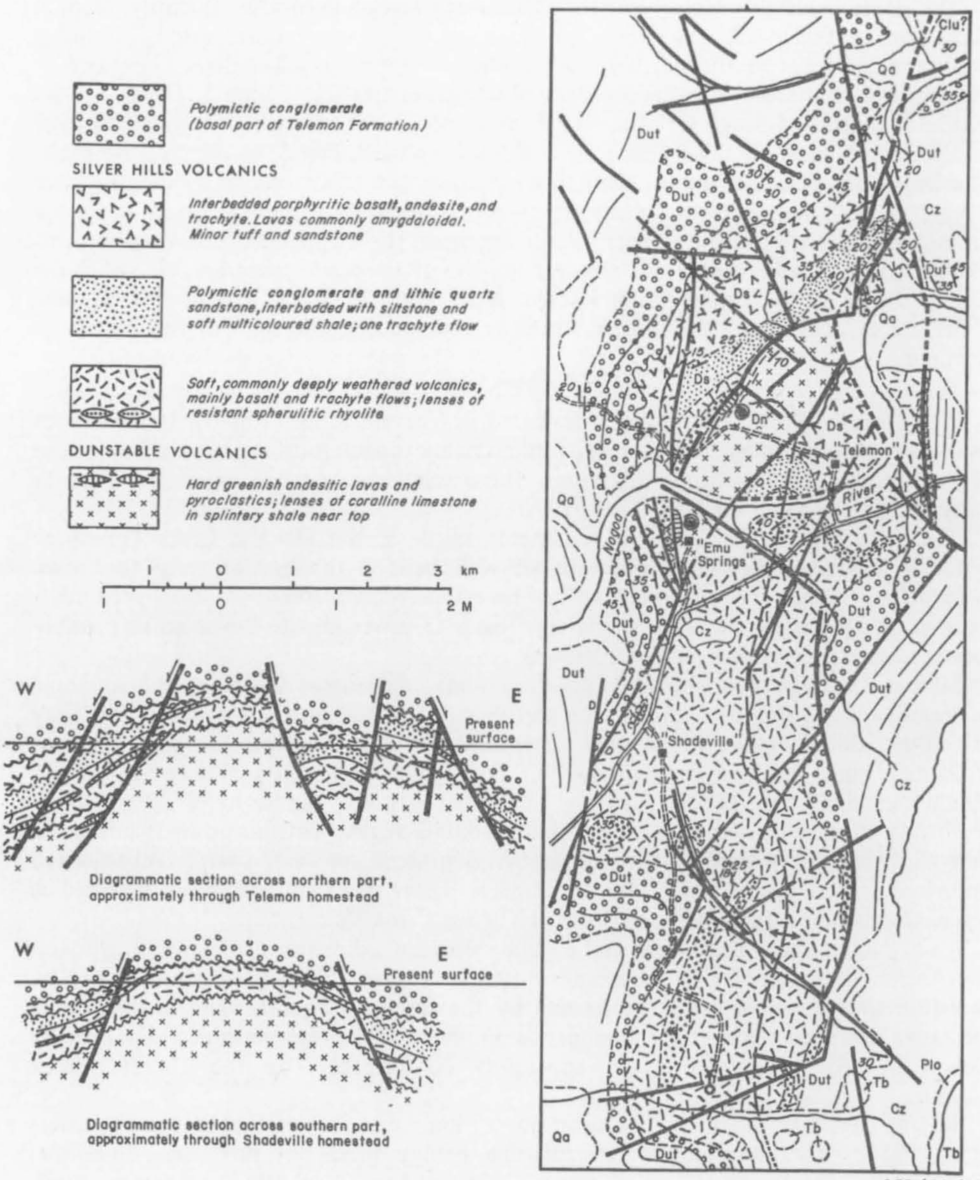

Figure 5. Distribution of Dunstable Volcanics. (For explanation of symbols see 1:250,000 Springsure sheet).

Unnamed Palaeozoic Metamorphics (Pz)

Granulite and metaquartzite crop out in a small area 40 km southeast of Theodore (Mollan, Forbes, Jensen, Exon, & Gregory, 1971). They overlie and were presumably metamorphosed by the Auburn Complex, although the contacts are not exposed. The metamorphics contain no intrinsic evidence of their age. They are older than the igneous rocks which have been dated isotopically at about 300 m.y. (Webb & McDougall, 1968). The metaquartzite is apparently a metamorphosed quartz sandstone and the granulite is a metamorphosed arkose.

DEVONIAN TO CARBONIFEROUS

In Devonian to Carboniferous times, sediments and volcanics were laid down in three large sedimentary basins: the Drummond Basin to the west of the Anakie Inlier, the basin to the east of the Anakie Inlier in which the Mount Rankin Beds were deposited, and the Yarrol Basin in the eastern part of the map area. Outside these three basins, the Theresa Creek Volcanics were laid down on the Anakie Inlier, possibly at the same time as and perhaps continuously with the Silver Hills Volcanics; the Campwyn Beds were deposited in what was probably the northern extension of the Yarrol Basin; and the Connors Volcanics were laid down to the west of the Yarrol Basin. The Connors Volcanics are older than Upper Carboniferous and are tentatively regarded as equivalents of the Campwyn Beds because of the similarity in lithology and structure, and are therefore included with the Devonian to Carboniferous rocks; they could be older and may be equivalents of the Silurian-Devonian rocks.

Volcanics which may be equivalent to the Connors Volcanics are included in the Camboon Andesite, which ranges from Upper Carboniferous or older to Lower Permian. The age of the older part of the Camboon Andesite is based on the isotopic age of certain intrusive igneous rocks.

Devonian-Carboniferous rock units of the Clermont Block are briefly described in Table 1 and those of the Eungella-Cracow Mobile Belt in Table 2.

Drummond Basin Sequence

The exposed Drummond Basin is an arcuate structure trending northwest from a point about 30 km southwest of Springsure for about 110 km to where it swings nearly north. The basin lies to the west of the map area about the latitude of Mount Coolon, but reappears in the northwest, where it trends northeast. The regional geology of the Drummond Basin has been described by Olgers (1972). Parts of the Drummond Basin which lie within the map area are described by Veevers et al. (1964a,b), Mollan et al. (1969), and Malone et al. (1964, 1966).

The sequence in the southern part of the Drummond Basin comprises the Silver Hills Volcanics, Telemon Formation, Mount Hall Conglomerate, Raymond Sandstone*, and Ducabrook Formation in order of decreasing age; the youngest three formations constitute the Drummond Group. In the northern part of the basin the Drummond Group has not been divided into formations. Apparently, no equivalents of the Silver Hills Volcanics are present in the north, though the sequence probably includes equivalents of the Telemon Formation.

The Silver Hills Volcanics were probably extruded in part before the downwarping of the Drummond Basin began, and were certainly deposited over a greater area than the overlying sedimentary sequence. The abundance of reworked material from the Silver Hills Volcanics in the Telemon Formation indicates that a large area of volcanics was being eroded during deposition of the Telemon Formation. The Silver Hills Volcanics, Theresa Creek Volcanics, and the volcanics of the Mount Rankin Beds may be remnants of an acid to intermediate volcanic province which covered most of the Clermont Block in the Upper Devonian.

*** Name changed to Raymond Formation by Olgers (1972).**

The boundary between the Telemon Formation and the underlying Silver Hills Volcanics corresponds with a marked lithological change from a volcanic to a predominantly sedimentary sequence, which was partly derived from older volcanics, but which also includes subordinate volcanic rocks. The boundary marks the start of deposition in the Drummond Basin. The disconformity and local slight angular unconformities between the Telemon Formation and the overlying formations are much less significant; they correspond with epeirogenic movements or changes in the rate of subsidence. The lithology of the Telemon Formation is similar to that of the Ducabrook Formation, and it appears that the mature quartz-rich sediments of the intervening Mount Hall Conglomerate and Raymond Sandstone represent only a temporary change in the depositional environment. Despite the presence of a disconformity at the top of the Telemon Formation it might be better to include it in the Drummond Group because of the lithogenetic unity of the sequences, rather than excluding it, as has generally been the case. This is why the Drummond Group has not been subdivided in the northern part of the Bowen Basin.

The Mount Hall Conglomerate and Raymond Sandstone are closely related, and the former is essentially a local conglomeratic phase at the base of the Raymond Sandstone. Their relationships may best be expressed by referring to them as the Snake Range Subgroup (originally Snake Range Group, SQD, 1952; Hill, 1957). The suggested nomenclature for the Drummond Basin sequence would be:

Drummond Group		Ducabrook Formation
	Snake Range Subgroup	Raymond Sandstone
		Mount Hall Conglomerate
		Telemon Formation
		....
		Silver Hills Volcanics

Mount Rankin Beds

The Mount Rankin Beds is the name proposed for the Upper Devonian to Lower Carboniferous volcanic and sedimentary rocks cropping out east of the Anakie Inlier. The use of this name was foreshadowed in Veevers et al. (1964b). The informal term 'Beds' is used since no further work has been done in the type area since 1960 (Veevers et al., 1964b).

The name is derived from Mount Rankin (grid ref. 60702193) in the Clermont Sheet area. The type area is west, north, and east of Mount Rankin, some 55 km north-northeast of Clermont. The Mount Rankin Beds crop out discontinuously in a belt extending from about 30 km northeast of Clermont to 60 km north of Mount Coolon, in the Clermont, Mount Coolon, and Bowen Sheet areas.

The beds consist of porphyritic rhyolite, dacite, sodic pitchstone, andesite, acid and intermediate pyroclastics, including agglomerate, volcanic conglomerate, and lapilli, crystal, and lithic tuff, and sediments, including tuffaceous arenite, siltstone, and conglomerate. The rhyolite exhibits regular flow banding and less commonly contorted flow banding, and is spherulitic in places. It contains numerous veins and irregular masses of quartz. Some of the flows may be terrestrial; the pyroclastics and sediments are generally well bedded and were apparently laid down under water. The sediments consist mainly of volcanic detritus. They include tough fine to medium-grained dark quartz-poor feldspathic and lithic tuffaceous arenite; thin-bedded brown, grey, and colour-banded siltstone; fine to coarse and pebbly feldspatholithic sandstone; pebble to cobble conglomerate; fossiliferous calcareous sandstone; and minor quartz sandstone. Conglomerate generally occurs in beds and lenses which grade laterally into arenite. The fossiliferous sandstone and the quartz sandstone occur only in the Mount Wyatt Beds at the base of the Mount Rankin Beds in the north and reflect a marine transgression in that area; the bulk of the Mount Rankin Beds were deposited in fresh water.

The thickness in the type area was estimated to be about 4800 m. The Lower Carboniferous fossil plants in the top 300 m include *Lepidodendron, Lepidophyllum,* and *Lepidostrobus* – all cf. *L. aculeatum* Sternberg – and *Stigmaria ficoides* Brong. An Upper Devonian brachiopod, *Cyrtospirifer* cf. *reidi* Maxwell, and plants including *Leptophloeum australe, Protolepidodendron,* psilophytes, and *Stigmaria* occur in the Mount Wyatt Beds at the base of the Mount Rankin Beds in the north. The fossils indicate that the Mount Rankin Beds range from Upper Devonian to Lower Carboniferous.

The Mount Rankin Beds are unconformable on the Anakie Metamorphics and Ukalunda Beds; they are unconformably overlain by the Upper Carboniferous Bulgonunna Volcanics and by Permian sediments. The volcanics at their base in the type area are considered to be part of the same Upper Devonian volcanic province as the Silver Hills and Theresa Creek Volcanics, the northern limit of which is about the latitude of Mount Coolon. North of Mount Coolon both the Drummond Basin sequence and the Mount Rankin Beds consist mainly of clastics, derived from volcanic rocks, with some tuff and minor flow rocks. The Mount Rankin Beds in the north and the upper part of the sequence in the type area are approximate correlates of and are lithologically similar to the Drummond Group including the Telemon Formation.

The Mount Wyatt Beds (Daintree, 1870) were defined in Malone et al. (1966). They form the basal part of the Mount Rankin Beds in the north and contain evidence of a short-lived marine incursion probably from the east or northeast. Neither top nor bottom of the unit has been accurately located and consequently it is not given formation rank.

A small westerly trending outcrop 60 km north of Mount Coolon is tentatively included in the Mount Rankin Beds. The sequence consists of dark deeply weathered and altered crystal tuff, with subordinate dark fine-grained flow-banded slightly porphyritic rhyolite and bedded conglomeratic tuff. The rocks have a general similarity to the volcanics in the lower part of the Mount Rankin Beds, but this outcrop lies north of the known limits of the volcanic sequence in the Mount Rankin Beds. They may belong to the Ukalunda Beds, which contain some similar rock types, although they do not generally consist mainly of volcanics. These rocks are structurally discordant with the overlying Bulgonunna Volcanics, which contain many similar rock types; the structural discordance may be the result of extrusion from different foci and may not justify their exclusion from the Bulgonunna Volcanics.

A small outcrop at the northern margin of the Anakie Inlier has been assigned to the Mount Wyatt Beds on the basis of lithology and flora. The outcrop is separated from the Drummond Basin by the overlying Bulgonunna Volcanics. Possibly, the Drummond Group and Mount Wyatt Beds were continuous around the northern end of the Anakie Inlier. If so, the basal part of the Drummond Group in the north may have been deposited in a marine environment.

Theresa Creek Volcanics

The stratigraphic position of the Theresa Creek Volcanics (Veevers et al., 1964b) is not known with certainty. Veevers et al. stated that they are conformable on unnamed Middle Devonian sediments and regarded them as approximate correlates of the Dunstable Volcanics (then the Dunstable Formation), unnamed Middle Devonian volcanics and sediments, the Silver Hills Volcanics, and the volcanics of the Mount Rankin Beds (see fig. 8 *in* Veevers et al., 1964b). Later work has shown that there are two suites of volcanics separated by an unconformity: a Middle Devonian suite of which the Dunstable Volcanics is typical, and an Upper Devonian suite to which the Silver Hills Volcanics and the volcanics of the Mount Rankin Beds belong. The Theresa Creek Volcanics probably contain representatives of both. The lithology of part of the Theresa Creek Volcanics suggests that they can be correlated with the Upper Devonian volcanics. The conformable relationship (Veevers et al., 1964b, p. 10) between the unnamed Middle Devonian sediments and the overlying Theresa Creek Volcanics, and the fact that the

Theresa Creek Volcanics are intruded by monzonite which is correlated with the Retreat Granite, suggest that part of the Theresa Creek Volcanics is Middle Devonian in age. The Retreat Granite was probably emplaced in the interval between the Middle Devonian and Upper Devonian volcanic suites, and is overlain nonconformably by the Upper Devonian Silver Hills Volcanics. The isotopic age of the Retreat Granite suggests that it is probably younger than the Middle Devonian volcanics.

Connors Volcanics

The Connors Volcanics, which consist mainly of massive volcanics, are exposed in small areas adjacent to the Urannah Complex and in a large area at the southern end of the Connors Arch, and in inliers nearby. Most of the outcrops lie within the Duaringa and Saint Lawrence Sheet areas (see Malone et al., 1969). The Connors Volcanics in the Bowen Sheet area are defined and described in Malone et al. (1966), and in the Mackay Sheet area they are referred to in Jensen, Gregory, & Forbes (1966). They were not recognized in the Mount Coolon Sheet area when it was mapped in 1960 (Malone et al., 1964) and were included in the Lower Bowen Volcanics, but they are distinguished from the Lizzie Creek Volcanics (= Lower Bowen Volcanics) in a later publication (Malone, 1968).

No intrinsic evidence of age has been found in the Connors Volcanics. Field relationships indicate that they are unconformably overlain by lower Permian volcanics and sediments. In the south they are intruded by a granodiorite stock which has an isotopic mineral age of about 305 m.y. (early Upper Carboniferous). The Connors Volcanics are only in contact with the overlying Permian rocks, with intrusive rocks of various ages, and with the partly Lower Permian Rannes Beds. The isolated blocks of Connors Volcanics have been recognized by lithology only, and may include rocks of different ages.

The Connors Volcanics may be correlated with either the Upper Silurian to Lower Devonian rocks of the Craigilee area or the Devonian-Carboniferous Campwyn Beds; both of which are not lithologically dissimilar. However, the Connors Volcanics are mainly terrestrial, and do not contain fossiliferous marine sediments, which are found in both the other units. Spilitic rocks have been tentatively identified in the Connors Volcanics, particularly in the south, and they may therefore, be partly submarine. It is unlikely that they can be correlated with the Upper Carboniferous Bulgonunna Volcanics cropping out northwest of the Bowen Basin. Tenuous deductions based on isotopic age determination suggest that the Bulgonunna Volcanics may be younger than the 300-m.y.-old granodiorite that intrudes the Connors Volcanics.

The relationships of the Connors Volcanics with the Rannes Beds and Camboon Andesite are discussed later.

The Connors Volcanics and Urannah Complex together form the Connors Arch, which forms part of a major axis of uplift, subsidence, and intrusion along the western margin of the Eungella-Cracow Mobile Belt; the linearity of the axis may be largely the result of post-Permian tectonics. The relationships with the overlying Permian rocks indicate that the blocks of Connors Volcanics resisted deformation during the post-Permian folding, although they were displaced relative to each other. No cleavage has been developed in the Permian sediments to the west of the largest block, whereas there is a well defined axial-plane cleavage in similar sediments to the south and east. The intense shearing of sediments between the blocks suggests considerable movement. The distribution of the overlying sediments indicates that some of the inliers of Connors Volcanics were partly emergent at the beginning of Lower Permian sedimentation and were progressively overlapped by younger sediments.

Campwyn Beds

The volcanics and sediments of the Campwyn Beds crop out near the coast from 80 km south of Mackay to beyond the northern margin of the map area. In the Mackay Sheet the unit was named and described by Jensen et al. (1966), and the occurrences in the southern part of the Proserpine Sheet area by Jensen (1963).

The identification of the Campwyn Beds near Koumala is based on lithology only. The beds are faulted against or intruded by the Urannah Complex, with which they form a block overlain unconformably by the Lower Permian Carmila Beds. The western margins of the blocks of Campwyn Beds along the coast are in faulted contact with Lower Permian rocks.

The Campwyn Beds possibly represent the northern extension of the Yarrol Basin sequence. The Upper Devonian and Carboniferous fauna and flora indicate that they were laid down at the same time as the Yarrol Basin sequence, but since their stratigraphy is not well known, no attempt has been made to correlate the two. The massive nature of the volcanics, the abundance of plant remains, and the presence of fossiliferous marine interbeds suggest that the Campwyn Beds were deposited near the shore in alternating terrestrial, freshwater, and marine environments, possibly on the northwest margin of the Yarrol Basin. The southernmost outcrop of the Campwyn Beds on West Hill Island is only 50 km from Long Island, where the Yarrol Basin sequence has been recognized. The distribution of the two sequences and the similarity in lithology and total thickness suggest that they probably were laid down in the same basin.

The style of folding is also similar to that of the Yarrol Basin sequence. The entire thickness of the Campwyn Beds was apparently folded into broad structures in which almost the complete sequence can be seen in the preserved limbs of the folds. Tight minor folding has developed in places, generally associated with faulting.

The Campwyn Beds and associated pre-Permian intrusive igneous rocks formed the basement on which part of the Carmila Beds was deposited. Near Koumala, the unconformity at the base of the Carmila Beds is exposed around a structural high of Campwyn Beds and igneous rocks. The Carmila Beds to the south are folded into the southerly plunging Carmila Syncline; to the north, they dip north from the high, but their structural configuration is obscure. The structurally high position of the Campwyn Beds may be due partly to post-Permian folding, and partly to the presence of a ridge on the pre-Permian basement. The blocks of Campwyn Beds along the coast have been uplifted as a result of post-Permian faulting. The faults have truncated the eastern flank of the Carmila Syncline; about 2100 m of the Lower Permian sequence has been removed and the underlying Campwyn Beds exposed. The apparent relative movement on the faults is east block up, but the nature of the fault system is unknown.

Yarrol Basin Sequence

Only the western edge of the Yarrol Basin sequence is exposed in the map area. Most of it lies within the Port Clinton, Rockhampton, and Monto Sheet areas. Recent reports describing the Yarrol Basin sequence include: Kirkegaard, Shaw, & Murray (1970; Rockhampton and Port Clinton Sheet areas); Dear (1968; Cania district, Monto Sheet area); and Dear, McKellar, & Tucker (1971; Monto Sheet area).

The Yarrol Basin sequence (D-Ca) has been mapped in a few small areas about 30 km south of Marlborough and in the southern part of Long Island. The faunas collected at various localities and the lithology suggest that most of the Yarrol Basin sequence is represented, but insufficient information was available to subdivide the sequence. The Neerkol Formation (Cu) and Lower Carboniferous sediments (C1) were mapped on the eastern and western flanks of the Craigilee Anticline and have been tentatively recognized at the northern end of Long Island. Lower Permian sediments occupy most of Quail Island.

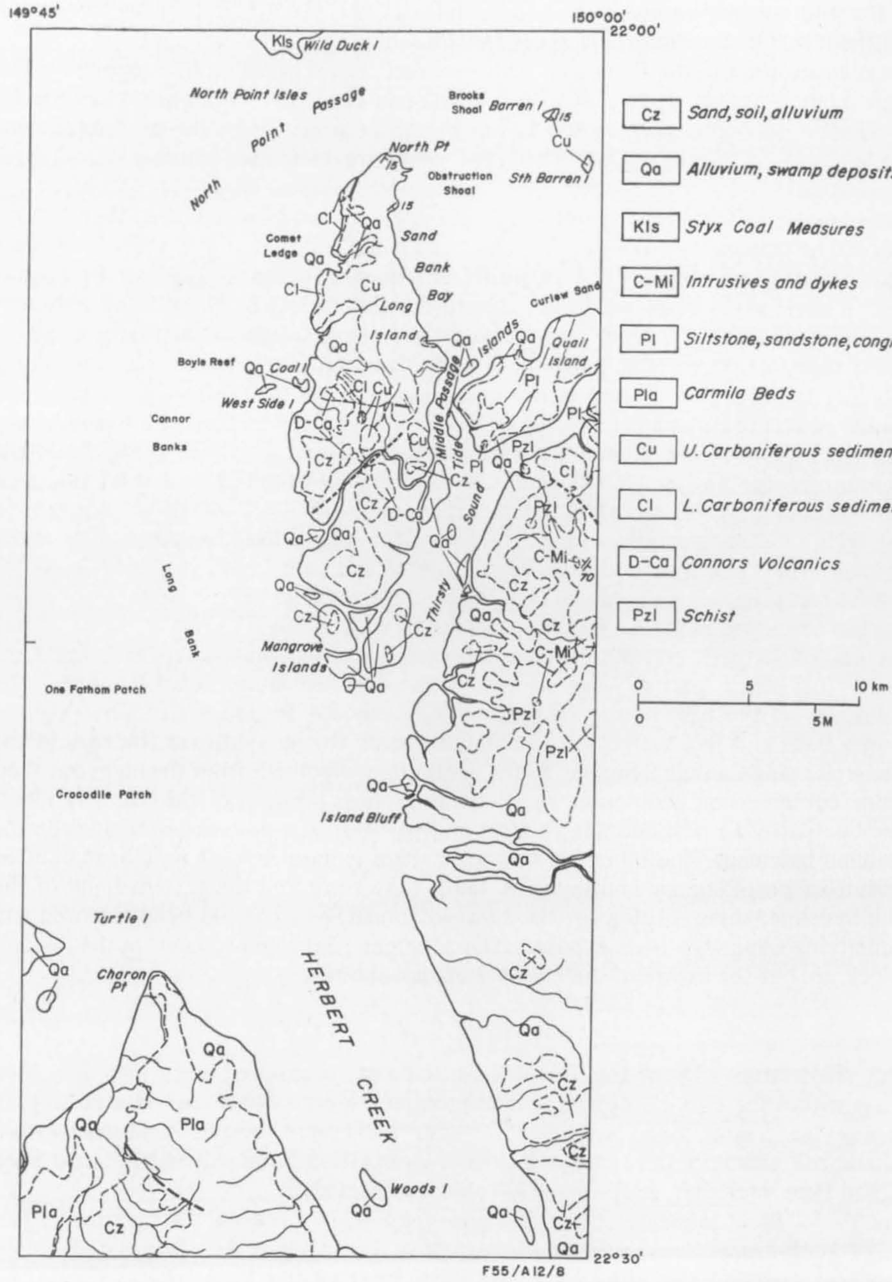

Figure 6. Geology of Long Island area (after Kirkegaard et al., 1970)

Revised mapping (Kirkegaard et al., 1970) of the Long Island area is presented in Figure 6. It differs from the 1:500,000 geological map in that Lower Permian sediments are recognized on Quail Island, and includes a more accurate map of the Upper Carboniferous, Lower Carboniferous, and undifferentiated Devonian-Carboniferous sequences.

The distribution and variations in thickness of the Yarrol Basin sequence suggest that the area south of Marlborough was near the western margin of the basin and that parts of the Silurian-Devonian rocks were emergent at times or throughout the whole period of deposition. The Lower Carboniferous sequence is thinnest on the southwest flank of the Craigilee Anticline where it is up to 600 m thick; east of the Craigilee Anticline, the thickness ranges from about 900 m in the south to about 2400 m in the north. The Lower Carboniferous sequence is disconformably overlain by the Neerkol Formation throughout this area, but there is no evidence that the thickness varies because of erosion of the top of the Lower Carboniferous sequence. Apparently, the Lower Carboniferous sediments onlapped from the northeast towards the south and west over an irregular basement of Silurian-Devonian rocks.

A Lower Carboniferous conglomerate containing clasts of coralline limestone occurs near the base of the Yarrol Basin sequence in the Rockhampton Sheet area, east of the northern end of the Craigilee Anticline. The lithology of the clasts, and their contained fauna, suggest that they were derived from Silurian-Devonian limestones such as now crop out at the northern end of the Craigilee Anticline, about 38 km south-southeast of Marlborough.

The Silurian-Devonian rocks along the northwest flank of the Craigilee Anticline and in inliers farther west are overlain by Permian rocks with no intervening Carboniferous sediments. The absence of Carboniferous sediments suggests that this area lay beyond the western limit of the Yarrol Basin.

The oldest Yarrol Basin sediments in this area are represented by the block of sediments (D-Ca) northwest of the Craigilee Anticline. The sequence includes basal volcanics containing an Upper Devonian fauna. No equivalents of this fauna or of the volcanics have been found in the Yarrol Basin sequence in the Craigilee Anticline. Sedimentation in this area probably began in a small embayment bordered to the west and south by Silurian-Devonian rocks. Detritus from Silurian-Devonian rocks was carried eastward into the main Yarrol Basin at least during the Lower Carboniferous, until the area was gradually onlapped from the northeast to southwest.

The palaeogeography of this part of the Yarrol Basin is complex, and is not well known.

The sequence of Long Island is not well known. There is apparently no thinning or onlapping of units and the sequence was presumably deposited away from the margin of the basin. The similarity of the rock types, sequence, and faunas to those in the main part of the Yarrol Basin indicates continuity of the depositional area. The separation of these sediments from the rest of the Yarrol Basin is apparently the result of post-depositional folding, faulting, and erosion.

UPPER CARBONIFEROUS TO PERMIAN

In Upper Carboniferous to Permian times the Bulgonunna Volcanics, Joe Joe Formation, and Torsdale Beds were deposited in widely separated areas around the margins of the Bowen Basin. The Bulgonunna Volcanics are probably the oldest of the three. They consist predominantly of terrestrial volcanic rocks and associated contemporaneous intrusive rocks on the northeast margin of the Clermont Stable Block. They were formed during the last episode of violent tectonism before stabilization of the

Clermont Block. The Joe Joe Formation consists of freshwater sediments some of which are of fluvioglacial origin (Pl. 5, fig.2); the Torsdale Beds contain ill sorted conglomerates of possible fluvioglacial origin; both may have been deposited during the same glacial epoch.

These three rock units are described in Table 3.

Bulgonunna Volcanics

The Bulgonunna Volcanics (named by Malone et al., 1964; revised by Malone et al., 1966) are a massive wedge of volcanic rocks. The formation thins to the west, where it unconformably overlies the Drummond Group, and disappears to the east under the unconformably overlying Lizzie Creek Volcanics. The southern boundary is obscured by Tertiary sediments. The Bulgonunna Volcanics lie between Lower Carboniferous and Lower Permian rocks. Several samples from Upper Carboniferous plutons intruding the Bulgonunna Volcanics have given concordant isotopic mineral ages of about 285 m.y. which set an upper limit to the age of the volcanics. Two samples from the Devonian-Carboniferous granodiorite near the western margin of the Bulgonunna Volcanics gave anomalous mineral ages of about 290 and 294 m.y. A third sample from the Devonian-Carboniferous granodiorite gave a minimum age of about 330 m.y., and stratigraphic data suggest that the real age may be about 360 m.y. The two samples which yielded anomalous results were probably collected at shallow depth below the surface on which the Bulgonunna Volcanics were extruded, and the low ages may be the result of reheating and recrystallization under the volcanic pile. The age of the Bulgonunna Volcanics and associated igneous intrusions probably ranges from about 295 to 285 m.y., which indicates that they are significantly younger than the Connors Volcanics.

The Bulgonunna Volcanics consist mainly of rhyolite extrusives. The rhyolite flows generally have contorted flow banding which wraps around the quartz, orthoclase, plagioclase, and hornblende phenocrysts. Two other types of porphyritic rhyolite are common: one contains scattered phenocrysts in a dark fine weakly flow-banded glassy or felsitic groundmass; the other, which consists mainly of phenocrysts set in a flow-aligned groundmass, may be a welded ash-flow tuff. The formation includes some dark grey rhyolite porphyry, containing phenocrysts of quartz and feldspar in a fine groundmass of biotite and aphanitic material, which may be the intrusive equivalent of the rhyolites. Possible intrusive rocks were noted in a number of localities, but they generally graded into flow-banded rhyolite of similar composition at their margins. Dacite, toscanite, trachyandesite, and rare augite trachyandesite are important constituents of some of the volcanic lenses which constitute the Bulgonunna Volcanics.

Crystal and lapilli tuffs, agglomerate, and volcanic conglomerate make up less than half of the formation. The volcanic conglomerate is possibly a mud-flow conglomerate; it is poorly sorted and contains rounded bombs(?) of porphyritic rhyolite set in a red-brown tuffaceous matrix. Sediments, mainly derived by reworking of tuffs, are a minor constituent of the formation. Near its western margin, the Bulgonunna Volcanics contain a 3-m bed of basal conglomerate which rests unconformably on the Drummond Group; the conglomerate contains rounded pebbles of acid volcanics and quartzite in a hard siliceous matrix.

The Bulgonunna Volcanics consist of a massive wedge composed of an imbricate pile of lenticular basin fills or sheets. The volcanics exhibit depositional dips up to 35° around the margins of the basins. Steeper dips occur on the faulted margins of the basin; the faults are possibly marginal to foundering blocks.

Faulting and jointing are common. In places the joints have a characteristic pattern consisting of an unjointed central boss of porphyritic rhyolite surrounded by porphyritic rhyolite flows with numerous tangential to radial joints.

The apparent absence of a fossil flora from the Bulgonunna Volcanics is surprising. The volcanics contain water-laid sediments, which were probably deposited without much reworking, in which one would expect to find some trace of the vegetation to be preserved. Possibly the growth of vegetation was inhibited by an extremely cold climate during a glacial epoch which persisted until deposition of the Joe Joe Formation began.

Joe Joe Formation

The Joe Joe Formation, the youngest unit in the Clermont Stable Block, was deposited on a peneplaned surface which truncates the folded Drummond Basin sequence. This surface and the overlying Joe Joe Formation were subsequently tilted gently to the south during subsidence of the Bowen Basin and the succeeding Great Artesian Basin. The base of the Joe Joe Formation is structurally conformable on the Ducabrook Formation in the troughs of synclines, but unconformably overlaps progressively older units on the eroded crests of plunging anticlines. The Joe Joe Formation was bevelled by erosion before the overlying thin discontinuous sequence of Reids Dome Beds was laid down. The Colinlea Sandstone, which disconformably succeeded the Reids Dome Beds, rests unconformably on the Joe Joe Formation in many places.

The formation was first described in unpublished reports by geologists of Shell (Qld) Development Pty Ltd (SQD, 1952) and the name was subsequently published by Hill (1957). The main reference to the Joe Joe Formation in the Bowen Basin map area is in Mollan et al. (1969).

Farther west, petroleum exploration wells have penetrated a section of the Joe Joe Formation which includes younger sediments than are present in the type area. Palynological studies (Evans, 1966b) indicate that the formation is mainly Upper Carboniferous, but may range into the Permian.

Torsdale Beds

The Torsdale Beds were first referred to by Dear (Dear & Jensen, 1965) and are defined and described by Dear et al. (1971), who regard it as Upper Carboniferous to Permian in age. Part of the Torsdale Beds, as mapped by Dear et al., are included in the pre-Permian part of the Camboon Andesite in the map area (see discussion below). The Torsdale Beds shown on the map overlie or are faulted against the Camboon Andesite, Auburn Complex, and Back Creek Group. Their relationships are uncertain.

The beds consist of conglomerate, coarse to very fine clastic sediments, some chert, and a variety of acid to intermediate volcanics. The conglomerates are possibly fluvioglacial in origin and the Torsdale Beds may have been deposited during the same glacial epoch as the Joe Joe Formation.

LOWER PERMIAN AND OLDER

The Camboon Andesite and Rannes Beds both contain rocks of known Lower Permian age and both also apparently contain pre-Permian rocks; the Rannes Beds also probably include some Upper Permian sediments.

Camboon Andesite

The name Camboon Andesite was first published by Derrington, Glover, & Morgan (1959) and was referred to by Derrington & Morgan *in* Hill & Denmead, eds, 1960, p. 204). As originally defined, the unit consists of andesitic volcanics unconformably overlain by the Back Creek Group. The type area is near Camboon homestead, after which the formation was named. The name was applied to all the volcanics between the Auburn Complex and the Back Creek Group (Laing *in* Hill & Denmead, eds, 1960, p. 216) and this usage has been followed on the accompanying 1:500,000 geological map, and in reports on the regional mapping of the Bowen Basin. The Camboon Andesite contains a *Glossopteris* flora near Cracow (Wass, 1965) and a Lower Permian marine fauna in limestone interbeds near Prospect Creek (J.F. Dear, pers. comm.). These fossils establish the Lower Permian age of part of the Camboon Andesite.

A unit between the Camboon Andesite and the Auburn Complex has been delineated on the preliminary edition of the Monto Geological Sheet (1965) as Torsdale Beds. The Torsdale Beds are shown on the geological map of the Bowen Basin in the Prospect Creek area only. The 'Torsdale Beds' shown west of the Auburn Complex on the Monto preliminary edition are thought to be intruded by the complex. Since samples from the Auburn Complex have given isotopic mineral and total rock ages of about 311 m.y., the unit mapped is older than Upper Carboniferous and is not equivalent to the Torsdale Beds of the Prospect Creek area, which are Upper Carboniferous or Lower Permian. The unit is not distinguished from the Lower Permian part of the Camboon Andesite on the 1:500,000 map. The precise age of the isolated blocks of Camboon Andesite is also unknown. Thus, the Camboon Andesite, as used in this Bulletin, consists of an upper unit of Lower Permian volcanics and a lower volcanic unit probably older than Upper Carboniferous which is intruded by the Auburn Complex.

The Camboon Andesite crops out along the western flank and around the northern end of the Auburn Arch and in isolated fault blocks and anticlinal cores to the north. It is overlapped to the south by the Great Artesian Basin sequence. The formation was mapped in the western part of the Mundubbera Sheet area (Mollan et al., 1971), in the Gogango Range area (Olgers, Webb, Smit, & Coxhead, 1964), and in the southeastern part of the Duaringa Sheet area (Malone et al., 1969). Descriptions of the Camboon Andesite and Torsdale Beds, including the older part of the Camboon Andesite in the Monto Sheet area, are contained in a forthcoming publication (Dear et al., 1971). The distribution and tentative subdivision of the Camboon Andesite is presented in Plate 1.

Gogango Range Area

The Gogango Range area includes adjacent corners of the Duaringa, Rockhampton, Baralaba, and Monto Sheet areas and extends north-northwest from 8 km south of Rannes to the Fitzroy River. The Camboon Andesite crops out in a series of elongate blocks, which are partly bounded by faults, or in the cores of anticlines. About two-thirds of the formation consists of flow rocks with minor intrusions; the remainder consists partly of pyroclastics and partly of sediments derived from volcanic rocks. Almost all the rocks show the effects of diagenetic or hydrothermal alteration, and are sheared, foliated, and recrystallized to varying degrees as a result of dynamic metamorphism.

Most of the intermediate to basic volcanics are so altered and deformed that it is difficult to distinguish flows, intrusions, and pyroclastics. About 100 thin sections from this area were examined*.

Most of the rocks are so altered that it is difficult to identify the original minerals present, but the descriptions provide a reliable guide to the main rock types present.

Most of the lavas range from andesite to basalt, but a few trachyte and rhyolite flows are present. The andesites are light greenish grey to dark or purplish grey, fine to medium-grained, commonly altered, sheared, and foliated. They consist of feldspar (usually andesine), clinopyroxene, chlorite, sericite, clinozoisite, epidote, quartz, and siderite. The textures are crudely fluidal, intersertal, subophitic, or rarely hypidiomorphic-granular. Some contain phenocrysts of feldspar and clinopyroxene or their alteration products. Some flows contain amygdales of epidote, chlorite, calcite, quartz, and penninite, and a few contain xenocrysts of quartz; the amygdales are elongated and aligned by shearing in some flows. Most of the feldspars are sericitized or

* All the thin sections were examined by Miss B.R. Houston of the Geological Survey of Queensland (see Malone, Mollan, Olgers, Jensen, Gregory, Kirkegaard, & Forbes, 1963, appendix 6; Olgers et al., 1964, appendix 6).

replaced by quartz, chlorite, epidote, and clinozoisite; and clinopyroxenes are largely replaced by actinolite, clinozoisite, chlorite, and epidote.

The basalt flows are as numerous as the andesites. They vary widely in the degree of alteration and shearing, and in composition. Some are nearly identical in texture and composition with the more basic andesite flows. Albite is present in some flows, and is the dominant feldspar in one, in which it is associated with calcite. In general, the basalt flows are very fine to medium-grained, grey to dark greenish or purplish grey, and are slightly to extensively sheared and foliated. The textures are subophitic, intersertal, or intergranular. They consist mainly of andesine or labradorite, with some oligoclase and albite, orthopyroxene, clinopyroxene, and olivine. The secondary minerals include sericite, chlorite, epidote, serpentine, hydrogrossularite, clinozoisite, and penninite. Some flows contain phenocrysts of altered feldspar, clinopyroxene, epidote pseudomorphs after pyroxene, serpentine pseudomorphs after olivine(?), and chlorite pseudomorphs. Some flows contain amygdales of quartz, chlorite, epidote, and calcite.

One of the flows, which contains about 35 percent albite, 40 percent chlorite, 10 percent calcite, minor hydrogrossularite, and about 15 percent calcite and chlorite amygdales, is possibly a spilite. The feldspars in other basalt flows are partly albitized, possibly during hydrothermal alteration or as a result of incipient spilitization.

High-level intrusions are moderately common in the volcanic pile. Most of them consist of grey-green fine-grained slightly to extensively altered and sheared diorite, composed of oligoclase-andesite (saussuritized and partly replaced by alkali feldspar), uralitized pyroxene or clinopyroxene, and chloritized tremolite. Some of the basalts may be high-level intrusions also.

All the flows and high-level intrusions are possibly comagmatic as they are generally similar in mineralogical composition, and in the type and degree of alteration. The Camboon Andesite in this area contains a little sheared and altered trachyte which could be related to the andesite-basalt extrusives and rare porphyritic rhyolite.

Pyroclastic rocks and sediments constitute about one-third of the Camboon Andesite in the Gogango Range area. The pyroclastics consist mainly of lithic, crystal, and vitric tuff, ash-flow tuff, and agglomerate. The pyroclastic rocks are sheared and hydrothermally altered, and in places the groundmass has been recrystallized. Most of the clasts in the pyroclastic rocks are similar to the andesite and basalt lavas.

The finer-grained sediments have been sheared and recrystallized to slate, phyllite, and mica schist and less commonly silicified to cherty mudstone. The coarser sediments include pebbly volcanolithic arenite. The clasts in the arenites were probably formed by reworking of unconsolidated volcanic detritus. The presence of graded bedding in interbedded volcanolithic greywacke and mudstone and the immaturity of the clasts suggest deposition from a turbid volcanic mud flow with little reworking. Some of the arenites have a calcite cement. At one place the formation contains foliated and slightly recrystallized calcirudite. The similarity of the calcirudite to those in the adjacent Rannes Beds suggests interfingering of the Camboon Andesite and Rannes Beds.

In places, the Camboon Andesite includes pahoehoe lava with ropy structures on the flow surfaces and lava rolls; it is closely associated with agglomerate, volcanic breccia, and tuff. The presence of pahoehoe lava indicates subaerial extrusion, but elsewhere, the flows interbedded with well bedded tuff and mudstone were probably laid down under water. The possible presence of spilite and spilitized flows suggests diagenetic adjustment to a hydrous environment, and the presence of crinoidal limestone in the Rannes Beds indicates a marine environment. Thus, the Camboon Andesite in the Gogango Range area is partly subaerial and partly marine. The Camboon Andesite in the Gogango Range area appears to consist of only one unit.

The Camboon Andesite is overlain by or is locally contemporaneous with the Rannes Beds. The contacts are generally gradational and in places the two interfinger. The common occurrence of Camboon Andesite in the cores of anticlines surrounded by Rannes Beds, however, indicates that most of the Camboon Andesite is older than the Rannes Beds.

Monto Sheet Area

The Lower Permian part of the Camboon Andesite in the southwest corner of the Monto Sheet area is similar in lithology to the sequence in the Gogango Range. In general, it lacks the shearing and intense hydrothermal alteration noted in the Gogango Range, but this may reflect the lack of structural deformation on the west flank of the Auburn Arch. The rocks in the tightly folded Prospect Creek area are more altered.

In the Prospect Creek area the Camboon Andesite includes beds of limestone containing early Lower Permian fossils. Species of the *Glossopteris* flora occur in sediments within the volcanics west of the Auburn Arch. In the west, the Camboon Andesite contains beds of conglomerate near the base. The boulders of granite in the conglomerate were presumably derived from the Auburn Complex.

The pre-Permian part of the Camboon Andesite is thought to be intruded by the Auburn Complex. The sequence consists mainly of acid to intermediate volcanics similar to those of the Camboon Andesite in the Mundubbera Sheet area.

Mundubbera Sheet Area

The Camboon Andesite in the Mundubbera Sheet area is described in Mollan et al. (1971). It occupies a narrow longitudinal strip between the Auburn Complex to the east and the overlying Back Creek Group to the west. It is overlapped by the Great Artesian Basin sequence to the south and extends northwards into the Monto Sheet area, where it has been divided into two parts (see Pl. 1).

The formation consists of lava flows, some pyroclastics, and minor sediments, mainly conglomerate. The lava flows consist mainly of andesite and dacite, with subordinate rhyolite and rare trachyandesite. Hornblende is the only mafic mineral present in the lavas. Hydrothermal alteration of the feldspar and hornblende to sericite, chlorite, epidote, and calcite is common, but the degree of alteration is less intense than in the Gogango Range area.

The crystal, lapilli, lithic, and vitric tuffs and agglomerates appear to be mainly andesitic to dacitic in composition. The local beds of conglomerate are up to 24 m thick, and possibly belong to the Lower Permian part of the unit. They contain rounded cobbles of andesite, dacite, and granite: the andesite and dacite clasts were probably derived from the underlying pre-Permian volcanics, and the granite clasts were presumably derived from the Auburn Complex. Similar beds of conglomerate occur at the base of the Lower Permian part of the formation in the Monto Sheet area to the north (J.F. Dear, pers. comm.).

The Camboon Andesite is intruded by a few small stocks of microdiorite, and by dykes of quartz basalt, andesite, and aplite.

The Camboon Andesite in the Mundubbera Sheet area consists mainly of intermediate to acid volcanics and associated sediments, but regional considerations indicate that the formation includes both the Lower Permian and pre-Permian parts. Since most rocks are unlike the Camboon Andesite in the Gogango Range area, most of the formation in the Mundubbera Sheet area is probably older than Upper Carboniferous, overlain by a relatively thin Lower Permian volcanic sequence. The relationship of the older unit with the Auburn Complex is uncertain, but is probably intrusive. The volcanics near the contact are extensively veined with quartz and are generally hydrothermally altered; the contact itself is locally irregular.

Rannes Beds

The Rannes Beds crop out in an elongate dogleg belt which extends from near Goovigen in the Monto Sheet area to west of Marlborough in the Saint Lawrence Sheet area. The beds have also been tentatively identified in an isolated block south of Biloela. The Rannes Beds in the Gogango Range area of the Duaringa, Rockhampton, Baralaba, and Monto Sheet areas were mapped in considerable detail in 1963; the results of this work and many petrographic descriptions by Miss B.R. Houston of the Geological Survey of Queensland are contained in an unpublished report (Olgers et al., 1964). The entire Rannes Beds are described in Malone et al. (1969), which incorporates much of the unpublished data.

The Rannes Beds consist predominantly of mudstone and arenite, but locally the sequence contains considerable amounts of volcanics, conglomerate, and calcareous sediments. The mudstone and arenite occur as thick to thin-bedded homogeneous units, or are thinly to thickly interbedded with one another or with the other rock types. The entire sequence has undergone low-grade regional metamorphism and low-grade to locally moderate dynamic metamorphism. The argillaceous sediments have been converted to foliated mudstone, slate, phyllite, mica schist, and sericite schist. In the arenites the matrix has been slightly or largely recrystallized, and the rocks are foliated or fracture-cleaved. Where mudstone and arenite are interbedded, the mudstone is closely foliated and the arenite is cut by widely spaced joints and fracture cleavage planes.

Shearing, foliation, and recrystallization of the fine lithic and crystal tuffs and tuffaceous sediments is common. The chlorite schist cropping out in one place was apparently formed by intense shearing of a very fine crystal-lithic tuff. The lavas and agglomerate are generally sheared and silicified, but show few affects of recrystallization. The basalt in the Gogango Range area is extremely altered and sheared and closely resembles similar rocks in the underlying Camboon Andesite. Silicification, shearing, incipient recrystallization of the matrix, and elongation and alignment of pebbles is common in the volcanic and quartz-lithic conglomerates.

Calcareous sediments are common only in the southern part of the Gogango Range. They include pinkish grey sheared and recrystallized crinoidal calcarenite; foliated fine-grained partly recrystallized pebbly limestone containing flattened and aligned pebbles of volcanic rocks; and fossiliferous pink and grey limestone, partly recrystallized to marble, interbedded with volcanics and tuffaceous sediments.

The Rannes Beds crop out in a structural zone referred to as the Gogango Overfolded Zone. The beds generally dip at between 40° and 70° to the east and are apparently tightly folded and overfolded. Recumbent folds are exposed in road cuttings in the Gogango Range west of Grantleigh siding (Pl. 4, fig. 2); all flanks of these folds dip to the east at less than 40° and the axial planes dip at 15° to the north-northeast. The Rannes Beds cropping out in a road cutting 6.5 km west of Grantleigh homestead are folded into small folds with flank dips of about 30° and vertical axial planes; these beds are cut by many normal faults and are less closely foliated than most of the Rannes Beds. In many areas, the bedding is obscured by shearing.

The foliation generally dips steeply east and generally cuts the bedding at angles of up to 45°. It does not appear to bear a constant relationship to the folds. Possibly, the beds were folded first and then foliated during a subsequent period of deformation which also modified the existing folds. Two directions of foliation were noted in a few outcrops. Small normal and thrust faults are common; the easterly dip of the thrust faults indicates compression from the east. Joints and quartz veins are common, particularly adjacent to lineaments, which can be readily identified on the air-photographs; the lineaments probably represent fault zones.

The Rannes Beds overlie and interfinger with the Camboon Andesite in the south and mainly overlie the Connors Volcanics in the north; in one area, they appear to underlie an east-dipping wedge of Connors Volcanics, but the contact is concealed and the relationship may be the result of faulting. The Rannes Beds are overlain by the Rookwood Volcanics to the east and are unconformably overlain by the Upper Permian

Boomer Formation. The unconformity is exposed 60 km north of Duaringa where the Boomer Formation dips at 10° to the west off the underlying Rannes Beds dipping at about 70° to the east. The relationship of the Rannes Beds to the Lower Permian basal part of the Back Creek Group is obscure. Rare fossils indicate that the basal part of the Back Creek Group has been included with the Rannes Beds in a few places, but the contacts in such places are possibly faulted. The basal part of the Back Creek Group is separated from the overlying Boomer Formation or its equivalents by a disconformity, or by a slight angular unconformity where the middle part of the Back Creek Group is missing. Where the group is complete, the Boomer Formation is conformable within the Back Creek Group. Where a marked angular unconformity separates the Rannes Beds from the Boomer Formation, the Rannes Beds presumably include sediments of pre-Permian age which are possibly the same age as the Connors Volcanics. However, most of the Rannes Beds in the Gogango Range are probably the same age as the Lower Permian part of the Camboon Andesite. In the north, the Rannes Beds include some of the lower part of the Back Creek Group and possibly some of the Carmila Beds.

The younger sediments included in the Rannes Beds belong mainly to the Boomer Formation, from which they are difficult to separate. The Boomer Formation includes lithic arenite and mudstone similar to those in the Rannes Beds, all of which in the Gogango Overfolded Zone have been folded, cleaved, and faulted. The abundance of faults in this zone precludes generalization over large areas.

Petrographic examination suggests that the Rannes Beds have been more strongly metamorphosed than the Boomer Formation. Recrystallization of argillaceous material is much farther advanced in the Rannes Beds, and the arenites in the Boomer Formation are indurated rather than metamorphosed as they are in the Rannes Beds. It may be possible to separate the two by detailed mapping and petrographic studies. Mapping of the pre-Permian part of the Rannes Beds, where they are markedly unconformable under the Boomer Formation, may be more difficult.

The block of Rannes Beds south of Biloela is lithologically similar to but more sheared than the Upper Permian Blenheim Subgroup sediments (shown on the 1:500,000 geological map as Back Creek Group, undifferentiated), from which it is separated by a fault. It may be of Upper Permian age, but is more structurally deformed than the Blenheim Subgroup. It is possible that the Rannes Beds in the Gogango Range and farther north contain equivalents of the Boomer Formation which are regarded as Rannes Beds because they have been more highly deformed than the bulk of the Boomer Formation. Such a situation may exist east of Duaringa, where the structures appear to cut across the boundary between the Rannes Beds and Boomer Formation, and where the Boomer Formation appears to underlie Rannes Beds, though the boundary is faulted. The distinction between the Rannes Beds and Boomer Formation is based on the difference in the degree of structural deformation and differences in gross lithology. The Rannes Beds are mainly lutites and are isoclinally folded and overfolded; the Boomer Formation consists of interbedded arenites and lutites folded into relatively broad asymmetrical folds. The structural differences may be due to differences in lithology: the lutites could have been shear-folded into an isoclinal pile, while the interbedded arenites/lutites were folded by flexural-slip folding into more open folds. Alternatively, the lutite sequence may belong to the Lower Permian Rannes Beds and the structures may have been developed partly during an earlier period of deformation and partly during the more important Upper Permian orogeny. If these Rannes Beds are Lower Permian, detailed structural studies may reveal the existence of a subfabric not present in the Boomer Formation; complete similarity of fabrics in the two units would suggest their time equivalence but would not be conclusive.

The data available at present are inadequate to determine the age and relationships of all the rocks mapped as Rannes Beds.

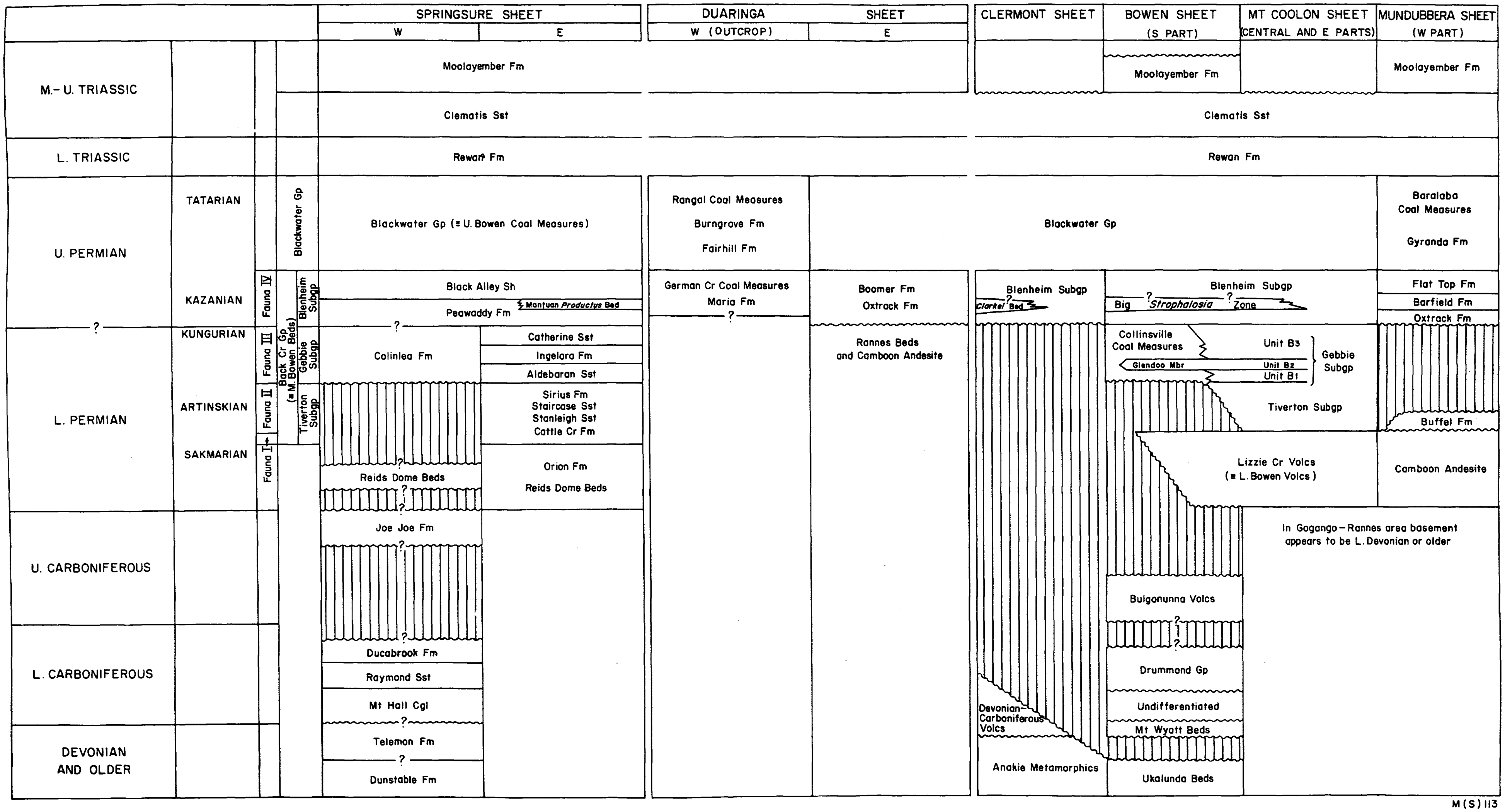

Figure 7. Correlation of Permian formations.

Conclusions

Three predominantly volcanic units can be recognized around the Auburn Arch: the pre-Upper Carboniferous acid to intermediate volcanics, intruded by the Auburn Complex and shown as Camboon Andesite on the 1:500,000 geological map, but tentatively distinguished separately on Plate 1; the Upper Carboniferous to Lower Permian Torsdale Beds in the Prospect Creek area; and the intermediate to basic volcanics belonging to the Lower Permian part of the Camboon Andesite.

The Rannes Beds are perhaps partly lateral equivalents of and partly younger than the Lower Permian part of the Camboon Andesite. North of Duaringa, they include rocks which are unconformable beneath the Boomer Formation and possibly of about the same age as the Connors Volcanics. Elsewhere, the Rannes Beds probably include equivalents of the basal part of the Back Creek Group, the top part of the Carmila Beds and, perhaps most commonly, of the Boomer Formation.

There is at least one other possibility. The Camboon Andesite and associated Rannes Beds of the Gogango Range area may not be of the same age as the fossiliferous Lower Permian Camboon Andesite on the flanks of the Auburn Arch. The Gogango Range units may be pre-Permian and are possibly of the same age as the Rannes Beds and associated Connors Volcanics which are unconformable beneath the Boomer Formation farther north. The pre-Permian age is supported by the size of the crinoid stem ossicles in the limestones in the Rannes Beds; the ossicles are generally about 3 mm in diameter, which is very much smaller than the ossicles found in the fossiliferous Permian rocks. No diagnostic fossil faunas have been found in the Gogango Range area. A small coral fauna has been collected near Thuriba homestead, 19 km northwest of Rannes. The corals have been recrystallized and the internal structure partly destroyed. However, they are similar in shape and size to the corals in the Silurian-Devonian faunas of the Craigilee Anticline to the north and are dissimilar to the corals in the Permian rocks of the Gogango Range area. This possible indication of pre-Permian age cannot be ignored in the absence of positive proof of a Permian age for the Camboon Andesite and Rannes Beds in the Gogango Range.

Even if the Rannes Beds in the Gogango Range area are pre-Permian, this does not affect the probability that the Rannes Beds, as mapped, include some Lower Permian and Upper Permian sediments.

PERMIAN-TRIASSIC STRATIGRAPHY OF THE BOWEN BASIN

The Permian-Triassic sequence was first mapped in the Bowen River area (Jack, 1879a,b). The basin is only part of the original depositional area. It has a structurally deformed eastern margin which bears little resemblance to the eastern boundary of the depositional basin, and a mildly deformed western margin which approximately coincides with the boundary of the depositional basin. To the south the Bowen Basin is concealed beneath the Jurassic-Cretaceous sequence of the Great Artesian Basin.

Deposition in the Bowen Basin began in four areas in the early Lower Permian, when the Reids Dome Beds were laid down in the Denison Trough, the Camboon Andesite in the Auburn area, and the laterally equivalent and locally continuous Lizzie Creek Volcanics and Carmila Beds in the northern part of the basin. These sequences were laid down in separate downwarps within the basin. Later, in the Lower Permian, sedimentation became more widespread, and from then onwards the sequence laid down was generally continuous throughout the basin. The rock units of basinwide extent comprise the Back Creek Group and its three subgroups, the Tiverton, Gebbie, and Blenheim Subgroups; the Blackwater Group; and the three formations of the Mimosa Group, the Rewan Formation, Clematis Sandstone, and Moolayember Formation. The thickness and lithology of these units varied from area to area and the loci of maximum sedimentation of successive units shifted from place to place through time. The term 'basinwide extent' indicates that each of the units was deposited over the entire depositional area existing at that time.

As a result of structural deformation, the Bowen Basin sequence is well displayed in several separate areas of outcrop which are mostly connected subsurface. Interpretation of the Permian-Triassic stratigraphy of the whole basin is based on identification of the rock units of basinwide extent in these various areas. The Back Creek Group and its subgroups and the Blackwater Group consist of different formations in different areas. The basinwide units can be identified by their gross lithology, stratigraphic sequence, and the type of lithological changes at unit boundaries, and they can be correlated from area to area by their outcrop and subsurface distribution and by palaeontological data. The Mimosa Group is represented by the same three formations everywhere (see Fig. 7).

EARLY LOWER PERMIAN

The Camboon Andesite and Rannes Beds have been discussed above. The Reids Dome Beds, Lizzie Creek Volcanics, and Carmila Beds are briefly described in Table 4. The distribution and thickness of the four early Lower Permian rock units are shown in Figure 8; the isopachs and estimated thicknesses are based on outcrop data and a limited amount of subsurface data.

The distribution of the Camboon Andesite shown on Figure 8 refers only to the known Permian part of the unit. The western limit of the Camboon Andesite is mainly hypothetical, except near the Burunga well.

Reids Dome Beds

The Reids Dome Beds crop out in the core of the Springsure Anticline, where the exposed sequence was named the Orion Formation in an unpublished report by Patterson (1955). The only other outcrop is the thin sequence between the Joe Joe Formation and Colinlea Sandstone 109 km west of Springsure. The Reids Dome Beds are best known in petroleum exploration wells. A maximum thickness of 9057 feet (2760.5 m) was penetrated in AAO Westgrove 3, though this well did not reach the bottom of the unit. The thicknesses penetrated in various wells are listed in Table 5.

The Reids Dome Beds are named and described in Mollan et al. (1969). They consist essentially of: (1) A basal unit of black shale and mudstone with coal seams and anhydrite layers and interbeds of hard carbonaceous anhydritic sandstone and orthoquartzite; the basal unit contains elements of the *Glossopteris* flora and is probably Permian in age. (2) A middle unit of black to grey carbonaceous micaceous shale, siltstone, and sandstone with minor coal and thin dolomite beds and local thick beds and polymictic conglomerate, particularly in the south; the thick sequence of interbedded volcanolithic pebble conglomerate and lithic feldspathic sandstone (volcanolithic?) at the base of AFO Rolleston 1 possibly belongs to this middle unit. (3) An upper unit of interbedded fine to coarse carbonaceous sandstone, dark carbonaceous siltstone and shale, and coal. The upper unit includes the Orion Formation.

The abundant *Glossopteris* flora in the middle and upper units indicates a Permian age. The stratigraphic position of the Reids Dome Beds indicates that they are no younger than early Lower Permian. Rare marine fossils were noted in the sequence in AAO Kildare 1, but the depositional environment was dominantly non-marine.

The stratigraphic relationships on the Springsure Anticline and in some of the well sections indicate that the Tiverton Subgroup transitionally succeeded the Reids Dome Beds in places. Relationships in other wells and the presence of conglomerate in the Tiverton Subgroup suggest that it is disconformable on the Reids Dome Beds elsewhere.

The possible distribution of the Reids Dome Beds is shown in Figure 8. The occurrence of andesite at the base of the Morella 1 well poses some problems. The occurrence of andesite pebbles in the basal beds of the overlying Tiverton Subgroup

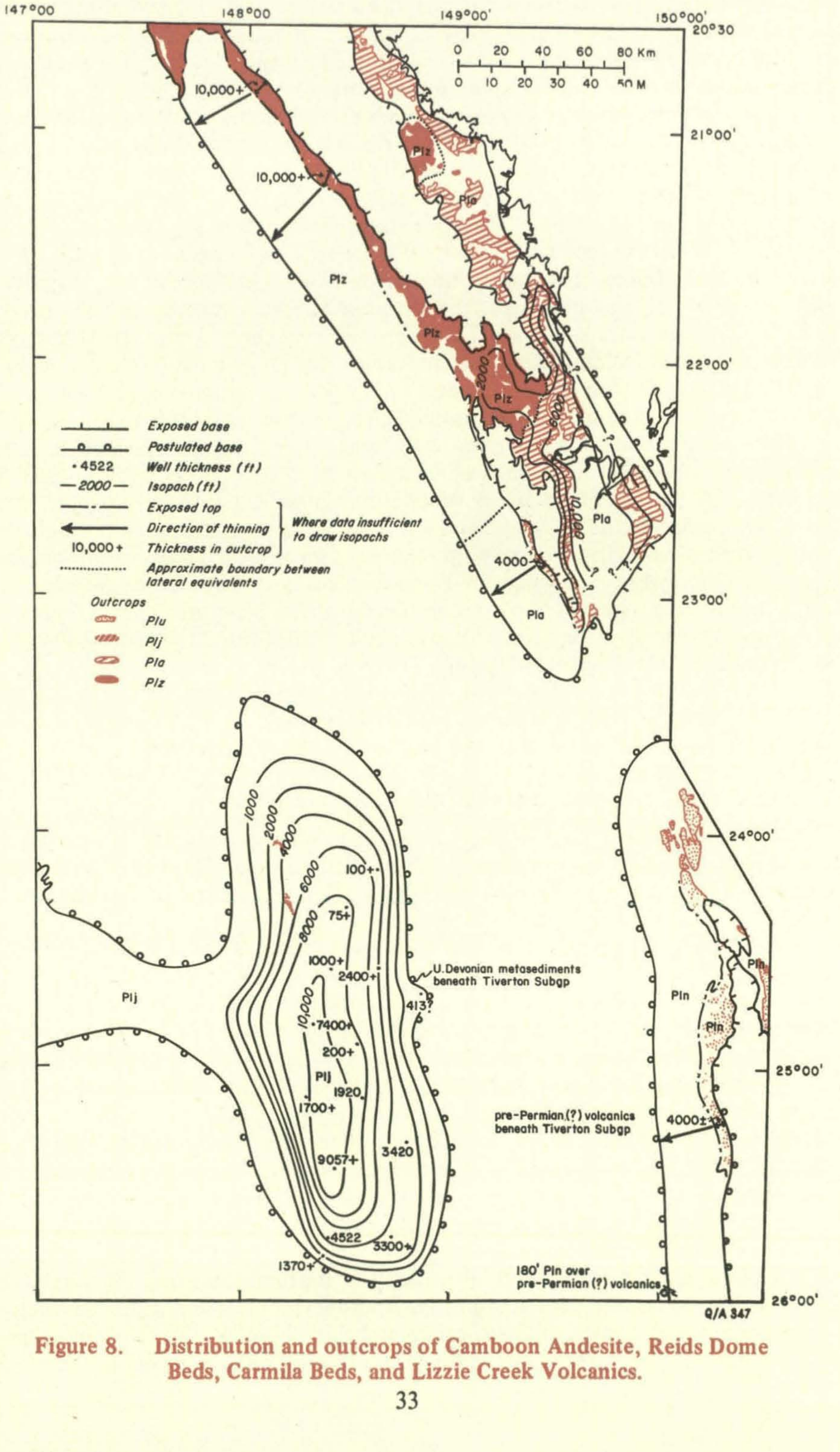

Figure 8. Distribution and outcrops of Camboon Andesite, Reids Dome Beds, Carmila Beds, and Lizzie Creek Volcanics.

suggests that the andesite is the older. If the andesite is also older than the Reids Dome Beds, then it was part of an irregular basement ridge projecting into the depositional area of the Reids Dome Beds. Alternatively, the andesite represents local volcanism during deposition of the Reids Dome Beds. The occurrence of volcanolithic(?) sandstone and volcanolithic pebble conglomerate in the Reids Dome Beds in the Rolleston 1 and AAO 7 (Arcadia) wells lends some support to this interpretation.

In previous interpretations (e.g. Malone, 1964a) the andesitic volcanics in the AAO 7 (Arcadia), Morella 1, and Glenhaughton 1 wells were correlated with the Camboon Andesite. The present interpretation, illustrated in Figure 8, suggests that the Reids Dome Beds are separated from the Camboon Andesite by a ridge of pre-Permian rocks. This is supported by the presence of plant-bearing metasediments below the Tiverton Subgroup in Purbrook 1. The rocks below the Tiverton Subgroup in other wells beyond the eastern extent of the Reids Dome Beds contain no palaeontological evidence of age. In Cabawin 1, 160 km south of the map area, the Tiverton Subgroup unconformably overlies probable pre-Permian volcanics of which the upper 60 m are deeply weathered. About 20 km farther south, the volcanic basement rocks beneath the Moonie oil field have been isotopically dated as Carboniferous or older. Although these meagre data refer to a very large area, they tend to support the hypothesis of a pre-Permian ridge between the Reids Dome Beds and the Camboon Andesite rather than to contradict it. So too does the following interpretation of the sequence at the base of Burunga 1. The volcanics at the base of this well consist of 54 m of white to green welded tuff and andesite flows overlying weathered calcitic hematitic andesite flows. The present interpretation is that the upper 54 m of volcanics represents the thin western edge of the Permian Camboon Andesite unconformably overlying pre-Permian volcanics. On this hypothesis, the volcanics beneath the Tiverton Subgroup in Glenhaughton 1 are pre-Permian, and were either beyond the limit of deposition of the Reids Dome Beds or exposed by erosion before deposition of the Tiverton Subgroup.

The ridge postulated as separating the depositional areas of the Reids Dome Beds and the Camboon Andesite may have been a positive topographic feature during the Lower Permian, but it has since been deeply depressed beneath the Mimosa Syncline.

Carmila Beds and Lizzie Creek Volcanics

The Carmila Beds in the Mackay Sheet area were named and described in Jensen et al. (1966). Their distribution in the southern half of the Proserpine Sheet area is described in Jensen (1963), and a more detailed description of other outcrops in the map area is given in Malone et al. (1969).

The Lizzie Creek Volcanics (previously the Lower Bowen Volcanics) were named in Malone et al. (1969). His report contains a resumé of the distribution and a full description of the formation in the Saint Lawrence Sheet area. The formation has been described as part of the Lower Bowen Volcanics in the Mount Coolon Sheet area by Malone et al. (1964), in the southern half of the Bowen Sheet area by Malone et al. (1966), in the Mackay Sheet area by Jensen et al. (1966), and in the southern half of the Proserpine Sheet area by Jensen (1963).

The distribution and some of the relationships of the Carmila Beds and Lizzie Creek Volcanics are illustrated in Figure 8. In the northeast the Carmila Beds are bounded by uplifted pre-Permian rocks, but the area of deposition probably extended farther northeast. The western boundary of the two units is largely hypothetical, except in the north, where the Lizzie Creek Volcanics wedge out rapidly to the west against a basement of Upper Carboniferous volcanics and intrusives. The conglomerates near the base of the Lizzie Creek Volcanics were deposited not far from their source, and it can be inferred that the westernmost outcrops of the volcanics probably lie near the shore of the original depositional basin. The exposed plan width of the Lizzie Creek Volcanics in the north, from the maximum thickness adjacent to the Urannah Complex to the western limit of outcrop, was used to locate the postulated western subsurface limit of the two units.

The areas of Urannah Complex and Connors Volcanics shown in Figure 8, flanked by the Carmila Beds and Lizzie Creek Volcanics, have been exposed as a result of post-Lower Permian tectonics which produced the Connors Arch (Pl. 3). Both Lower Permian units contain some probable terrestrial volcanics, but both contain near the top fossiliferous marine sediments which crop out east and west of the Connors Arch as well as in a few places on the arch. Thus, the entire depositional area had subsided beneath the sea by the end of the early Lower Permian. The area has since been uplifted. The thickness of the early Lower Permian units on the Connors Arch is uncertain, but was apparently considerably less than to the east or west. The crest of the Connors Arch was possibly an area of moderate subsidence flanked to the west and east by deep narrow troughs.

The gross lithology of the Lizzie Creek Volcanics is distinctly different from that of the Carmila Beds. In general they occupy separate areas, the Lizzie Creek Volcanics to the west of the Connors Arch and the Carmila Beds to the east and south. The contact on the Connors Arch is placed between acid crystal tuff of the Carmila Beds (above) and andesite agglomerate and tuff of the Lizzie Creek Volcanics: the two probably interfinger. The andesitic volcanics and associated sediments of the Lizzie Creek Volcanics were deposited in the trough to the west of the Connors Arch at about the same time as the acid volcanics and sediments of the Carmila Beds were laid down in the trough to the east. The sequence on the Connors Arch, which was probably deposited mainly late in the early Lower Permian, is a mixture of both types. The Lizzie Creek Volcanics near Hazelwood Creek contain thick sills of microdiorite, which lie along the locus of maximum thickness of the formation; possibly many of the vents from which the Lizzie Creek Volcanics were erupted lay along this line of maximum downwarping and crustal tension west of the Connors Arch. The vents supplying the Carmila Beds were possibly situated in a similar position on the eastern flank of the arch. The crest of the Connors Arch subsided below the sea late in the early Lower Permian, and at the same time volcanism ceased over most of the area. Subsidence of the Connors Arch reduced the crustal tension beneath the adjacent downwarped linear troughs, and may have been one of the causes of the cessation of volcanism.

The westernmost outcrops of Lizzie Creek Volcanics consist mainly of basaltic volcanics, and their tectonic setting is also different from that of the main outcrops. Here the formation consists of a relatively thin and only slightly folded sequence of interbedded volcanics and sediments which were laid down on a slowly subsiding stable block rather than in a narrow trough. The sediments were mainly derived from the west.

The southern boundary of the Carmila Beds (Fig. 8) is partly conjectural. In part, it is faulted against a block of serpentinite and Lower(?) Palaeozoic metamorphics which were probably uplifted in the late Lower Permian. Farther southwest, the extent of the Carmila Beds is obscured by overlying units, but it appears to be wedging out to the southeast as a result of non-deposition or of erosion after uplift in the late Lower Permian. The Carmila Beds are not present between the Boomer Formation and underlying pre-Permian rocks, and the distribution of the Tiverton and Gebbie Subgroups indicates that a large area in the southeast part of the map area was one of non-deposition and erosion during the late Lower Permian.

Relationships and Tectonics

The presence of marine fossils of approximately the same age near the top of all four early Lower Permian units or in the transitional sediments immediately above indicates a widespread marine transgression which marks the upper boundary of the non-marine early Lower Permian units. Deposition of the four units may not have started at the same time, but they must be largely contemporaneous.

The early Lower Permian units are preserved in three areas each of which has a different tectonic history (Fig. 8).

The Reids Dome Beds were deposited in the northerly trending Denison Trough, which was later uplifted along a few long north-trending anticlinal axes. The thin veneer of Reids Dome Beds west of the Denison Trough was laid down on a slowly subsiding shelf, and in the south and east, abundance of conglomerate in the Reids Dome Beds suggests considerable topographic relief along the shores of the trough.

Most of the Lizzie Creek Volcanics and Carmila Beds was deposited in long narrow troughs separated by a geanticline which provided a source of detritus for both troughs. Later the geanticline subsided beneath the sea, and finally became the locus of great uplift. The northeastern margin of the depositional basin is unknown. To the south and west, it was flanked by a slowly subsiding stable shelf on which a thin cover of sediments was laid down.

The Lower Permian Camboon Andesite consists mainly of andesite and rhyolite with only minor sediments. The formation was possibly deposited as a single elongate body, which was later cut into two parts by erosion after the uplift of the Auburn Arch. Most of the formation was possibly laid down in a terrestrial environment, but fossiliferous marine limestone occurs near the top of the sequence in the east. The presence of a disconformity in the west between the Camboon Andesite and the overlying marine sediments suggests that the marine transgression came somewhat later. The Camboon Andesite wedged out to the west against the postulated ridge which separated its depositional area from that of the Reids Dome Beds. Its relationship to the rocks in the north is obscure. They possibly wedge out against or were eroded off a block of Rannes Beds and the pre-Permian(?) part of the Camboon Andesite. An alternative explanation assumes that the Rannes Beds and both parts of the Camboon Andesite are of Lower Permian age and that the Camboon Andesite is replaced to the north by contemporaneous rock units of very different lithology. The solution of this problem is essential to an understanding of the tectonics in this area.

The abundance of conglomerate in the Reids Dome Beds indicates the presence of elevated land to the east and south of the Denison Trough, but the relief was probably greatly reduced before the fine clastics and coal of the upper part of the sequence were deposited. The land areas between the early Lower Permian depositional basins were apparently gradually eroded and perhaps peneplaned before, at the end of the early Lower Permian, the sea transgressed the entire area. The distribution of the overlying units indicates, however, that the rate of subsidence varied from place to place.

BACK CREEK GROUP

The stratigraphical unit now known as the Back Creek Group was first recognized by Jack (1879a, b; Jack & Etheridge, 1892), who applied the name 'Middle Bowen Beds' to the predominantly marine sediments of the Bowen Basin. Subsequent work has confirmed that the unit is stratigraphically well defined and of considerable extent in both space and time. It can be subdivided, and contains no major unconformities. It was referred to as the Middle Bowen Group in some publications – notably the Geological Map of Queensland (Hill, ed., 1953). The formal name Back Creek Group was first used by Derrington et al. (1959) and Derrington & Morgan (*in* Hill & Denmead, eds, 1960, pp. 204-7) for the succession in the Theodore-Cracow area, and is now applied throughout the basin.

In the northern part of the basin, Malone et al. (1966) divided the group into the Tiverton, Gebbie, and Blenheim Formations; and it was later recognized that this tripartite division was also apparent in the Springsure area, where an almost complete sequence of Back Creek Group had been mapped as many distinguishable formations.

Hence the three formations were raised to subgroup rank, and the names and concepts applied throughout the basin.

Since the three subgroups are not continuous in outcrop through the basin, this extension needs to be justified. Justification rests on four grounds, which together are thought adequate though no single one is conclusive.

First, the exposed thicknesses of the subgroups and the pattern of their surface distribution indicate that they are almost certainly continuous at depth: the Blenheim Subgroup in particular is concealed only for short distances.

Secondly, the subdivisions can be correlated throughout the basin by their faunal content. Dickins (*in* Dickins, Malone, & Jensen, 1964; Malone et al., 1969) distinguished four faunas in the northern part of the basin, of which Faunas II, III, and IV coincide with the boundaries of the subgroups erected in the same area. The faunas can be recognized throughout the basin.

Thirdly, the gross lithology of each subgroup is generally similar throughout the basin; and, more importantly, certain lithological changes occur everywhere at about the same stratigraphic level. For example, in the middle of the Gebbie Subgroup, a marine mudstone lies between paralic sandstones in the Springsure area; a marine sandstone between coal measures near Collinsville; and deeper water siltstone between shallow marine sandstones south of Collinsville. The change, according to the palaeontological evidence, took place at about the same time throughout the basin, and apparently signifies a marine transgression, followed by regression.

Lithological changes at the boundaries of the subgroups, which are roughly contemporaneous, also show a similar relationship throughout the basin; though of course over such a broad depositional area lithology varies laterally. Such lithological changes warrant the use of local formation names, but do not invalidate the concept of the subgroups as basinwide units.

Fourthly, subsurface data, particularly from petroleum exploration wells, have helped to bridge the gap between outcrops and confirm the continuity of the group and subgroups. Well data have enabled the exposed units of the Springsure area to be traced far to the east and north; and seismic and limited well data on the sequence below the Mimosa Syncline confirm the continuity of the Back Creek Group between the Springsure and Theodore-Cracow areas.

Deposition of the Back Creek Group began in the Lower Permian, possibly in early Artinskian, and continued into the Upper Permian. It was generally laid down in a marine environment, though brackish and even freshwater environments existed at times around the margins of the basin. Most of the main fossils in the Bowen Basin sequence (Faunas II, III, and IV) are contained in the group.

TIVERTON SUBGROUP

The formations of the Tiverton Subgroup are listed in Table 6 together with brief descriptions of their lithology, relationships, distribution, type area and important references. The distribution of the Tiverton Subgroup is shown in Figure 9 and the lateral relationships between the formations are diagrammatically presented in Figure 10.

The Tiverton Subgroup consists essentially of four overlapping or interfingering lithofacies: limestone, limestone/clastic, mudstone, and deltaic sandstone. The limestone facies in the southeast (the Buffel Formation) consists of a thin sequence of limestone which contains only a small proportion of fine terrigenous detritus and some coarse detritus at the base. The lithology and the type of thick-shelled brachiopods and pelecypods present, including abundant *Eurydesma,* suggest deposition in cold shallow water at a considerable distance from land. To the south, the Buffel Formation contains a greater proportion of clastics, mainly derived from volcanics. To the north in the vicinity of the Broadsound Range the sequence consists mainly of limestone with some volcanic rocks and volcanolithic sediments. Farther north, the basal part of the Tiverton

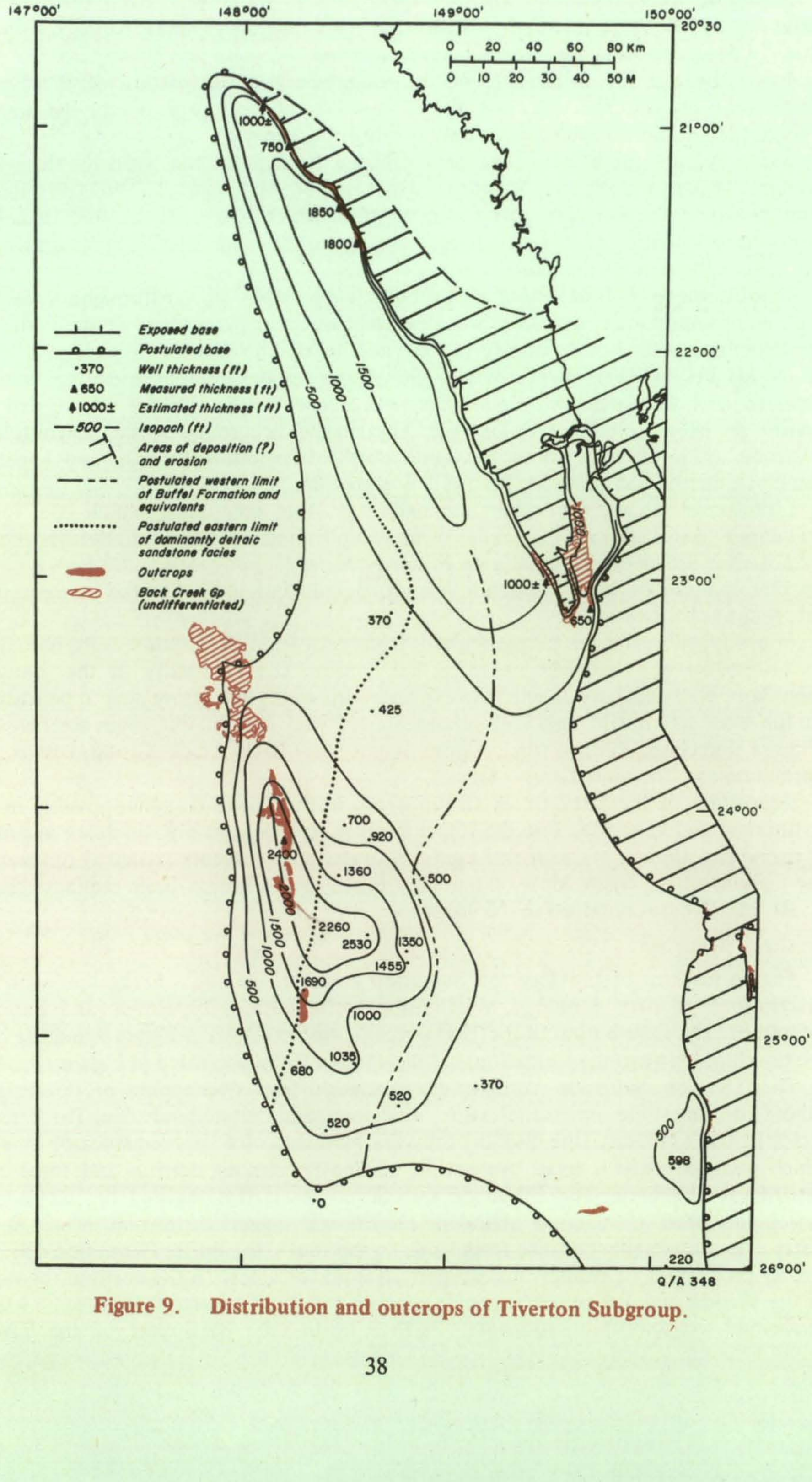

Figure 9. Distribution and outcrops of Tiverton Subgroup.

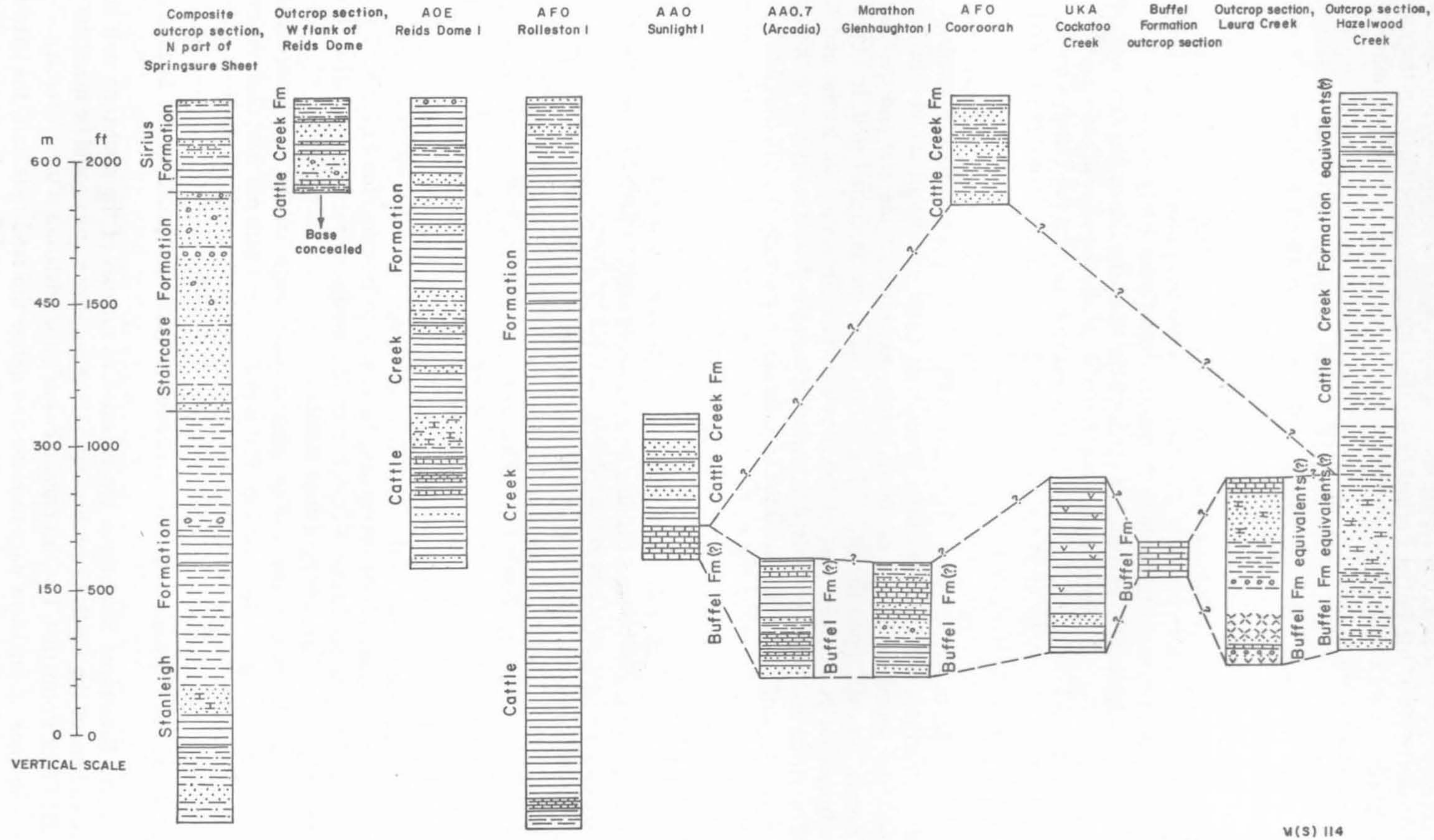

Figure 10. Sections of Tiverton Subgroup.

Subgroup, which is equivalent to the Buffel Formation, consists of sandstone with numerous interbeds of calcareous sandstone, coquinite, and limestone. The change from the limestone facies of the Buffel Formation to the limestone/clastic facies in the north reflects the persistence of volcanism in the Broadsound Range area and the proximity of a clastic provenance in the north.

The postulated western limit of the Buffel Formation as shown on Figure 9 is based on limited subsurface data. In the wells, the Buffel Formation apparently rests unconformably on pre-Permian basement or eroded Reids Dome Beds.

In the AAO 7 (Arcadia) and Glenhaughton 1 wells, near the southwestern limit of the Buffel Formation, the sequence contains conglomerate and other clastics in addition to limestone. The clastics were probably derived from a southern provenance area. Farther north, the Buffel Formation in Sunlight 1 consists almost completely of limestone. The Sunlight area was apparently beyond the reach of clastics from the southern source, and the clastics from the western source were trapped in the rapidly subsiding Denison Trough. The Buffel Formation in the west unconformably overlies pre-Permian basement or is possibly unconformable on eroded Reids Dome Beds; an unconformable relationship to the Reids Dome Beds is suggested in AAO 7 (Arcadia).

Farther west, the mudstone of the Cattle Creek Formation (Pl. 6, fig. 2) transitionally succeeded the Reids Dome Beds. The basal part of the Cattle Creek Formation is probably a time equivalent of the Buffel Formation. Later, as deposition and subsidence continued, the depositional area of the mudstone extended to the east and the Cattle Creek Formation overlapped the Buffel Formation, as in the Sunlight 1 well. In Figure 9 the mudstone facies occupies part of the area between the deltaic sandstone and the Buffel Formation and its equivalents; it interfingers with the deltaic sandstone to the west and overlaps the Buffel Formation to the east, though it generally thins in that direction. The mudstone sequence at the top of the Tiverton Subgroup in the northern part of the basin is similar to the Cattle Creek Formation and may be continuous with it.

The deltaic sandstone is confined to the north and west of the Denison Trough and possibly extends north onto the Comet Ridge. The provenance was mainly to the north and west; a small number of cross-bedding measurements made in the Staircase Sandstone suggests a westerly provenance as in the overlying Gebbie Subgroup.

This sandstone crops out best in the Springsure Anticline, where the Tiverton Subgroup consists of the Stanleigh Formation, Staircase Sandstone (Pl. 6, fig. 1), and Sirius Formation. Recently, Power (1966) has suggested that the Staircase Sandstone and a lower sandstone sequence (the Riverstone Sandstone Member of Power, 1966) within the Stanleigh Formation represents the distal portions of sandstone tongues which interfinger with the mudstone of the Cattle Creek Formation. Power has therefore revised the nomenclature. He considers that the Tiverton Subgroup here consists of only the Cattle Creek Formation, which comprises, from top to bottom, the Sirius Mudstone Member, the Staircase Sandstone Member, a middle mudstone member, the Riverstone Sandstone Member, and a lower mudstone member.

In his paper, Power presents a diagrammatic north-south section which shows the mudstone units lensing out to the north. This is in agreement with our field observations, although the sequence in the north is poorly exposed. In a general way, the data suggest the replacement of a mudstone sequence (the Cattle Creek Formation) to the north and west by sandstone. The Stanleigh-Staircase-Sirius sequence, exposed in the Springsure Anticline, apparently represents the zone of interfingering between them. Thus, the Staircase and Riverstone Sandstones are regarded as tongues of the sandstone unit and not as members of the Cattle Creek Formation; the mudstone units could be members of the Cattle Creek Formation. For this reason, Power's nomenclature is unacceptable.

In the absence of sufficient data to name and define the sandstone unit, the existing nomenclature of Stanleigh Formation, Staircase Sandstone, and Sirius Formation will be used here for the sequence in the Springsure Anticline. Farther north, the Tiverton Subgroup was not subdivided.

The Tiverton Subgroup in the northern part of the Bowen Basin consists of a limestone/clastic sequence overlain by mudstone. Most of the information on these units was obtained in the Strathmuir Synclinorium and western flank of the Connors Arch. The clastics in the lower unit are interbedded with tuff and tuffaceous sandstone around the Broadsound Range and in the Strathmuir Synclinorium. Farther north, the clastics include considerable lithic sandstone, which was possibly derived from the Lizzie Creek Volcanics. The western limit of the limestone/clastic facies is concealed beneath sediments of the Gebbie and Blenheim Subgroups; the facies may have been laid down over most of the northern depositional area after the marine transgression. The limestone/clastic facies was succeeded by a sequence of poorly exposed mudstone which superficially resembles the Cattle Creek Formation. It is not known whether clastic equivalents of the mudstone extend beneath the younger sediments in the western part of the trough.

Tectonics and Sedimentation

The Buffel Formation is relatively thin around the margins of the basin, and probably no thicker throughout its depositional area, including most of the ridge separating the Reids Dome Beds from the Camboon Andesite. The ridge was peneplaned by the time deposition of the Reids Dome Beds was completed, and it apparently subsided as a single block together with the Auburn Arch. There is no seismic evidence for the presence of thick linear wedges of the Tiverton Subgroup in the Mimosa Syncline and it appears that subsidence and sedimentation continued uniformly. This Lower Permian stable block was continuous with the Comet Ridge to the northwest where a thin sequence was laid down during a period of slow subsidence; most of the sediment was derived from the northwest. The Lower Permian stable block was flanked to the southwest by the Denison Trough, which continued to be a zone of active subsidence and sedimentation. The sea gained

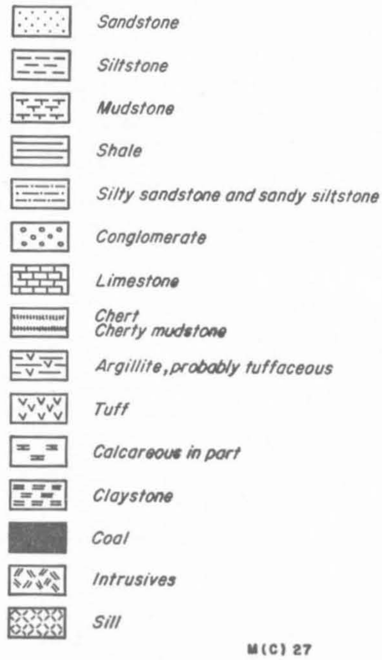

Figure 11. Symbols used in columnar sections.

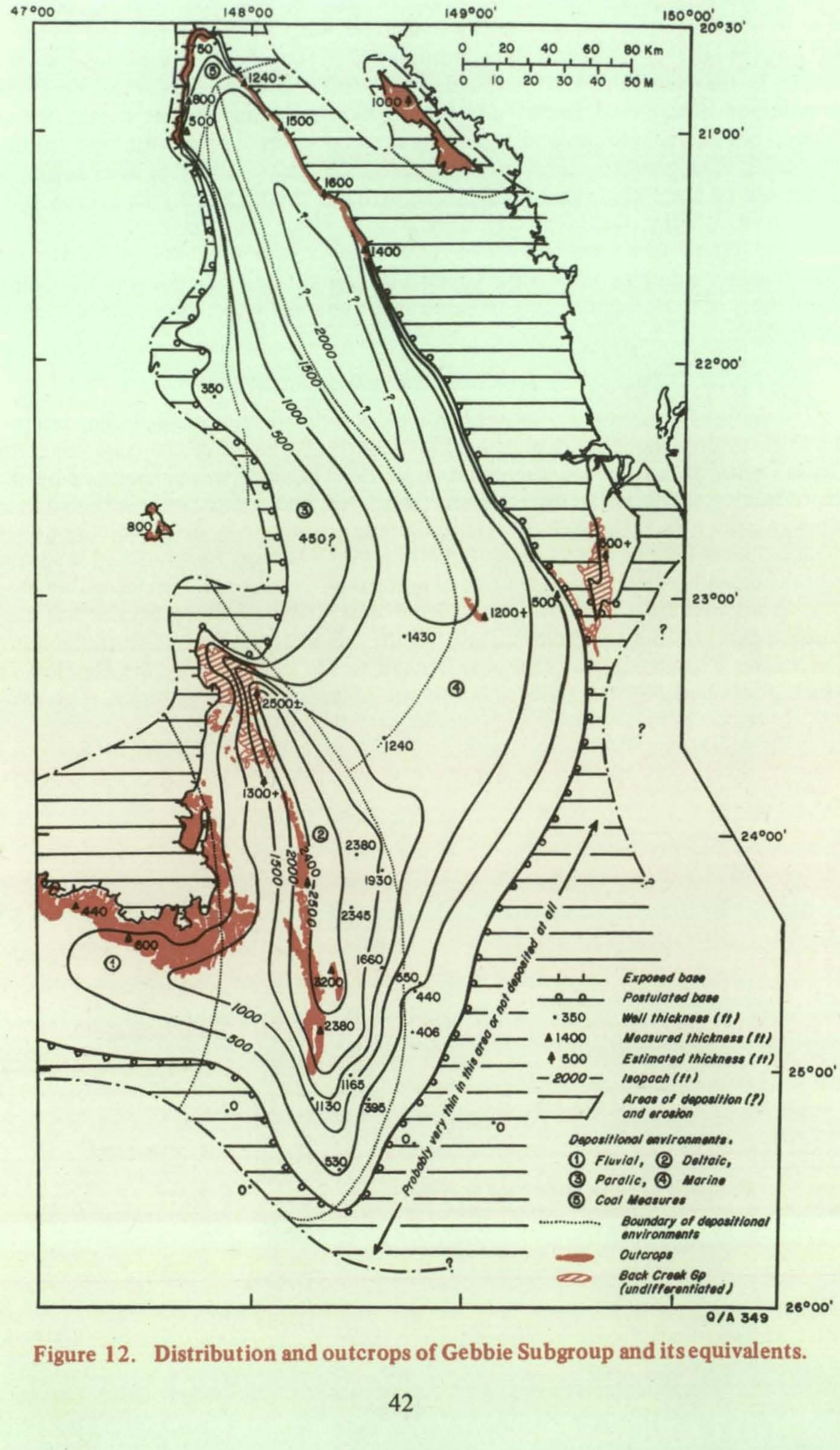

Figure 12. Distribution and outcrops of Gebbie Subgroup and its equivalents.

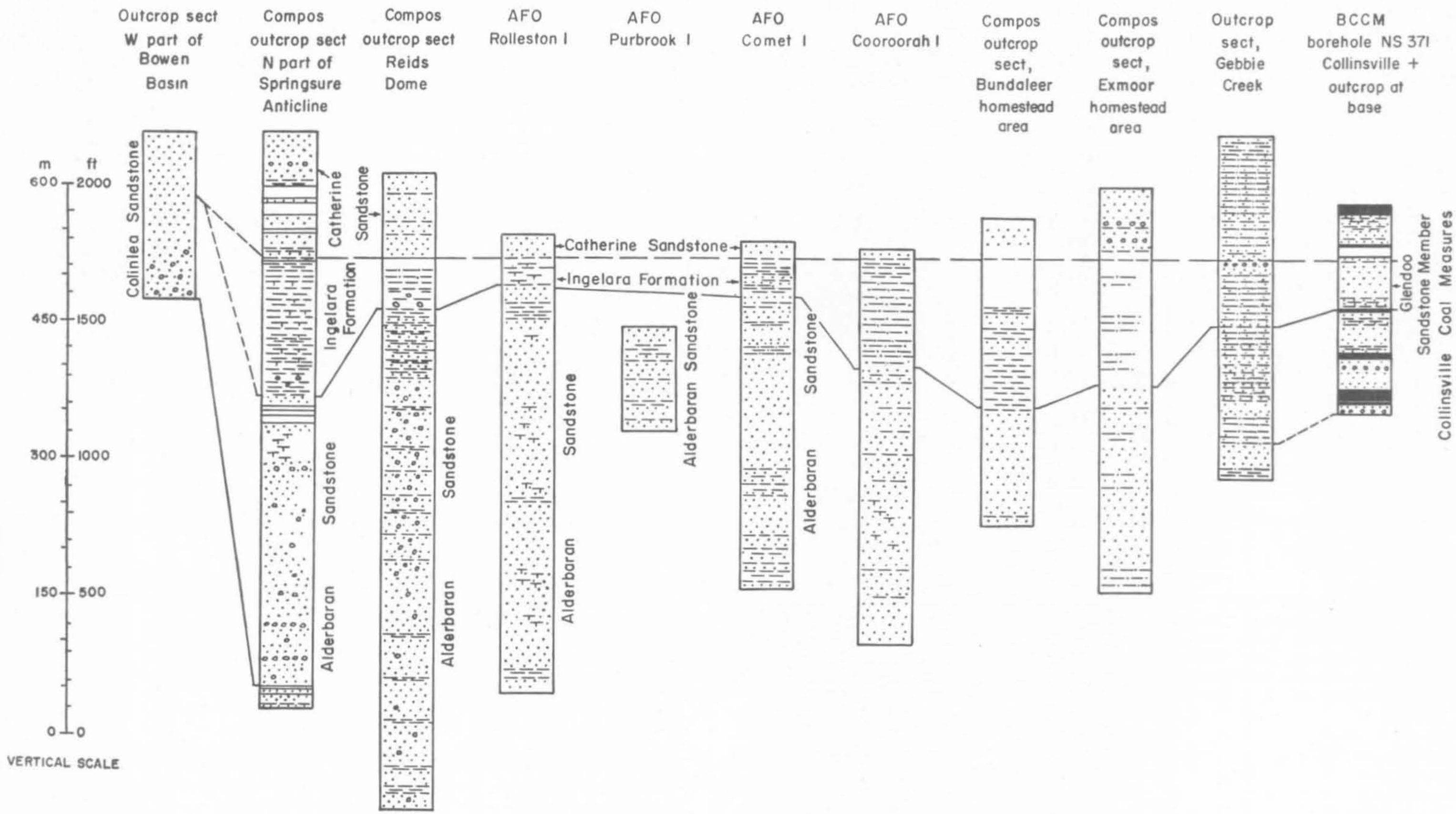

Figure 13. Sections of Gebbie Subgroup.

access to the Denison Trough across the stable block from the northeast, and there may also have been a tenuous connexion southwards through the Sydney Basin. The Yarrol Basin to the east of the stable block consists of a zone of linear belts which have been tectonically active from Lower Permian time onwards. The stable block probably extended as far north as the Broadsound Range, which represents the northern limit of non-deposition, or deposition and erosion, during the late Lower Permian. Here the stable block descended gradually into the northern depositional downwarp, which had direct access to the open sea. This downwarp was subsequently deformed, mainly by uplift of the Connors Arch, and now consists of two elongate, almost separate, belts of sediments.

Deposition of the Tiverton Subgroup in the Denison Trough was mainly confined to the area of maximum sedimentation of the Reids Dome Beds. The Tiverton Subgroup is not preserved west of the trough and the facies distribution suggests that deposition did not extend far to the west or northwest.

The northern depositional area was a broader, less elongate, downwarp than the Denison Trough and received a thinner sequence of sediments.

Gebbie Subgroup

The late Lower Permian Gebbie Subgroup is well developed in the Denison Trough (Pl. 7, fig. 1) and in the northern part of the Bowen Basin (Pl. 7, fig. 2); it thins across the intervening Comet Ridge, and is represented by a thin sheet of sandstone west of the Denison Trough. It is not present in the southeastern part of the Bowen Basin. The distribution and depositional environments are shown on Figure 12. The formations within the subgroup are described in Tables 7, 8, and 9 and the lateral variations and relationships are illustrated in Figure 13.

Relationships to Underlying Rocks

The Gebbie Subgroup transitionally succeeded the Tiverton Subgroup in the Denison Trough. The trough subsided actively during the Lower Permian, and sedimentation was probably continuous from one unit to the next. To the west, the Colinlea Sandstone disconformably overlies the Reids Dome Beds. The basal beds of the Colinlea Sandstone are correlated with the middle member of the Aldebaran Sandstone on lithological and palynological data, and the western part of the Bowen Basin was apparently subject to erosion during the early part of Gebbie Subgroup time.

In the north, the contact between the Gebbie and Tiverton Subgroups is not exposed on the west flank of the Connors Arch. The base of the Gebbie Subgroup consists of micaceous coarse siltstone with carbonaceous streaks, grading up rapidly into silty sandstone followed by quartzose sandstone. This sequence may transitionally succeed the roughly laminated grey and blue siltstone at the top of the Tiverton Subgroup, and subsidence and sedimentation were probably continuous throughout the Permian. The Gebbie Subgroup overlapped the Tiverton Subgroup to the north and west. The Collinsville Coal Measures, which represent the subgroup in the northwest, disconformably overlie the Lizzie Creek Volcanics. Correlation with the type area of the Gebbie Subgroup indicates that the basal beds are absent or poorly represented at the base of the coal measures. Similar relationships obtain on the western margin of the Denison Trough, where the depositional area also expanded later than in the type area of the subgroup.

Well data indicate that the subgroup thins rapidly to the east of the Denison Trough and in the southeastern part of the basin the subgroup is absent owing to non-deposition or to erosion.

The change from the Tiverton Subgroup to the Gebbie Subgroup was the result of a moderate regression from a marine environment to shallow marine or paralic. The area of deposition was unchanged initially, but later expanded to the west of the Denison Trough and to the north and west in the northern part of the basin. Apparently the supply of sediment matched the rate of subsidence within the basin, so that the shallow marine environment was maintained, and the marginal areas west of the Denison Trough and north and west of the northern part of the basin subsided proportionally to permit accumulation of sediments in a paralic environment.

Fluviatile Environment of Western Bowen Basin

The Colinlea Sandstone is a sheet of fluviatile sand ranging from 135 to 240 m thick, which was laid down on a slowly subsiding shelf in the southwest. It represents a period of very slow sedimentation compared with that in the adjacent Denison Trough, where a great thickness was deposited during the same time interval. The petrological data (Mollan et al., 1969; Bastian, 1965b) and palynological data (Evans, 1966b) indicate that the Colinlea Sandstone can be correlated with most of the Aldebaran Sandstone and the Catherine Sandstone; no equivalent of the Ingelara Formation can be recognized.

The sediment was derived from the north (Anakie Metamorphics, Retreat Granodiorite, Drummond Basin sequence) and from the south (now concealed Timbury Hills Formation and granite penetrated in petroleum exploration wells). Variations in the composition of the sandstone suggest that most of the detritus was derived from particular provenance areas at times. Measurement of cross-bedding dip directions are equivocal (Mollan et al., 1969), but the distribution and relationships of the Colinlea Sandstone to the Gebbie Subgroup in the Denison Trough indicate that the main direction of transport of sediment was across the shelf into the trough. The absence of the Ingelara Formation on the Colinlea Sandstone shelf may be due to a disconformity. The Ingelara formation was laid down during a period of widespread subsidence, but the transgression apparently did not extend on to the shelf west of the Denison Trough. The Ingelara Formation may have been formed of sediment derived entirely from the north and south, and not of sediment which had been transported across the Colinlea Sandstone shelf. The conglomeratic mudstone in the south and most of the other sediments in the Ingelara Formation appear to have undergone little reworking, and it seems unlikely that they were transported across the shelf. The shelf area in which the Colinlea Sandstone was laid down was probably the site of local alluvial aggradation and degradation during the period when the Ingelara Formation was deposited.

Deltaic Environment of Denison Trough

The greatest thickness of the Gebbie Subgroup was laid down in the Denison Trough. The basal sandstone member of the *Aldebaran Sandstone* was deposited in a deltaic environment, probably partly brackish, which gradually replaced the marine environment of the Cattle Creek Formation. The presence of thick interbeds of siltstone and mudstone with local coal seams indicates a greatly reduced supply of sand and coarser detritus at times.

The middle conglomeratic member of the Aldebaran Sandstone represents a period of rapid sedimentation of mainly arenite and coarser detritus, which began about the same time as deposition of the Colinlea Sandstone. The supply of sediment matched the rate of subsidence of the Denison Trough so that a deltaic, probably partly brackish, environment was maintained despite an increase in the area of subsidence. The increase in average grainsize from the basal member to the middle member suggests more vigorous uplift and erosion of the source areas. The quartz and quartz sandstone clasts in the conglomerate in the middle member were derived from a different source from those in the conglomerates in the Cattle Creek and Ingelara Formations.

The conglomerate clasts resemble some of the rocks exposed in and around the Drummond Basin to the northwest, and the cross-bedding measurements also indicate a northwesterly source

The upper member of the Aldebaran Sandstone, which consists of interbedded quartzose sandstone and mudstone, was laid down in an environment transitional between the brackish environment and the deltaic marine environment of the succeeding Ingelara Formation. The abundance of worm tracks and the presence of oscillation ripple marks suggest deposition in the tidal zone. The rate of subsidence was apparently slightly faster than the rate of sedimentation so that the depth of water gradually increased.

The *Ingelara Formation* consists mainly of poorly sorted and poorly bedded conglomeratic sandy siltstone and mudstone laid down in relatively deep water where there was little effective reworking. The presence of calcareous concretions containing abundant shelly fossils indicates that the sea had unrestricted access to the area.

On the southern margin of Reids Dome the siltstone contains some angular boulders of granite, porphyritic volcanics, and low-grade metamorphics, which were probably derived from a southerly or southwesterly source area like the boulders in the Cattle Creek Formation. These kinds of boulders are not found in the Aldebaran or Catherine Sandstones. Their origin is uncertain, but Hill (1957) and others have suggested that they are glacial erratics dropped from icebergs. Alternatively, they could have been transported from eroded cliffs to the south or southwest by turbidity currents. Angular blocks are found in the sediments deposited during marine transgressions, particularly in the widespread coquinite beds such as the Big *Strophalosia* Zone.

The *Catherine Sandstone* marks the close of sedimentation in the Denison Trough. It was laid down in a shallow sea, and is transitional from the Ingelara Formation. The formation consists of fine to medium-grained well sorted quartzose sandstone with thin interbeds of siltstone. The planar bedding or low-angle cross-bedding, the relative abundance of heavy minerals, the good sorting, and the presence of scattered glauconite and marine fossils indicate deposition in a shallow marine environment where there was considerable reworking. The Catherine Sandstone is disconformably overlain by the Peawaddy Formation, and to the south it is overlapped.

Paralic Environment of Comet Ridge and Collinsville Shelf

Two depositional environments have been tentatively recognized east and north of the Denison Trough: a sandy paralic environment over most of the Comet Ridge and Collinsville Shelf, and a marine environment over most of the eastern part of the Bowen Basin. The sandy paralic sediments extend for a short distance to the west on to the Capella Block, but apparently lens out beneath the Blenheim Subgroup.

In the west the paralic sediments are not exposed, but were penetrated in the Comet 1, Cooroorah 1, and Norwich Park Scout 1 wells. In the first two wells the sequence consists of a thick basal sandstone which can be correlated with the Aldebaran Sandstone and a thinner mudstone sequence which is a probable correlate of the Ingelara Formation. The Catherine Sandstone is tentatively recognized in the Comet 1 well as a very thin sandstone, but is possibly not present in the Cooroorah well. Only part of the Aldebaran Sandstone equivalent was probably penetrated in Norwich Park 1. The Gebbie Subgroup is very much thinner on the Comet Ridge than in the Denison Trough. The sediment was apparently derived mainly from the northwest, as most of the sediment from the west would have been trapped in the Denison Trough. The Aldebaran Sandstone was laid down on the Comet Ridge during a period of slow subsidence with extensive reworking of the sediment. The finer material was winnowed out and transported farther southeast, and both the coarse and fine sediments were probably swept southwest into the Denison Trough. The extensive reworking may have been responsible for the diagenetic silicification of the quartzose Aldebaran Sandstone observed in the Cooroorah 1 and Norwich Park Scout 1 wells. In the Comet 1 well near the eastern margin of the paralic environment, the Aldebaran Sandstone includes thick intervals of siltstone and mudstone and very little diagenetically silicified sandstone.

Little information is available on the Gebbie Subgroup over most of the Collinsville Shelf. The coal measures intersected in water bores about 80 km north-northeast of Clermont appear to be stratigraphically below the basal beds of the Blenheim Subgroup: they are considered to be part of the Gebbie Subgroup and probably equivalent to the Collinsville Coal Measures. The coal measures were laid down in a terrestrial environment on the western margin of the paralic sea.

The thickness of the Gebbie Subgroup at the northern end of the Collinsville Shelf and on the west flank of the Connors Arch suggests that the slowly subsiding paralic environment on the Collinsville Shelf was relatively narrow compared with its extent on the Comet Ridge. This may have resulted in less diagenetic silicification of sandstone in this area.

Marine Environment of Eastern Bowen Basin

The Gebbie Subgroup laid down in the marine environment in the eastern part of the Bowen Basin is exposed near the Mackenzie River, 56 km north of Bluff, and along the western flank of the Connors Arch. On the 1:500,000 map the equivalent sequence is not separated from the Back Creek Group in the Strathmuir Synclinorium The Gebbie Subgroup in the Mackenzie River outcrops consists of upper and lower sandstone units separated by siltstone.

Mackenzie River Area

The basal sandstone sequence consists mainly of cross-bedded fine to coarse sandstone, most of which contains a large proportion of grains of volcanic rocks. The volcanic detritus was apparently derived from a source to the east. The cross-bedding indicates considerable current action, but the high proportion of labile constituents indicates little reworking of the sediment. The presence of rare scattered marine shelly fossils throughout the sandstone indicates a marine environment which was shallow at times. The cross-bedding may be related to tidal currents.

The distribution of the subgroup indicates that access to the open sea was restricted and that strong tidal currents were probably active. The middle unit is mainly siltstone and contains hard smooth calcareous fossiliferous nodules in places. Some of the fossils (e.g. *Conocardium* sp.) suggest deposition in a muddy environment below the depth of wave action, and the water was probably much deeper than during deposition of the basal sandstone. The fossils in the middle unit are similar to those in the Ingelara Formation of the Denison Trough, and the deeper water was probably the result of the marıne transgression during which the Ingelara Formation was laid down. Comparison of the Mackenzie River section with the sequence in Cooroorah 1, 40 km to the west, suggests that the basal sandstone may be continuous with the Aldebaran Sandstone and the siltstone with the Ingelara Formation.

The upper unit in the Mackenzie River area is a poorly exposed sequence of relatively thin sandstone.

Strathmuir Synclinorium Area

The sediments in the Strathmuir Synclinorium which are correlated with the Gebbie Subgroup include fossiliferous calcareous volcanolithic sandstone and nodular siltstone. The problem of separating the Tiverton and Gebbie Subgroups in this area (and about the southern end of the Connors Arch) may be related to its position relative to the depositional environments. Throughout the Lower Permian, this part of the basin had direct access to the open sea and was continuously marine. The transgressions and regressions which produced marked changes of lithology in most parts of the basin did not significantly alter the depositional environment in this area.

Western Flank of Connors Arch

The Gebbie Subgroup is concealed for about 160 km to the north of the Mackenzie River outcrops. Thereafter, it crops out on the west flank of the Connors Arch to near Collinsville. The subgroup contains three formations, as in the Mackenzie River area.

The basal part of the lower unit consists of about 60 m of sandy siltstone and some fossiliferous calcareous beds which grade up into quartzose sandstone. The basal sequence was probably deposited during the transition from the deeper water environment of the Tiverton Subgroup. The basal beds are overlain by the Wall Sandstone Member, which consists of silicified cross-bedded and rarely ripple-marked quartzose sandstone. The member is about 30 m thick and extends for about 50 km; a similar sandstone bed has been tentatively recognized throughout the outcrop area. The Wall Sandstone Member contains rare marine fossils and was apparently deposited in a shallow sea where there was considerable reworking of the sediment. It may represent a sand bar. The overlying sandstones are less well sorted and less mature, and were possibly laid down in slightly deeper water. Some thin coal seams are present just above the Wall Sandstone Member, at the northern end of the belt. The coal may have been transported from elsewhere, as the associated sediments contain abundant carbonaceous debris. If the coal was formed in situ, then a freshwater environment existed for at least a short time during deposition of the Gebbie Subgroup.

At the northern end of the belt the middle unit contains slightly more sandstone than siltstone. The sequence is similar to those in the units above and below, but siltstone and fossiliferous beds are more common. Farther south, the middle unit consists mainly of sandy siltstone, which crops out in a valley between the sandstone ridges formed by the underlying and overlying units.

The upper unit is thickest in the north, where it consists of about 120 m of sublabile sandstone, ripple-marked quartz sandstone, and thin interbeds of siltstone. It thins to 75 m or less to the south, where the basal unit thickens to slightly more than half of the entire subgroup.

Near the southern limit of the belt only the upper and lower units are exposed; both contain some richly fossiliferous horizons. The lithology is much the same as farther north.

The absence of grains of volcanic rocks in the sandstones distinguishes them from the beds in the Mackenzie River area; the change is probably due to differences in the provenance areas. The sediments on the flank of the Connors Arch were probably derived from the north, and the abundance of sandstone in the coal measures indicates a copious supply of arenaceous material from the northern provenance. The sediment was transported by streams moving through or between the areas in which the Collinsville and Calen Coal Measures were deposited. Some of the sediment may have come from the west, but the distribution of the subgroup suggests that the axis of deepest subsidence in the north at this time may have been west of the Connors Arch (see Fig. 12), and thus relatively deep water would have trapped most of the sediment supplied from the west.

Coal Measure Environments

The Collinsville Coal Measures undoubtedly belong to the Gebbie Subgroup, and the Calen Coal Measures, northwest of Mackay, are correlated with the subgroup because of their lithological similarity. Both were probably laid down in swamps on the margin of the depositional area of the Gebbie Subgroup. The coal measures encountered in water bores about 80 km north-northeast of Clermont appear to be stratigraphically below the Blenheim Subgroup, and are also probably part of the Gebbie Subgroup (see also Veevers et al., 1964b). The Blair Athol Coal Measures were deposited in an isolated basin, but are possibly time equivalents of the Gebbie Subgroup.

Collinsville Coal Measures

The Collinsville Coal Measures comprise two sets of coal measures separated by a sequence of marine sandstone. The coal measures are composed mainly of sandstone, conglomerate, coal, and minor siltstone and carbonaceous mudstone. The three units can be correlated with the three formations of the Gebbie Subgroup in the northern part of the basin. The conglomerate bed at the base of the coal measures rests on Lizzie Creek Volcanics and on Carboniferous volcanics and intrusives in the southwest. The conglomerate marks an expansion of the depositional area to the north and west; it is not present in the Gebbie Subgroup southeast of Collinsville, where deposition continued after the Tiverton Subgroup was laid down.

The Collinsville Coal Measures were probably laid down in swamps, not far from the sea. The sandstone is similar to that in the Gebbie Subgroup to the south, but is generally finer in grain. The coal may have been formed in swamps at the back of a large delta or between the main distributary channels which carried the medium-sized sand and coarser detritus into the sea. The fine sandstone, siltstone, and carbonaceous mudstone were probably deposited in flood-plains between the main distributaries, which migrated laterally from time to time. Some of the coal seams are cut by washouts filled with conglomerate and coarse sandstone; the washouts were probably formed as a result of lateral migration of the distributary channels.

Webb & Crapp (1960) have suggested that the Bowen Seam may be autochthonous in the north and allochthonous in the south. The seams generally thin towards the south, whereas the sediments between the seams thicken towards the centre of the basin. The reworking of the coals, the variations in thickness, and the predominance of arenites suggest that the depositional area was not a broad flat coastal plain, but a surface which sloped gradually towards the basin. The swamps in which the coal was laid down may have formed behind sand bars formed by longshore currents.

The marine sandstone in the middle of the Collinsville Coal Measures was laid down when the sea transgressed over the delta. The marine beds can be traced for considerable distances, and some thin fossiliferous sandstone beds, 15 cm to about a metre thick, persist along strike for several kilometres.

Calen Coal Measures

The Calen Coal Measures consist of about 300 m of coarse quartzose sandstone, mainly in thick cross-bedded sets, thinly interbedded sandstone and siltstone, siltstone grading laterally into soft brown claystone, and thin coal seams. They contain the Permian plants *Glossopteris* and *Vertebraria* but no marine fossils, and unconformably overlie the Carmila Beds and Lizzie Creek Volcanics. The Calen Coal Measures are situated about 50 km from the nearest outcrops of the Gebbie Subgroup, which is the only Permian unit containing similar rock types. The coal measures are largely fluviatile, but were partly laid down in lakes or local swamps.

Blair Athol Coal Measures

The Blair Athol Coal Measures are described in Veevers et al. (1964b). They consist of about 240 m of sandstone, coal, carbonaceous claystone and shale, and a little fine conglomerate. A basal pebble conglomerate is locally present. The main coal seam has a maximum thickness of 33 m. The coal measures were probably laid down in an isolated basin within the Anakie Metamorphics. The basin is about 16 km long by about 3 km wide in the north and about 13 km wide in the south. The surface of the underlying Anakie Metamorphics is very irregular in places and rises steeply to the north and gently to the south. The coal seams interfinger with the sediments around the margins of the basin. The great thickness of individual seams suggests that the coal measures accumulated during a period of steady subsidence. There are no tectonic breaks in the sequence and the subsidence was probably of regional extent. The Blair Athol Coal

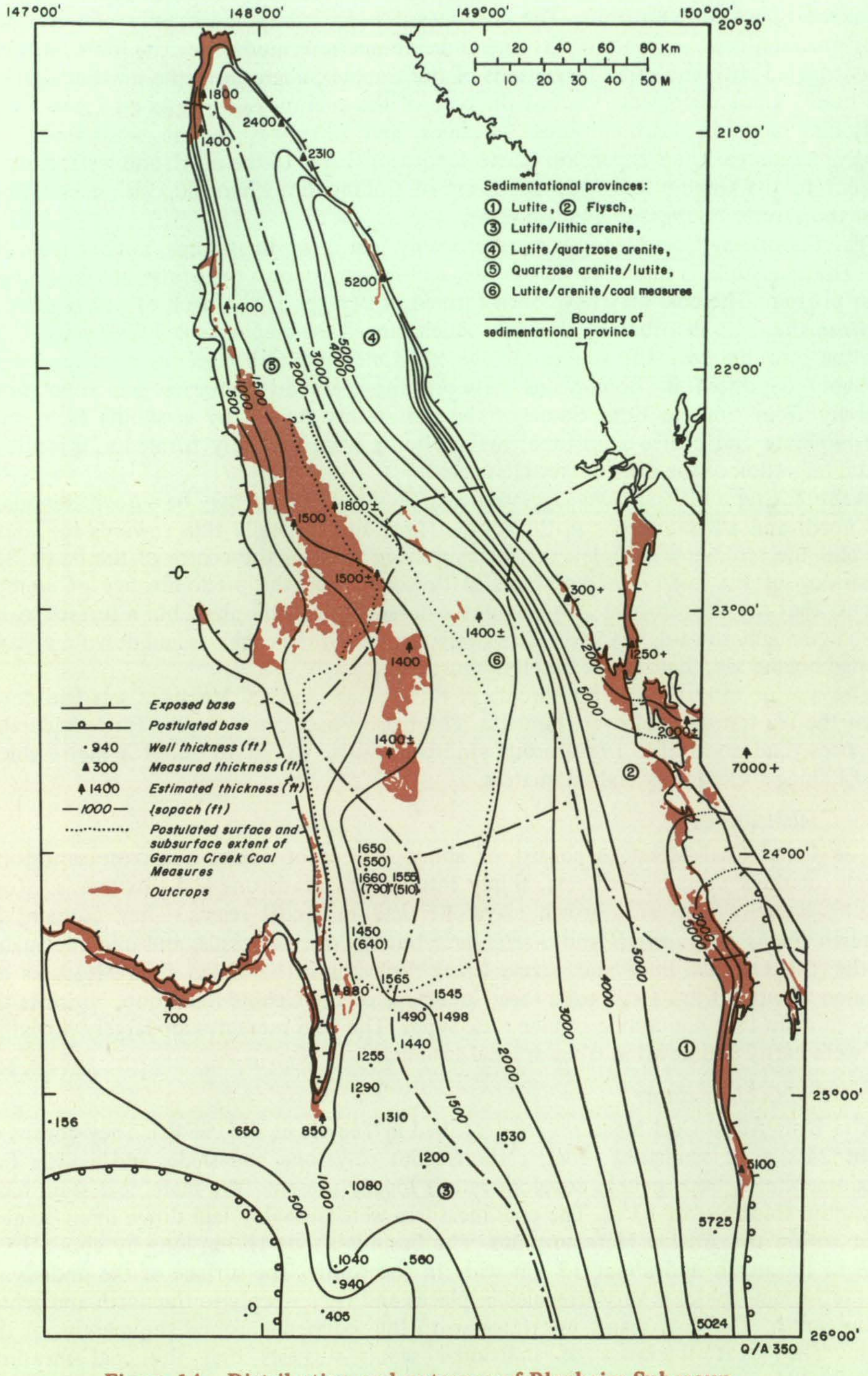

Figure 14. Distribution and outcrops of Blenheim Subgroup.

Measure basin is in line with the long axis of the Denison Trough, where maximum subsidence occurred during deposition of the Gebbie Subgroup. For this reason it is suggested that the Blair Athol Coal Measures are time equivalents of the Gebbie Subgroup. It is possible that the Blair Athol basin was formed at the same time as the Tiverton Subgroup or Reids Dome Beds, but the Denison Trough was not then so elongated in the direction of the basin as in Gebbie Subgroup time. Palynology (Evans, 1966c) suggests that the Blair Athol Coal Measures may be correlated with the Aldebaran Sandstone, but the evidence is not conclusive.

Tectonics

The main tectonic feature in Gebbie Subgroup time was the elongate Denison Trough, which was the locus of maximum sedimentation. The elongate shape of the northern depositional basin as shown in Figure 12 is mainly due to post-depositional uplift and erosion of the Gebbie Subgroup adjacent to the Connors Arch. The Gebbie Subgroup was probably laid down as a sheet of fairly uniform thickness over most of Connors Arch and the area to the east. The whole of the northern part of the Bowen Basin and the area to the east probably subsided more or less uniformly. It was separated from the Denison Trough by the Comet Ridge, where subsidence and sedimentation were less pronounced.

In the southeast any sediments laid down were later removed by erosion. The well sections indicate that little sediment was derived from this area during the deposition of the Gebbie Subgroup. The area was apparently part of a large stable peneplaned block, which may have been slightly submerged at times.

The eastern limit of the Gebbie Subgroup is uncertain. Presumably, the sea had direct access to the basin through the Strathmuir Synclinorium and to the north. The disconformity between the Tiverton Subgroup and the Blenheim Subgroup south and east of the synclinorium indicate that it was probably an area of non-deposition. The only time equivalents of the Gebbie Subgroup to the east are part of the Berserker Beds in an elongate northerly trending graben, east of Rockhampton. The Berserker Beds consist mainly of volcanics and coarse clastics laid down near their source. The graben and the Bowen Basin to the west were probably separated by land during most of the late Lower Permian.

Blenheim Subgroup

The Blenheim Subgroup, at the top of the Back Creek Group, was deposited in the early Upper Permian (Kazanian) during a major marine transgression which overlapped the Gebbie Subgroup to the west and southeast. Most of the changes in lithology are the result of the marine transgression, but the Blenheim Subgroup is also characterized by the presence of acid volcanic detritus and tuff. There was also a major shift in the locus of maximum sedimentation. The thickest part of the Blenheim Subgroup was laid down in a trough extending from the north to the southeastern corner of the basin, and in an eastern extension now largely occupied by the Gogango Overfolded Zone (see Fig. 14). The greatest known thickness of the Blenheim Subgroup or its equivalents is the 2100 m of Moah Creek Beds (Kirkegaard et al., 1970) in the eastern extension of the basin in the Rockhampton Sheet area. Over 1500 m of sediment was laid down in the main trough, whose elongation and asymmetry are largely the result of post-depositional uplift of the Connors and Auburn Arches. The Blenheim Subgroup thins steadily to the west and forms a uniform blanket across the Denison Trough, which had apparently ceased subsiding relative to the areas on either side.

The Blenheim Subgroup is more widespread and displays much more lateral variation than the preceding subgroups. The constituent formations, including some unnamed units, are briefly described in Table 10 and some of their lateral relationships are illustrated in Figure 15.

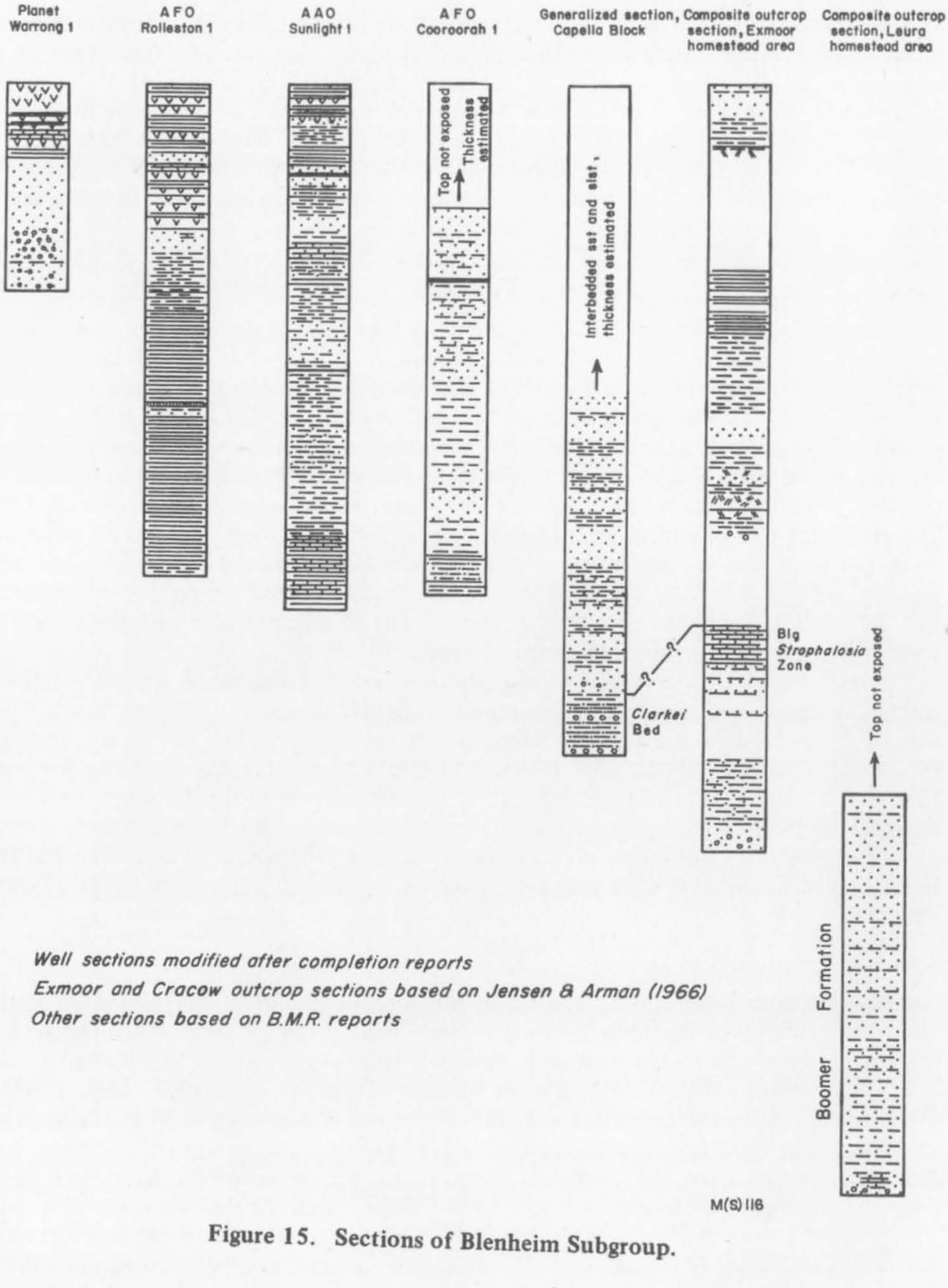

Figure 15. Sections of Blenheim Subgroup.

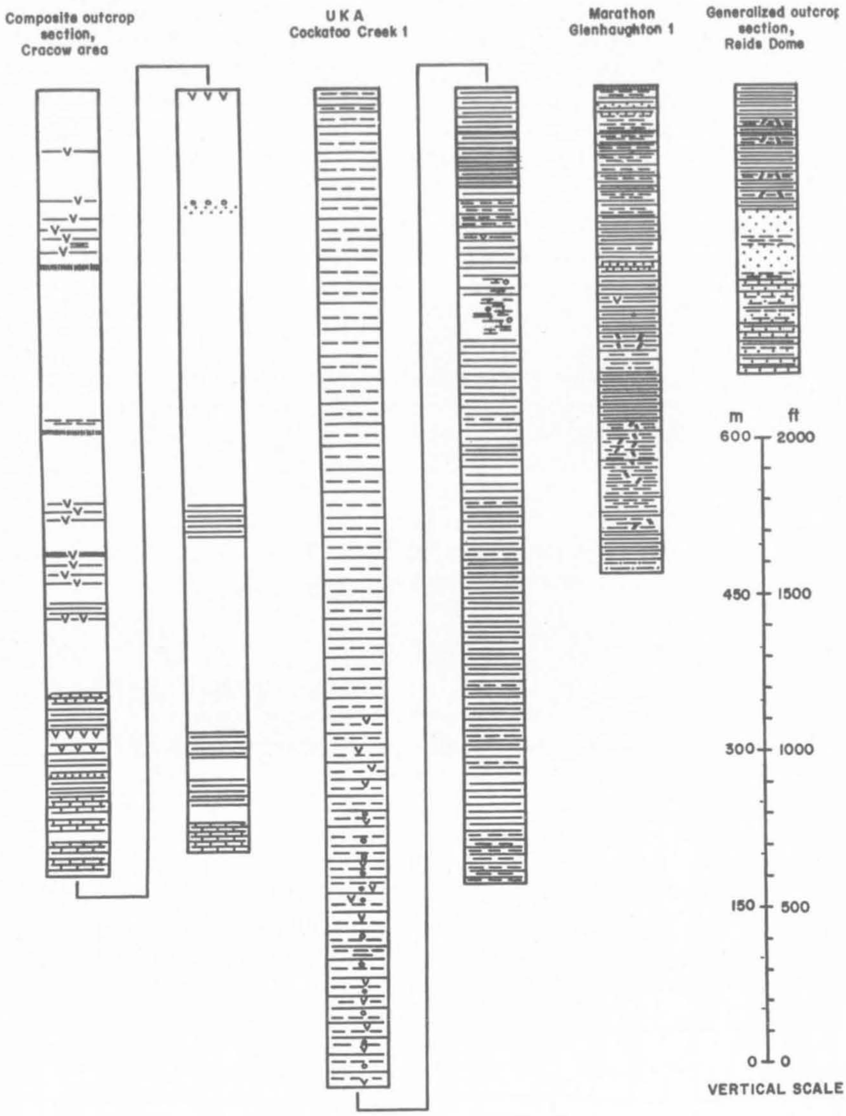

Figure 15. (Cont'd)

In the southeast, where the subgroup comprises the Oxtrack, Barfield, Flat Top, and Banana Formations, lutites, with thick lenses of tuffaceous clastic sediments, were predominant. To the west the lutite province grades into a lutite/arenite/coal measure province on the Comet Ridge, and into a lutite/arenite province, containing significant volcanic detritus and local volcanic rocks, in the Denison Trough and western part of the Bowen Basin; to the north the lutite province grades into a flysch(?) province (Boomer Formation).

The Boomer Formation grades into more conglomeratic sediments which were possibly laid down in a synorogenic molasse province east of the map area. The arenites in all the provinces consist predominantly of lithic sandstones which were possibly derived from volcanic rocks; quartz-rich sandstone is more common on the Comet Ridge and in the west.

There was also a lutite/quartzose arenite province to the north of the flysch province on the west flank of the Connors Arch, and a paralic quartzose arenite/lutite province to the west on the Collinsville Shelf. Towards the close of deposition of the Blenheim Subgroup deltaic coal measures were laid down on adjacent parts of the Comet Ridge and Denison Trough. Quartz-rich arenites predominate in all the northern provinces. This change reflects the difference between the predominant volcanolithic detritus supplied by the provenance area to the east and south and the predominant quartz-rich detritus supplied by the provenance area to the north and west.

Lutite Province

The oldest sediments in the lutite province are the thin neritic limestone and calcilutite of the Oxtrack Formation. The abundance of fossils suggests deposition in a shallow sea, somewhat warmer than the sea in which the disconformably underlying Buffel Formation was laid down. The Oxtrack Formation was succeeded by thick massive mudstone of the Barfield Formation. This formation contains minor beds of lithic arenite and in the upper part some beds of tuff and agglomerate and lava flows; calcareous concretions are common throughout. Fossils are abundant in some of the calcareous concretions and in beds of calcareous mudstone. Glendonites are common in the upper part of the formation. The volcanics occur in at least two stratigraphic levels, and can probably be correlated with the thick volcanics intersected in the Cockatoo Creek 1 well. The upper part of the Barfield Formation, including the volcanics, was originally called the Acacia Formation (Derrington et al., 1959), but it is now regarded as a volcanic member within the Barfield Formation. The Barfield Formation was probably laid down in moderately deep water. The presence of black pyritic mudstone indicates a reducing environment at times. Most of the fossils are abraded and worn, and were apparently transported for some distance. Some of the calcilutite beds contain corals, brachiopods, and worm tubes and were presumably laid down in shallow well oxygenated water. The neritic environment of the underlying Oxtrack Formation apparently migrated southeast during the deposition of the Barfield Formation. The environmental significance of the glendonites is not clear, though it has been suggested that they indicate glacial conditions (see Carey & Ahmad, 1961).

The Flat Top Formation consists of tough blue or buff mudstone containing numerous thin layers of blue mudstone with intricately contorted laminae. Poorly sorted lithofeldspathic sandy siltstone containing a high proportion of volcanic detritus is interbedded with the mudstone in places. Marine fossils are more abundant in the north; in the south, fossil wood impressions are common near the top of the formation, and still farther south thin coal seams are present in the Cockatoo Creek 1 well. The Flat Top Formation was possibly deposited in a partly marine and partly freshwater environment. The fine grainsize of the sediments suggests a distant provenance area or one of low relief.

The Banana Formation is lenticular; it consists of mudstone, similar to the Barfield Formation, and is restricted to the area near Banana. It may have been deposited in a partly non-marine environment. J.F. Dear (pers. comm.) considers the Banana Formation to be part of the Flat Top Formation.

The presence of a thin lutitic sequence of the Blenheim Subgroup in the Glenhaughton 1 and Purbrook South 1 wells indicates that the lutite province extended a considerable distance to the west. As the proportion of arenite increases to the west the lutite province grades into the lutite/arenite province.

Lutite/Arenite Province

In the lutite/arenite province the Peawaddy Formation is overlain by the Black Alley Shale. To the southwest, beneath the Great Artesian Basin sequence, the Peawaddy Formation becomes more arenaceous and disconformably overlaps progressively older rocks; in the far southwest, it unconformably overlies pre-Permian rocks*.

The Peawaddy Formation consists mainly of mudstone and sandy siltstone, but lithic sandstone forms about half of the upper part of the unit. Coquinitic lenses of the Mantuan *Productus* bed occur at the top of the formation in places. The basal part of what we recognize as Peawaddy Formation in wells south of the exposed part of the Denison Trough includes sandstone, pebbly sandstone, and conglomerate, and the same rock types are predominant in the Peawaddy Formation in the far southwest of the basin. Marine fossils are particularly abundant in the Mantuan *Productus* bed; they are common in some of the lower beds and are also scattered throughout the formation. The fossils indicate a marine environment. The basal conglomeratic unit in the southwest reflects the transgressive nature of the marine environment.

The arenaceous basal unit crops out poorly around the Springsure Anticline and northern end of Reids Dome. This is also the area of maximum development of the Catherine Sandstone, which is truncated beneath the Peawaddy Formation farther south. Sedimentation was possibly nearly continuous in this area in Gebbie Subgroup time, although the Peawaddy Formation and Catherine Sandstone may be disconformable.

The Black Alley Shale is a thin claystone sequence resting conformably or disconformably on the Peawaddy Formation. The formation contains beds of bentonitic clay, which were formed from volcanic ash laid down in an aqueous environment with restricted circulation. The presence of gypsum and jarosite on bedding planes and joints also indicates a restricted environment, which possibly developed during the transition from marine to freshwater conditions. The Black Alley Shale contains few marine macrofossils, but acritarchs are present throughout. There is a swarm of one particular species in one interval near the base. The abundance of acritarchs distinguishes the Black Alley Shale from the palynological assemblage in the overlying Blackwater Group. Some of the shale beds near the base of the formation contain a mosaic of overlapping spines on bedding surfaces which resemble moulds of ice crystals. The shale was probably laid down in cold stagnant brackish water with limited access to the open sea. The presence of bentonitic clay and beds of tuff indicate contemporaneous volcanism.

The Black Alley Shale lenses out to the northeast or is replaced by the upper part of the German Creek Coal Measures. It thickens to the southeast and east and is probably

* The stratigraphic synthesis is based on correlation of subsurface data with the exposed section in the Denison Trough and is discussed in detail in Mollan et al. (1969). Most recent workers agree on the stratigraphy of the exposed section, but not all agree on the subsurface stratigraphy. The correlation presented here fits the available stratigraphical, lithological, and palaeontological data reasonably well, but is certainly not proven. The alternative correlations contradict the palaeontological data to some extent, generally on the grounds that the faunal changes reflect environmental rather than evolutionary changes. We consider that the changes in the macrofaunas were mainly the result of evolution, and that the evolutionary changes are of stratigraphic significance. Alternative stratigraphic reconstructions for the southwestern part of the basin have been discussed elsewhere (see Cundill & Meyers, 1964; and Power, 1967).

continuous beneath the Mimosa Syncline with the upper part of the Blenheim Subgroup in the lutite province.

The upper part of the Peawaddy Formation, including the Mantuan *Productus* bed, grades laterally to the northeast into the basal part of the German Creek Coal Measures. The lower part of the Peawaddy Formation grades laterally into the lithologically similar Maria Formation and is probably continuous with the sediments in the northern part of the basin. The Peawaddy Formation possibly grades laterally into the lower part of the Blenheim Subgroup in the lutite province, where the Barfield Formation and lower part of the Flat Top Formation probably represent most of the Peawaddy Formation. Possibly, the Black Alley Shale was laid down in a westerly extension of the lutite province in the closing stages of deposition of the Blenheim Subgroup; the Black Alley Shale and the Flat Top Formation are lithologically similar and may be equivalent in part. The Peawaddy Formation in the northern part of the Denison Trough may include some of the oldest sediments in the Blenheim Subgroup, which may account for the near-conformity between the Catherine Sandstone and Peawaddy Formation. Presumably the basal beds of the Peawaddy Formation became progressively younger as the formation transgressed to the southwest.

Flysch(?) Province

The Oxtrack Formation extends northwards from the lutite province into the flysch(?) province, where it is overlain by the Boomer Formation. The Oxtrack Formation was laid down during a period of widespread neritic carbonate sedimentation before downwarping initiated the deposition of thick mudstone in the lutite province and the deposition of the Boomer Formation in the flysch(?) province. The Boomer Formation is apparently a lateral equivalent of the Barfield Formation and possibly of the Flat Top Formation also.

The Boomer Formation is the only unit recognized in the flysch(?) province. It consists of interbedded quartz-poor lithic sandstone and dark blue siltstone. The contact between siltstone and overlying sandstone beds is sharp, but there is generally a narrow transitional zone between the sandstone and overlying siltstone. In places, convolute lamination can be seen in the upper part of sandstone beds. The uniform thickness and lithology of individual beds over considerable distances suggest that they were deposited by turbidity currents (see Sanders, 1965). In places, the sandstone beds are very thick and are separated by thin partings of siltstone. Elsewhere, the sequence generally consists of thinly interbedded coarse and fine siltstone, although thick massive beds occur in places. Polymictic pebble conglomerate and conglomeratic mudstone are locally abundant. In some of the conglomerates, the pebbles consist mainly of volcanic rocks and tuffaceous sandstone. The conglomeratic mudstone contains small to medium-sized pebbles of sandstone, argillite, and tuffaceous sediments set in a sheared silty matrix; the pebbles are aligned parallel to the shear planes, and some of them have been flattened.

West of the Broadsound Range and in the Strathmuir Synclinorium the Boomer Formation appears to be more or less conformable within the Back Creek Group, but to the southeast of the range, it unconformably overlies the basal beds of the Back Creek Group, and farther south it rests unconformably on the Rannes Beds and Connors Volcanics. In the eastern part of the Gogango Overfolded Zone, the Boomer Formation rests unconformably on inliers of Silurian-Devonian rocks and is generally conformable on, or locally interfingers with, the Rookwood Volcanics. Farther east, beyond the Bowen Basin, the Boomer Formation interfingers with and is overlain by the Moah Creek Beds.

In the area where the Boomer Formation was laid down the Tiverton and Gebbie Subgroups were either not deposited or were completely removed by erosion. The area of sedimentation corresponds with the central part of the Gogango Overfolded Zone, which was strongly downwarped about the end of the Lower Permian, when the submarine spilitic Rookwood Volcanics were extruded, followed by deposition of the Boomer Formation. The thickness is difficult to measure, but is estimated to be 1800 to 3000 m. The Moah Creek Beds to the east of the Boomer Formation appear to be partly younger, and pass eastwards into the coarser Dinner Creek Beds which appear to be generally younger still. At this time the area of sedimentation extended eastwards to where 'molasse' sediments were deposited adjacent to uplifted blocks of the Yarrol Basin.

The thickness and nature of the sediments suggest that they were laid down in local downwarps associated with vigorous uplift of the adjacent land. These movements culminated in middle Upper Permian time in the folding, deformation, uplift, and igneous intrusion associated with the formation of the Gogango Overfolded Zone.

Organic remains are almost completely absent from the Boomer Formation: the only marine fossils are found in the most southerly outcrops, near the lutite province. Marine fossils are also rare in the Moah Creek Beds. The fossils, lithology, and stratigraphic position are the main reasons for regarding the Boomer Formation as part of the Blenheim Subgroup (on the 1:500,000 geological map, the Boomer Formation is shown as a separate unit from the Blenheim Subgroup). The formation was presumably deposited in a marine environment, and the reason for the paucity of fossils is uncertain. Possibly the type of sedimentation, involving the rapid deposition of sheets of sediment over large areas, inhibited the development of fauna.

Lutite/Quartzose Arenite Province

The lutite/quartzose arenite province is exposed on the west flank of Connors Arch, on the northern part of the Collinsville Shelf, and around the Bundarra Granodiorite; the most southerly outcrops are about 130 km from the nearest outcrops of the Boomer Formation. The Blenheim Subgroup in the Folded Zone may be transitional between the flysch(?) province and the lutite/quartzose arenite province.

The Blenheim Subgroup in the lutite/quartzose arenite province comprises three unnamed units. The basal unit consists of mudstone, siltstone, and silty sublabile sandstone; the sequence is conglomeratic locally near the base, and contains scattered pebbles and boulders and coquinitic beds. The Big *Strophalosia* Zone consists of up to 30 m of calcareous siltstone or fine sandstone; it contains abundant transported brachiopod valves, and scattered pebbles and angular blocks. The bed is apparently continuous throughout the province. The middle unit consists mainly of dark blue micaceous siltstone, and the upper of a thin sequence of quartzose sandstone. Around the Bundarra Granodiorite, the upper unit is thicker, and lenses of quartzose sandstone occur in the middle unit. Coquinitic beds, scattered marine fossils, bryozoans, and abundant evidence of reworking of the sediments by a benthonic fauna are found throughout.

The arenites contain from 75 to 90 percent quartz grains. The siltstone and mudstone contain more mica than the siltstone of the Boomer Formation and the arenites are much richer in quartz. Organic remains are common in the lutite/quartzose arenite province, but are almost completely absent in the Boomer Formation.

The maximum thickness is the lutite/quartzose arenite province is estimated at 1560 m at the southern end of the outcrop belt. A similar thickness is exposed around the Bundarra Granodiorite. The sediments were laid down below the depth of vigorous wave action, in a moderately shallow sea which was apparently well aerated and unrestricted. The Blenheim Subgroup conformably or disconformably overlies the Gebbie Subgroup.

Coquinite Horizons

The Big *Strophalosia* Zone is a particularly thick and extensive example of the coquinitic lenses which occur in the Back Creek Group. Other named examples are the *Streptorhynchus* bed in the Collinsville area, the *Strophalosia clarkei* bed and 'pelecypod bed' on the Capella Block, and the Mantuan *Productus* bed in the Denison Trough and western part of the basin. All five occur in the Blenheim Subgroup. The Big *Strophalosia* Zone and the *Strophalosia clarkei* bed may be time equivalents; the Mantuan *Productus* bed may be slightly younger or equivalent to the other two. They were named because they are sufficiently distinctive and widespread to be useful in mapping. In general, all the coquinites have a matrix of calcareous siltstone or fine sandstone, and are packed with mainly separate valves of brachiopods and other fossils.

They contain scattered rounded pebbles and large angular blocks up to 60 cm across. The coquinites usually include some unfossiliferous interbeds of siltstone or sandstone similar to the coquinite matrix. The fossils are uniform in size, possibly because of sorting during transport or because of selective removal from the source area. As most of the fossils are only slightly worn and as some of the strophalosiids still have spines attached it appears that they were not transported far.

Other coquinites in the Back Creek Group, such as in the basal formation of the Tiverton Subgroup near Homevale and farther north, are generally similar to the Big *Strophalosia* Zone. Again, the fossils do not seem to have been transported far: they are only slightly worn, and the strophalosiid valves are separated; the species are mixed together, though individual species generally predominate in particular bands. Most of these coquinites are not so well sorted as the three named coquinites, but they do contain pebbles and scattered angular clasts.

On the west flank of Connors Arch coquinitic beds ranging from 15 to 33 cm thick occur throughout the Back Creek Group. Their relative stratigraphic positions can be accurately determined and, as they contain most of the species found in the Back Creek Group, they have provided most of the data on which the faunas have been subdivided into Faunas II, III, and IV. Their stratigraphic relationships and lithological similarity indicate that the faunal subdivisions reflect evolutionary development as well as environmental changes. The continuity and completeness of the faunal and stratigraphic sequence in this area permits isolated faunas from sediments of diverse depositional environments in other parts of the basin to be assigned with confidence to a particular faunal subdivision.

Paralic Province

The silty Blenheim Subgroup in the northern part of the Collinsville Shelf grades to the southwest into the sandy sequence of the paralic province. In the north the paralic sediments are exposed south of the Bowen River, but farther south they are covered by Tertiary sediments or crop out sporadically between expanses of Cainozoic alluvium. The main area of outcrop on the Capella Block extends from near the Peak Downs Highway to east of Capella. The sequence consists of a lower unit of silty sandstone and siltstone with a basal conglomerate; it includes the *Strophalosia clarkei* bed near the base and a higher coquinite, the 'pelecypod bed', near the top. The *S. clarkei* bed is a probable time equivalent of the Big *Strophalosia* Zone and may be continuous with it; but it lies nearer the base of the subgroup, which suggests that the basal beds become appreciably younger as the subgroup transgresses to the west. On the Capella Block, the Blenheim Subgroup rests unconformably on pre-Permian rocks and overlaps the lower subgroups of the Back Creek Group. The lower unit was deposited in a shallow advancing sea. The abundance, in places, of large blocks in the basal conglomerate and the irregular distribution of the subgroup indicate the irregularity of the surface transgressed.

The upper unit (the 'Passage Beds' of Reid, 1924) on the Capella Block consists of cross-bedded quartzose sandstone with interbeds of siltstone and minor coal seams; it is much thicker than the lower unit. It contains plant and wood remains but few marine fossils, and was possibly deposited partly in fresh water.

The lower unit thickens greatly at the southern margin of the Capella Block, where it is overlain by the German Creek Coal Measures and apparently grades laterally into the Maria Formation of the Comet Ridge*.

*** An alternative correlation is discussed in Devine & Power (1967) and Dickins & Malone (1968).**

The German Creek Coal Measures were probably laid down during the same regressive phase as the 'Passage Beds' farther north, but the lateral relationships are uncertain. The coal measures were laid down in a marine and at times brackish delta which overlapped the silty Maria Formation. The basal beds of the coal measures appear to be lateral equivalents of the sandy upper part of the Peawaddy Formation, including the Mantuan *Productus* bed. The distribution of the coal measures is shown in Figure 14.

The boundary of the German Creek Coal Measures coincides with the southeast margin of the Capella Block. The southern part of the block is covered by a thin sequence of Permian sediments, comprising 60 to 90 m of the lower unit of the Blenheim Subgroup disconformably overlying equivalents(?) of the Aldebaran Sandstone near the eastern margin. In the Norwich Park 1 well, near the eastern edge of the block, the sequence consists of about 135 m of possible Aldebaran Sandstone below about 45 m of basal Blenheim Subgroup. This thin veneer of gently folded basal Blenheim Subgroup sediments dips east and south parallel to the regional fall of the topography. At the edge of the block the regional dip steepens slightly and the sequence thickens. The Maria Formation, which is the lateral equivalent of the basal part of the Blenheim Subgroup on the Comet Ridge, is about 245 m thick in the Cooroorah 1 well 24 km southeast of the edge of the shelf.

The palaeontological data suggest that the basal Blenheim Subgroup unit is the lateral equivalent of the complete Maria Formation. The 'pelecypod bed' at the top of the unit is considered to be a correlate of a coquinitic sandstone in the basal beds of the German Creek Coal Measures. Only a thin veneer of sediment was laid down on the Capella Block, while a much greater thickness was deposited to the east on the Comet Ridge. The style of folding on the Capella Block consists of very low-amplitude drape structures, quite different from the sinuous anticlines and synclines of slightly greater amplitude on the Comet Ridge. The thin sedimentation can be related to the relatively small subsidence of the underlying basement block, which also controlled the style of folding.

The thin basal unit of the Blenheim Subgroup extends throughout this belt of outcrop on the Capella Block. In the north the basal beds are overlain by the thick but areally restricted 'Passage Beds'. The style of folding is consistent throughout this belt, which is underlain by part of the tectonically stable Clermont Stable Block. The 'Passage Beds' represent predominantly freshwater sedimentation on the block, and they may be replaced by marine sediments of the same age to the east beyond the basement block.

Comet Ridge – Folded Zone

The Maria Formation is recognized only on the Comet Ridge. Lithologically, it resembles the lower part of the Peawaddy Formation, and to some extent the lower part of the Blenheim Subgroup in the lutite/quartzose arenite province. The arenites in the Maria Formation consist mainly of quartz-poor lithic sandstone, unlike those in the northern part of the basin. However, the Maria Formation is probably continuous with the Blenheim Subgroup in the north. Outcrops of the Blenheim Subgroup in the Folded Zone are mainly time equivalents of the German Creek Coal Measures. They consist of interbedded worm-tracked cross-bedded sublabile sandstone, micaceous siltstone, carbonaceous mudstone, and widespread thin sandy coquinites. The coquinites are correlated with those near the base of the German Creek Coal Measures, and are approximate correlates of the Mantuan *Productus* bed, the 'pelecypod bed', and the *Streptorhynchus* bed. The sediments resemble the upper part of the Blenheim Subgroup in the northern part of the basin, but the arenites contain a greater proportion of lithic grains. The lithic material may have come from the same provenance area as the Boomer Formation. The Blenheim Subgroup in the Folded Zone may consist of a mixture of material from the southeast, north, and west. No coal seams have been recorded, and presumably the beds were laid down in a shallow marine environment. The contact with the overlying Blackwater Group may be transitional.

Depositional Tectonics

The Blenheim Subgroup is the most widespread unit of the Back Creek Group, and indeed of the entire Bowen Basin sequence. It was laid down during a major marine transgression which culminated some time after deposition of the Blenheim Subgroup began. Thereafter, the sea gradually regressed and finally withdrew or was cut off from the basin about the end of Blenheim Subgroup time.

The marine transgression was initiated by slow regional subsidence which gradually spread farther inland. In the deeper water environment in the northern part of the basin and the Denison Trough marine sedimentation was continuous or almost continuous during the late Lower Permian, and may have continued into the Upper Permian. On the stable block in the southeastern part of the basin, which was a land area of low relief during the late Lower Permian, a thin veneer of neritic sediments (the Oxtrack Formation) was now laid down. Thereafter, subsidence proceeded more rapidly in the east, and the predominance of fine-grained epineritic sediments indicates that the rate of subsidence generally kept pace with or exceeded the rate of sedimentation.

The area of major subsidence is partly indicated in Figure 14, but has been distorted by late Permian and later uplifts in the east. It probably extended much farther east across both the Connors and Auburn Arches. The sediment was probably derived from a landmass to the east near Rockhampton. The open sea to the north of the Rockhampton landmass was probably connected with the northern part of the basin. It may also have been connected with the lutite province, and with the Yarrol Basin to the south of the Rockhampton landmass. Certainly, any land bounding the lutite province was well east of the outcrop belt on the west flank of the Auburn Arch. Reconstruction of the Upper Permian palaeogeography of the basin obviously involves the areas to the east and south, and cannot be attempted at this stage.

The Rookwood Volcanics are restricted to the Gogango Overfolded Zone, which was the site of maximum early Upper Permian sedimentation. The Overfolded Zone lies between the more stable Connors and Auburn Arches, and was the site of maximum subsidence followed by uplift and deformation. The igneous intrusions in the Overfolded Zone were emplaced about the middle of the Upper Permian, probably during uplift and folding. The orogeny was possibly accompanied by uplift of the Connors Arch and, to a lesser extent, of the Auburn Arch, which cut off the Bowen Basin from the sea. The deposition of the Blenheim Subgroup was followed by freshwater sedimentation. The change from fossiliferous marine sediments to plant-bearing freshwater sediments is generally very sharp. In the Folded Zone, the boundary is transitional, and deposition possibly continued throughout the transition from a marine to a brackish environment, and finally to a freshwater environment. The difference in the eastern provenance areas of the Blackwater Group was probably due to uplift. In the west the provenance areas were probably not greatly different.

PERMIAN ROCK UNITS OF THE EUNGELLA-CRACOW MOBILE BELT

In the map area the Youlambie Conglomerate and Rookwood Volcanics occur only in the Eungella-Cracow Mobile Belt. The early Lower Permian Youlambie Conglomerate is part of the Yarrol Basin sequence which extends westwards into the Bowen Basin. The Rookwood Volcanics of probable early Upper Permian age rest unconformably on the Youlambie Conglomerate, and interfinger with and are overlain by the Boomer Formation. The volcanics were laid down during a period of submarine volcanism in the strongly downwarped eastern extension of the Bowen Basin. The two formations are summarized in Table 11.

The Youlambie Conglomerate is probably a time equivalent of the Lower Permian sediments of Quail Island which are similar in gross lithology. The conglomerate may possibly be equivalent to and continuous with the upper part of the Torsdale Beds. The few fossils indicate that the conglomerate was deposited about the same time as the Carmila Beds or the lower part of the Back Creek Group, but the precise stratigraphic relationships are unknown. The Youlambie Conglomerate may have been laid down on the western margin of Lower Permian marine sequence in the Yarrol Basin, which is separated from the Carmila Beds and Back Creek Group by a ridge of Connors Volcanics and Rannes Beds. Alternatively, it may have been continuous with part of the Carmila Beds or lower part of the Back Creek Group; the connexion may be buried beneath or included in the Rannes Beds, or possibly was removed by erosion.

The uncertainty about the stratigraphic position of the Rannes Beds makes it difficult to interpret the stratigraphy of the Gogango Overfolded Zone.

Unnamed Lower Permian

Quail Island, immediately east of Long Island, is occupied by at least 4500 m of Lower Permian siltstone, feldspathic sandstone, and lithic conglomerate. The sequence overlies the Neerkol Formation, though the contact has not been observed. Lower Permian sediments were tentatively identified on the mainland to the south of Quail Island, where they are possibly faulted against Lower Palaeozoic metamorphics (see Fig. 6).

The Lower Permian rocks of Quail Island contain a marine fauna and can probably be correlated with the Youlambie Conglomerate (see Kirkegaard et al., 1970).

Rookwood Volcanics

The Rookwood Volcanics have been defined and described by Malone et al. (1969). The formation consists mainly of spilitic pillow lavas with some agglomerate, volcanic breccia, and chert, and a little tuffaceous sandstone and siltstone. The pillow structures are well developed (Pl. 8, fig. 1). The pillows range from 15 cm to 1 m in diameter and have a thin fine-grained skin and radial cracks; some have a thin vesicular layer beneath the skin. The pillow lavas grade in places into volcanic agglomerate and breccia, and in places they are silicified.

The Rookwood Volcanics are essentially massive. The contacts are not well exposed, but their regional distribution indicates that they rest unconformably on the Rannes Beds, Silurian-Devonian rocks, the Yarrol Basin sequence, and the Youlambie Conglomerate; they are overlain and overlapped by and interfinger with the Boomer Formation. In the Fitzroy River, the contact with the Boomer Formation appears to be conformable. In the Boomer Range the Boomer Formation consists of sediments interbedded with thin flows of pillow lava resting on Silurian-Devonian rocks; elsewhere the sediments overlap the volcanics and rest directly on the Silurian-Devonian rocks.

The Rookwood Volcanics are intruded by a granodiorite stock that has been isotopically dated at about 240 m.y. Near their contact the Rookwood Volcanics and the Rannes Beds are intruded by gabbroic stocks which may represent two of the vents from which the spilites were extruded.

The Rookwood Volcanics apparently consist of several thick overlapping lenses of spilitic volcanics, rather than a single extensive sheet. A thickness of more than 900 m was estimated on the southwest flank of the Craigilee Anticline, based on the dip of the underlying and overlying units, but they are very thin over the inlier of Silurian-Devonian volcanics 45 km north-northeast of Duaringa where their distribution was possibly partly controlled by the topography.

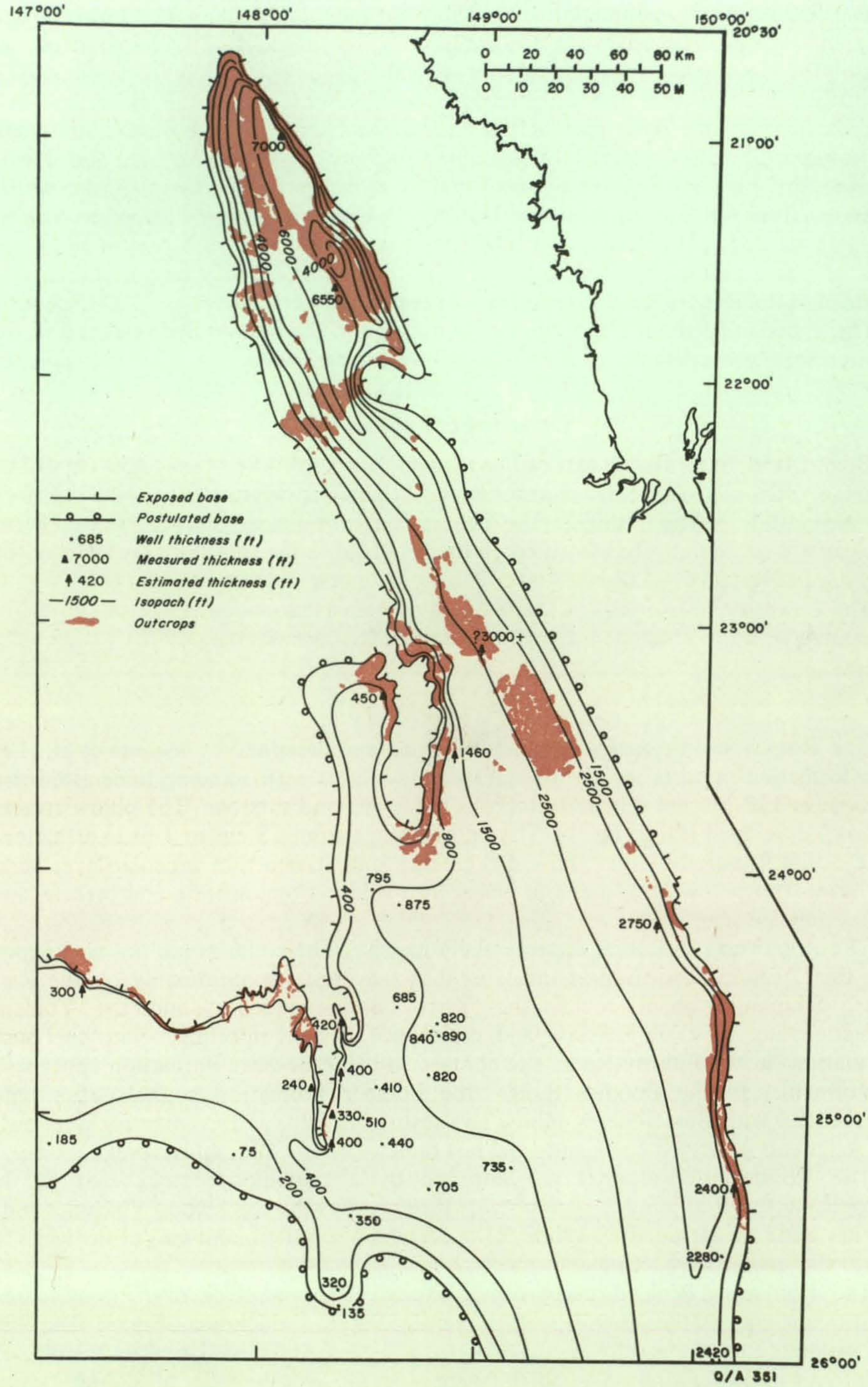

Figure 16. Distribution and outcrops of Blackwater Group.

The Rookwood Volcanics were possibly contemporaneous with the intrusive serpentinite near Marlborough, just north of the most northerly exposure of volcanics. The volcanics are confined to the Gogango Overfolded Zone, where strong subsidence took place in the early Upper Permian. The subsidence may have been mainly the result of faulting, and it is possible that extrusion of the Rookwood Volcanics was localized by the faults. Certainly, faulting played an important part in the emplacement of the serpentinite and in the uplift of the Marlborough Block

BLACKWATER GROUP

The Blackwater Group was deposited in much the same trough as the Blenheim Subgroup, but apparently did not extend eastwards into the Gogango Overfolded Zone (see Fig. 16). Maximum sedimentation was localized at the northern end of the trough, where the sequence is up to 2100 m thick. Thus there was a major change in the pattern of subsidence and sedimentation compared with that which prevailed during deposition of the Blenheim Subgroup. In the west, the Blackwater Group extended as far as the Blenheim Subgroup transgression, but in the north it possibly did not extend so far west.

The Blackwater Group is divided into three formations in the type area on the Comet Ridge and into two in the Baralaba-Cracow area; elsewhere the group has not been subdivided. The stratigraphy is briefly described in Table 12. Typical well and outcrop sections, illustrating the lateral variations, are presented in Figure 17.

In the type area the Rangal Coal Measures at the top of the group are probably widely distributed. The remaining formations of the group vary from area to area, particularly from south to north. The sequence in the north probably consists of thicker lateral equivalents of the same formations as on the Comet Ridge, but other formations are possibly present. In both areas, the Blackwater Group is structurally conformable on the youngest part of the Blenheim Subgroup. The contact is generally sharp in the north, but in places on the Comet Ridge and in the Folded Zone nearby it appears to be transitional. There is no evidence of uplift and erosion between the Blenheim Subgroup and Blackwater Group, but there may have been a brief hiatus. The Blackwater Group is overlain by the Rewan Formation on the Comet Ridge and in the north. The contact is locally disconformable, but is generally transitional and is probably slightly diachronous.

The relationships of the Blackwater Group in the Baralaba-Cracow area are similar to those on the Comet Ridge. The group is structurally conformable on the Flat Top Formation, and the contact may be transitional. The gradual reduction in the number of marine fossils towards the top of the Flat Top Formation suggests that the water became progressively fresher. The Rewan Formation appears to rest conformably on the Blackwater Group, but the presence of a thick basal pebble conglomerate suggests that they may be disconformable. The contact is too poorly exposed to determine the precise relationship. The formations in the Baralaba-Cracow area are similar to those in the type area. The Baralaba Coal Measures at the top are similar to and probably continuous with the Rangal Coal Measures. The volcanic member at the top of the Gyranda Formation is comparable with the Burngrove Formation, though it is much coarser in grain, probably because it was closer to the volcanic source. The Gyranda Formation volcanic member contains medium to coarse-grained tuffs, some of which contain biotite; the Burngrove Formation consists mainly of fine ashstone. The lower part of the Gyranda Formation differs considerably from the Fair Hill Formation and they were probably derived from different provenance areas.

The Blackwater Group in the Denison Trough and in the western part of the basin is less than 150 m thick. It consists mainly of coal measures underlain by a thin sequence of fine to coarse conglomeratic sandstone and a thin cherty tuffaceous (?) bed containing many fossil logs (Pl. 8, fig. 2). The group is disconformably, or in places unconformably,

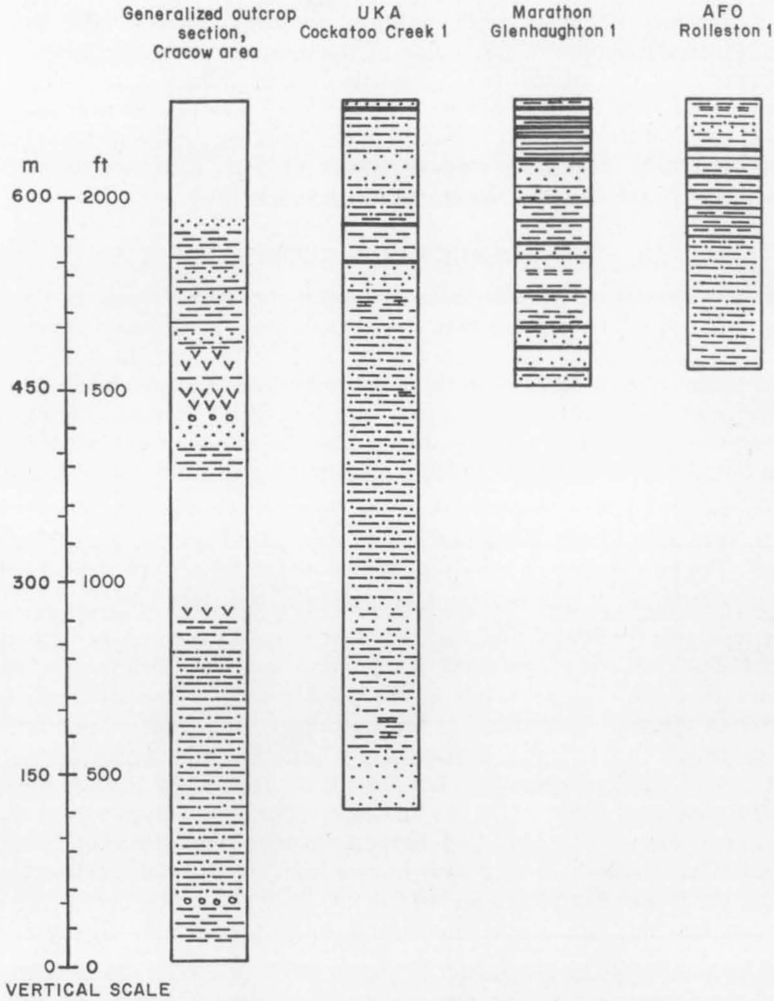

Figure 17. Sections of Blackwater Group.

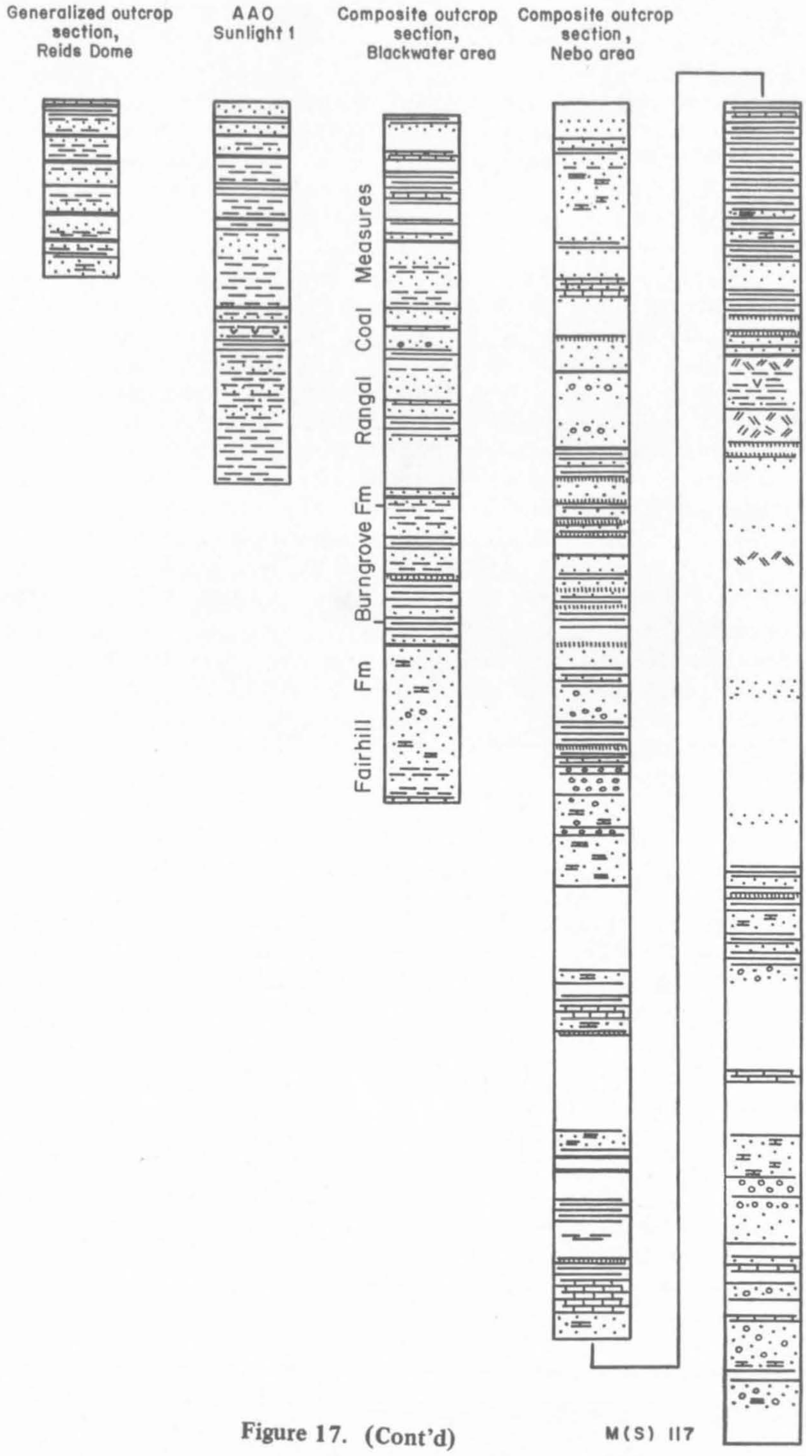

Figure 17. (Cont'd)

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overlain by the Rewan Formation, and is probably disconformable on the Black Alley Shale.

The thick sequence in the north, which is partly illustrated in Figure 16 (near Nebo), can probably be subdivided (see Jensen, 1968). The basal part of the sequence consists of 450 m of lithic sandstone, which is mainly calcareous and pebbly, with bands of conglomerate and interbeds of mudstone near the top. The basal sandstone is overlain by a poorly exposed sequence, about 420 m thick, which includes tuffaceous and muddy lithic sandstone and siltstone, chert, and hornblende diorite sills. The next unit is about 600 m thick. The lower part consists mainly of brown carbonaceous mudstone with thick interbeds of muddy labile sandstone and sandy limestone; the upper part is poorly exposed, but outcrops consist mainly of sandstone and limestone with thin interbeds of mudstone. The uppermost part of the group is about 520 m thick. It consists of calcareous pebbly labile sandstone, with conglomerate bands, sandy limestone, mudstone, carbonaceous shale, coal, cherty fine tuff, and tuffaceous sandstone. The lithology of the Blackwater Group in the type area on the Comet Ridge is similar to that in the north, but the sequence is different. For example, the fine cherty beds with abundant plants are generally confined to the Burngrove Formation in the type area, but in the north they occur throughout most of the group. For this reason, and because of the greatly increased thickness, it is not possible to correlate the formations in the type area with those in the north, and considerable drilling will be required to trace the formations along the Collinsville Shelf and into the Nebo Synclinorium, where the thickest sequence is located.

The Blackwater Group was apparently laid down in a terrestrial environment. Most of the sediments were deposited by rivers, but in places beds were laid down in lakes or swamps, and towards the top of the sequence coal measures were deposited in an extensive system of swamps and sluggish rivers. Although most of the coal occurs in the upper part of the group, thin seams are present in the Burngrove Formation and local thick seams near the base.

Calcite is abundant in the Blackwater Group. It occurs as matrix or cement in the calcareous sandstone and siltstone, or as sandy or silty limestone. The abundance of calcite in this type of environment seems unusual. The arenites in the Blackwater Group, particularly in the north, where calcite is most abundant, consist mainly of plagioclase grains and fragments of volcanic rock derived from a volcanic provenance. The calcite may have been derived from the same volcanic source, and was probably formed during diagenesis of the volcanic rocks. The Connors Arch is considered to have been the main provenance in the north; some of the calcite may have been derived from the Lower Permian and older volcanics, but some of the volcanic detritus was provided by contemporaneous volcanism.

The Blackwater Group contains an abundant and varied fossil flora, which indicates a Permian to Lower Triassic age. The lower age limit is fixed by the early Upper Permian (Kazanian) marine fauna in the Blenheim Subgroup. The Blackwater Group is probably entirely Upper Permian. The spore assemblage in the Blackwater Group is distinctly different from that in the overlying Rewan Formation, and the break may lie at the Permian-Triassic boundary or late in the Upper Permian.

Biotite from a tuff at the top of the Gyranda Formations has been dated isotopically at about 240 m.y. (Webb & McDougall, 1967), which is about the same age as many of the igneous intrusions farther east. This date is regarded as late Upper Permian by Webb & McDougall, who suggest 235 m.y. as the geochronological age of the Permian-Triassic boundary.

Depositional Tectonics

The Bowen Basin was probably cut off from the sea by uplift of the Eungella-Cracow Mobile Belt. The amount of uplift probably increased from south to north, and the

Connors Arch and Gogango Overfolded Zone rose more than the Auburn Arch. This is reflected in the changes in sedimentation from the Blenheim Subgroup to the Blackwater Group in different areas. In the north, quartz-rich moderately deep-water marine sediments, mainly lutites, are succeeded by labile freshwater beds which include considerable conglomerate near the base. Most of the labile sediment in the Blackwater Group was probably derived from Lower Permian and older volcanics on the Connors Arch, but some of the detritus was provided by contemporaneous volcanism. In the south, the youngest part of the Blenheim Subgroup was possibly deposited in a transitional environment where only slight uplift was required to complete the transition from marine to fresh water. The sequence at the base of the Blackwater Group consists mainly of fine-grained lithic sandstone overlying a predominantly lutite sequence; the change indicates a slight rejuvenation of the provenance areas, although the composition of the sediment was not greatly altered. The thickness of the Blackwater Group in the north and the sporadic volcanism indicate that this was the area of greatest tectonic activity. There is abundant evidence that the beds in the north were laid down by strong fluvial currents. The structure of the Permian sequence indicates that the Connors Arch was uplifted further than the Auburn Arch. The Back Creek and Blackwater Group dip west off the Auburn Arch at no more than 30°; they generally dip southwest off the Connors Arch at 45° or more, but in places they are vertical or overturned. Much of the uplift took place after the Permian.

The sequence in the Gogango Overfolded Zone was probably folded and uplifted about the start of Blackwater Group time, possibly in response to the same tectonism that uplifted the Connors Arch; some uplift in the Overfolded Zone or to the east must have taken place at this time to cut off the Bowen Basin from the sea. The Blackwater Group does not extend into the Overfolded Zone. This may be due to erosion, but possibly the group was never deposited in the area. The predominant Upper Permian isotopic age of the igneous rocks intruding the Gogango Overfolded Zone and the area to the east suggests an Upper Permian age for at least one pulse of the orogeny which affected the Eungella-Cracow Mobile Belt.

Most of the southern part of the Bowen Basin was the site of slow steady subsidence and accumulation of sediment. The sequences deposited east and west of the central part of the basin have been removed by erosion, except in the west, where the lower part of the group is very thin. The upper coal measures are better developed, and possibly, by that time, the rate of sedimentation exceeded subsidence and extensive shallow lakes and swamps were formed.

PERMIAN PALAEONTOLOGY AND CORRELATION BASED ON MARINE INVERTEBRATES

In 1845 Leichhardt (1847) found masses of coniferous wood associated with coal measures in what has now become known as the Bowen Basin; and in 1862 Clarke recorded marine invertebrates. In correctly recognizing their Permian age by comparison with the Magnesian Limestone of England, Clarke was ahead of his time. Daintree (letter *in* Clarke, 1867, p. 11) reports marine fossils and the plant *Glossopteris.* Fossils were first described by Etheridge (1872) from collections made by Daintree. References to recent descriptions of the invertebrate marine fossils are given in the appendices prepared by Dickins for the Reports on the 1:250,000 Sheet areas. These appendices also contain reports on the flora by Mary E. White (macroplants), and Evans (1969) has discussed the palynology.

Teichert (1951) recognized a Western Australian faunal province and an eastern Australian province. The faunas from the Bowen Basin belong to the eastern Australian faunal province along with those from the rest of Queensland, New South Wales, Tasmania, and the recently described faunas from New Zealand (Waterhouse, 1958, 1963a,b,c,d, 1964, 1965a,b; Waterhouse & Vella, 1965). The flora is representative of the *Glossopteris-Gangamopteris* flora.

Foraminifera, corals, blastoids, crinoids, ammonites, and ostracods, although locally abundant, are on the whole poorly represented. No fusulinids, conodonts, or colonial corals have been found, and trilobites are rare. Foraminifera are represented mainly by arenaceous forms (Crespin, 1958) and only a few genera of crinoids are found. On the other hand polyzoans, brachiopods, pelecypods, and gastropods are richly developed in numbers and species. Although these groups show closer relationship with the Western Australian province than they do with New South Wales (Dickins, 1970), they show a strong indigenous eastern Australian aspect. Tracks and burrowing are common. Vertebrates are very poorly represented: fish are rare, and apart from possible tracks (Malone et al., 1969), amphibians and reptiles have not been recorded. Some species of brachiopods and pelecypods attain an unusually large size.

Although at times, the water may have been warmer, the absence of fusulinids and colonial corals, the limited numbers of ammonites, and the indigenous developments in other groups suggest that cool water conditions persisted to the end of Back Creek Group time. More recent evidence supports Teichert's (1950 p. 207) contention that there was a marked amelioration in climate in early Artinskian time because the only ammonites found are in rocks of this age; at one locality (Homevale) they are relatively abundant (Armstrong, Dear, & Runnegar, 1967).

The plants are characteristic of the *Gangamopteris-Glossopteris* flora with its distinctive associated microflora (Balme, 1962, 1963). In the Springsure area the *Gangamopteris-Glossopteris* flora in the Reids Dome Beds marks a distinct floral change from the *Rhacopteris* flora in the underlying Joe Joe Formation (White, appendix *in* Mollan et al., 1969). Although it has been suggested that *Gangamopteris* does not occur in the Upper Permian (e.g. Plumstead, 1962, p. 113), White (appendix *in* Mollan et al., 1971) has identified *Gangamopteris cyclopteroides* Feistmantel in the Gyranda Formation. The Gyranda Formation in a general way is equivalent in age to the Tomago and Newcastle Coal Measures of New South Wales and the evidence for its Upper Permian age seems clear. Taeniopteroid leaves have been recorded by White (appendix *in* Malone et al., 1969), but the *Glossopteris* flora does not persist above the Blackwater Group and has never been recorded in the Rewan Formation.

Palaeoecological Setting

The Permian sequence consists mainly of clastic rocks. Limestones are rare, and where present generally impure. Much of the sediment was derived from an igneous terrain and the sequence includes volcanic flows and pyroclastics. Reefs are entirely unknown and, whatever effects the clastic sedimentation may have had on their development, the cool water conditions were unsuitable for reef growth.

The basin apparently represented an unstable trough with sharp, and at times high, relief in the hinterland; deltas and swamps formed at the margins in times of slow sinking.

The sea entered the basin about the middle of the early Permian, probably through a wide embayment which later became restricted to the east and south. During this time swamps were formed around the margins of the marine basin. In the wet climatic conditions a rich vegetation and extensive forests flourished in the swamps. Prolific marine life developed under suitable conditions, and on occasions the fauna was killed and swept into deeper water by torrential floods or violent earth movements. At times life was inhibited by the depth of water or by floods of detritus. Active volcanoes killed off the animals and plants and supplied detritus to the sinking trough. Ice may have been present from time to time on the hinterland, and floating ice on the sea. By the late Permian the sea was cut off by the rising mountains in the east.

As described for Western Australia (Thomas, 1958, p. 26; Dickins, 1963, p. 25) the pelecypods are commonly associated with sandy sediments and the brachiopods and pelecypods with muds.

Faunal Subdivision and Correlation

Whitehouse (appendix 1 *in* Reid, 1928a, p. 286) was apparently the first to attempt the stratigraphic use of the faunas within the basin. He concluded that the older faunas of the basal 'Middle Bowen' in the Mount Britton area and in the Yatton Limestone on the east side of the basin were absent in the Clermont area in the west. The regional survey of the basin has confirmed this conclusion. The stratigraphical distribution of the faunas has also been studied by Hill (1950, 1957), Campbell (1953, 1959, 1960, 1961), and Maxwell (1954).

During the first year of the regional survey, the faunas of the thin sequence on the west side of the basin in the Clermont area were compared with those from the thicker sequence in the east (Dickins, *in* Malone et al., 1964, and *in* Veevers et al., 1964b). Four stratigraphically discrete faunal assemblages were distinguished in the east, Faunas I, II, III, and IV, from oldest to youngest. Only Fauna IV was represented in the western part of the basin, where the sequence overlies the Carboniferous rocks unconformably.

In the following year it became apparent that the four faunas, each corresponding to one or several fossil zones, were characteristic of four distinctive rock units, namely the upper part of the Lizzie Creek Volcanics and the Tiverton, Gebbie, and Blenheim Subgroups of the Back Creek Group.

Fauna III was subsequently subdivided into Faunas IIIA, B, and C. Unexpectedly it has been found that the faunal subdivisions in the Bowen Basin are in the main also applicable in New South Wales (Brown, Campbell, & Crook, 1968; Dickins, 1969; Runnegar, 1967a,b) and in Tasmania (Brown et al., 1968; Runnegar, 1967a,b,), and the work of Waterhouse shows that the scheme can also be applied in New Zealand.

The species and genera found in each of the faunal subdivisions are discussed in the Reports on the 1:250,000 Sheet areas and in Dickins et al. (1964). The accompanying chart (Table 13) shows the species identified from the various parts of the basin. The taxonomic identifications are those used in the Reports. The following have been showr separately in the chart in order that their relationship can be specially examined: the probable Fauna I of the basal part of the Stanleigh Formation in the Springsure area, the faunas of the Ingelara Formation and the Catherine Sandstone, the fauna of the probable equivalent of the Ingelara Formation in the Folded Zone, and the fauna of the Oxtrack Formation.

The progressive change in the faunas is shown clearly in the chart and not more than one or two species, if any at all, range through the whole sequence. There is a marked change between Fauna II and Fauna III: of the 74 species in Fauna II only 26 are recorded higher in the sequence. Fauna IV is marked by the absence of species from lower levels: of the 83 species recorded in Fauna IV (excepting those from the Oxtrack Formation), only 38 are recorded below, and of the 62 species in Fauna III 25 do not extend into Fauna IV.

The fossils have been collected from a large number of localities, where many different rock types and environments are represented. The lateral distribution of the fossils in different environments, such as siltstone, sandstone, mudstone, and limestone, etc., can be compared with their vertical distribution in similar rock types and environments. These comparisons ensure that the changes, which are in part evolutionary, reflect changes with time, and they can then be used with confidence for time-correlation within the basin. Indeed the identification of the assemblages outside the basin not only confirms this conclusion, but shows they are also valid for general time-correlation throughout eastern Australia and New Zealand (for application to other parts of eastern Australia see Runnegar, 1967a).

Although only a few species distinguish Fauna I from Fauna II, Fauna I does help to distinguish the earliest marine horizons within the Bowen Basin. The recognition of Fauna I in the lower part of the Stanleigh Formation is dependent on the slim evidence provided by the presence of an *Aviculopecten* with unspecialized ribbing. *'Megadesmus'* cf. *antiquatus*, referred by Runnegar (1967b) to *Pyramus concentricus?* is now apparently known also from Fauna II at Homevale (B.N. Runnegar, pers. comm.). The identification, however, of Fauna I in the Stanleigh Formation fits the other geological evidence that the earliest part of the marine sequence in the Springsure area was coeval with the final phase of the volcanic activity in Lizzie Creek Volcanics time.

The time relationship between the Ingelara Formation, Catherine Sandstone, and Oxtrack Formation poses a more complex problem, especially as both the Catherine Sandstone and Oxtrack Formation contain a relatively small fauna. This is considered in detail elsewhere (Dickins, *in* Mollan et al., 1969, and *in* Mollan et al., 1971). The comparison of the faunas of the Ingelara and Peawaddy Formations from the Springsure area is particularly important. The two formations are similar in lithology and contain similar associations of fossils. Detailed examination shows, however, that there are a number of species which are not common to both. Species which are found in both can be put aside when a faunal comparison is made. This is illustrated, for example, by the age relationship of the Barfield Formation to the Ingelara and Peawaddy Formations. The similarity in lithology and environment of deposition of all three formations is reflected in similar faunal associations and all three contain a number of species in common. The species which do not occur in common are therefore of consequence in determining the time relationships, and in this respect Table 13 shows that the Oxtrack and Barfield Formations contain species that elsewhere are not older than Fauna IV, and that the Catherine Sandstone and Ingelara Formation contain species not elsewhere restricted to Fauna IV.

One difficulty in correlating the Ingelara Formation with the sequence in the northern part of the basin has been the predominance of brachiopods in the Ingelara Formation in contrast to the predominance of molluscs in the north. Important information on this question has been obtained in the Folded Zone where the sequence is regarded as equivalent to the Ingelara Formation. In the Folded Zone Ingelara Formation brachiopods are associated with Fauna III molluscs, and it has therefore been concluded that the Ingelara Formation is older than the Oxtrack Formation and other formations of the Blenheim Subgroup which contain Fauna IV (Dickins, *in* Mollan et al., 1969).

MIMOSA GROUP

The Mimosa Group consists of the Rewan Formation, Clematis Sandstone, and Moolayember Formation (see Table 14; Figs 18, 19, 20). The three formations constitute a lithogenetic unit. In most places the contacts are conformable, and where the sequence is well developed they are generally transitional. They were laid down in much the same depositional area and in similar environments. The group consists of a thick sequence of mudstone and labile clastics with the quartzose Clematis Sandstone in the middle. The Mimosa Group has been separated from the Blackwater Group because (i) the marked shift in the locus of maximum sedimentation and vigorous uplift of provenance areas to the southeast indicate a major change in the tectonic regime; (ii) the abundance of carbonaceous matter and plants in the Blackwater Group and their comparative rarity in the Mimosa Group represent a major change in the environment or climate, or both; and (iii) because of the marked difference in gross lithology.

Rewan Formation

The Rewan Formation was laid down about the end of the Upper Permian mainly as the result of renewed tectonism. The distribution of the formation (Fig. 18) reveals a major shift in the locus of maximum sedimentation from northeast to southeast. The trough along the east side of the basin is preserved, but maximum subsidence and sedimentation took place in the Mimosa Syncline at the southern end The type of

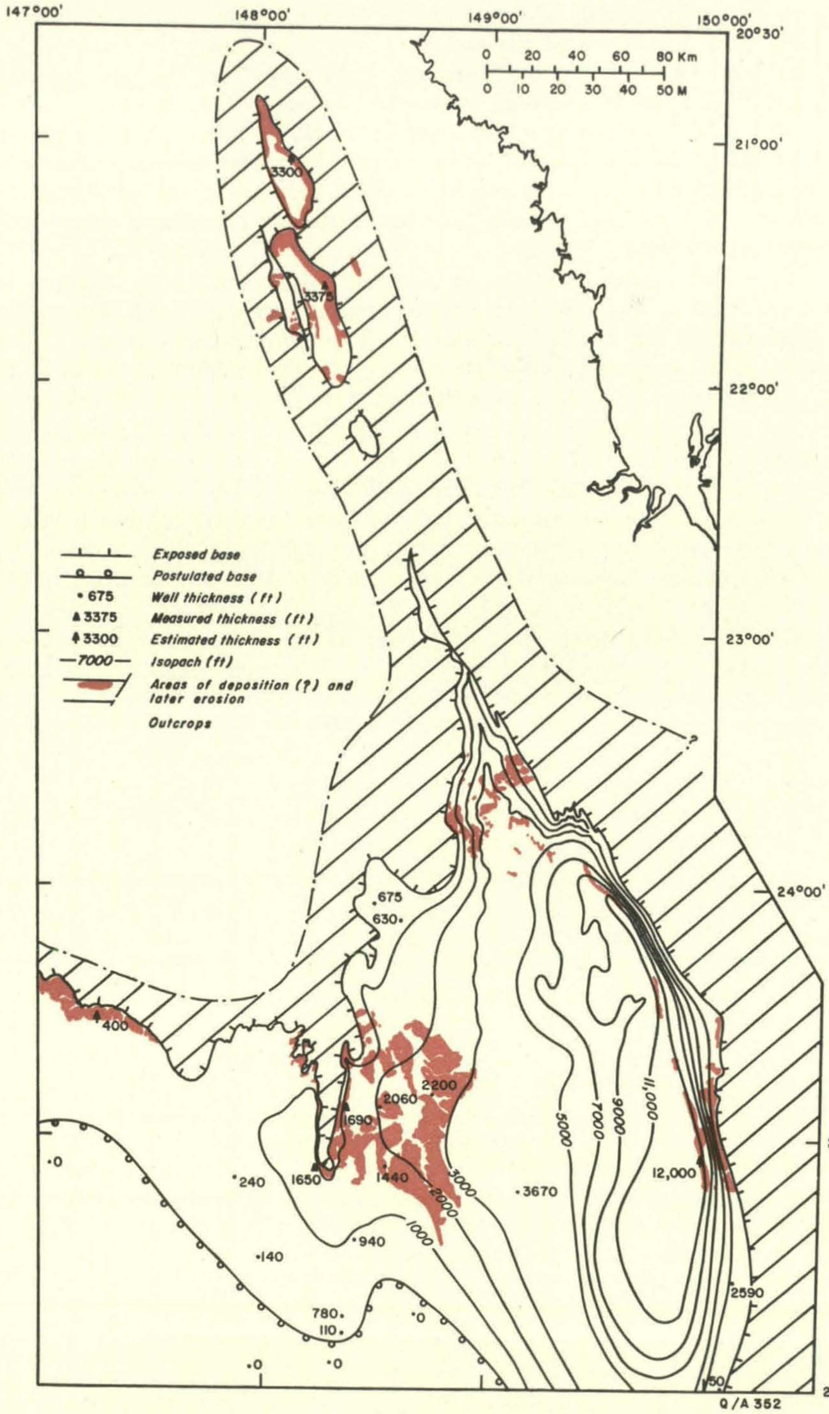

Figure 18. Distribution and outcrops of Rewan Formation.

sediments laid down indicates vigorous uplift in the southeast and south. In the southeast, the basal part of the Rewan Formation contains beds of tuff and volcanolithic pebble conglomerate, and fragments of volcanic rocks predominate in the arenites. Quartz grains form only 5 to 10 percent of the arenites in the lower part of the formation in the southeast, but constitute up to 50 percent of the rocks near the top. These changes reflect a gradual decrease in tectonic activity and volcanism. Several igneous intrusions to the east of the Auburn Arch have been dated isotopically at about 220 m.y. (possibly late Lower Triassic to Middle Triassic), and they may have been emplaced about the same time as the Mimosa Group was laid down. As in the case of the mid-Upper Permian orogeny, the isotopic ages suggest that the intrusions crystallized after uplift and sedimentation had begun.

Seismic surveys across the Mimosa Syncline (Marathon, 1963) indicate that the greatest thickness of the Rewan Formation is on the east side of the Mimosa Syncline. The asymmetry of the Rewan Formation (see Fig. 18) is probably largely the result of post-depositional movements, although it was probably a depositional feature in part; presumably the depositional area extended slightly farther east on to the Auburn Arch.

The Rewan Formation is much thinner to the west of the Mimosa Syncline, where it consists mainly of mudstone and fine sandstone (Pl. 9, fig. 2), with some coarse and pebbly sandstone near the base. The arenites in the west contain more quartz than those in the Mimosa Syncline, but exhibit a similar increase in quartz content upwards. They contain a large proportion of volcanic detritus, though less contemporaneous volcanic material than in the southeast; they consist mainly of volcanolithic labile to sublabile sandstone.

A prominent pebbly coarse lithic sandstone, the Brumby Sandstone Member, occurs near the base of the Rewan Formation west of the Mimosa Syncline. The member forms the base of the formation in places, but elsewhere overlies a thin basal sequence with slight angular unconformity. The western provenance area was apparently slightly rejuvenated, and the basal sequence of the Rewan Formation was tilted and eroded before the Brumby Sandstone Member was laid down. The presence of recycled Carboniferous spores (Evans, 1966c) in samples from low in the Rewan Formation also suggests rejuvenation of the western provenance area.

North of the Mimosa Syncline, near Blackwater, and in the northern part of the basin, the contact between the Rewan Formation and Blackwater Group is locally disconformable and sharp, but apparently is more commonly transitional. Near Blackwater the basal sequence consists of lithic sandstone and siltstone known as the Sagittarius Sandstone Member. The red-brown mudstone, which is so characteristic of the Rewan Formation in the south, is predominant only in the upper part of the formation in the north. The Sagittarius Sandstone Member and its equivalent farther north can be distinguished from the Blackwater Group by the absence of plant remains, coal seams, and carbonaceous matter. In the north, careful examination is required to separate the topmost 30 m of the Blackwater Group, above the highest coal seam, from the overlying Rewan Formation. In the south, the boundary is quite sharp and probably disconformable, and is defined by the presence of red-brown and green mudstone near the base of the Rewan Formation. In the southwest, the Rewan Formation rests in places with angular unconformity on the Blackwater Group.

The Rewan Formation contains a great volume of red-brown mudstone (Pl. 10, fig. 1). The mudstone contains spots and filaments of very fine red-brown iron oxide which was probably deposited contemporaneously with the clay particles (Bastian, 1965d). The presence of ferric oxide may indicate deposition in an oxidizing environment, but this alone does not explain the abundance of ferruginous clay. The green mudstone, which is also quite common, possibly contains ferrous iron. The presence of desiccation cracks in the mudstone indicates intermittent drying up of the lakes in which the mudstone was deposited, and the ferric iron may have been formed while the beds were exposed. However, the red-brown mudstone occurs in massive unbedded units up to 30 m thick, which were presumably laid down in relatively deep water. The red-brown mudstone was probably laid down during a prolonged period when there was an abundant supply of clay particles with occluded ferric oxide and a lack of carbonaceous material which could have led to the reduction of the iron. A change in climate is the most likely cause of the abundance of ferruginous clay, which was possibly derived from lateritic soil. The abundance of red-beds of this age in eastern Australia, and in fact throughout the world, suggests that the controlling factors operated on a continental or world-wide scale and this would be compatible with a climatological control. Most of the arenites in the Rewan Formation are trough cross-stratified, and were probably laid down in an environment similar to that of much of the Blackwater Group. This also suggests that the change from the carbonaceous sediments of the Blackwater Group to the non-carbonaceous, oxidized(?) red-beds of the Rewan Formation reflects a general factor not confined to the area of deposition.

Clematis Sandstone

The Clematis Sandstone succeeded the Rewan Formation during a period when the intensity of tectonic activity was temporarily reduced. The increase in the ratio of quartz grains to fragments of volcanic rock towards the top of the Rewan Formation in the southeast indicates the slackening of extrusive activity, but not its end. The Clematis Sandstone in the southeast contains a significant proportion of volcanic detritus and generally consists of volcanolithic sublabile sandstone rather than quartzose sandstone; elsewhere quartzose sandstone is predominant (Pl. 10, fig. 2) and the sublabile sandstone was derived mainly from a metamorphic provenance area. The Clematis Sandstone is much more uniformly distributed than the Rewan Formation. The thickness ranges from about 100 m in the west to 300 m in the Mimosa Syncline, and to a maximum of 450 m in the north (see Fig. 19). The distribution of the formation indicates that the Mimosa Syncline was not subsiding as rapidly as during deposition of the Rewan Formation. The slower rate of subsidence and burial of sediment could explain the greater mineralogical maturity of the Clematis Sandstone, which is mainly quartzose to sublabile. The sediments were derived from much the same provenance areas as the Rewan Formation, but were possibly subjected to considerably more chemical weathering and reworking in the fluvial environment because of the slower rate of subsidence. Mechanical reworking was not severe, however, as most of the quartz grains are of low sphericity. Most of the Clematis Sandstone consists of planar cross-bedded sandstone, probably deposited in braided river channels. The interbeds of grey and white flaggy siltstone were probably laid down on short-lived flood-plains. Thin beds of red-brown mudstone and bands of red and yellow ochre occur between sets of cross-bedded sandstone in places; the mudstone is identical with that in the Rewan Formation.

Measurements of the cross-bedding azimuths are presented on Figure 19. In the northern part of the basin, sediment from the Clermont Stable Block and Connors Arch was transported southwards along the length of the basin, probably by a series of braided river channels. The sequence is generally coarser in grain than farther south, and consists almost exclusively of cross-bedded sandstone. As the sequence in the north is about 160 km from the nearest outcrop of Clematis Sandstone, it was originally given a separate name (the Carborough Sandstone, Malone et al., 1964, 1966), but as it is now considered to have been laid down in the same basin as a continuous sequence with the Clematis Sandstone the name 'Carborough Sandstone' has been abandoned.

The cross-bedding azimuths on the west limb of the Mimosa Syncline indicate that much of the detritus was derived from the southern end of the Clermont Stable Block. Measurements at the most southerly site reveal a northeasterly component, away from

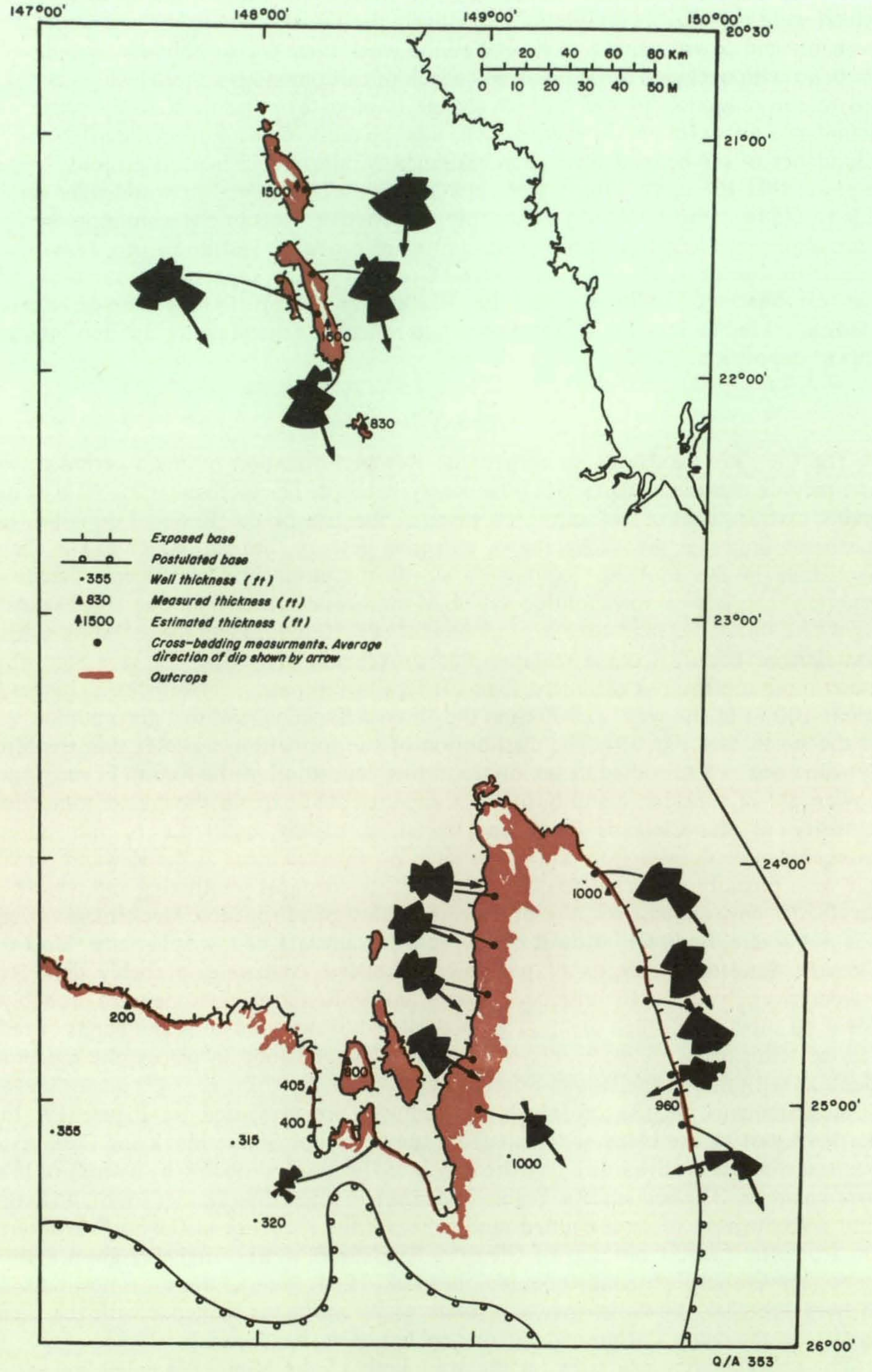

Figure 19. Distribution and outcrops of Clematis Sandstone and directions of cross-bedding.

the southern block of pre-Clematis Sandstone rocks outlined on Figure 19. Measurements on the east limb mainly indicate transport in a south to southeasterly direction, which suggests that the eastern margin of sedimentation probably extended farther east on to the Auburn Arch. In the south there is a strong westerly direction of transport. The sediments here contain the highest proportion of volcanic detritus, which was presumably derived from an easterly provenance area. The presence of beds of conglomerate in the Clematis Sandstone in the south suggests that the source area may have been fairly close.

The influence of the eastern volcanics provenance was probably limited to the relatively small area of Clematis Sandstone which contains a significant proportion of volcanic detritus Even in this area, a south-southeasterly direction of transport is recognizable.

In the north, the Clematis Sandstone was probably laid down in the braided channels of a major river system flowing south along the length of the Bowen Basin. In the west the formation may have been deposited by a tributary of the main river system, but the presence of more fine sandstone and siltstone, which were possibly laid down on flood-plains, suggests that the environment was different from that in the north. The section of the Clematis Sandstone in the Glenhaughton 1 well shows that finer sediments are also abundant in the southern part of the Mimosa Syncline. Possibly the palaeoslopes were gentler in the south, so that the braided channel type of deposition in the north was succeeded by a more normal fluvial environment of river-channel and floodplain deposition.

Moolayember Formation

The Moolayember Formation transitionally succeeded the Clematis Sandstone with a progressive increase in the proportion of labile constituents and the reappearance of calcite in the arenites and to a lesser extent in the lutites. Calcite is abundant in the Blackwater Group arenites and is present in many of the coarse and pebbly arenites of the Rewan Formation, such as the Brumby Sandstone Member, but is absent in the Clematis Sandstone. The calcite commonly replaces feldspar grains and fragments of volcanic rock, but does not replace or encrust the quartz grains. The absence of calcite in the Clematis Sandstone may be related to the paucity of volcanic detritus.

The abundance of trough and planar cross-stratified labile arenites in the Moolayember Formation suggests deposition in a partly fluvial environment which differed from that of the Clematis Sandstone in that rate of subsidence was greater and the sediments were buried with considerably less reworking. The presence of thick beds of polymictic, mainly volcanolithic, pebble and cobble conglomerate in the Moolayember Formation, particularly in the east limb of the Mimosa Syncline, testifies to renewed uplift of the southeastern provenance areas. The Moolayember Formation (Fig. 20) is very thick along the axis of the Mimosa Syncline and thins rapidly to the west, in contrast with the relatively uniform distribution of the Clematis Sandstone. The distribution of the Moolayember Formation resembles that of the Rewan Formation, though the locus of maximum sedimentation is farther west. The Rewan Formation was laid down during a period of vigorous uplift, intrusion, and volcanism to the east or southeast of the basin, associated with linear subsidence in the Mimosa Syncline. The intensity of tectonism waned considerably in Clematis Sandstone time and was renewed during deposition of the Moolayember Formation. The last pulse of tectonism was less vigorous than that during the deposition of the Rewan Formation and represents the final tectonic activity in the Mimosa Syncline. The syncline is the only area of considerable subsidence within the Bowen Basin which has not been subsequently uplifted or folded, and the Moolayember Formation within the syncline has not been greatly disturbed since it was deposited.

The Moolayember Formation is generally finer in grain to the west and north· conglomerate and coarse arenite are confined to the east limb of the Mimosa Syncline

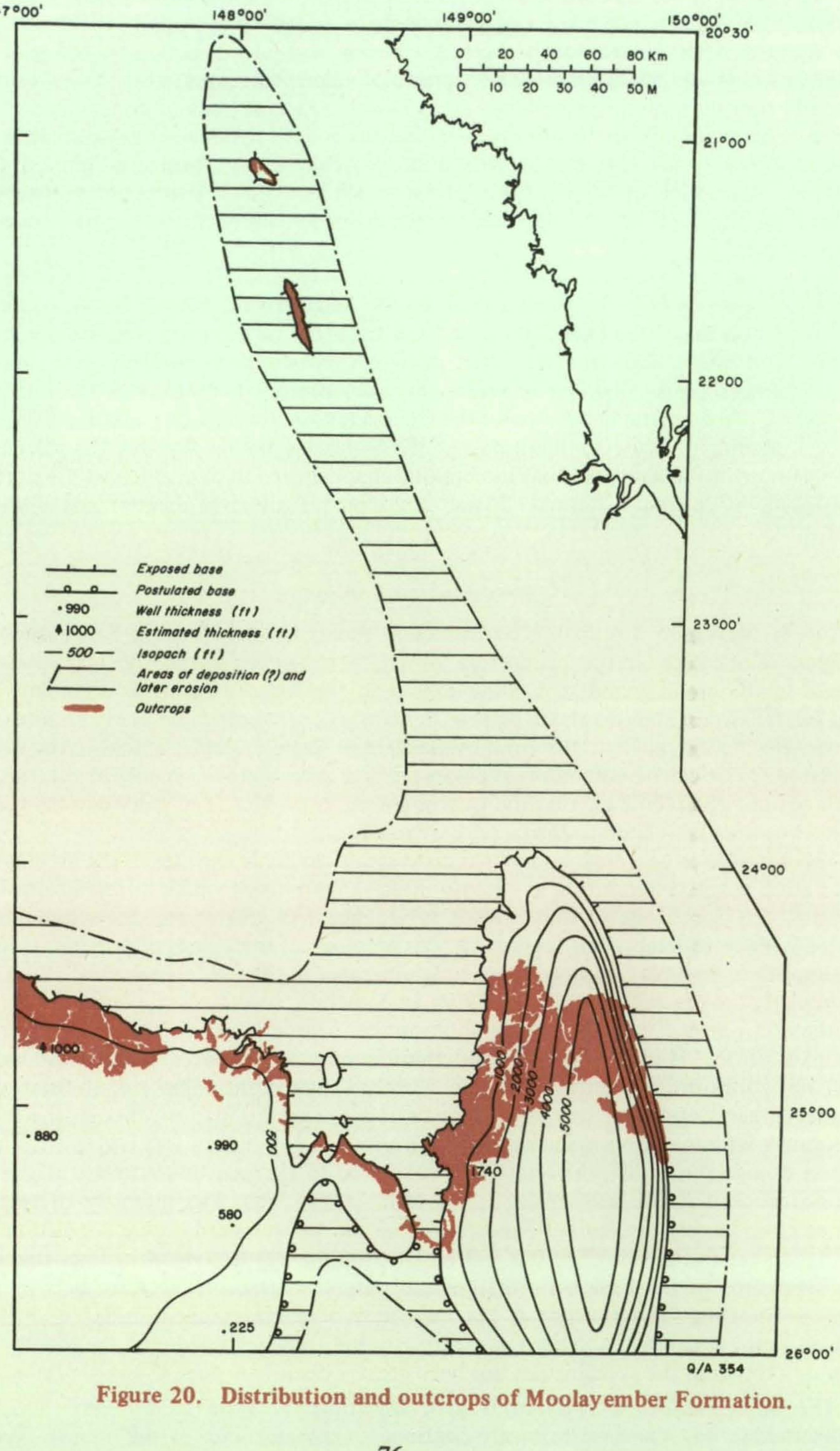

Figure 20. Distribution and outcrops of Moolayember Formation.

Quartz is more abundant in the west, but this may be partly due to the finer grain size. The Moolayember Formation contains a large proportion of yellow-green swollen and leached biotite, which is rare in the Clematis Sandstone in the southeast. The most likely source of the biotite is the granodiorite and other plutonic rocks of the Urannah Complex and other plutonic rocks east of the Auburn Arch. Biotite and its alteration products are abundant in the west limb of the Mimosa Syncline and for some distance farther west, but are less common in the west. West of the syncline, the formation contains less volcanic detritus and more fragments of sedimentary and metamorphic rocks; this reflects the distance from the eastern provenance area and the supply of material from provenances to the northwest and southwest (Bastian, 1965c).

The mudstone in the Moolayember Formation commonly contains plants and carbonaceous debris and locally grades into carbonaceous shale; thin coal seams are present in places. The red-brown mudstone of the Rewan Formation and Clematis Sandstone is absent. The presence of carbonaceous matter suggests that the Moolayember Formation was deposited in a reducing environment. The fine grainsize and regular bedding in parts of the formation suggest that the sequence was laid down in lakes, and the abundance of cross-bedding indicates the importance of traction currents, probably fluvial. The Moolayember Formation was probably laid down in a fluvio-lacustrine environment, and the presence of acritarchs (Evans, 1964a) possibly indicates occasional incursions of the sea.

Age of Mimosa Group

The macroflora in the Moolayember Formation and Clematis Sandstone indicates a Triassic to Lower Jurassic age. The abundant microflora provides an effective means of determining the relative age of formations in the Upper Permian and Mesozoic sequence, including the Mimosa Group; but correlation between the microfloral units and the geological time scale is uncertain, particularly with regard to the position of the Permian-Triassic boundary (see Evans, 1964a). In the Bowen Basin the sharp break between the microfloral assemblages at the top of the Blackwater Group and in the Rewan Formation is regarded as marking the boundary. Similarly the microfloral change between the Newcastle Coal Measures and the Narrabeen Group is accepted as the Permian-Triassic boundary in the Sydney Basin. The *Glossopteris* flora is not found above this horizon in either basin, but a thick florally barren sequence separates it from the oldest sediments containing the *Dicroidium* flora. The Permian-Triassic boundary could lie within the barren sequence, that is, within the Rewan Formation in the Bowen Basin, but can be no lower than its base if the *Glossopteris* flora is accepted as diagnostic of the Permian. Referring to correlation with Western Australia, Evans (1964a) points out that the basal part of the Rewan Formation could be Upper Permian, but this is as yet unproved. The bulk of the formation is Lower Triassic.

The boundary between the Lower and Middle Triassic is also uncertain. In the Sydney Basin, the *Dicroidium* flora becomes well established in what is regarded as a late Lower or early Middle Triassic formation. The appreciable microfloral change accompanying the establishment of the macroflora is regarded as approximately marking the boundary between Lower and Middle Triassic. In the Bowen Basin, this change occurs above the base of the Clematis Sandstone, but its position cannot be determined because of poor preservation of the spores. This implies that the Rewan Formation is no younger than Lower Triassic and that the Clematis Sandstone extends from Lower Triassic to Middle Triassic.

The boundary between Middle and Upper Triassic cannot be recognized and the Moolayember Formation is regarded as Middle to Upper(?) Triassic in age. The upper boundary of the Moolayember Formation is taken at the angular and erosional unconformity which separates it from the Lower Jurassic Precipice Sandstone (Evans, 1964c).

Relationships of Mimosa Group

On the east limb of the Mimosa Syncline, where the Mimosa Group is best developed, the sequence consists of three generally conformable formations with transitional boundaries. Farther west and southwest, where the peripheral sediments are preserved, the sequence includes unconformities, disconformities, and overlaps. The angular unconformity above the basal part of the Rewan Formation in the Arcadia area has been mentioned. In the west the Clematis Sandstone overlaps the Rewan Formation and rests directly on the Blackwater Group. The overlap straddles the trend of the Nogoa Anticline in the pre-Permian rocks, but it is not known whether the Rewan Formation was ever deposited in the area, or was removed by erosion. Subsurface data, mainly from southern part of the map area, reveal many areas on the west flank of the basin where the Rewan Formation is truncated beneath or is overlapped by the Clematis Sandstone. This situation is less common on the east limb of the basin, where the sequence is thicker. However, seismic data across the anticline on which the Wandoan 1 well was drilled suggest that the Rewan Formation is truncated beneath the Clematis Sandstone across the crest of the structure (Bastian & Arman, 1965). This fold apparently began to grow and to be eroded before deposition of the Clematis Sandstone, but also continued to grow afterwards and affected both the Clematis Sandstone and Moolayember Formation.

The Clematis Sandstone penetrated in wells drilled to the south of the map area consists mainly of lutites with only a small proportion of sandstone. Possibly, this area was occupied by lakes into which flowed the rivers transporting the sediments. Whether these lakes occupied an internal drainage basin or were connected to the sea is not known.

The Mimosa Group was truncated by erosion before the Precipice Sandstone was deposited at the base of the Great Artesian Basin sequence. This unconformity is best displayed in the southeast, where it truncates the entire Bowen Basin sequence from the Moolayember Formation to the Camboon Andesite and pre-Permian rocks in the east. Erosion of the Precipice Sandstone has exhumed a regolith which developed on the Bowen Basin sequence during the peneplanation preceding the deposition of the Precipice Sandstone. The mesa cappings of the regolith can easily be mistaken for outliers of the Precipice Sandstone. The regolith consists of a siliceous weathering profile which dips gently to the southwest, parallel to the regional dip of the Precipice Sandstone, and truncates the more steeply dipping Permian and Triassic rocks. The pre-Jurassic peneplain was reduced to a remarkably plane surface considering the differences in resistance to weathering of the Permian and Triassic rocks (Pl. 11, fig. 1).

In the Denison Trough and west of the Mimosa Syncline, the unconformity is an obvious regional angular unconformity; the Precipice Sandstone is not in contact with as many older units and the fossil weathering profile has not been preserved. Farther west, in the western part of the basin, which is occupied by a gently southerly dipping sequence, there is no angular discordance and the boundary is disconformable. This reflects the tectonic stability of the Clermont Stable Block which underlies this part of the basin.

GREAT ARTESIAN BASIN SEQUENCE

Deposition of the Great Artesian Basin sequence began in the early Lower Jurassic after a brief late Triassic episode of uplift, minor folding, and widespread erosion and peneplanation of the pre-Jurassic rocks. The unconformity at the base of the sequence ranges from a marked angular erosional unconformity in the east to a structurally conformable disconformity in the west (see above).

The Great Artesian Basin developed as a broad regional downwarp of epi-continental proportions. Its growth marks the change from the Palaeozoic to Triassic tectonic regime of linear geosynclinal sedimentation and deformation to a regime of platform tectonics.

The linear geosynclinal tectonic regime migrated east and continued to affect the north and northeastern parts of the Bowen Basin at least until the Cretaceous.

The Great Artesian Basin consisted of a number of sub-basins, one of which, the Surat Basin, overlapped the southern end of the Bowen Basin. It originally extended farther north than the present eroded margin of the Great Artesian Basin sequence. The Surat Basin downwarp overlapped a number of older elongate tectonic units, but the sequence in the Great Artesian Basin is hardly affected by them. Effects include thicker sedimentation over depositional downwarps such as the Mimosa Syncline, thinner sedimentation over basement features such as the Comet Ridge, and drape structures over older anticlines. Most of these are the result of different rates of compaction of the underlying sediments which generally reflect variations in thickness of the sequence.

The Great Artesian Basin sequence is best developed in the southwest corner of the map area, where the Roma Formation is exposed. The sequence in the Eddystone, Taroom, and Mundubbera Sheet areas is described in Mollan et al. (1971). To the north the sequences in the Springsure and Baralaba Sheet areas are described by Mollan et al. (1969) and Olgers, Webb, Smit, & Coxhead (1966). An outlier of Precipice Sandstone in the Duaringa Sheet area is described in Malone et al. (1969).

The only marine fossils in the Great Artesian Basin are found in the Roma Formation. The remainder of the sequence was deposited in fresh water, with occasional brief incursions by the sea. The microfloral assemblages have been subdivided into a number of palyno-biostratigraphic zones (Evans, 1965, 1966a) which are used for local correlation and for determining the approximate position of the rock units in the geological time scale.

Further mapping and palynological studies since the Bowen Basin map went to press have resulted in some modification and refinement of the Jurassic-Cretaceous stratigraphy. Part of the revised stratigraphy is presented in Mollan et al. (1971). The sequence about 40 km southwest of Injune, which is shown on the geological map as Orallo Formation, belongs to the Southlands Formation. The Blythesdale Formation in the same area is represented by only the Claravale Sandstone Member. The Southlands Formation is a lateral equivalent of the Orallo Formation plus the basal members of the Blythesdale Formation in the Roma area. The Claravale Sandstone Member is a local member within the Blythesdale Formation and is at the top of the Great Artesian Basin sequence southwest of Injune.

The stratigraphy of the Roma Formation has been revised by Vine, Day, Milligan, Casey, Galloway, & Exon (1967). The changes include the introduction of the name Wallumbilla Formation for the part of the sequence in the map area.

The bulk of the Great Artesian Basin sequence consists of sandstone and mudstone with minor conglomerate in places. The sequence can generally be subdivided locally into a succession of predominantly sandstone or mudstone units, which can only be traced laterally for short distances. In practice, only units of group rank and some of the thicker and more distinctive formations can be traced throughout the map area. The stratigraphic interval represented by a particular formation in one area may fall within or may overlap the formation boundaries in an adjacent area. The relationship between the Southlands Formation southwest of Injune and the Orallo and Blythesdale Formations in the Roma area is a typical example.

Some lateral variations within the sequence apparently take place over a short distance. A sequence of formations or members may persist along strike for 150 km or more, and is then replaced by a different sequence over 15 to 30 km. The entire sequence generally crops out poorly, and the transition zones are not fully exposed but appear to be located along anticlinal trends related to major structures in the pre-Jurassic rocks. The Maranoa Anticline is a sinuous southerly plunging anticlinal nose of low amplitude along the course of the upper Maranoa River. The structure in the Jurassic-Cretaceous sequence overlies the buried Nebine Ridge, which is the southerly extension of the Clermont Stable Block. The Maranoa Anticline can be traced southwards beyond the map area to where it forms an axis separating the depositional basins of the Hooray Sandstone to the west from its lateral equivalents, the Gubberamunda Sandstone, Southlands Formation, and Blythesdale Formation, to the east.

Other lateral changes take place gradually over great distances. A good example is the gradual increase of the thickness of the Boxvale Sandstone Member compared with the total thickness of the Evergreen Formation. The member tongues out to the east in the trough of the Mimosa Syncline, but in the northwest it constitutes the entire formation.

Structure

The rock units of the Great Artesian Basin sequence are described in Table 15. The entire sequence is generally structurally conformable.

The sequence is only very gently folded or not folded at all. Most of the folds are compactional or drape structures, although some of them may have grown in Jurassic or Cretaceous times as a result of renewed movement on faults in the pre-Jurassic rocks. One of the main structures is the Mimosa Syncline in the east, in which the tectonic dips on the limbs are usually about 2°. The syncline possibly developed as a depositional structure due to compaction of the underlying great thickness of Permian and Triassic sediments.

The anticline plunging gently southeast to the west of the Mimosa Syncline is on strike with the Arcadia Anticline. It is defined by inliers of Precipice Sandstone in the Evergreen Formation and by a southeasterly deflection of the formation boundaries. The Hutton Creek Dome farther west is part of an anticlinal trend extending southeast and south, adjacent to the northern end of the Hutton-Wallumbilla Fault Zone; movement on this fault zone has apparently faulted Boxvale Sandstone against Precipice Sandstone.

The southerly plunging Merivale Syncline is farther west, on the west side of the Merivale Fault. A monocline dipping west at 5° to 10° was probably formed as a result of slight movement on the Merivale Fault during the Jurassic. The structures farther west still include the southwesterly plunging Maranoa Anticline, and a sinuous anticlinal axis to the east. The flank dips on the anticlines are up to 5°. The presence of an inlier of pre-Jurassic rocks on the axis of the Maranoa Anticline indicates post-Jurassic uplift on this axis. These structures overlie the Nebine Ridge, which is possibly a southerly extension of the Clermont Stable Block. The west-southwesterly trending Chesterton Syncline, near the western margin of the map area, is a depositional syncline between the Nebine Ridge to the east and the Birkhead Ridge to the west. The Birkhead Ridge is a basement ridge extending southwest from the southwest corner of the Clermont Stable Block; it is the locus of thin Jurassic-Cretaceous sedimentation. Most of the Lower Jurassic units of the Surat Basin lens out or lose their identity across the Birkhead Ridge, but the Hutton Sandstone and younger units extend across the ridge.

The thicker sedimentation in the synclines is largely due to a faster rate of subsidence in the synclines, which overlie thicker piles of pre-Jurassic sediments than those beneath the anticlines. Some of the broad anticlinal zones of thin sedimentation are probably drape structures over basement features such as the Nebine Ridge and, near Injune, the southern end of the Comet Ridge. Other anticlines, such as the Maranoa Anticline and the Hutton Creek Dome, have been actively uplifted, and possibly some were occasionally raised above water level during sedimentation.

Depositional History

Deposition began with fluviatile sands of the Precipice Sandstone (Pl. 11, fig. 2), which were transported mainly from west to east. The fact that the greatest thicknesses are preserved in the most northerly outcrops and in the outlier near Bluff indicates that the formation originally extended much farther north up the centre of the Bowen Basin. The sequence thinned to the east against a basement of low relief, and to the south it overlapped the basement to link up with other areas of Triassic-Jurassic sedimentation in southeast Queensland.

The finer-grained and thinner-bedded sediments of the Evergreen Formation (Pl. 12, fig. 1), were laid down in a lacustrine environment, but the Boxvale Sandstone Member, which constitutes the whole of the formation in the northwest, was deposited in a partly fluvial and partly lacustrine environment. The presence of acritarchs in the pelletal chamositic mudstone in the Evergreen Formation possibly indicates a marine incursion into the Surat Basin. The arenites in the Evergreen Formation, though finer in grain, generally contain more feldspar and lithic material than those in the Precipice Sandstone. The finer grainsize possibly reflects low relief in the provenance areas. Preservation of the labile constituents may have been due to rapid fluvial transport and to little or no reworking. The mineralogical maturity of the Precipice Sandstone may be due mainly to chemical weathering in the fluviatile environment, but the maturity of part of the Boxvale Sandstone Member was probably due to reworking by waves and currents in the shallow water on the western margin of the lake in which the Evergreen Formation was laid down. The change from the fluviatile environment of the Precipice Sandstone to the lacustrine environment of the Evergreen Formation was probably due to regional subsidence.

Renewed uplift in the hinterland resulted in the deposition of the poorly sorted cross-bedded feldspathic sublabile to quartzose sands of the lower Hutton Sandstone in a predominantly fluviatile environment. The comparative immaturity of the sediment suggests more rapid transportation and burial than in Precipice Sandstone time, and the presence of salt water suggests that the beds were laid down in brackish water. The thick massive beds of fine quartzose sandstone in the upper part of the formation were probably laid down in shallow water where there was considerable reworking of the sediment. The original distribution of the Hutton Sandstone is unknown. It is very much thicker in the Mimosa and Merivale Synclines than over the Comet or Nebine Ridges and appears to be thinner to the northwest The Precipice Sandstone and Evergreen Formation lens out across the Birkhead Ridge, but the Hutton Sandstone continues across the ridge into the Eromanga Basin. During the deposition of the Hutton Sandstone the Surat and Eromanga Basins coalesced, and thereafter, sedimentation was continuous from one basin to the other. The Hutton Sandstone also marks a major change in provenance areas. Only thin equivalents of the Precipice Sandstone and Evergreen Formation were deposited in local depressions in the Eromanga Basin and the surrounding higher areas probably supplied sediment to the Surat Basin. This agrees with the cross-bedding dip directions in the Precipice Sandstone, with the westward thinning of both formations, and with the westward migration of the fluviatile environment during deposition of the Evergreen Formation. The lensing out of the oolite member and the Westgrove Ironstone Member to the north along the limbs of the Mimosa Syncline indicates the approximate northern limit of the marine(?) incursion into the Surat Basin.

The Hutton Sandstone was probably derived mainly from provenance areas on the Clermont Stable Block and in the northern part of the Bowen Basin. The labile clasts in the Evergreen Formation consist mainly of granite and metamorphic rocks, while those in the Hutton Sandstone are mainly volcanic rocks (Allan & Houston, 1964). The difference suggests a change in provenance.

The Injune Creek Group was laid down during the Middle Jurassic in a series of basins separated by basement ridges, such as the Nebine Ridge. The Birkhead Formation was laid down in a fluvio-lacustrine environment which grades up into a lacustrine-paludal environment in which coal measures were deposited. West of the Maranoa Anticline, the environment was fluviatile and lacustrine, and rarely paludal, and in this area the fluviatile Adori Sandstone was laid down on the Birkhead Formation. The cross-bedding azimuths in the Adori Sandstone suggest that it is a tongue of fluvial sand transported south along the synclinal trough west of the Nebine Ridge. The Springbok Sandstone Member at the top of the Birkhead Formation to the east of the Nebine Ridge may be an equivalent tongue of fluvial sand laid down along the trough of the Merivale Syncline. These sands do not extend to the east of the Merivale Syncline. The Westbourne Formation was deposited in a large lake. It rests on the Birkhead Formation in the east and on the Adori Sandstone in the west. The cross-bedded and slumped sediments in the Westbourne Formation may have been laid down in deltas on the margins of the lake. Possibly the sea invaded the area at times.

In Upper Jurassic to Lower Cretaceous times sedimentation continued to the east and west of the Nebine Ridge. The Hooray Sandstone was deposited in a mainly fluviatile environment to the west, and the Gubberamunda Sandstone in a similar environment to the east. The 'Orallo Formation' (Southlands Formation) above the Gubberamunda Sandstone was laid down in a fluviatile environment followed by a lacustrine environment. The greater proportion of labile material in the 'Orallo Formation' suggests that it was derived from a different provenance from that of the Gubberamunda Sandstone. The Blythesdale Formation consists mainly of thin quartzose sandstone, probably deposited in rivers or lakes, though the abundance of worm borings possibly indicates a paralic environment. The presence of a band of ironstone at the top of the 'Orallo Formation' may indicate a period of brief subaerial weathering before the Blythesdale Formation was laid down. All three formations are essentially conformable.

The youngest unit of the Great Artesian Basin sequence in the map area is the Roma Formation, which was laid down during a major marine transgression in Aptian time. The presence of coarse and gritty sandstone at the base may indicate some winnowing of the sediment in turbulent water during the initial transgression, but most of the formation was laid down in still water.

STYX COAL MEASURES

The Styx Coal Measures are poorly exposed in a broad area extending south from St Lawrence. The best exposures are in cuestas along the western margin of the outcrop area. The coal measures were named by Dunstan (*in* Walkom, 1915), described by Rands (1892) and Morton (1955), and reviewed by Malone et al. (1969). They consist mainly of thick lenses or interbedded sequences of fine grey sandstone and mudstone, green labile sandstone, coal seams, and a basal pebble conglomerate in places. The coal measures unconformably overlie the Permian Back Creek Group; they dip regionally to the east at about 5°, but are faulted and folded near their eastern margin against an upfaulted block of the Back Creek Group. The coal measures were deposited on the irregular floor of a valley in the trough of the Permian Strathmuir Synclinorium. They were laid down mainly in fresh water, though the presence of microplankton may indicate an occasional marine incursion. The flora (Walkom, 1919) and spores and microplankton (Cookson & Dettman, 1958) indicate a Lower Cretaceous (Albian?) age.

Isolated outcrops to the south and north are correlated with the Styx Coal Measures because of the similarity in lithology, flora, and stratigraphic position.

CAINOZOIC

Tertiary Sediments

Tertiary sedimentary rocks are widely distributed throughout the map area, but most of the beds were laid down in isolated basins. No fossil remains suitable for correlation have been found, but a crude correlation can be based on the relationships of the beds to the basalt flows and main laterite profiles. The basalts have been isotopically dated in some areas, but the age of the laterites has not been established.

During the regional survey no attempt was made to subdivide the Tertiary sediments. Several formations have been distinguished in various parts of the basin, and the local stratigraphy has been presented in various BMR Reports (see Fig. 3).

The Tertiary sediments consist of argillaceous quartzose sandstone, conglomerate, siltstone, and claystone, with oil shale and low-rank coal in places. They are generally about 100 m thick in the north, but the sequence may be considerably thicker where deep channels were present in the pre-Tertiary surface. They are much thicker in the Emerald and Duaringa Sheet areas and in the Callide Valley, where they are up to 210 m thick. The sediments were deposited in fluviatile, lacustrine, and paludal environments, and as piedmont fans. The relative uniformity in thickness over most of the area west of the Eungella-Cracow Mobile Belt indicates that they were laid down on a stable land surface. In some areas they are interbedded with extensive sheets of basalt, and in places were deposited in lakes formed by the damming of rivers by the basalt flows.

Up to 1000 m of sediment, all apparently of Tertiary age, was laid down in the elongate Duaringa Basin on the western margin of the Eungella-Cracow Mobile Belt. The basin is bounded in the west by a normal fault, and may have begun to subside about the end of the Cretaceous, possibly as a result of relaxation of compressive stress generated by uplift of the Connors Arch during the Cretaceous orogeny. Seismic surveys indicate that the thick Tertiary sequence is unconformable on more steeply dipping Permian beds. The shot-hole and water-bore samples, including material down to a depth of 200 m near Duaringa, contain Tertiary spores and fish remains. No information is available on the age of the beds at depth, and the sequence may include Cretaceous rocks.

The Tertiary sediments in the Eungella-Cracow Mobile Belt are restricted to mature valleys such as those west of Marlborough and east of Rannes. The lack of Tertiary cover in the northern part of the belt is due to uplift, probably by block faulting during the late Tertiary. Only a few small Tertiary valley fill deposits are preserved on the Connors Arch. One of them, south of Eungella, is capped by Tertiary volcanics, and the total thickness of volcanics and sediments is over 200 m.

The age of the Tertiary sediments is not known precisely. Isotopic ages indicate an Oligocene to Miocene age for the basalts and acid volcanics in the Clermont, Emerald, and Springsure Sheet areas. Here the sediments underlie the basalts and hence are at least as old as Oligocene. Farther north, some of the Tertiary sediments are interbedded with and overlie basalt sheets and could be as young as Miocene. However, the basalts in the north have not been dated and there is no certainty that they are the same age as those in the Emerald Sheet area.

A laterite profile is well developed on the Tertiary sediments capping the mesas around Duaringa and in the Emerald and Springsure Sheet areas. Here, the Tertiary sediments largely antedate the laterite. The post-basalt sediments in the north, particularly around the headwaters of the Suttor River, have been lateritized to some extent, though the profile is rarely as well developed as in the Duaringa Sheet area. The sediments in the north may have been deposited during a period of lateritization which began in the mid-Tertiary. However, the thickness of the laterite profile may be more closely related to the thickness of easily leached sediments than to the duration of the period of lateritization. Thus, the thinner profiles in the north may reflect the thinness of the Tertiary sequence on which they formed, rather than a younger age.

Unconsolidated Cainozoic Sediments

The unconsolidated Cainozoic deposits range from thin soils formed in situ to alluvial deposits up to 120 m thick. They include redistributed Tertiary sediments, lateritic gravels, and sand. Many of the extensive alluvial deposits beside the main watercourses are being incised by the present-day drainage. Many of the black-soil flats represent the remains of decomposed basalt sheets, but elsewhere they appear to overlie Permian sediments.

Sandy soils and lateritic gravels with patches of black soil are most common to the west of the northern part of the basin. Black-soil flats predominate between Emerald and Clermont and north of Clermont.

IGNEOUS ROCKS

The igneous rocks are mainly confined to the Clermont Stable Block, the Eungella-Cracow Mobile Belt, and the Nebo Synclinorium. They were mapped during the regional survey but were not studied in detail.

The largest intrusions are the Urannah Complex, the Auburn Complex, and the Retreat Granite. Most of the smaller intrusions are unnamed. The distribution, lithology, and relationships of the igneous rocks, including the Tertiary volcanics, are summarized in Table 16. The isotopic ages are based on the results of determinations by Webb (Webb & McDougall, 1968). Most of the results were obtained by the K/Ar method on mineral concentrates, but others are based on the Rb/Sr method on total rocks, many of which were checked by the K/Ar method. The validity and significance of the isotopic ages vary considerably. The K/Ar results are subject to an experimental error of about 2 to 3 percent, and the results obtained may not indicate the age of intrusion, but a subsequent period of recrystallization and loss of argon. The Rb/Sr results are dependent on the chemical composition of the samples and their absolute values are suspect because of doubts as to the real value of the Rb/Sr decay constants. The irregular geographical distribution of the samples analysed is another factor which limits the value of the results.

Intrusive History

The oldest known intrusive is the poorly exposed granite in the core of the Telemon Anticline, 58 km west of Springsure, which gave an isotopic age of 450 m.y. A similar age was obtained on mica schist from the Anakie Metamorphics 16 km west of Clermont. Both ages are subject to large experimental errors, but their agreement indicates an intrusive and metamorphic event, probably in the Ordovician, which was significantly older than the known ages of other intrusions in the area. The small area of Ravenswood Granodiorite, which crops out in the extreme northwest corner of the map area, is part of an extensive batholith of Silurian to Lower Devonian age (Paine et al., 1970). The batholith and surrounding metamorphics form the northern margin of the Drummond Basin.

The pre-Jurassic gabbro and altered ultrabasic(?) rocks on the axis of the Maranoa Anticline are unsuitable for age determination. They are probably much older than Jurassic, but their contacts are not exposed.

Retreat Granite

The Retreat Granite (Veevers et al., 1964a) occupies most of the southern end of the Anakie Inlier. It intrudes the Anakie Metamorphics and is unconformably overlain by the Silver Hills Volcanics. Recent mapping in the Clermont area (Olgers, Doutch, & Eftekharnezhad, 1967) indicates that the Retreat Granite intrudes volcanics correlated with the lower Middle Devonian sequence of Douglas Creek and is unconformably overlain by the Theresa Creek Volcanics. The older volcanics are included with the Theresa Creek Volcanics on the geological map. The Theresa Creek Volcanics are correlated with the Silver Hills Volcanics on lithology and are thought to be late(?) Upper Devonian in age. The Retreat Granite is therefore considered to have been emplaced between the lower Middle Devonian and the late(?) Upper Devonian. The isotopic age of the granite ranges from 345 to 372 m.y. The younger ages were obtained on biotite, which suggests some loss of argon. Biotite and hornblende from six samples gave approximately concordant results of about 365 m.y., and this figure is accepted as the approximate age of intrusion.

Devonian-Carboniferous Intrusives

The Devonian-Carboniferous intrusives intrude the Lower to Middle Devonian Ukalunda Beds at the northern end of the Anakie Inlier and are nonconformably overlain by the Upper Devonian(?) to Lower Carboniferous Drummond Basin sequence. Possibly, they also antedate the Upper Devonian Mount Wyatt Beds, but this has not been proved. Most of the samples collected were found to be unsuitable for isotopic age determination, and only three results were obtained. Two samples from near the contact with the overlying Bulgonunna Volcanics gave isotopic ages of 290 and 295 m.y., and a third sample collected farther from the contact gave an age of 330 m.y. The younger ages agree with the isotopic age of the Bulgonunna Volcanics and probably date a period of recrystallization of the intrusives beneath the thick pile of volcanics. The age of 330 m.y. appears to be too young as it conflicts with the observed relationship between the intrusions and the Drummond Basin sequence. This is possibly due to loss of argon, or it may be the age of younger components within the Devonian-Carboniferous intrusives.

Carboniferous Intrusives

The Carboniferous intrusives include the youngest plutonic rocks in the Clermont Stable Block. They intrude the unfossiliferous Bulgonunna Volcanics, which rest unconformably on the Drummond Basin sequence, and are probably Upper Carboniferous in age. This agrees with the isotopic age of the Bulgonunna Volcanics of 290 to 295 m.y. The Carboniferous intrusives are unconformably overlain by the Lower Permian Lizzie Creek Volcanics. The relationships of the Carboniferous intrusives indicate that they are Upper Carboniferous, and this is confirmed by concordant K/Ar and Rb/Sr ages of 285± 5 m.y. Some of the Carboniferous intrusives may be comagmatic with parts of the Bulgonunna Volcanics.

Auburn and Urannah Complexes

The composite Auburn and Urannah Complexes include intrusives of mid-Carboniferous and younger ages. Part of the *Auburn Complex* lies within the southeast corner of the map area. The complex is poorly exposed and the relationship of its components to the adjacent Camboon Andesite is uncertain. A number of samples have been dated by both the K/Ar and Rb/Sr methods at 311±29 m.y.; others from east of the map area have been dated at about 240 m.y. The results suggest that the Auburn Complex consists of a western mid-Carboniferous body and an eastern Upper Permian body.

The *Urannah Complex* (Pl. 12, fig. 2), extends to the north of the map area. Its composite nature is indicated by its relationships to adjacent rock units, and this has been confirmed by the isotopic age determinations. Parts of the complex intrude the Connors Volcanics of Devonian or Carboniferous age. Some elements of the complex intrude the Lizzie Creek Volcanics, but some of the boulders in the basal conglomerates of the Lizzie Creek Volcanics were derived from older parts of the Urannah Complex. The intrusive relationships between different components of the complex indicate a number of episodes of intrusion. However, many of the rocks may be genetically related, and may not be very much younger than the rocks they intrude.

A number of samples from the complex were dated by the K/Ar method, and some of the results were checked by the Rb/Sr method. The combined results indicate three main groups of intrusive rocks, and also suggest that there was extensive recrystallization and loss of argon at times. The oldest group ranges from 311 to 290 m.y.: the upper limit is the age of intrusion of the western part of the Auburn Complex and probably dates a major intrusive event within the Urannah Complex; the lower limit of 290 m.y. is about the average age of the extrusive and intrusive rocks of the Bulgonunna Volcanics and the

Carboniferous intrusions near the Urannah Complex. The bulk of the northern part of the complex possibly consists of intrusives emplaced about 290 m.y. ago.

Many of the samples from the northern part of the complex gave K/Ar ages of about 270 m.y. Hornblende from one of these samples gave an age of 283 m.y., and the Rb/Sr results also suggested an older age. These results indicate a period of metamorphism about 270 m.y. ago, which resulted in complete recrystallization of parts of the complex and partial recrystallization and loss of argon elsewhere. The recrystallization may have coincided with the extrusion of the Lizzie Creek Volcanics and Carmila Beds and may be the result of a combination of factors, such as an increase in the geothermal gradient and subsidence of the crust beneath the volcanic pile, and contact metamorphism by the feeder dykes in the volcanics. This part of the Urannah Complex is cut by innumerable dykes, some of which also cut the Lizzie Creek Volcanics. The few dykes which have been isotopically dated are apparently early Upper Permian in age, and are therefore too young to be feeders of the Lizzie Creek Volcanics.

The adamellite in the northern part of the complex (see Thunderbolt Granite, Paine et al., 1970) gave isotopic ages ranging from 260 to 270 m.y. The adamellite was apparently emplaced at depth, and may represent a separate period of intrusion. It is not intruded by the swarms of dykes found in the adjacent parts of the Urannah Complex, so many of the dykes are older than 270 m.y. Correlation of the dykes with the Lizzie Creek Volcanics implies that the adamellite is younger than the Lizzie Creek Volcanics, and this is compatible with the stratigraphic data and isotopic ages. It appears therefore that the adamellite was emplaced in the Connors Arch during the deposition of the thick conformable sequence of sediments in the northern part of the Bowen Basin.

The youngest group of intrusives in the Urannah Complex have isotopic ages of about 125 m.y. – probably early Lower Cretaceous. They are known only in the northern part of the complex. The intrusives of the same isotopic age intruding the Nebo Synclinorium at the northern end of the basin (Pl. 13, fig. 1), appear to be contemporaneous with the folding of the Bowen Basin sequence. These Lower Cretaceous intrusives were probably emplaced during a period of uplift of the Connors Arch and folding in the northern part of the basin. Most of the known mineralization is apparently associated with these intrusives.

The Urannah Complex was treated as a single unit during the regional mapping, but more recent mapping in the Bowen Sheet area (Paine et al., 1970) has delineated intrusions of different ages within the complex and no doubt this could be extended to other parts of the complex.

The age of the isolated Carboniferous to Mesozoic intrusives, which intrude the Connors Volcanics and possibly the younger rocks to the south of the Urannah Complex, indicates that they are related to the Urannah Complex. They include mid-Carboniferous intrusions and dykes of possible Triassic age.

Other Carboniferous to Mesozoic and Permian to Mesozoic intrusives have been mapped east and southeast of the Connors Arch. They are mainly adamellite or granodiorite and intrude Carboniferous or Permian rocks.

The only Lower Permian intrusives known outside the Urannah Complex are concordant sills of diorite or gabbro in the Lizzie Creek Volcanics west of Eungella. They are probably contemporaneous with the lavas of the Lizzie Creek Volcanics.

Serpentinite

The serpentinite near Marlborough in the Rockhampton Sheet area is intrusive in places into Lower Permian sediments (Kirkegaard et al., 1970), although most of the contacts are faulted. The serpentinite is mainly massive, except near faulted contacts, and has contact-metamorphosed the sediments to a moderate extent. It was possibly intruded about the start of the Upper Permian. In the southeast, outside the map area, a thin wedge of serpentinite overlies Lower Palaeozoic metamorphics. The structure suggests that it was intruded as a laccolith or large sill. The serpentinite is intruded by a granodiorite with an isotopic age of about 235 m.y. The serpentinite may be genetically related to the early Upper Permian spilitic Rookwood Volcanics farther south.

Upper Permian Intrusives

The Upper Permian stocks and plutons are confined to the Gogango Overfolded Zone and the Marlborough Block. Farther east and south in the Port Clinton, Rockhampton, Monto, and Mundubbera Sheet areas, Upper Permian intrusives of batholithic proportions have been recognized.

The intrusions consist mainly of adamellite, granodiorite, and minor diorite with some small stocks of gabbro and granite. Possibly many of the intrusives described as Permian or Carboniferous to Mesozoic belong to the Upper Permian period of intrusion. No Upper Permian intrusives are known in the northern part of the Eungella-Cracow Mobile Belt north of the Gogango Overfolded Zone, but the Cretaceous intrusives are apparently confined to this area.

Cretaceous Intrusives

The Cretaceous intrusives can be divided into two groups – early Lower Cretaceous and late Lower Cretaceous. The older group was emplaced about 125 m.y. ago; they include part of the Urannah Complex, and small to large stocks and probably laccoliths intruding the Permian sequence in the Nebo Synclinorium. The largest stock is the Bundarra Granodiorite, which is about 16 km across. The Lower Cretaceous intrusives in the Urannah Complex include the Hecate Granite (see Paine et al., 1970) in the Bowen Sheet area, which crops out over an area of several hundred square kilometres. The intrusives in the Nebo Synclinorium mainly occupy the cores of domes and are roughly concordant with the sediments. They have produced little high-grade contact metamorphism but the country rock is extensively indurated. Vertical shearing can be seen along the contact between the Bundarra Granodiorite and the metasediments. Some of the intrusives on the east flank of the Nebo Synclinorium, where the sediments have a moderate to steep regional southwesterly dip, are sills, or composite plugs and sills, or dykes.

The Lower Cretaceous intrusives were emplaced during uplift of the Connors Arch and folding in the Nebo Synclinorium. This orogenic pulse affected the northern part of the Bowen Basin only.

The younger Cretaceous intrusives were emplaced about 110 m.y. ago. Only a few isotopic age determinations are available. The late Lower Cretaceous intrusives are confined to the northeast coast. The intrusive rocks (Ti) on the islands between Cape Conway and Long Island are similar in lithology and are probably of the same age. They may be roughly contemporaneous with the volcanics (Tv) on Cape Conway and the islands. The volcanics on Cape Conway have been provisionally dated at 112 m.y.

The Mesozoic intrusives around Mackay have not been dated. Some of them intrude Lower Permian rocks; others intrude the Devonian-Carboniferous Campwyn Beds. They could be as old as Lower Permian, but probably belong to one or other of the Lower Cretaceous groups of intrusives. Certainly, the relationships between them indicate more than one period of intrusion.

Cretaceous or Tertiary Intrusives and Extrusives

A trachyte stock intruding the Blackwater Group southeast of Baralaba has given an isotopic age of 70 m.y., approximately at the Cretaceous-Tertiary boundary. A trachysyenite sill 110 km east of Clermont is possibly of the same age as it is similar in lithology.

The post-Permian volcanics crop out only on or near the Connors Arch. They are tentatively regarded as Cretaceous or Tertiary because they appear to be deformed and because they include some plugs similar to those with an isotopic age of 70 m.y. They are possibly related to the late Lower Cretaceous intrusive and extrusive activity on the northeast coast and islands, although they appear to have a different tectonic setting.

Tertiary Intrusives and Extrusives

Basalt

Remnants of basalt flows are widespread in the Bowen Basin. The distribution of the basalt, and the plugs and dykes, indicates three main areas of extrusion, the largest of which covered the southern part of the Clermont Stable Block and the Denison Trough, where 540 m of basalt have been recorded in the Peak Range.

There is another major basalt province in the northern part of the basin, where extensive flows and many plugs are preserved. The smaller quantity of basalt in the axial region of the Mimosa Syncline, was probably extruded from local vents. The scattered outcrops of basalt in other parts of the basin indicate that basalt flows were very widespread, and that most of them have been stripped off by erosion.

The Hoy Basalt consists of a group of basalt plugs which mainly intrude the Retreat Granite. The plugs fill vents from which basalt flowed eastwards into a broad valley trending north through Emerald. The flows around the plugs have been removed by erosion. The plugs are aligned mainly in a north-northeasterly direction with a subordinate easterly trend, and the alignment of the vents was probably controlled by lineaments in the Palaeozoic basement.

Acid to Intermediate Volcanics

The acid to intermediate volcanics include the Peak Range Volcanics (Pl. 13, fig. 2) and Minerva Hills Volcanics in the Clermont and Springsure Sheet areas, and unnamed volcanics in the northern part of the basin. Mollan (1965) has made a detailed study of the Peak Range Volcanics. He has shown that the acid to intermediate intrusive and extrusive rocks are differentiates of alkali basalt magma. The Minerva Hills Volcanics are also thought to have been derived from the same parent magma. The Minerva Hills Volcanics (Pl. 14, fig. 1) crop out at the intersection of two prominent lineaments in the basement: the southeasterly trending partly faulted boundary between the Drummond Basin and the Anakie Inlier, and the northern extension of the Merivale Fault which forms a hinge-line on the western margin of the Denison Trough. The Peak Range Volcanics are also believed to be associated with deep-seated fractures in the basement.

The volcanics in the northern part of the basin have not been studied closely, but appear to be similar to the Peak Range and Minerva Hills Volcanics. They also are intimately associated with extrusive and intrusive basalt.

The isotopic age of the basalt from the Emerald and Springsure Sheet areas ranges from 33 to 20 m.y., and the Minerva Hills Volcanics from 28 to 24 m.y. The Tertiary volcanics were probably erupted during a number of separate episodes ranging in age from Oligocene to Miocene.

STRUCTURE

The main tectonic units and structural subdivisions are outlined on Plate 3. The four tectonic units are the Great Artesian Basin in the south, the Clermont Stable Block in the northwest, the central and western parts of the Bowen Basin in the centre, and the Eungella-Cracow Mobile Belt in the east.

The Clermont Stable Block was the site of vigorous orogenic and post-orogenic tectonic movement in pre-Permian times, but has behaved as a stable cratonic block since the inception of the Bowen Basin. The Eungella-Cracow Mobile Belt was the site of repeated orogenic and epi-orogenic tectonism until the end of the Permian and, in the north, again in the Lower Cretaceous. Both are now part of the stable Australian continent.

The Bowen Basin sequence is stratigraphically equivalent to and continuous with the Bowen Group of Etheridge (1872), which was first studied in the Bowen River area. In this sense the basin is a tectonically deformed depositional structure which extends into much of the Eungella-Cracow Mobile Belt. This definition of the basin facilitates a unified treatment of the depositional history and stratigraphy of the entire sequence. Structurally the Bowen Basin is confined to the area west of the Eungella-Cracow Mobile Belt. However, the term 'basin' suggests a depositional rather than a tectonic structure, and we prefer to define it as a deformed depositional structure.

Plate 2 is a block diagram showing the structural units of the basin and of part of the Eungella-Cracow Mobile Belt; the diagram is based on the geological map and sections (Pl. 1) and part of the Eungella-Cracow Mobile Belt.

Clermont Stable Block

The Clermont Stable Block is overlapped in the east and south by a thin mantle of gently folded sediments of the Bowen Basin sequence. It forms the shallow basement on the Collinsville Shelf and the Capella Block. If bifurcates to the south around the Denison Trough to form the thinly covered Comet Ridge in the east and the shallow basement of the western part of the Bowen Basin in the west.

The Anakie Inlier is the core of the Clermont Stable Block. The inlier consists of Ordovician or older metasediments which are unconformably overlain by and folded with lower Middle Devonian sediments and volcanics, and intruded by Devonian or Carboniferous acid plutonic rocks. Regional metamorphism has produced quartz-mica schist and phyllite in the Anakie Metamorphics and locally in the Middle Devonian Ukalunda Beds. Elsewhere, the Middle Devonian sediments are unmetamorphosed. Little is known of the complex structure of the inlier.

The Drummond Basin was a major depositional downwarp which was later deformed into an arcuate synclinorium. The rough alignment of the fold axes in the basin parallel to the margin with the Anakie Inlier suggests compressional folding involving westward movement or uplift, or both, of the inlier. The presence of rocks correlated with the Anakie Metamorphics in the core of the Telemon Anticline indicates that the basement to the Drummond Basin was involved in the folding.

In the south, the Drummond Basin trends northwest and has a straight, partly faulted, boundary against the Anakie Inlier. Farther north, the basin trends nearly north and the Drummond Basin sequence laps on to the Anakie Inlier. The northeasterly trend of the Drummond Basin in the northwest may be due to compression against the massive Silurian-Devonian igneous rocks and older metamorphics of the Ravenswood Block in the northwest corner of the map area.

Most of the structures in the Drummond Basin are elongate sinuous faulted domes and basins of great amplitude. In some of the structures the sedimentary sequence is up to 600 m thick. The flanks of the structures rarely dip at more than 40°, and in most of the domes the western flanks are the more steeply dipping.

The Drummond sequence probably encircled the northern end of the Anakie Inlier and probably transgressed the inlier near Clermont.

The Mount Rankin Volcanics are a thick sequence of volcanics and sediments overlying the eastern part of the Anakie Inlier. They are only slightly folded and dip east at angles up to 45°. The formation is poorly exposed and has not been studied in detail.

The Bulgonunna Wedge in the northeastern part of the Clermont Stable Block consists of a thick pile of acid volcanics (Bulgonunna Volcanics) which lenses out to the west and plunges gently east beneath the northwestern part of the basin. The wedge consists of large overlapping lenses of extrusive and intrusive volcanic rocks. There are few folds in the volcanics and most of the dips are probably depositional.

The Joe Joe Formation occupies a wedge at the southern end of the Clermont Stable Block. The wedge is truncated by erosion against the Drummond Basin sequence and dips southwest beneath the western part of the Bowen Basin. The formation has been only gently folded and is gently dipping. The folds are mainly weak reflections of structures in the Drummond Basin.

The Blair Athol Basin within the Clermont Stable Block is filled with coal measures which have not been disturbed since they were laid down. The coal measures are contemporaneous with part of the Bowen Basin sequence.

Central and Western Parts of Bowen Basin

Western Bowen Basin (= Springsure Shelf)

The Western Bowen Basin or Springsure Shelf (see Pl. 3) is covered by a thin uniform sedimentary sequence, laid down over a long period. The sequence probably includes many disconformities, but as it rests on the Clermont Stable Block it has been very little affected by tectonism. At various times during the Permian and Triassic, the Roma Ridge (Traves, 1966), which is the southern extension of the Clermont Stable Block, emerged as a landmass in the southwestern part of the map area. The block diagram (Pl. 2) illustrates the contrasting tectonic styles on the Springsure Shelf and in adjacent Denison Trough. In effect, the Springsure Shelf occupies a saddle between the Clermont Stable Block and the Roma and Nebine Ridges.

The western limit of the Springsure Shelf lies beyond the map area on the southwesterly trending Birkhead Anticline, which separates the Bowen and Galilee Basins (Lindner, 1966; Exon, Galloway, Casey, & Kirkegaard, in press). The lithology of the sediments, particularly the Triassic sediments, changes across the anticline.

Denison Trough (Derrington, 1962)

The Denison Trough was an elongate intracratonic depositional downwarp, flanked to east and west by areas of thinner sedimentation, which shallows abruptly to the north and south on to pre-Permian basement. Most of the downwarping took place in the Lower Permian, when up to 4500 m of sediment accumulated. From Upper Permian to Middle Triassic times the area subsided slowly and about the same thickness of sediment was laid down as on the Springsure Shelf. The sequence, including the Moolayember Formation, was folded during the late Triassic into the Springsure Anticline and subsidiary anticlines and synclines to the east. The structure of the Springsure Anticline and adjacent folds has been described by Mollan et al. (1969). The fold axes generally trend north, parallel to the axis of the Denison Trough. Dips are generally less than 40°, with steeper dips on the western flanks of the anticlines.

The Denison Trough lies within a large basement block. The Comet Ridge to the east and southern extension of the Clermont Stable Block to the west coalesce around the southern end of the trough (see Pl. 2) to form the Roma Ridge.

The thick sequence in the Denison Trough passes laterally into the thin sequence on the Springsure Shelf. The transition takes place across a narrow zone where the basement subsided into the Denison Trough. The western boundary of the Denison Trough is probably located along a fault zone in the basement. The Merivale Fault (Traves, 1966) along the western boundary of the Denison Trough affected the Bowen Basin sequence, but not the Great Artesian Basin sequence. The movement is west block down – the reverse of the Lower Permian movement along the same line. The Merivale Fault may reflect renewed movement on the fault zone along the western boundary of the Denison Trough in post-Permian/pre-Jurassic time. This movement probably involved uplift of the basement on the west side of the Denison Trough, and was possibly the cause of the folding in the trough. The main structure in the Denison Trough is the Springsure

Anticline parallel to the western boundary of the trough. The parallel folds to the east of the Springsure Anticline are much smaller in amplitude and length. Farther east, they pass into low-amplitude sinuous folds similar to those on the Comet Ridge. To the west of the Springsure Anticline a low-amplitude broad syncline overlaps the Western Bowen Basin.

Plate 2 illustrates the intracratonic nature and steeply dipping margins of the Denison Trough during the deposition of the Reids Dome Beds. The steep plunge at the southern end of the trough has been substantiated in the Westgrove, Kildare, and Glentulloch wells. Later in the Lower Permian, the trough became more extensive and less pronounced, and the Tiverton and Gebbie Subgroups overlapped it to the east and northeast across the Comet Ridge.

Comet Ridge

The Comet Ridge (or Comet Platform of Derrington, 1962) was part of a landmass bordering the Denison Trough in early Permian time. Later in the Lower Permian, the block subsided and was covered by a thin mantle of sediments. Deep subsidence of the eastern part of the block in Upper Permian and Triassic times reduced it to a prominent ridge as shown on Plate 2. In the south, the Comet Ridge merges with the Roma Ridge which extends southeastwards from the Clermont Stable Block. To the north, the ridge broadens and merges into the Clermont Stable Block and with the basement of the Capella Block and Collinsville Shelf.

The broad drape structures on the Comet Ridge are best displayed around Comet by the dome of Blenheim Subgroup surrounded by the Blackwater Group. Most of the folds in the thin sedimentary sequence on the Comet Ridge are of very low amplitude; they generally involve only 100 to 200 m of section and die out in the beds above and below. Dips are generally 5° or less. Minor ripple folds can be seen on the east flank of the Comet Ridge, particularly in the Sagittarius Sandstone Member; they may be partly due to compaction of the thick coal seams in the underlying Rangal Coal Measures.

Seismic surveys over the Comet Ridge indicate the presence of low-amplitude sinuous anastomosing folds. The anticlines are gently plunging, with small isolated culminations.

Capella Block

The Capella Block is covered by a thin basal marine sequence overlain, mainly in the north, by a thick sequence of partly freshwater sandstone. The structural style is consistent throughout the block and consists of broad drape structures over irregularities in the basement. Flank dips rarely exceed 3°. The horizontal sediments on the Capella Block can be distinguished from those on the Collinsville Shelf, where the sequence is thicker and has a gentle regional easterly dip. The boundary between the Capella Block and the Collinsville Shelf or Comet Ridge acted as a hinge-line; the basement to the east and southeast was tilted downwards during subsidence of the Bowen Basin, but to the west, the basement was overlapped during the Upper Permian transgression and subsided vertically to accommodate the freshwater sequence. The rigid basement block protected the sediments on the Capella Block from tectonic folding. The Tertiary Peak Range Volcanics are located near the western margin of the Capella Block, which is probably bounded by a major fracture zone in the basement.

Collinsville Shelf (Malone, 1964b)

The Permian to Triassic sediments on the Collinsville Shelf are only gently folded. They dip gently and thicken towards the east (UGC, 1963). Folding increases towards the margin of the shelf, where it grades into the Nebo Synclinorium. The transitional zone between the Collinsville Shelf and Nebo Synclinorium is probably a basement hinge-line where the basement dips more steeply to the east below the synclinorium (see Pl. 2). In places, the boundary is marked by thrust faulting, east block up.

Nebo Synclinorium (Malone, 1964b)

The sedimentary sequence in the Nebo Synclinorium is up to 6000 m thick. The synclinorium was the site of deep subsidence of the basement and severe tectonic folding of the sediments, particularly in the east. Some of the zones of local uplift associated with the folding may be the result of igneous intrusion. There is no evidence of post-depositional uplift of the underlying basement.

The folds consist mainly of large-amplitude elongate domes, anticlines, and synclines, which tend to die out up section: the Triassic Clematis Sandstone and Moolayember Formation are much less tightly folded than the underlying Rewan Formation and Blackwater Group. The Clematis Sandstone and Rewan Formation are apparently conformable, but in places the Clematis Sandstone is faulted against more steeply dipping Rewan Formation. During the orogeny the Clematis Sandstone was possibly covered by only a small thickness of sediment, and the competent sandstone tended to shear rather than fold. The Clematis Sandstone is intruded only by dykes associated with a gabbro plug at the northern end of the Redcliffe Tableland. The sandstone is gently domed about the intrusion, and the dykes occupy a set of radial fractures.

On the east limb of the Nebo Synclinorium, in the northern part of the basin, most of the Permian sequence crops out along a strike length of about 130 km. The sequence generally dips southwest into the basin at 30° to 45°, but in places the limb is vertical and locally overturned, with severe shearing and minor thrust faulting. The steep dips, overturning, and shearing are probably related to block uplift of the Connors Arch.

Folded Zone (Malone, 1964b)

The Folded Zone (part of the Dawson Tectonic Zone of Derrington, 1962) is described in Malone et al. (1969). It has been separated from the Nebo Synclinorium because of its distinctive tectonic style, but the boundary between them is poorly exposed. The Folded Zone contains a great thickness of indurated and tightly folded sediments, which have apparently not been intruded by igneous rocks. The folds are generally very tight steep-flanked structures with sharp, gently to steeply plunging, noses. Reversals of plunge along the axes are common. Tight low-amplitude minor folds are common on the flanks of the larger structures. In general, the folds become broader and the flank dips gentler to the west and north. The tightness of folding appears to decrease in depth, as the folds in the oldest rocks are more open and of larger amplitude than those in younger sediments. Seismic surveys across the Folded Zone indicate a flat-lying basement at about 6000 m (Robertson, 1961), and it appears that the folds probably die out near a décollement surface.

Cleavage is virtually absent, and jointing and faulting are relatively uncommon in the Folded Zone. The lack of shear cleavage in the Folded Zone contrasts with the strongly developed axial-plane cleavage in the Gogango Overfolded Zone, even in only moderately folded rocks.

The Folded Zone generally grades into the Comet Ridge and Mimosa Syncline with a gradual reduction in the intensity of folding, but locally the boundaries are sharply defined by thrust faults or high-angle reverse faults separating the tightly folded sediments to the east from the gently dipping sediments to the west. The movement on the faults is usually east block up.

The presence of a possible décollement below the zone, the reduction in intensity of folding to the west, the presence of local thrust faults on the western margin, and the lack of cleavage suggest gravity tectonics as the most likely mechanism of folding. The Connors Arch has been greatly uplifted since the Permian, and this uplift may have been the source of energy for the gravity tectonics.

The southern part of the Folded Zone, between the Mimosa Syncline and the Gogango Overfolded Zone, is poorly exposed. The folds were probably produced by compressive stress from the northeast, probably during deformation of the Gogango Overfolded Zone. Seismic surveys (Marathon, 1963) indicate numerous easterly dipping thrust faults in this area. The intensity of folding dies out down dip into the broad Mimosa Syncline, and increases to the northeast towards the Gogango Overfolded Zone. Farther north, the relationship between the Folded Zone and the Gogango Overfolded Zone is concealed by the Duaringa Basin.

Mimosa Syncline

The Mimosa Syncline is the main structure in the southern part of the Bowen Basin and in the area to the south. The syncline was mainly developed and filled with sediment in the Triassic, when about 5400 m of sedimentary rocks were laid down. In the trough of the syncline the underlying Permian sequence is probably less than 1500 m thick, but it thickens in the east limb. The Mimosa Syncline is mainly an unfolded depositional downwarp. Extensive seismic surveys (Marathon, 1963) in the north reveal that there has been very little minor folding within the syncline. To the south, some relatively large anticlines have been developed, particularly on the east limb of the syncline. Some of these structures grew during the Triassic, and seismic surveys suggest that the Clematis Sandstone rests on a truncated sequence of the Rewan Formation across the crest. The shape, extent, and nature of the Mimosa Syncline are illustrated in Plate 2. The block diagram extends about 25 km south of the map area and presents a simplified picture of the structure near the Wandoan 1 and Burunga 1 wells.

Duaringa Basin

The Duaringa Basin is a narrow trough between the Folded Zone to the west and the Connors Arch and Gogango Overfolded Zone to the east. Seismic surveys across the basin (Robertson, 1961) indicate that it contains about 1000 m of sedimentary rocks overlying folded Permian beds. The western margin of the basin is faulted. Most of the rocks are of Tertiary age, but it is possible that the basal part of the sequence is Cretaceous. The basin lies along a line of moderate gravity minima (Darby, 1966); the gravity data suggest that the deepest part of the basin is at the northern end. There is no evidence of folding in the Duaringa Basin, which is essentially a Tertiary structure superimposed on the Bowen Basin. The basin is bounded by a normal fault on the west, and was possibly developed in response to relaxation of compression after the uplift and folding during the Cretaceous.

Eungella-Cracow Mobile Belt

Connors Arch (Malone, 1964b)

The Connors Arch is part of the 'Eungella strip' of Hill *in* Hill & Denmead, eds, 1960, p.11). In the north, the arch consists mainly of the igneous Urannah Complex and remnants of the Connors Volcanics. Farther south, it consists mainly of Connors Volcanics and isolated intrusives, and northwest of St Lawrence it is overlapped by the Lizzie Creek Volcanics and Carmila Beds from the west and east. The arch is a broad simple rigid structure which has been subject to considerable vertical movement since the early Permian. The Lower Permian sediments mainly occupy synclines, and were probably laid down in depressions in the pre-Permian surface. Elsewhere, the Lower Permian sequence is gently dipping and only gently folded.

In the south, the Carmila Beds dip off the arch at 20° to 40° to the east, and the Lizzie Creek Volcanics and Back Creek Group generally dip to the west at less than 20°. In the north, the arch has been uplifted far enough to expose the granitic core. The western boundaries are commonly faulted and, in places, the adjacent Permian sequence dips vertically or is overturned. In the north, the eastern margin of the arch is faulted in places, but elsewhere the Cretaceous part of the Urannah Complex intrudes the adjacent Carmila Beds.

Several blocks of volcanics (probably Connors Volcanics) crop out near the south end of the arch. The blocks have a complex relationship to the overlying Carmila Beds and Back Creek Group, in contrast to the simple relationship between the southern part of the arch and the overlying Permian rocks. These separate blocks of Connors Volcanics apparently formed local land areas during the deposition of the Permian sequence, and appear to have moved independently of the arch during the deposition and deformation of the Permian sequence. The geology of the blocks has been described in detail by Malone et al. (1969) and is only briefly discussed below (Leura area and Strathmuir Synclinorium).

Calen Area

The Calen area, between the Connors Arch and the Campwyn Block, is separated from the Carmila Syncline to the south by a ridge of Devonian-Carboniferous rocks linking the Connors Arch and Campwyn Block. The structure of the area is uncertain. The central part is occupied by the Calen Coal Measures, which are folded into a broad northerly trending syncline or elongate basin complicated by faulting and minor folding. The Calen Coal Measures generally dip at 20° or less and rest unconformably on the Carmila Beds and Lizzie Creek Volcanics.

The block of Lizzie Creek Volcanics is partly faulted against the Urannah Complex. The Cretaceous intrusives of the Urannah Complex to the north of the fault may intrude the Lizzie Creek Volcanics. The volcanics are thought to be a tongue interfingering with the Carmila Beds.

In the south, the Carmila Beds are apparently folded into a broad complex northerly plunging syncline, interrupted by isolated blocks of the Urannah Complex, which may be unconformable beneath or intrusive into the Carmila Beds. In the north, the Carmila Beds are steeply dipping adjacent to the Urannah Complex, which may partly intrude them. The Carmila Beds generally dip away from the contact towards the Urannah Complex.

The eastern boundary of the Calen area is commonly defined by faults separating the Carmila and Campwyn Beds. The faults are mainly east block up. Elsewhere, the Carmila Beds rest unconformably on the Campwyn Beds.

The major east-west lineament, which crosses the area from Mackay to Eungella, coincides roughly with the southern margin of the Calen Coal Measures. The valley of the Pioneer River follows the lineament, but the structure is concealed by thick alluvial deposits.

Campwyn Block

The Campwyn Block consists of an upfaulted block of Devonian to Carboniferous Campwyn Beds which extends along the coast from Repulse Bay to West Hill Island. In the south, the Campwyn Beds are folded into an anticline which trends parallel to the block, but elsewhere their folding does not appear to be related to the block.

The Campwyn Block is flanked to the east by a Tertiary graben, most of which lies beneath the sea and was mapped by aeromagnetic survey (Aero Service Ltd, 1963) and marine seismic surveys (UGC, 1966; WGC, 1964). The basin extends southwards from Repulse Bay and probably links up with the Cretaceous Styx Basin. About 1260 m of probable Tertiary sediments were intersected in the Proserpine 1 well, a few kilometres north of the map area.

The islands to the east of the Tertiary basin, which are aligned along a northwesterly axis, are composed of probable Cretaceous volcanics and intrusives.

Carmila Syncline (Jensen et al., 1966)

The nose and west limb of the Carmila Syncline are exposed east of Connors Arch. The east limb is partly truncated by the uplifted Campwyn Block and, farther south, is overlapped by the Tertiary offshore basin. The Carmila Syncline is a broad structure occupied by the thick Carmila Beds. Near St Lawrence, the folding of the Carmila Beds becomes more complex and the Carmila Syncline passes into the Strathmuir Synclinorium.

Strathmuir Synclinorium (Malone et al., 1969)

The northerly trending Strathmuir Synclinorium is occupied by the Carmila Beds and Back Creek Group. Near St Lawrence, the Carmila Beds are folded into many tight minor folds and the Back Creek Group is preserved in a fairly broad, but poorly exposed, easterly to southeasterly trending syncline. The west limb of the synclinorium dips mainly to the east, with some local tight folding. It is interrupted by a block of Connors Volcanics, which is faulted against the easterly dipping Carmila Beds between the block and the Connors Arch. The Apis Creek Syncline to the south of the block of Connors Volcanics is partly squeezed between the block and the Connors Arch.

The central part of the synclinorium is moderately tightly folded and faulted; the intensity of deformation increases eastwards towards the overfolded and sheared rocks in the Gogango Overfolded Zone. The east limb of the synclinorium is represented by a single block of Carmila Beds, west of Herbert Creek, in which the beds dip southeast to south into the synclinorium. At the boundary with the Gogango Overfolded Zone, the strike of the beds swings almost north and the dip is generally to the east.

Styx Basin

The Styx Basin is an elongate basin, plunging gently to the north, superimposed on the Strathmuir Synclinorium. The basin is filled with Lower Cretaceous sediments, which dip gently east and rest unconformably on the Back Creek Group. The basin is bounded on the east by a high-angle reverse fault, along which the block of tightly folded Back Creek Group to the east has been uplifted, and against which the Cretaceous sediments are folded and faulted.

The Styx Basin is open to the north under the sea and is possibly continuous with the offshore Tertiary basin flanking the Campwyn Block.

Leura Area

The Leura area is a small structural unit at the southern end of the Connors Arch. It consists of folded sediments of the Back Creek Group and a large inlier of Connors Volcanics. The sediments are folded into a series of domes and basins, elongated north-south. The regional dips are generally less than 30°, and although the beds are not overturned, cleavage is well developed. Farther north, near the Connors Arch, the sediments are folded into broad anticlines and synclines plunging south parallel to the plunge of the arch. A steep easterly dipping cleavage is common in the lutites. The sediments a few kilometres to the northwest, on the west flank of the Connors Arch, are uncleaved, probably because they were protected from deformation by the rigid arch.

The inlier of Connors Volcanics in the Leura area has greatly influenced the deformation of the sediments. The lowermost 600 m of sediments dips consistently east at low angles, but in the sequence above the structural complexity rapidly increases and the rocks grade into the Gogango Overfolded Zone. The structural complexity appears to be directly proportional to distance above the Connors Volcanics.

Farther west, in the elongate embayment within the inlier of Connors Volcanics, the Back Creek Group is tightly and complexly folded and cleaved, and in places sheared. The western margin of the embayment is possibly faulted. The intense folding of the Back Creek Group in the embayment is attributed to squeezing between blocks of Connors Volcanics. On the western margin of the inlier of Connors Volcanics the Back Creek Group is tightly folded and cleaved, but the intensity of folding decreases rapidly to the west. It appears therefore that the blocks of Connors Volcanics acted as rigid mobile blocks which transmitted the compressive stress from east to west, while to some extent protecting the overlying sediments from deformation. Relative movement between the blocks of Connors Volcanics has produced the most severe deformation of the sediments.

Gogango Overfolded Zone (Malone, 1964b)

The Gogango Overfolded Zone is a long arcuate belt composed mainly of Permian sedimentary volcanic rocks with some inliers of pre-Permian volcanics. The zone is characterized by overfolding, with easterly dipping axial planes, by faulting and possibly thrust faulting, and by the widespread development of cleavage in the finer sediments. It is difficult to interpret the structure because of the complex stratigraphic relationships and the similarity of the rocks. In general, the pre-Permian inliers and blocks of Lower Permian volcanics have acted as competent masses during the post-Permian folding. They are only moderately folded and are commonly faulted against the tightly folded and sheared sedimentary rocks.

The Boomer Formation, the youngest unit in the zone, is the most intensely folded, particularly where it consists of thinly interbedded siltstone and sandstone. The well developed bedding and rapid alternation of beds with a different degree of competence resulted in flexural slip folding. The style of folding varies with the thickness and competence of the sandstone interbeds. Flexural slip folding, with rectangular troughs and crests, is common where the sandstone beds are up to 30 cm thick and constitute more than half the section. Tight complex folding with many recumbent structures has been developed where the formation consists of thinly interbedded mudstone and fine sandstone. Cleavage is well developed in the Boomer Formation, but there is no evidence of shear folding involving movement along cleavage planes. The Rannes Beds are fairly massive and fine-grained, and have been deformed mainly by movement along shear and cleavage planes. In most areas, the Rannes Beds have been overturned and have a consistent easterly dip. Recumbent folds have been developed in places.

In the eastern part of the zone, a complex syncline, west of the Craigilee area, is outlined by broadly folded Rookwood Volcanics, and the trough is filled with tightly folded beds of the Boomer Formation. Farther west, there are complex structures involving inliers of Silurian-Devonian volcanics with the Rookwood Volcanics and Boomer Formation. The Boomer Formation apparently overlapped the Rookwood Volcanics and rests directly on the Silurian-Devonian volcanics in places. During deformation, the Boomer Formation was folded and the volcanics were moved by block faulting, so that in one place the Boomer Formation dips steeply beneath the Rookwood Volcanics and in another place, a few kilometres to the south, it rests conformably on the Rookwood Volcanics.

Craigilee Area

The Craigilee Anticline is composed of Carboniferous sediments resting unconformably on Silurian-Devonian rocks in the core of the structure. The Devonian-Carboniferous rocks extend to the west. The Silurian-Devonian rocks consist mainly of massive volcanics, with some steeply dipping sediments which are tightly folded in places. The strike of the older rocks is almost at right angles to the strike of the younger sediments. On the east flank of the anticline the Carboniferous rocks dip at about 45°, but in the west they are locally overturned, and in places the Rookwood Volcanics overlap the Carboniferous sediments and rest directly on the Silurian-Devonian rocks. The Devonian-Carboniferous sediments to the northwest of the Craigilee Anticline dip east and northeast at 40° to 70°. The sediments are overlain by the Rookwood Volcanics, and in the west by the Youlambie Conglomerate, which is possibly faulted against the Rannes Beds.

Marlborough Block

The Marlborough Block consists of possible Lower Palaeozoic metamorphics and late Lower Permian serpentinite intruded by Upper(?) Permian gabbro and granodiorite. The serpentinite sheet is generally unsheared. It forms a long narrow strip along the northwest margin of the Marlborough Block, where it is faulted against Lower Permian rocks and is commonly sheared. The faulted margin dips steeply southeast. The metamorphics generally have a well developed steeply dipping schistosity trending east to northeast. One of the faults in the Marlborough Block has displaced the laterite profile on the serpentinite and is probably of Tertiary age. The boundary between the Marlborough Block and the Craigilee area is not exposed, but in the Port Clinton Sheet area to the east, the serpentinite intrudes sediments which are probably equivalent to the Silurian-Devonian rocks. The serpentinite was intruded in the late Lower Permian, possibly at the same time as the Rookwood Volcanics were extruded farther south. The Marlborough Block was possibly upfaulted against the Carmila Beds in the Upper Permian, before or during the Upper Permian intrusive episode.

Long Island Area

The Long Island area consists of moderately folded Devonian to Permian rocks of the Yarrol Basin sequence faulted to the south against Lower Palaeozoic(?) metamorphics which are intruded by a poorly exposed Carboniferous or younger granodiorite. The Yarrol Basin sequence strikes north to northeast and generally dips east. The sequence has probably been folded into a large north-trending syncline, only the western limb of which is exposed.

Auburn Arch (Malone, 1964b)

The Auburn Arch consists mainly of the massive Auburn Complex overlain by pre-Permian volcanics. In the north, it may include some Lower Permian volcanics which extend into the Gogango Overfolded Zone. The arch acted as a moderately stable rigid block during the Permian and younger deformations. It is flanked to the west by the moderately steeply dipping east limb of the Mimosa Syncline. To the east, tightly folded and faulted Permian sediments are compressed against the arch. The most recent mapping (Dear et al., 1971) indicates that the arch is cut by a number of northeasterly faults.

Prospect Creek Area

The Prospect Creek area is occupied by tightly folded and faulted Permian sedimentary and volcanic rocks. The fold axes and faults generally trend nearly north, parallel to the boundary of the Auburn Arch, which suggests that the sediments have been compressed against the arch by stress from the east.

Biloela Basin

The Biloela Basin is covered by an extensive but thin sequence of Tertiary sediments and Cainozoic alluvium, which totally conceals the underlying rocks.

GEOLOGICAL HISTORY

Clermont Stable Block
(pre-Permian rock units)

The Anakie Metamorphics include the oldest known rocks in the Clermont Stable Block. Samples of mica schist, and of one of the granites which probably intrudes the metamorphics, have given isotopic ages of about 450 m.y. The metamorphics are therefore Ordovician or older. The formation was folded, intruded, and thermally and regionally metamorphosed before the marine Lower to Middle Devonian sediments were deposited.

The Middle Devonian sediments were laid down in a warm sea, which favoured the growth of reef limestones, and the marine clastic and carbonate sedimentation was accompanied by considerable contemporaneous volcanism. The thick and extensive Ukalunda Beds were deposited at the northern end of the Anakie Inlier. Only small areas of Middle Devonian rocks have been recognized farther south, the most southerly of which consists of about 600 m of Dunstable Volcanics. The Middle Devonian sedimentation was probably extensive, and some unrecognized Middle Devonian sediments may be present in the Anakie Metamorphics. Volcanism was most active in the south, where volcanics form the bulk of the Dunstable Volcanics and much of the Middle Devonian rocks west of Emerald and near Douglas Creek. The fossils in the Ukalunda Beds, and in the Douglas Creek Limestone and equivalents, probably range from Lower Devonian to early Middle Devonian; the fauna in the Dunstable Volcanics have a similar range. Sedimentation, therefore, probably began in the Lower Devonian and continued into the late Middle Devonian.

The Middle Devonian sediments were deposited unconformably on the Anakie Metamorphics, and both were folded and intruded by the Retreat Granite and Devonian-Carboniferous intrusives, probably during the Upper Devonian.

The only Upper Devonian sediments known in the Clermont Stable Block are the fossiliferous marine Mount Wyatt Beds, which were laid down near the northern end of the Anakie Inlier in the Famennian. They are the only record of a brief incursion of the sea into the area after the Middle Devonian, and all the succeeding sediments were apparently deposited in fresh water.

In the late Upper Devonian or early Carboniferous, acid to intermediate volcanics were extruded in a province which overlapped the Anakie Inlier to west and east, but probably did not extend much farther north than Mount Coolon. The volcanism produced the Silver Hills Volcanics in the west, the Theresa Creek Volcanics on the Anakie Inlier, and the volcanics in the lower part of the Mount Rankin Beds to the east. The volcanism was probably largely terrestrial and took place before uplift of the Anakie Inlier and subsidence of the Drummond Basin.

The Telemon Formation at the base of the Drummond Basin sequence contains considerable reworked volcanic detritus, which was probably derived from the Silver Hills Volcanics. The quartz-rich Mount Hall Conglomerate and Raymond Sandstone succeeded the Telemon Formation with local slight unconformity. They were possibly laid down during a period of slower subsidence and greater reworking of the sediment. The lenses of Mount Hall Conglomerate and similar conglomerates farther north possibly indicate local vigorous uplift of the provenance areas. The Ducabrook Formation, the youngest unit in the Drummond Basin is similar to the Telemon Formation. At this time, the depositional area possibly overlapped the Anakie Inlier eastwards into the area where the sequence at the top of the Mount Rankin Beds was deposited. Volcanism on a relatively small scale continued while the Drummond Basin sequence was being deposited.

No equivalent of the Silver Hills Volcanics is present in the northern part of the Drummond Basin, where sedimentation probably began earlier – possibly with the marine equivalents of the Mount Wyatt Beds, which are probably older than the Telemon Formation. The remainder of the sequence is similar to the Telemon and Ducabrook Formations, but includes, in places, thick lenses of conglomerate.

The Drummond Basin sequence was strongly folded, probably in the late Lower Carboniferous. The fold axes are generally parallel with the margin of the Anakie Inlier, which influenced and was involved in the folding. Rocks correlated with those in the Anakie Inlier are exposed in the cores of anticlines in the southern part of the Drummond Basin, west of Springsure. In the northwestern part of the Anakie Inlier the shear cleavage in the mudstone is roughly parallel to the axial planes of the folds in the Drummond Basin to the west, and was possibly developed in response to the stress which caused the folding in the Drummond Basin. The boundary between the Drummond Basin and the Anakie Inlier is faulted in places. Presumably, the inlier was displaced laterally to the west during the folding, but since then the inlier and the Drummond Basin have retained their present positions. The swing to a northeasterly trend at the northern end of the Drummond Basin and the Anakie Inlier is possibly due to the resistance offered by the Ravenswood Block to westward displacement. The shear stress concentrated near the change of trend probably explains the phyllitic cleavage and schistosity in the Ukalunda Beds in this area.

No igneous activity occurred during the folding of the Drummond Basin.

The Mount Rankin Beds are not well exposed, but are apparently not tightly folded. They may have been protected from folding by the Anakie Inlier on which they lie.

Renewed volcanism in the Upper Carboniferous produced the thick acid Bulgonunna Volcanics, which rest unconformably on the Mount Rankin Beds and the folded Drummond Basin sequence. The Bulgonunna Volcanics consist of a pile of heterogeneous volcanic lenses, each of which was probably erupted from a single volcanic focus or group of foci. Some of the lenses probably consist of contemporaneous intrusive and extrusive rocks. The formation is gently folded in places and is on the whole flat-lying, or dips to the east. In the late Upper Carboniferous the volcanics were intruded by acid stocks and small batholiths, some of which may be comagmatic with the Bulgonunna Volcanics. A solitary stock, with an isotopic age similar to the late Upper Carboniferous intrusives, intruded the Drummond Basin sequence west of Emerald.

In the south, the late Upper Carboniferous sediments contain glacial detritus. The presence of abundant striated and faceted cobbles and boulders in poorly stratified conglomerate and thinly laminated (varve?) shale in the Joe Joe Formation indicate a glacigene source. The sediments are possibly fluvioglacial deposits laid down beyond the glaciated uplands. The Joe Joe Formation rests unconformably on the Drummond Basin sequence and dips southwest below the Western Bowen Basin; the beds are only slightly folded and the area has been stable since the end of the Lower Carboniferous.

Eungella-Cracow Mobile Belt
(pre-Permian rock units)

The Eungella-Cracow Mobile Belt has a complex geological history. Major tectonic activity had ceased in the Clermont Stable Block by the end of the Carboniferous, but in the Eungella-Cracow Mobile Belt it continued spasmodically until the Cretaceous. The rock units are discussed below in probable order of descending age, but little information is available on the age and relationships of many of the units.

Possibly, the oldest rocks in the east are the metamorphics (Pzl) of the Marlborough Block. No fossils have been found, and no isotopic ages are available. They are assumed to be the oldest rocks because they are the most strongly metamorphosed. The metamorphics were intruded by serpentinite about the end of the Lower Permian, when they were possibly uplifted by block faulting into approximately their present position; they were intruded by a granodiorite pluton and smaller stocks in the Upper Permian.

The unnamed Palaeozoic metamorphic rocks (Pz) cropping out 40 km southeast of Theodore are of unknown age. As they are presumably intruded by the Auburn Complex they are probably Lower Carboniferous or older.

The Silurian-Devonian rocks in the core of the Craigilee Anticline are the oldest fossiliferous rocks. They contain an Upper Silurian fauna in one place, and a probable Lower Devonian fauna in others. The sequence contains extensive intermediate to basic volcanics and marine carbonate and minor clastic rocks laid down about the end of the Silurian. The palaeontological data indicate that the sequence is significantly older than the Middle Devonian rocks of the Clermont Stable Block. The volcanics are mainly massive, but the bedded limestone and clastic sediments show that the sequence has been tightly folded. Folding and uplift took place in the Devonian as the overlying Yarrol Basin sequence strikes at right angles to the structures in the Silurian-Devonian rocks. The Silurian-Devonian rocks partly controlled the distribution of the Yarrol Basin sequence in the Craigilee area. A conglomerate at the base of the Yarrol Basin sequence contains clasts of fossiliferous limestone from the Silurian-Devonian sediments, and the onlapping of the Carboniferous and Lower Permian units indicates that the Silurian-Devonian rocks were exposed during Yarrol Basin and Bowen Basin sedimentation.

The inliers to the west of the Craigilee area are correlated with the Silurian-Devonian rocks on lithology only. Their relationship to the Permian sediments indicates that they were exposed at times.

The Yarrol Basin sequence has been recognized in the Craigilee and Long Island areas. The Campwyn Beds were probably laid down in a northerly extension of the Yarrol Basin. Deposition of the Yarrol Basin sequence probably began in the Upper Devonian, and consisted mainly of volcanics. Volcanics with an Upper Devonian fauna crop out in the northwest part of the Craigilee area. In the Craigilee Anticline the lithology and fauna are different. The base of the sequence consists of Lower Carboniferous sediments resting unconformably on the Silurian-Devonian rocks. The Silurian-Devonian rocks apparently formed a ridge, which extended into the Yarrol Basin and was progressively overlapped from northeast to southwest. Probable Upper Devonian volcanics and sediments were deposited east of the ridge, but were overlapped by the Lower Carboniferous sediments.

The Yarrol Basin sequence in the Long Island area includes Upper Devonian, Lower and Upper Carboniferous, and Lower Permian volcanics and sediments. The sequence was probably laid down well within the basin, whereas the beds in the Craigilee area were deposited near the shore. The connexion between the Yarrol Basin sequences in the Craigilee and Long Island areas is not exposed; it may be covered by Bowen Basin sediments or may have been eroded when the Marlborough Block was uplifted.

The history of the Yarrol Basin began with the deposition of volcanics and interbedded sediments in the Upper Devonian. These were succeeded in the Lower Carboniferous by lutite, conglomerate, and oolitic limestone, followed in turn in the Upper Carboniferous by lutite and sandstone, with a little conglomerate and limestone. In the Lower Permian the Youlambie Conglomerate and the conglomerate sequence on Quail Island were laid down. The separate distribution of these units and gaps in the faunal succession suggest the presence of disconformities, some of which are possibly quite large. The disconformities are possibly related to epeirogenic movements as no angular unconformities have been recorded to indicate vigorous folding in Upper Devonian/Upper Carboniferous times. The predominance of coarse clastics and the irregular distribution of the Lower Permian sediments in the Yarrol Basin, and local unconformities on the Upper Carboniferous, suggest that they were associated with renewed tectonism, probably mainly vertical block movements. The Yarrol Basin sequence was folded into large structures with local steep flanks, probably during the late Upper Permian orogeny.

The Campwyn Beds consist mainly of pyroclastics and extrusive flows, with minor sediments. The faunas indicate an Upper Devonian and Lower Carboniferous age. Some of the volcanics may be terrestrial, and the Campwyn Beds were possibly deposited along the northwest margin of the Yarrol Basin. They are folded into fairly large structures and are extensively intruded by small igneous bodies and dykes. They were uplifted and faulted against the Carmila Beds after the early Lower Permian.

The Yarrol Basin sequence is partly contemporaneous with the Mount Rankin Beds and the Drummond Basin sequence, but they were all probably laid down in completely separate areas.

The Connors Volcanics and the older part of the Camboon Andesite, and possibly the older part of the Rannes Beds, are Carboniferous or older. They occupy a structurally high position along the western edge of the Eungella-Cracow Mobile Belt and are unconformably overlain by Permian strata. The Connors Volcanics and the older part of the Camboon Andesite are intruded by igneous rocks with isotopic ages up to 311 m.y.

The Connors Volcanics consist of massive volcanics, which are extensively silicified, jointed, and intruded. The Connors Arch, which is composed of volcanics and intrusive rocks, was partly exposed at times during the Permian, and had a marked influence on the structural deformation of the Permian rocks. The northern part of the arch was intruded by igneous rocks in Upper Carboniferous and early Permian times, and again in the early Cretaceous. The early Permian intrusions apparently post-date the extrusion of the Lizzie Creek Volcanics.

The Auburn Arch is composed of massive volcanics of the older part of the Camboon Andesite and the intrusive Auburn Complex. Both the Connors Volcanics and the older part of the Camboon Andesite probably include terrestrial volcanics. They may be correlates of the volcanics at the base of the Yarrol Basin sequence, or possibly of the Silurian-Devonian volcanics, or they may represent one or more independent periods of volcanism which were not related to the activity in the Eungella-Cracow Mobile Belt.

The Rannes Beds between the Connors and Auburn Arches consist mainly of fine clastics with some lenses of limestone and volcanics. Unlike the massive rocks of the Connors and Auburn Arches, they have been cleaved, sheared, faulted, folded, and overfolded. Much of the deformation was the result of Upper Permian or younger tectonic activity, and consequently the Rannes Beds are difficult to distinguish from folded and cleaved Permian rocks of similar lithology. The older part of the Rannes Beds is associated with Connors Volcanics and both are unconformably overlain by the Boomer Formation. The magnitude of the unconformity suggests that this part of the Rannes Beds may be pre-Permian. Most of the unit, however, is probably Lower Permian and was deposited in a marine environment.

The Torsdale Beds at the northern end of the Auburn Arch are considered to be Upper Carboniferous in age (Dear et al., 1971), but they probably extend into the Lower Permian. They include conglomerate of possible fluvioglacial origin, and are roughly the same age as the Joe Joe Formation.

Permian-Triassic

Sedimentation in the Bowen Basin began in three areas in the early Lower Permian with the deposition of the Reids Dome Beds, Lizzie Creek Volcanics, and Carmila Beds. A great thickness of terrestrial sediments (the Reids Dome Beds) accumulated in the Denison Trough, and a thin sheet was laid down across the Springsure Shelf. The sequence includes mudstone and interbedded coal seams laid down during a period of slow subsidence, and thick lenses of conglomerate deposited during periods of more rapid subsidence associated with uplift of the source areas. Minor contemporaneous volcanism probably occurred near the eastern margin of the Denison Trough. At the same time, there was a period of major volcanism to the north and south. In the north the Lizzie Creek Volcanics and Carmila Beds were laid down to the west and east of the Connors Arch, and in the south the upper part of the Camboon Andesite was formed on the Auburn Arch. The two areas of volcanism were probably separate. The sediments of the younger part of the Rannes Beds were deposited between the Connors and Auburn Arches, and in the north they were possibly continuous with the Carmila Beds. The Youlambie Conglomerate and its probable equivalent on Quail Island were laid down in the early Lower Permian. Most of the Youlambie Conglomerate was deposited in the Yarrol Basin, but it extended westward into the Bowen Basin, where it was possibly continuous with part of the Rannes Beds.

In the north, the period of terrestrial volcanism was followed by freshwater sedimentation and volcanism, and finally by marine sedimentation. The upper part of the Camboon Andesite contains lenses of fossiliferous marine limestone northeast of the Auburn Arch. About this time, marine sediments were being deposited in the Yarrol

Basin. The sea was apparently to the east of the Connors Arch/Auburn Arch in the early Permian, but transgressed westward into the Bowen Basin about the end of the volcanic cycle. Marine fossils are present towards the top of both the Lizzie Creek Volcanics and the Carmila Beds.

Deposition of the marine Back Creek Group followed during the remainder of the Lower Permian and early Upper Permian. The thick Tiverton Subgroup was laid down in the Denison Trough and in a northern trough extending approximately across the site of the Connors Arch and Nebo Synclinorium. Both sequences consist predominantly of marine mudstone; lenses of littoral and fluviatile sandstone interfinger with the mudstone on the northwest flank of the Denison Trough, and in the north the base of the sequence consists of sandstone, siltstone, and coquinite. Volcanism continued at the southern end of the Connors Arch, where the Tiverton Subgroup pyroclastics include reworked volcanic material. A thinner and possibly discontinuous sequence was laid down on the Comet Ridge between the two troughs. Only the basal part of the subgroup is represented in the southeastern part of the basin, where thin neritic limestone and calcareous tuffaceous rocks were deposited over the Auburn Arch and discontinuously over the area between the Connors and Auburn Arches. The area was apparently uplifted during the late Lower Permian and the Boomer Formation rests with moderate angular unconformity on the Lower Permian sediments.

The Gebbie Subgroup was deposited in the late Lower Permian. The northern trough became more shallow and expanded westwards beyond the Nebo Synclinorium. Near the Connors Arch, interbedded quartz sandstone and mudstone were laid down on the underlying mudstone, and in the northwest the Collinsville Coal Measures were deposited in a deltaic environment. East of the Connors Arch, the Calen Coal Measures were possibly deposited at about this time. In the late Lower Permian a thick sequence of fluviatile and marine littoral sandstone with interbeds of mudstone was laid down in the Denison Trough. At the same time a thinner sandstone sequence was deposited over the Comet Ridge and a thin sheet of fluviatile sandstone (the Colinlea Sandstone) was laid down on the Springsure Shelf.

The Blair Athol Coal Measures were laid down in an isolated basin within the Clermont Stable Block during deposition of the Gebbie Subgroup. The Blair Athol basin is in line with, and may represent an extension of, the Denison Trough.

The Blenheim Subgroup was deposited in the early Upper Permian. It consists of a thin blanket of marine sediments on the Springsure Shelf and in the Denison Trough. At the same time, the northern trough deepened and expanded, and a thick pile of sediments was laid down near the western margin of the Connors Arch; farther west, a thinner sequence of sandy sediments, with local freshwater and marine coal measures, was deposited on the Collinsville Shelf, the Capella Block, and Comet Ridge. The sea transgressed farther west in the Upper Permian than in the Lower Permian, and on the Clermont Stable Block the Blenheim Subgroup rests unconformably on the pre-Permian rocks.

The most marked early Upper Permian subsidence took place on the site of the Auburn Arch and Gogango Overfolded Zone, and beyond the eastern margin of the map area. In the Gogango Overfolded Zone, the submarine spilitic Rookwood Volcanics were extruded unconformably on the Lower Permian Youlambie Conglomerate and older rocks. They initiated the cycle of sedimentation in this deep but restricted Upper Permian downwarp. The serpentinite of the Marlborough area was emplaced about the end of the Lower Permian. It may be comagmatic with the Rookwood Volcanics, and both were possibly related to the Upper Permian downwarping. The Boomer Formation was deposited in the Gogango Overfolded Zone downwarp. It overlapped and locally interfingered with units containing immature conglomerate derived mainly from the east. At the same time, a predominantly lutite sequence was deposited near the Auburn Arch.

Considerable local extrusive volcanic activity was associated with Blenheim Subgroup sedimentation near the Auburn Arch, and tuffaceous clays occur far to the west in the Back Alley Shale in the Denison Trough and Springsure Shelf. No pyroclastic rocks or flows have been recognized in the Blenheim Subgroup in the north. Some of the youngest sediments of the subgroup are non-marine, and almost all the sediments laid down in the Bowen Basin from this time onwards are non-marine.

In late Upper Permian time, the Blackwater Group was deposited in a changing system of river channels, braided streams, flood-plains, lakes, and swamps, in the central and western parts of the basin. In the east, uplift along the line of the Connors and Auburn Arches converted the marine basin to a freshwater depositional area. In the late Upper Permian numerous acid intrusions were emplaced in the southern part of the Eungella-Cracow Mobile Belt, particularly in the southeast. The intrusive activity was probably associated with uplift of the mobile belt, although the isotopic ages indicate that most of the intrusions were emplaced during or at the end of Blackwater Group time. This late Upper Permian orogeny probably produced most of the deformation within the Gogango Overfolded Zone.

The Blackwater Group consists of coarse to fine clastics, followed by a sequence of fine clastics with widespread interbeds of volcanic ash, and finally of coal measures composed mainly of carbonaceous mudstone, minor sandstone, and many thick seams of coal. The group is about 2000 m thick in the Nebo Synclinorium, where the northern trough continued to subside. It ranges from 360 to 600 m thick on the Comet Ridge and under the Mimosa Syncline, but is very thin and probably not fully represented over the Denison Trough and on the Springsure Shelf. In the Nebo Synclinorium there were probably several episodes of volcanism which contributed detritus to the Blackwater Group, but elsewhere only one, about the middle of the unit, is recognized.

The Lower Triassic Rewan Formation, which succeeded the Blackwater Group, was deposited over much the same area, but the locus of sedimentation shifted from the Nebo Synclinorium to the Mimosa Syncline. The Rewan Formation consists mainly of red and green mudstone and siltstone, with green sandstone. Beds of conglomerate are found near the base in places. Little carbonaceous material and few plants are preserved in the Rewan Formation, though they are abundant in the Blackwater Group. The paucity of carbonaceous material and the red colour of the sediments suggest that the Rewan Formation was deposited in a non-reducing environment, possibly as a result of climatic changes at the end of the Permian. The red sediments were apparently derived from laterite profiles developed during post-Permian lateritization of the provenance areas.

The fluviatile Clematis Sandstone was laid down over the Rewan Formation. Its maturity and uniform thickness indicate deposition under conditions of slow uniform subsidence of the central and western parts of the basin. Rapid subsidence of the Mimosa Syncline began again in the Middle or Upper Triassic, and the immature Moolayember Formation succeeded the Clematis Sandstone. The thickest part of the Moolayember Formation was laid down in the Mimosa Syncline, and the sequence is relatively thin in the western and north-central parts of the basin. About 5400 m of sediments were deposited in the Mimosa Syncline during the Triassic. Acid igneous rocks intruded the eastern zone during the Triassic, and the downwarping of the Mimosa Syncline was possibly counterbalanced by uplift and intrusion to the east.

During the Upper Triassic deposition ceased in the Bowen Basin, and the sediments were uplifted and eroded. During these movements, the east flank of the Mimosa Syncline was steepened, and the major structures in the Denison Trough, which probably started to form during downwarping of the Mimosa Syncline, were more tightly folded and then truncated by erosion.

Jurassic-Cretaceous

Deposition in the Great Artesian Basin began early in the Jurassic with the fluviatile Precipice Sandstone, which blanketed the area as the basin began to subside. A lacustrine, and at times possibly marine, environment developed in the east, where the fine sediments and some oolitic ironstone of the Evergreen Formation were deposited. Farther west, the Evergreen Formation consists mainly of the cross-bedded Boxvale Sandstone Member, which was laid down in a persistent fluviatile environment. The fluviatile environment advanced over the whole area again when the Hutton Sandstone was deposited at the end of the Lower Jurassic. In the Middle Jurassic, the area was occupied by lakes and swamps in which the fine sediments and minor chemical precipitates and coal of the Injune Creek Beds were deposited. In the Upper Jurassic and early Cretaceous, alternating fluviatile sand and partly lacustrine sands and muds were laid down. A major marine transgression covered the area in the Lower Cretaceous, when the mudstone, glauconitic sandstone, and limestone of the Roma Formation were deposited. These sediments are the youngest in the Great Artesian Basin within the map area.

Cretaceous sedimentation outside the Great Artesian Basin was confined to small areas. Freshwater sandstone, conglomerate, siltstone, and coal, of Lower Cretaceous age, are preserved in the Styx Basin and in small areas to the south and northeast, but they were probably deposited over a much wider area. The minor marine incursion in the Styx Basin sequence may be related to the major marine transgression of the Roma Formation in the Great Artesian Basin.

The early Lower Cretaceous was a time of considerable tectonic activity in the north. Acid to basic igneous rocks intruded the northern end of the Connors Arch and the Permian-Triassic sequence of the Nebo Synclinorium, probably during folding of the Permian-Triassic rocks. The Eungella-Cracow Mobile Belt was possibly again uplifted at this time and the sediments of the Gogango Overfolded Zone were further deformed. The folding of the Folded Zone is tentatively correlated with this uplift.

Intrusive and extrusive activity was renewed about the end of the Lower Cretaceous along the northeast coast and offshore to the northeast.

Trachyte stocks, such as those south of Baralaba, were intruded about the end of the Cretaceous.

Cainozoic

Most of the Tertiary volcanics and sediments are poorly known, and as mapped they may include some pre-Tertiary rocks. The isotopic age determinations indicate that the main period of extrusion of the basalts and associated acid differentiates took place 30 to 20 million years ago, that is during the late Oligocene to early Miocene.

The Tertiary sediments were deposited in rivers, flood-plains, and temporary lakes on a land surface similar to the present topography. Some of the lakes were formed as a result of damming of the rivers by basalt flows. The sediments rarely exceed 200 m in thickness, but much greater thicknesses accumulated in small faulted basins, such as the Duaringa Basin, where they are about 1000 m thick.

The area was subjected to a prolonged period of lateritization during the Tertiary, and thick laterite profiles were developed on the permeable poorly consolidated Tertiary sediments. Locally, laterite profiles were also developed on the basalt sheets and pre-Tertiary rocks, and on the serpentinite and igneous rocks of the Marlborough area. Some of the laterites on the older rocks may be of Cretaceous age. The laterite profiles on the serpentinite have been displaced by late Tertiary faulting and the laterite is preserved on the downfaulted block only. The laterite profile on the Tertiary sediments has been preserved on tablelands and mesas in many areas, and once the laterite profile has been completely removed, the Tertiary sediments are readily eroded.

The Cainozoic sediments were deposited in braided streams, flood-plains, and river channels closely related to the present drainage system, which is actively eroding the older Cainozoic rocks. The sediments are generally less than 60 m thick, though thicknesses of up to 120 m are known in some river valleys.

Uplift of the Connors Arch during the late Tertiary is indicated by the difference in lithology between Tertiary sediments and younger Cainozoic sediments in the same position relative to the arch: the older rocks are mainly fine sandstone and siltstone; the younger sequence is a locally derived boulder conglomerate. Other minor uplifts are indicated by incised younger streams which truncate the probable Pleistocene or younger river-channel deposits.

ECONOMIC GEOLOGY

Most of the metalliferous deposits are found in two belts of igneous and metamorphic rocks to the east and west of the basin proper, but the Mount Flora copper deposits are associated with the Bundarra Granite in the Back Creek Group. The sapphires of Anakie are derived from Tertiary volcanics in the western belt of igneous and metamorphic rocks. The Bowen Basin contains important deposits of coal and groundwater. Despite extensive exploration and drilling no oil or gas is being produced, although commercial oil and gas fields have been found to the south.

The mineral occurrences and production have been given by McLeod (1965), and information on minerals, mining, and groundwater is being prepared for the Department of National Development, Fitzroy region, Queensland, Resources Series. Detailed information is available in the Reports on the 1:250,000 Sheet areas (see Fig. 3).

Groundwater

A survey of the underground water resources of most of the area has been made by the Department of National Development in conjunction with the Geological Survey of Queensland and the Irrigation and Water Supply Commission of Queensland (DND, 1969). During the regional survey, data on water bores were collected, and the results have been tabulated in the Reports on the Sheet areas. In the south some of the important aquifers lie in the Great Artesian Basin and form part of the intake area for the basin. They include the Precipice Sandstone and the Boxvale Sandstone Member of the Evergreen Formation, both of Jurassic age.

Coal

The Bowen Basin is one of the most important black coal-producing areas in Australia, second only to the Sydney Basin. King (1968) and King & Goscombe (1968) have recently given a comprehensive account of the occurrence, type, resources, and production of coal.

Coal has been recorded from many stratigraphical levels in the Permian, Jurassic, and Cretaceous rocks.

Permian

Coal has been recorded in the Reids Dome Beds (subsurface only), Aldebaran and Colinlea Sandstones, Blair Athol Coal Measures, Collinsville Coal Measures (Gebbie Subgroup), Calen Coal Measures, and German Creek Coal Measures (Blenheim Subgroup). The most widespread and commercially important are the coal measures of the Blackwater Group (previously known as the Upper Bowen Coal Measures), which have different names in different areas.

Steaming coal is being produced from the Blair Athol and Collinsville Coal Measures and the first generators of the Northern Electric Authority's Collinsville power scheme have been commissioned. Metallurgical coking coal is being mined extensively from the

Moura (Pl. 14, fig. 2), Baralaba, and Rangal Measures in the Blackwater Group, mainly for export to Japan.

Mesozoic

Coal has been produced from the Jurassic Injune Coal Measures and the Cretaceous measures in the Styx Coalfield.

Oil and Gas

In the search for petroleum extensive seismic surveys have been made in the south, and much drilling has been done, especially in the central and southern part of the Denison Trough.

Adequate source rocks and reservoirs, and suitable structures, seem to be present, but no commercial quantities of oil or gas have been found to date.

Nebo Synclinorium

The Permian succession in the Nebo Synclinorium contains thick marine sequences with coal measures in places. Although folded, the detailed structure is poorly known, and a large part of the synclinorium is masked by superficial deposits. Most of the sequence lacks porosity and post-Permian intrusion makes much of the area unfavourable for the accumulation of oil and gas.

To the west the prospects may be more favourable, especially if the quartz sands of the Collinsville Shelf extend eastwards into the synclinorium.

Collinsville Shelf

The marine sequence on the Collinsville Shelf is considerably thinner than to the east, and the quartz sands are exposed or have only a thin cover. The junction of the shelf with the Nebo Synclinorium, where any sands present will be more deeply buried and capped by the Blackwater Group, may represent a more favourable area. The Collinsville Coal Measures are of moderate rank, and any oil and gas present may still be preserved.

Capella Shelf and Comet Ridge

The oil potential on the Capella Shelf and Comet Ridge is similar to that on the Collinsville Shelf, except that the Comet Ridge is bounded by troughs both to the east and west. The Comet Ridge, however, was apparently considerably more extensive, and formed a platform during the early part of the Permian marine sedimentation. The development of the Mimosa Syncline in this platform may have considerably affected the migration of oil and gas.

Folded Zone

The sequence in the Folded Zone is similar to that in the Nebo Synclinorium, but the intense faulting and tight folding make this an unfavourable area. The presence of anthracite at Bluff is a further unfavourable indication.

Mimosa Syncline

Although the middle part of the marine sequence found to the north and west is not present in the Mimosa Syncline, the marine rocks are thick enough to form a favourable source. However, the rocks are even less porous than in the Nebo Synclinorium, and the prospects are not good. Hydrocarbons may have migrated westwards into the porous sands associated with the Comet Ridge and the eastern part of the Denison Trough. The few wells drilled, however, have failed to locate oil or gas in useful quantities.

Denison Trough

The amount of drilling in the Denison Trough indicates that it has been regarded as an area with good prospects, but the results to date have been disappointing. Porous sands are interbedded with and grade laterally into a thick marine sequence, and favourable structures have been formed by moderate folding.

Gold

Gold production has been important. The Clermont area was one of the main alluvial producers in Queensland, and the Golden Plateau mine near Cracow has been one of the few important producers in recent years. Gold has also been produced from the Lady Norman mine near Eungella, Mount Britton, Mount Coolon, Mount Flora, Mount Wyatt, Normanby, near Sarina, Yatton, and from the deep leads on the Rutherford Table. Most of the gold is associated with granitic or dioritic intrusions.

At Clermont reef gold has been relatively unimportant, and the main production has come from Permian deep leads and Tertiary(?) and Recent alluvial deposits. Near Cracow production is from a gold-silver alloy in a quartz gangue in the Camboon Andesite, close to the contact with the Auburn Complex.

Copper

The first significant production of copper in Queensland came from the Peak Downs Copper Beds near Clermont. Between 1862 and 1877 (when the mine was closed) 100,000 tons of ore averaging 17 percent copper were mined. Copper has also been mined at Mount Flora and on the Sellheim River near Mount Wyatt.

Other Metals and Minerals

Other metals and minerals produced commercially include silver (usually in association with other metal ores), bismuth, arsenic, lead, wolfram, molybdenite, nickel, and chromite, but only silver has been produced in important quantities. The Cracow Goldfield with the Golden Plateau mine as its major producer, yielded more than a quarter of a million ounces of silver.

Sapphire

Valuable sapphires have been produced in the Anakie Field. The sapphires are found as waterworn fragments derived from the weathering of Tertiary basalt plugs and possibly from flows. The total estimated value of the rough sapphires produced is $1,410,956. The stones are mostly blue, green, yellow, orange-yellow, and white. A few diamonds have also been found on this field.

Chrysoprase

Chrysoprase of gemstone quality occur as veins in the laterite profile on the serpentinite near Marlborough (Brooks, 1964). Since 1963, several tons mined from shallow pits have been exported, mainly to Germany and the USA.

Graphite has been mined at Jacks Creek, near Collinsville, and small amounts of magnesite have been produced.

Deposits of bentonite, diatomite, and phosphate have been found, but there has been no commercial production.

TABLE 1. DEVONIAN-CARBONIFEROUS ROCK UNITS OF THE CLERMONT BLOCK

Age		Rock Unit (map symbol)	Distribution and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
U. Devonian to L. Carboniferous	MOUNT RANKIN BEDS	Undifferentiated (D/Cr)	Discontinuous outcrops E of Anakie Inlier from E of Blair Athol to N of Mt Coolon (Malone et al., 1964, 1966; Veevers et al., 1964b)	Quartz-veined spherulitic flow-banded porphyritic rhyolite, dacite, pitchstone, andesite; acid and intermediate pyroclastics including agglomerate, volcanic conglomerate, and lapilli, crystal, and lithic tuff; tough fine to medium quartz-poor tuffaceous arenite, brown and grey siltstone. About 4800 m thick 65 km NE of Clermont	Only slightly folded. Dips at 20°-50° in N and in type area; gentler dips W of type area possibly due to presence of shallow basement of Anakie Metamorphics. Unconformable on Anakie Metamorphics and Ukalunda Beds; unconformably overlain by Bulgonunna Volc	L. Carboniferous plants near top include *Lepidodendron, Lepidophyllum, Lepidostrobus* all cf. *L. aculaetum Stigmaria ficoides.* Probably equivalent to and originally partly continuous with Drummond Basin sequence
U. Devonian	MOUNT RANKIN BEDS	Mount Wyatt Beds (Dum)	Type area and four smaller areas of outcrop about 50 km N of Mt Coolon (Malone et al., 1966)	Thin-bedded brown grey-green siltstone; fine to coarse and pebbly grey feldspatholithic sandstone, largely composed of volcanic detritus, quartzose sandstone; fossiliferous calcareous sandstone; beds and lenses of pebble to cobble conglomerate; green volcanic conglomerate; small-scale slump structures and clastic dykes common. About 300 m thick in type area	Dips at up to 55° away from underlying Ukalunda Beds. Appears to be local formation at base of Mt Rankin Beds, which unconformably overlie Ukalunda Beds	U. Devonian brachiopod *Cyrtospirifer* cf. *reidi* and *Leptophloeum australe, Protolepidodendron,* psilophytes, *Stigmaria*
U. Devonian to L. Carboniferous	DRUMMOND GROUP	Undifferentiated (Cld)	NW corner of map area (Malone et al., 1966)	Lithic sandstone, pebble to boulder conglomerate, and siltstone composed mainly of reworked volcanic detritus; minor quartz sandstone, grey chert, and thin beds and lenses of limestone. Acid to intermediate tuff, crystal tuff, agglomerate, and lava flows. Up to 3000 m thick	Moderately tight NE-trending folds; dips up to 80°, generally 30°-60°. Unconformable on Ukalunda Beds and Devonian-Carboniferous intrusions. Unconformably overlain by Bulgonunna Volc and intruded by U. Carboniferous intrusions	Carboniferous plants include *Lepidodendron* sp., *Rhodia* sp., *Calamites* sp.
L. Carboniferous	DRUMMOND GROUP	Ducabrook Formation (Clu)	Widespread in S part of Drummond Basin (Hill, 1952, 1957; Veevers et al., 1964a,b)	Typical sequence consists of coarse lithic sandstone with pink to pale green tuff, overlain by thin-bedded light green and brown fine sandstone, siltstone, mudstone, and shale, overlain by interbedded massive mottled sandstone and multicoloured mudstone with thin beds of pink vitric tuff and dark oolitic and algal limestone. Proportion of each rock type varies from place to place. 2100-2700 m thick	Moderately elongate broad anticlines and synclines persisting for up to 80 km; dips rarely exceed 30°. Conformable or disconformable on Raymond Sst. Unconformably overlain by Joe Joe Fm	L. Carboniferous plants and fish include *Lepidodendron* cf. *L. veltheimianum* Sternberg, *Gyracanthides murrayi,* cf. *Elonichthys*

TABLE 1. DEVONIAN-CARBONIFEROUS ROCK UNITS OF THE CLERMONT BLOCK (continued)

Age		Rock Unit (map symbol)	Distribution and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
L. Carboniferous	DRUMMOND GROUP	Raymond Sandstone* (Clr)	Along NE margin of S part of Drummond Basin W of Anakie and large anticline to W (Veevers et al., 1964a); in Nogoa and Telemon Anticlines and adjacent structures (Mollan et al., 1969; Hill, 1952, 1957)	Medium to fine light-coloured flaggy micaceous quartzose and sublabile sandstone. Near Anakie: interbedded mudstone, siltstone, medium to coarse feldspatholithic sandstone, arkose, thin basalt flows. Up to 660 m thick	Broad elongate anticlines; SW-dipping flank of Drummond Basin. Dips up to 40°	
		Mount Hall Conglomerate (Clh)	As for Raymond Sst	Cross-bedded quartz-pebble conglomerate and pebbly quartzose sandstone, feldspathic and kaolinitic quartzose sandstone, mudstone. Lenticular unit up to 780 m thick	Raymond Sst conformable and transitional on Mt Hall Cgl where present; elsewhere disconformable on Telemon Fm. Mt Hall Cgl overlies Telemon Fm with disconformity or angular unconformity	Mt Hall Cgl contains Carboniferous plants including *Lepidodendron veltheimianum.* Whole Drummond Basin sequence probably deposited in fresh water
U. Devonian		Telemon Formation (Dut)	Along NE margin of S part of Drummond Basin (Veevers et al., 1964a,b); in Telemon and Nogoa Anticlines and adjacent structures (Mollan et al., 1969; Telemon Fm: Hill, 1957)	Basal part: cross-bedded massive conglomerate with lithofeldspathic tuffaceous matrix; pebbly sandstone. 600 m in Nogoa Anticline, lenses out to W Top part: thinly interbedded multicoloured lutite and arenite, with cross-bedding, graded bedding, current striations, and sole markings; lenses of algal limestone. 1500 m in Nogoa Anticline, thins to W	Telemon Fm unconformably overlies and overlaps Silver Hill Volc, which rest unconformably on Anakie Metamorphics and Retreat Granite. Structures similar to those of overlying units, but both units cut by many faults in Nogoa and Telemon Anticlines	Basal conglomerate of Telemon Fm derived in part from Silver Hills Volc. Telemon Fm contains algae, fish scales, freshwater? branchiopod *Leaia,* and plants, including *Leptophloeum australe,* of U.? Devonian age
		Silver Hills Volcanics (Ds)	As for Telemon Fm (Veevers et al., 1964a)	Basal part: 240 m of weathered basalt and trachyte flows with lenses of resistant spherulitic rhyolite Middle part: 150 m of conglomerate, lithic arenite, siltstone, shale, trachyte flows Top part: 210 m of amygdaloidal porphyritic basalt, trachyte, andesite, agglomerate, crystal tuff, spilite, sandstone, and lithic greywacke		
M. & U.Devonian		Theresa Creek Volcanics (Dt)	Many isolated outcrops in small area SW of Clermont (Veevers et al., 1964b)	Andesite, trachyandesite, flow-banded and spheroidal rhyolite, rhyolite breccia, dacite, basalt, crystal and lithic tuff; minor arkose, well bedded lithic arenite and siltstone, fine to medium cross-bedded calcareous feldspathic sandstone, and laminated red-brown micaceous siltstone. Thickness unknown	Structure obscured by massive nature of extrusions; thrust-faulted against Anakie Metamorphics. Relationships obscure: unconformable on Anakie Metamorphics, apparently conformable on M. Devonian sediments	No intrinsic evidence of age. Regarded as equivalent to Silver Hills Volc and basal volcanics of Mt Rankin Beds; may be older, equivalent? to Dunstable Volc

*Name amended to Raymond Formation (Olgers, 1972)

TABLE 2. DEVONIAN-CARBONIFEROUS ROCK UNITS OF THE EUNGELLA-CRACOW MOBILE BELT

Age		Rock Unit (map symbol)	Distribution and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
U. Carboniferous	YARROL BASIN SEQUENCE	Neerkol Formation (Cu)	Long strips on E and W flanks of Craigilee Anticline; N part of Long Is (Malone et al., 1969; Kirkegaard et al., 1970; named in Reid, 1930b)	Mainly mudstone to sandy siltstone, blue-grey to black, tough poorly bedded to massive, locally grading into fine sandstone; labile sandstone, fine to medium-grained, greenish grey, poorly bedded, scattered pebbles near base; minor crinoidal limestone, coquinite, and conglomerate beds near base. Estimated thickness 1500 m+ in Craigilee area	Broadly folded on Craigilee Anticline: moderate dips on E flank and steep dips on W flank; some minor cross-folding and faulting. Moderately folded and locally sheared on Long Is. Structurally conformable on L. Carboniferous, but faunas suggest disconformity; unconformably overlain by Youlambie Cgl and Rookwood Volc	Mudstone contains richly fossiliferous bands throughout, particularly bryozoans. Fauna includes *Levipustula levis, Spinuliplica* cf. *Spinulosa, Composita* cf. *magnicarina, Alispirifer, Neospirifer, Reticulatia, Phricodothyris, Evactinopora, fenestellids*, bryozoans, which indicate U. Carboniferous age
L. Carboniferous	YARROL BASIN SEQUENCE	(Cl)	Long strips on E and W flanks of Craigilee Anticline; N part of Long Is (Malone et al., 1969; Kirkegaard et al., 1970)	Basal part: siltstone and mudstone, grey to greenish grey, massive, cherty in part; some interbeds of fine to medium sandstone, commonly graded Middle part: granule to pebble conglomerate, clasts mainly rounded volcanics, interbedded with beds of oolitic limestone up to 6 m thick Upper part: tough grey siltstone with thin to thick interbeds of fine to medium labile sandstone and coarse calcareous sandstone at top. Up to 600 m thick W of Craigilee Anticline; 2400 m E of anticline	Structure as for Neerkol Fm. Unconformable on Silurian-Devonian of Craigilee area; decrease in thickness of L. Carboniferous to W suggests this unit onlapped subsiding Silurian-Devonian block from E	Some richly fossiliferous bands; limestones generally poorly fossiliferous. Fauna includes *Productina, Pliocochonetes, Schizophoria* cf. *resupinata, Rhipidomella, Lithostrotion* spp., *Syringopora*, which indicate L. Carboniferous age
U. Devonian to U. Carboniferous	YARROL BASIN SEQUENCE	(D-Ca)	Small areas 30 km S of Marlborough and Long Is (Malone et al., 1969; Kirkegaard et al., 1970)	S of Marlborough: green basic volcanics, mainly tuff, lapilli tuff, flows; volcanic conglomerate, greenish grey siltstone, interbeds of sandstone, oolitic limestone, and green tuff Long Is: sandstone, blue-grey, coarse-grained, locally calcareous, thin interbeds of pebble conglomerate; dark grey siltstone and mudstone, cherty in part; volcanics, limestone	Unconformably overlain by Rookwood Volc; faulted E margin; relationships to serpentinite and Youlambie Cgl obscure. Few dip measurements steeply E Broad folds with some cross-folding and faulting	U. Devonian corals in lower volcanic part and L. Carboniferous fossils in limestone beds of middle-upper part *Cyrtospirifer?* sp. suggests U. Devonian age; rock types suggest sequence includes Carboniferous rocks

TABLE 2. DEVONIAN-CARBONIFEROUS ROCK UNITS OF THE EUNGELLA-CRACOW MOBILE BELT (continued)

Age	Rock Unit (map symbol)	Distribution and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
U. Devonian to Carboniferous	Campwyn Beds (D-Cc)	Isolated blocks along coast from Repulse Bay to Carmila and inland at Koumala (Jensen et al., 1966; Jensen, 1963)	Dark green and purple andesite agglomerate, and tuff, andesite, basalt, rhyolite, red and green rhyolite tuff, lapilli tuff, and volcanic breccia, minor trachytic volcanics, dark grey to black thin-bedded mudstone, well bedded or massive siltstone, calcareous siltstone, calcilutite, and labile sandstone, pebble conglomerate, oolitic limestone. Contact metamorphosed in places. Up to 7200 m thick	Broadly folded with dip rarely exceeding 45°. W margins faulted against Permian rocks; nature of faulting unknown, but relative movement E block up. Equivalent in age and lithologically similar to Yarrol Basin sequence with which they may have been continuous	L. Carboniferous fauna, including *Schuchertella* sp., *Rugosochonetes kennedyensis, Avonia kennedyensis, Athyris, Prospira tellebangensis, Camarotoechia, Aviculopecten, Chonetes, Bellerophon* in places; elsewhere contains U. Devonian fauna: *Alveolites* sp., *Thamnopora* sp., *Cyrtospirifer* sp., *Stenosia* sp., *Syringopora*
Devonian to Carboniferous	Connors Volcanics (D/Co)	S end of Connors Arch and isolated inliers to E and S; isolated blocks on E and W margins of N part of Connors Arch (Malone et al., 1966, 1969)	Mainly massive rhyolite, dacite, trachyte, and andesite flows, tuff, agglomerate, breccia; extensively silicified, jointed, and quartz-veined. Some tuffaceous sediments and volcanic conglomerate, commonly jointed and quartz-veined. Intruded and contact metamorphosed in places	Structure obscure: rare bedding generally dips E; volcanics apparently consist of small folded wedge cut by many faults. Intruded by Carboniferous granodiorite and younger intrusives. Unconformably overlain by L. Permian rocks. Onlapping of successively younger Permian units suggests parts of Connors Volc emerged at times during L. Permian	No known flora or fauna. Intruded by granodiorite with isotopic mineral ages of about 305 m.y. Tentatively correlated with Campwyn Beds because of similarity of lithology and structural position; S end may include equivalents of Silurian-Devonian volcanics

TABLE 3. UPPER CARBONIFEROUS TO PERMIAN ROCK UNITS

Age	Rock Unit (Map symbol)	Distribution and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
U. Carboniferous to Permian	Joe Joe Formation (C-Pj)	Irregular area around SW margin of Drummond Basin (Hill, 1952, 1957; Mollan et al., 1969)	Lower part: lithic conglomerate with subangular to rounded polymictic pebbles and boulders, some striated and faceted; unsorted conglomeratic light green sandy mudstone; lithic sandstone Upper part: fine sandstone grading to siltstone, interlaminated siltstone and claystone (varves?), fine to medium lithic sandstone, carbonaceous shale, thin coaly beds, fine-grained grey limestone, vitric tuff; sediments: thin-bedded, laminated, cross-bedded on small scale, interference ripple marks. About 600 m thick	Only gently folded; gentle regional dip to S and SW; some slight drape folding over pre-existing structures. Unconformable on Ducabrook Fm and overlaps older units; contact structurally conformable in places. Unconformably overlain by Reids Dome Beds and Colinlea Sst	Carboniferous plants, including *Cardiopteria polymorpha*, and spores. Spores suggest unit extends into Permian in subsurface to W. Basal part: mainly fluvioglacial; some beds of till; most of striated and faceted cobbles partly rounded. Upper part: mainly lacustrine
U. Carboniferous to Permian?	Torsdale Beds (Ct)	Elongate area 15 km NE of Banana and small area 50 km SE of Banana (Dear et al., 1971)	Conglomerate, lithic sandstone, mudstone, chert, andesite, rhyolite, acid tuff, agglomerate	Faulted against Camboon Andesite, Auburn Complex, and Back Cr Gp; overlain by Back Cr Gp to E	May be partly fluvioglacial. Age and relationships not firmly established
U. Carboniferous	Bulgonunna Volcanics (Cub)	Large irregular area in NW part of map area (Malone et al., 1964, 1966)	Mainly porphyritic rhyolite with some trachyandesite; rhyolite weakly to strongly flow-banded, some with eutaxitic texture. Rhyolite and dacite crystal tuff, tuff, lapilli tuff, tuffaceous and volcanic conglomerate, rhyolite breccia and agglomerate; minor well bedded fine to coarse tuffaceous sandstone, siltstone, and conglomerate. Probably includes some intrusive rocks	Unfolded massive wedge of volcanics composed of overlapping, interfingering, or separate homogeneous lenses; gentle depositional dips around margins of lenses, steep in some lenses where bounded by faults, possibly marginal to foundering blocks. Unconformable on Drummond Gp, Mt Rankin Beds, and Ukalunda Beds; unconformably overlain by L. Permian volcanics and sediments	No fossils recorded. Intruded by plutons about 285 m.y. old. Probably U. Carboniferous; may be partly coeval with intrusive rocks

TABLE 4. EARLY LOWER PERMIAN ROCK UNITS

Rock Unit (map symbol)	Distribution and Main References	Lithology	Structure and Relationships	General Remarks
Reids Dome Beds (Plj) Orion Formation (Plg)	Denison Trough and W part of basin (Mollan et al., 1969) Outcrops in core of Springsure Anticline (Mollan et al., 1969)	Sequence varies from place to place. Alternating carbonaceous sandstone, grey siltstone and shale, and coal (Orion Fm) above thick dark shale with anhydrite, dolomite, coal, sandstone, and siltstone. Thick volcanolithic pebble conglomerate and volcanolithic sandstone near middle and base in places	Moderately folded in Denison Trough with dips up to 40°; gently dipping elsewhere. Sequence generally indurated; locally fractured and slickensided. Unconformable on Joe Joe Fm and pre-Permian basement in SW. Conformably and transitionally? overlain by Cattle Cr Fm in Denison Trough; unconformably overlapped by Colinlea Sst in W	Abundant *Glossopteris/ Gangamopteris* flora. Rare marine fossils indicate occasional marine incursions. Orion Fm is only named unit of Reids Dome Beds which crops out
Lizzie Creek Volcanics (Plz)	N part of basin, mainly W of Connors Arch (as L. Bowen Volc: Malone et al., 1964, 1966; Malone et al., 1969; Jensen et al., 1966)	Andesite, dacite, rhyolite, trachyte, and basalt flows, tuff, agglomerate, breccia; sublabile, labile, volcanolithic, and tuffaceous sandstone, greywacke, siltstone, argillite, ashstone; pebble, cobble, and boulder conglomerate, volcanic conglomerate; fossiliferous limestone, calcareous lithic sandstone, calcareous tuff	Unconformable on Connors Volc and Bulgonunna Volc. Laterally equivalent to and locally continuous with Carmila Beds. Transitionally overlain and locally overlapped by Tiverton Subgp in most places; disconformably or unconformably overlain by Gebbie Subgp in Collinsville area; unconformably overlain by Calen Coal Measures in NE	Fossil wood and plants, including *Glossopteris, Noeggerathiopsis, Cordaites, Samaropsis.* L. Permian marine fossils of Fauna I near top
Carmila Beds (Pla)	N part of basin, mainly E and S of Connors Arch (Jensen et al., 1966; Malone et al., 1969)	Rhyolite, dacite; minor andesite flows and crystal tuff, volcanic conglomerate, lithic, feldspathic, and volcanolithic sandstone, tuff, ashstone, siltstone, mudstone; alternating tuffs and sediments. Fossiliferous calcareous tuff, limestone, and sandstone	Unconformable on Connors Volc; unconformable on Campwyn Beds, but contacts generally faulted. Laterally equivalent to and locally continuous with Lizzie Cr Volc. Transitionally overlain and locally overlapped by Back Cr Gp; unconformably overlain by Calen Coal Measures in NE	*Noeggerathiopsis, Glossopteris, Gangamopteris,* and near top L. Permian marine fossils of Fauna I and possibly Fauna II

***TABLE 5. SEQUENCES PENETRATED IN PETROLEUM EXPLORATION WELLS**

						Blenheim Subgroup			Gebbie Subgroup			Tiverton Subgroup					
Well Name and Ground Elevation (ft) / Rock Units	Post-Triassic	Moolayember Fm	Clematis Sst	Rewan Fm	Blackwater Gp	Black Alley Sh	German Cr Coal Measures	Peawaddy Fm	Catherine Sst	Ingelara Fm	Aldebaran Sst	Cattle Cr Fm	Buffel Fm & equivalents	Reids Dome Beds	Camboon Andesite	Pre-Permian	Total Depth (ft)
OSL3 (Arcadia) GE1392 AA07 (Arcadia) GE1222	– 5* (10) +Cz	–	–	– 15 (330)	– 345 (705)	– 1050 (150)	– – –	– 1200 (1050)	– – –	– – –	– – –	– – –	– 2250 (520)	– 2770 (510)	– – –	– – –	6036 3280
AFO Arcturus No. 1 GE590	14 (126)T	–	–	140 (480)	620 (850)	1470 (110)	1580 (550)	2130 (990)	3120 (200)	3320 (90)	3410 (2090)	5500 (703)	–	–	–	–	6203
AAO Bandanna No. 1 GE1420	–	–	–	–	–	–	–	10 (290)	–	300 (180)	480 (950)	1430 (680)	–	2110 (1933)	–	–	4043
UKA Burunga No. 1 GE1074	18 (2013)	–	–	2031 (50)	2081 (2575)	–	4656.x. (4924)	–	–	–	–	–	9580 (221)	–	9801 (180)	9981 (261)	10242
UKA Cockatoo Creek No. 1 GE656	1.8 (707) J-K	–	–	725 (2590)	3315 (2280)	–	5595.x. (5725)	–	–	–	–	–	11320 (598)	–	11918 (164)	–	12082
AFO Comet No. 1 GE600	–	–	–	–	–	–	–	15 (675)	690 (30)	720 (155)	875 (1055)	1930 (425)	–	–	–	2355 (655)	3010
AP Cometside No. 1 GE824	–	–	–	12 (838)	850 (890)	1740 (340)	–	2080 (1150)	–	–	3230 (430)	3660 (1455)	–	5115 (446)	–	–	5561
AOE3 (Consuelo) GE988	–	–	–	–	–	–	–	–	–	–	12 (2168)	2180 (2257)	–	–	–	–	4437
AFO Cooroorah No. 1 GE595	–	–	–	–	–	–	10 (380)	390 (820)	1210° (428)		1638 (1002)	2640 (370)	–	–	–	3010 (513)	3523
Planet Crystalbrook No. 1 GE1647	11 949 J-K	960 (580)	1540 (320)	1860 (140)	–	–	–	–	–	–	–	–	–	–	–	2000 (61)	2061
Amoseas Cunno No. 1 GE1796	12 (1193) J-K	1205 (880)	2085 (355)	–	2440 (185)	–	2625.x. (156)	–	–	–	–	–	–	–	–	2781 (47)	2828
Marathon Glenhaughton No. 1 GE1814	15 (260)	275 (1740)	2015 (1000)	3015 (3670)	6685 (735)	–	7420.x. (1525)	–	–	–	–	–	8945 (370)	–	–	9315 (103)	9418
AAO Glentulloch No. 1 GE 1507	11 (1564) J-K	–	–	1575 (110)	1685 (135)	–	–	1820 (840)	–	–	–	–	–	2660 (1345)	–	4005 (83)	4088

TABLE 5. SEQUENCES PENETRATED IN PETROLEUM EXPLORATION WELLS (continued)

						Blenheim Subgroup			Gebbie Subgroup			Tiverton Subgroup					
Well Name and Ground Elevation (ft) / Rock Units	Post Triassic	Moolayember Fm	Clematis Sst	Rewan Fm	Blackwater Gp	Black Alley Sh	German Cr Coal Measures	Peawaddy Fm	Catherine Sst	Ingelara Fm	Aldebaran Sst	Cattle Cr Fm	Buffel Fm & equivalents	Reids Dome Beds	Camboon Andesite	Pre-Permian	Total Depth (ft)
OSL2 (Hutton Creek) GE1510	7 (333) J-K	–	–	–	–	–	340·x· (550)	–	–	–	–	–	–	890 (3798)	–	–	4688
AFO Inderi No. 1 GE710	10 (90) Cz				100 (90)	190 (100)	290 (640)	930 (740)	1670 (20)	1690 (180)	1870 (2140)	4010 (1360)	–	5370 (63)	–	–	5433
AAO Kildare No. 1 GE1590	14 (1610) J-K	–	–	1624 (786)	2410 (320)	2730 (260)	–	2990 (770)	–	–	–	–	–	3760 (1964)	–	–	5724
AAO Kildare No. 2 GE1613	14 (1612) J-K	–	–	1626 (179)	1805 (355)	2160 (289)	–	2449 (696)	–	–	–	–	–	3145 (4522)	–	–	7667
AAO Killoran No. 1 GE1697	10 (1890) J-K						1900·x· (405)	–	–	–	–	–	–	–	–	2305 (44)	2349
SQD Morella No. 1 RT965	–	–	–	0 (900)	900 (510)	1410 (470)	–	1880 (820)	–	–	2700 (1165)	3865 (495)	–	4360 (274)	–	–	4634
AP Motley No. 1 GE769	–	–	–	13 (887)	900 (820)	1730 (340)	–	2070 (1150)	–	–	3220 (440)	3660 (527)	–	–	–	–	4187
AAO Purbrook No. 1 GE783	–	–	–	10 (660)	670 (820)	1490 (345)	–	1835 (1200)	–	–	3035 (365)	3400 (1350)	–	–	–	4750 (199)	4949
AP Purbrook South No. 1 GE817	–	–	–	13 (2187)	2200 (820)	3020 (290)	–	3310 (1150)	–	–	4460 (406)	4866 (716)	–	–	–	–	5582
AOE Reids Dome No. 1 GE969	–	–	–	–	–	–	–	–	–	–	–	10 (1685)	–	1695 (7365)	–	–	9060
AFO Rolleston No. 1 GE683	9 (66)Cz	–	–	75 (625)	700 (685)	1385 (465)	–	1850 (1090)	2940 (80)	3020 (105)	3125 (1475)	4600 (2530)	–	7130 (2378)	–	–	9508
AFO Struan No. 1 GE650	–	–	–	15 (615)	630 (870)	1500 (120)	1620 (510)	2130 (930)	3060 (110)	3170 (170)	3340 (1660)	5000 (920)	–	5920 (114)	–	–	6034
AFO Sunlight No. 1 GE835	–	–	–	15 (1280)	1295 (985)	2280 (260)	2540 (330)	2870 (1060)	3930 (12)	3942 (43)	3985 (468)	4453 (409)	4862 (91)	–	–	4953 (47)	5000
Planet Tooloombilla No. 1 GE1358	9 (1511) J-K	1520 (208)	–	–	–	–	–	–	–	–	–	–				1748 (2) (Granite)	1750
Planet Warrinilla No. 1 GE1005	16 (74)Cz	–	–	90 (1440)	1530 (440)	1970 (505)	–	2475 (805)	–	–	3280 (395)	3675 (1035)	–	4710 (1991)	–	–	6701

TABLE 5. SEQUENCES PENETRATED IN PETROLEUM EXPLORATION WELLS (continued)

Well Name and Ground Elevation (ft) / Rock Units	Post-Triassic	Moolayember Fm	Clematis Sst	Rewan Fm	Blenheim Subgroup: Blackwater Gp	Blenheim Subgroup: Black Alley Sh	Blenheim Subgroup: German Cr Coal Measures	Blenheim Subgroup: Peawaddy Fm	Gebbie Subgroup: Catherine Sst	Gebbie Subgroup: Ingelara Fm	Gebbie Subgroup: Aldebaran Sst	Tiverton Subgroup: Cattle Cr Fm	Tiverton Subgroup: Buffel Fm & equivalents	Reids Dome Beds	Camboon Andesite	Pre-Permian	Total Depth (ft)
Planet Warrinilla N. No. 1 GE1020	16 (39)Cz	–	–	55 (1005)	2060 (410)	2470 (475)	–	2945 (780)	3725 (125)	3850 (160)	4010 (1635)	5645 (1000)	–	6645 (234)	–	–	6879
Planet Warrong No. 1 GE2043	9 (506) J-K	515 (990)	1505 (315)	1820 (240)	2060 (75)	–	2135.x. (650)	–	–	–	–	–	–	–	–	2785 (789)	3574
AAO Westgrove No. 1 GE1702	13 (697)	–	–	710 (940)	1650 (350)	2000 (270)	–	2270 (810)	–	–	3080 (530)	3610 (520)	–	4130 (2312)	–	–	6442
AAO Westgrove No. 3 GE1719	13 (749)	–	–	762 (631)	1393 (327)	1720 (230)	–	1950 (670)	–	–	2620 (730)	3350 (226)	–	3576 (9057)	–	–	12663
AFO Yandina No. 1 GE660	15 (205)T	–	–	–	220 (190)	410 (190)	600 (790)	1390 (680)	2070 (30)	2100 (190)	2290 (268)	–	–	–	–	–	2558

* Depth from RT or KB to formation top
+ Formation thickness
.x. Undifferentiated Blenheim Subgroup
o Undifferentiated Catherine Sst and Ingelara Fm

TABLE 6. ROCK UNITS OF THE TIVERTON SUBGROUP

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Sirius Formation (Pls)	Stanleigh Fm, Staircase Sst, and Sirius Fm crop out in parallel elongate belts around N-trending Springsure Anticline, from 40 km N to 48 km SSE of Springsure in Springsure and Emerald Sheet areas. Formations difficult to distinguish W of Emerald where they are mapped as Tiverton Subgp	Staircase Cr just S of Springsure-Rolleston road (Webb, 1956; Mollan et al., 1969)	Interbedded grey-blue mudstone, grey to buff siltstone containing flakes and encrustations of gypsum and jarosite, and soft brown poorly bedded argillaceous lithic sandstone. 105 m thick in type area; thins to N and S	Three formations form conformable sequence; Sirius/Staircase contact sharp, Staircase/Stanleigh contact gradational. Sequence grades to E and S into Cattle Cr Fm with reduction in proportion of sandstone. Stanleigh Fm transitionally overlies Orion Fm at top of Reids Dome Beds. Sequence folded into elongate N-trending Springsure Anticline	L. Permian marine fossils (Fauna II)
Staircase Sandstone (Plt)	As for Sirius Fm above	Type section along Springsure-Rolleston road near Staircase Cr (Reid, 1930a; Mollan et al., 1969)	Mainly cross-bedded quartzose sandstone containing some lithic grains and feldspar in type area; to S, sandstone better sorted and more mature; to N and S contains interbeds of siltstone and mudstone. 210 m thick in type area; thins to 126 m in N	As for Sirius Fm above	Cross-bedding azimuths suggest W source. Rare marine fossils; some casts of logs and plants
Stanleigh Formation (Plh)	As for Sirius Fm above	Near Stanleigh homestead; type section in Orion Cr 8 km N of homestead, Springsure Sheet area (Phillips, *in* Hill & Denmead, 1960; Mollan et al., 1969)	Upper unit: dark grey to dark blue poorly bedded carbonaceous mudstone and siltstone, locally micaceous with gypsum and jarosite along bedding planes and joints; some beds contain ferruginous accretions containing pebbles and fossil shells Middle unit (Riverstone Sst Mbr: Power, 1966): cross-bedded pebbly lithic sublabile sandstone with minor tuff, feldspar, and biotite, interbedded with mudstone and siltstone as above Lower unit: mudstone and siltstone, as for upper unit; thin sandstone interbeds and bed of coquinitic limestone ('*Eurydesma* limestone) near base in N. Total thickness 438 m in type area	As for Sirius Fm above	Locally abundant L. Permian marine fossils (Fauna II). Rare *Glossopteris*

TABLE 6. ROCK UNITS OF THE TIVERTON SUBGROUP (continued)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Cattle Creek Formation (Plk)	Exposed in core of Reids Dome, Springsure Sheet area; recognized subsurface throughout Denison Trough	Cattle Cr, 53 km SW of Rolleston, and section in AOE 1 (Reids Dome) from surface to 1695 ft (516.6 m) (Hill, 1957; SQD, 1952; Mollan et al., 1969)	Upper part in type area consists of dark grey poorly sorted poorly bedded conglomeratic silty sandstone and mudstone containing scattered large angular boulders, with thin interbeds of limestone and calcareous sandstone; sandstone argillaceous, lithic sublabile, contains mica, carbonaceous material, and lenses and bands of gypsum and jarosite along bedding planes. Complete sequence in AOE 1 consists predominantly of dark grey mudstone, with interbeds of sandstone, calcareous siltstone, and silty limestone. 1685 ft (513.6 m) thick in AOE 1 (Reids Dome)	Generally gently dipping; crops out only along crest of Reids Dome. Transitionally overlies Reids Dome Beds in Denison Trough. To SE and E, basal part replaced by predominantly calcareous unit (Buffel Fm), which unconformably overlies eroded Reids Dome Beds or pre-Permian rocks	Abundant L. Permian marine fossils (Fauna II). Near Top contains 3-m bed of limestone, called '*Eurydesma* limestone' by Reid (1930a), but not equivalent to '*Eurydesma* limestone' at base of Stanleigh Fm
Buffel Formation (Plu)	Exposed in isolated lenses from Cracow to near Banana and S of Biloela; tentatively identified in wells to W	Buffel Hill 8 km S of Cracow (Wass, 1965; Mollan et al., 1971)	Fossiliferous limestone grading laterally and vertically into hard white aphanitic chert or silicified limestone, in places overlain by blue-green hard mudstone with lenses of dark blue-grey calcilutite; volcanolithic pebble conglomerate with grey fossiliferous limestone matrix at base in places; limestone: purple, brown, or white, coarse, and commonly thickbedded. Max of 60 m exposed, but top eroded	Unconformable or disconformable on Camboon Andesite; disconformably overlain by Oxtrack Fm. Mainly dips gently W between Cracow and Banana; preserved in trough of tight syncline near Cracow; more tightly folded S of Banana. Probable equivalent of Buffel Fm included in undifferentiated Back Cr Gp between Nebo and Fitzroy R	Abundant L. Permian marine fossils (Fauna II)
Tiverton Subgroup (undifferentiated) (Plp)	N part of basin from near Nebo to near Collinsville	Narrow strip extending for 20 km NNW from Hazelwood Cr (Malone et al., 1966, 1969)	Upper unit (Cattle Cr Fm equivalent?): grey-blue siltstone and mudstone, roughly laminated with irregular dark mudstone partings, generally hard and closely jointed, some gypsum and rare jarosite; hard calcareous siltstone nodules or accretions up to 2.5 m across, either scattered or in layers; fossiliferous calcareous siltstone near base. 390 m thick Lower unit (Buffel Fm equivalent?): grey medium to fine feldspathic and lithic labile and sublabile sandstone with carbonaceous streaks and laminae in places, interbedded with dark grey-blue laminated to medium-bedded siltstone and mudstone, fossiliferous calcareous siltstone and sandstone, limestone and coquinite; hard volcanolithic sandstone at base. Max thickness 330 m	Conformable or locally disconformable on Lizzie Cr Volc; conformably overlain and overlapped to N by Gebbie Subgp. Dips moderately to steeply SW off Connors Arch; locally indurated, jointed, and sheared. Upper unit very poorly exposed, and apparently locally faulted out in part at N end of type area	Abundant L. Permian marine fossils (Fauna II), mainly in lower unit

TABLE 7. ROCK UNITS OF THE GEBBIE SUBGROUP (Southern part of Bowen Basin)

Rock Unit (map symbol)	Distribution	Type area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Colinlea Sandstone (Plo)	W part of basin. (Fluvial environment. Fig. 12)	Along Central Western Highway in Colinlea Holding (Hill, 1957; SQD, 1952; Mollan et al., 1969)	Fine to medium planar and festoon cross-bedded kaolinitic quartz sandstone with interbeds of thin soft purple siltstone and granule-pebble-cobble conglomerate, mainly near base; clasts in conglomerates include milky quartz, fine sandstone, quartzite, chert, and acid volcanics. Sandstone thick to medium-bedded near base, thin-bedded to laminate near top	Dips gently to S and E off Drummond Basin. Lateral equivalent of middle and top parts of Aldebaran Sst and of Catherine Sst; Ingelara Fm not represented. Unconformable on Reids Dome Beds and pre-Permian units; conformably overlain by Peawaddy Fm	Plant fossils including *Vertebraria*; ferruginized logs in basal conglomerate. Palynological data support correlation with Aldebaran Sst and Catherine Sst. Mainly fluviatile sedimentation
Aldebaran Sandstone (Pll)	Denison Trough; recognized in SW part of basin as far N as Cooroorah	S branch of Aldebaran Cr 40 km SSE of Springsure (Reid, 1930a; Mollan et al., 1969)	Upper member (Freitag Fm: Power, 1966): quartzose sandstone, rarely conglomeratic and micaceous, thinly interbedded with fissile siltstone; worm tubes and oscillation ripple marks common. 45-75 m thick Middle member: conglomeratic quartzose sandstone with beds of conglomerate containing pebbles as for Colinlea Sst conglomerate; truncated planar cross-bedding, festoon cross-bedding, and scour channels common. 90-240 m thick Lower member: fine to medium feldspathic quartzose sandstone containing pebbles of fine sandstone, siltstone, and milky quartz, interbedded with carbonaceous mudstone and rare thin coal seams. 90-330 m thick	Dips at up to 40° on flanks of Springsure and Consuelo Anticlines and Reids Dome; gently dipping elsewhere. Lower member transitional on Tiverton Subgp; separated by local erosional unconformity from middle member. Upper member conformable on middle member in outcrop; Power (1966) suggests Upper member overlies major erosional unconformity in subsurface to E and S; Ingelara Fm transitionally succeeds upper member	L. Permian marine fossils (Fauna III) in upper member. Mainly deposited in deltaic, rarely fluvial environment; member boundaries mark major regression and transgression. Irregular lateral thickness variations suggest several distributaries supplied sediment to delta
Ingelara Formation (Pli)	Denison Trough; subsurface distribution as for Aldebaran Sst	5 km NNW of Ingelara homestead (Raggatt & Fletcher, 1937; Hill, 1957; Mollan et al., 1969)	Poorly sorted, poorly bedded, carbonaceous, pyritic, conglomeratic sandy siltstone and mudstone, with lenses and bands of gypsum and jarosite and large calcareous fossiliferous concretions. Large angular boulders, similar to those in Cattle Cr Fm, around S nose of Reids Dome. 36 m thick in type area; max of 160 m 65 km to N	Dip up to 35° on flanks of Springsure and Consuelo Anticlines and Reids Dome. Transitionally overlies Aldebaran Sst; conformably, in places transitionally, overlain by Catherine Sst; S of S nose of Reids Dome disconformably overlain by Peawaddy Fm	L. Permian marine fossils of Fauna III, possibly of same age as fauna in middle unit of Gebbie Subgp in N part of basin. Deposited in rapidly subsiding marine basin with little sorting
Catherine Sandstone (Plf)	Denison Trough as far S as S nose of Reids Dome; in subsurface: E to Rolleston 1 and N to Comet 1	Mt Catherine area (Reid, 1930a; Mollan et al., 1969)	Cross-bedded fine to medium well sorted quartzose to sublabile sandstone, containing up to 15% potash feldspar in places, interbedded with thin intervals of poorly exposed mudstone. 80 m thick in type area; max 135 m	Lateral equivalent to upper part of Colinlea Sst. Disconformably overlain and overlapped by Peawaddy Fm; wedges out because of non-deposition or erosion beneath Peawaddy Fm to S and E	L. Permian marine fossils (Fauna III). Deposited in paralic and shallow marine environments during last stage of subsidence of Denison Trough

TABLE 8. ROCK UNITS OF THE GEBBIE SUBGROUP (Northern part of Bowen Basin)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Gebbie Subgroup (Plb)	Long strip along W flank of Connors Arch and in large anticline in Folded Zone, 55 km N of Bluff	Gebbie Cr 22 km SSE of Collinsville (Malone et al., 1966, 1969)	Upper unit: fine to medium sublabile sandstone, interbedded with grey-blue siltstone, dark carbonaceous mudstone, and rare ripple-marked quartzose sandstone; scattered pebbles, conglomerate beds, and calcareous fossiliferous layers in places. 120 m thick; thins to 69 m S of type area Middle unit: interbedded grey-blue siltstone and quartzose to sublabile sandstone in type area; mainly blue-grey coarse siltstone grading to semifriable silty sandstone to S. 120-150 m thick Lower unit: quartzose to sublabile sandstone, micaceous, feldspathic, carbonaceous in part, with interbeds of grey-blue siltstone; at base 30 m of grey-blue coarse micaceous, locally carbonaceous, siltstone with worm tubes and calcareous fossiliferous beds, grading up into silty sandstone and quartzose sandstone. 150 m thick in type area; thickens to 225 m to S	Moderate to steep SW dips along flank of Connors Arch. Moderately tight asymmetric large-amplitude folds in Folded Zone. Sequence exposed in Folded Zone consists of adjacent parts of lower and middle units. Three units have transitional contacts. Gebbie Subgp disconformably overlies, and to N overlaps, Tiverton Subgp. Disconformably overlain in type area and possibly conformably overlain S of type area by Blenheim Subgp. Gebbie Subgp, above middle of lower unit, dominantly marine lateral equivalent of Collinsville Coal Measures	L. Permian marine fossils of Fauna III abundant in basal 30 m and sporadically distributed throughout rest of subgp. Lower unit includes Wall Sst Mbr (Reid, 1924-25). Middle unit contains same fauna as Glendoo Sst Mbr (Webb & Crapp, 1960) of Collinsville Coal Measures. Deposited in paralic environment; Wall Sst Mbr may have been deposited as sand bar
Collinsville Coal Measures (Plc)	Broad belt extending 65 km W and S from Collinsville	Collinsville area (Reid, 1924; Webb & Crapp, 1960; Malone et al., 1966)	Mainly grey very fine to medium micaceous sandstone, conglomeratic in places, interbedded with dark grey siltstone, mudstone, carbonaceous shale, and coal seams; poorly sorted polymictic pebble-cobble conglomerate at base; Glendoo Sst Mbr, marine sandstone as above, fossiliferous and calcareous in places, with thin siltstone member or coal measures; sequence includes 11 named coal seams including 2 about 6 m thick. 255 m thick in type area	Dips gently S and E; faulted E margin near Collinsville; cut by minor faults to W. Disconformably overlies and overlaps Lizzie Cr Volc. Overlapped SW of Collinsville by Blenheim Subgp. Glendoo Sst Mbr correlates with part of middle unit of Gebbie Subgp in type area	L. Permian marine fossils (Fauna III) in Glendoo Sst Mbr and abundant *Glossopteris* flora above and below. Deposited in swampy, brackish, or freshwater lagoon, with occasional marine transgression

TABLE 9. POSSIBLE EQUIVALENTS OF THE GEBBIE SUBGROUP

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Blair Athol Coal Measures (Pa)	5 small areas centred about 10 km NNW of Clermont	Blair Athol area (Reid, 1936a; Veevers et al., 1964b)	Fine sandstone, dark blue-grey carbonaceous mudstone and shale, coal, fine conglomerate; quartz-pebble conglomerate, locally auriferous, at base in places. Main coal seam 33 m thick. Max thickness 240 m	Depositional dip locally modified by compaction of coal; some minor faulting. Unconformable on irregular basement of Anakie Metamorphics. Coal seams interfinger with sediments near margins of basin	Abundant *Glossopteris* flora; some possibly L. Permian spores. Deposited in isolated small depression near margin of basin
Calen Coal Measures (Ple)	Elongate belt extending 55 km NW from Pioneer R to about 25 km W of Mackay	Calen area (Hill *in* Hill & Denmead, 1960, p. 222; Reid, 1929c; Jensen et al., 1966)	Cross-bedded thick-bedded brown to white coarse well sorted quartzose sandstone, with quartz and quartzite pebble bands; thinly interbedded sandstone, as above, and siltstone grading into soft brown mudstone; thin coal seams. 300 m thick	Folded into elongate basin; dips around margin up to 20°. Some local minor folds. Intruded by many sills and dykes and cut by numerous, mainly NW-trending, faults. Unconformable on Carmila Beds and Lizzie Cr Volc	*Glossopteris* and *Vertebraria.* Possibly deposited in small, partly marine, basin on margin of marine depositional area of Gebbie Subgp

TABLE 10. ROCK UNITS OF THE BLENHEIM SUBGROUP

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Undifferentiated Blenheim Subgroup (Pue)	On W flank of Connors Arch and at N end of Collinsville Shelf. Forms most of sequence exposed around Bundarra Granodiorite	Blenheim Cr 67 km SE of Collinsville (Malone et al., 1966, 1969; Jensen, 1968).	Upper unit: fine to coarse quartzose sandstone, silty, micaceous, calcareous, cross-laminated, abundant worm tubes in places; minor dark micaceous mudstone, 35 m thick Middle unit: dark blue to dark grey micaceous mudstone, grading into shale in places; some calcareous fossiliferous mudstone and coquinite horizons, rare scattered pebbles. 270 m thick Lower unit: coarse grey-blue micaceous carbonaceous mudstone and siltstone interbedded with and grading into fine to coarse silty sublabile sandstone. Sequence calcareous and fossiliferous in places; contains scattered pebbles and angular boulders. Abundant worm tracks in some beds; some beds of conglomeratic coquinitic mudstone and sandstone. About 420 m thick	Dips moderately to steeply SW off Connors Arch; steeply dipping to overturned locally near Blenheim Cr; SW dip interrupted by minor folding in places. Low S dips and minor folds on N end of Collinsville Shelf. Three units form conformable sequence which conformably succeeds Gebbie Subgp. Overlaps Gebbie Subgp to W and rests nonconformably on Bulgonunna Volc and U. Carboniferous intrusions	Abundant early U. Permian marine fossils of Fauna IV. Most fossils found in discrete coquinitic beds, which are usually conglomeratic; bryozoans, crinoid ossicles, and worm tracks much more widespread. Deposited in shallow to moderately deep sea. Sandstone more abundant in W. Lower unit includes Big *Strophalosia* Zone (Reid, 1925)
Undifferentiated Blenheim Subgroup (Pue)	Capella Block and outliers to W	(Veevers et al., 1964b)	Top unit: medium to coarse cross-bedded quartzose to sublabile sandstone, argillaceous in places, alternating with siltstone, locally micaceous and carbonaceous; contains plants, wood, and thin coal seams. (Passage Beds: Reid, 1924-25). Up to 600 m thick; thins to S Lower unit: silty sandstone, siltstone, rare coal, basal conglomerate with boulders of granite and schist, conglomeratic coquinitic *Strophalosia clarkei* bed and pelecypod beds. About 45-60 m thick	Dips gently E. Unconformable on Mt Rankin Beds and Anakie Metamorphics farther S. Overlaps Gebbie Subgp in most places; conformably overlain by Blackwater Gp. 'Passage Beds' lens out to S or are replaced by part of German Cr Coal Measures which overlie lower unit	Abundant marine fossils of Fauna IV in some beds. Top unit contains freshwater sediments with plants, rootlets, and wood. Deposited in partly marine and partly freshwater environment near margin of depositional area. Lower unit deposited in advancing sea
German Creek Coal Measures (Pud)	N part of Comet Ridge; in subsurface, tentatively recognized as far S as Rolleston	German Cr 7 km NE of Emerald (Malone et al., 1969)	Quartz sandstone and sublabile sandstone, cross-bedded, rarely ripple-marked, worm-tracked, micaceous and carbonaceous on cross-laminae; micaceous, carbonaceous siltstone and mudstone; coal; quartz-pebble conglomerate; interbedded sandstone, sandy siltstone, and siltstone. Max thickness 240 m	Gently folded on Comet Ridge and to S; regional E dip on S margin of Capella Block. Conformable on Maria Fm on Comet Ridge and on undifferentiated basal part of Blenheim Subgp to N. Basal part appears to be lateral equivalent of upper sandy part (including Mantuan *Productus* bed) of Peawaddy Fm	Marine fossils of Fauna IV and plant remains in some beds. Possibly deposited in mainly marine deltaic environment

TABLE 10. ROCK UNITS OF THE BLENHEIM SUBGROUP (continued)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Maria Formation (Pum)	Exposed on N part of Comet Ridge	Maria Cr about 48 km ESE of Emerald (Derrington et al., 1959; Malone et al., 1969)	Sandstone and silty sandstone, fine to medium-grained, argillaceous, calcareous, micaceous and carbonaceous; grey and dark grey siltstone and silty mudstone, micaceous, calcareous, locally pyritic; minor thin coal seams. Up to 240 m thick	Gently folded on Comet Ridge. Lateral equivalent of Peawaddy Fm below Mantuan *Productus* bed. Possibly disconformable on Gebbie Subgp	Some marine fossil detritus, but no diagnostic faunas known. Deposited in marine environment
Black Alley Shale (Puc)	Exposed on flanks of Springsure and Consuelo Anticlines and in W part of basin	W branch of Dry Cr, 3 km SE of Black Alley Peak, 64 km SSW of Rolleston (Mollan et al., 1969)	Dark shale and claystone, with 0.3-0.6-m beds of soft green soapy bentonite and several beds of tuff and tuffaceous claystone with glass shards; thin hard ferruginous beds, minor siltstone, rare sandstone. 90-150 m thick; may be thicker in subsurface to SE	Moderately tightly folded in Denison Trough; gently dipping to S in W part of basin. Structurally conformable on Peawaddy Fm; in part lateral equivalent of and in part younger than German Cr Coal Measures	No diagnostic marine fossils. Presence of swarms of acritarchs suggests marine environment. Bentonite produced from volcanic ash by diagenesis in restricted freshwater or marine environment
Peawaddy Formation (Pup)	Exposed on flanks of Springsure and Consuelo Anticlines, and in W part of basin	Peawaddy Cr 64 km SSE of Springsure (Mollan et al., 1964, 1969)	Thinly interbedded and interlaminated micaceous grey siltstone and dark carbonaceous mudstone, with abundant plant debris, local worm burrows, and gypsum and jarosite? on bedding planes; lithic sandstone predominant in upper half of unit; fossiliferous coquinitic siltstone and sandstone of Mantuan *Productus* bed at top in places	Structure as for Black Alley Sh. Basal unit of Blenheim Subgp in SW part of basin. Conformable or disconformable on Gebbie Subgp in Denison Trough, but disconformably overlaps older units to SW	Abundant U. Permian marine fossils of Fauna IV, particularly at top. Probably deposited in marine environment throughout
Banana Formation (Pun)	Exposed on W flank of Auburn Arch from 16 km S of Cracow to near Banana, and on E edge of arch S of Biloela	Banana area (Derrington et al., 1959; Dear et al., 1971)	Grey, dark grey, and olive green mudstone and siltstone; thin beds of feldspatholithic labile sandstone. Local thickness up to 600 m· lenses out to S	Dips W at 10°-30° off W flank of Auburn Arch. Near Banana: involved in faulting and folding which becomes tighter towards E; S of Biloela: very tight folds within fault slices; in north: some shearing and cleavage in sediments. Local mudstone development at top of Blenheim Subgp	U. Permian sediments deposited in environment transitional from marine to freshwater
Flat Top Formation (Puf)		Flat Top Mt, Banana district (Derrington et al., 1959; Dear et al., 1971; Mollan et al., 1971)	Hard buff to blue mudstone grading laterally into buff argillite, interbedded with light grey calcareous lithofeldspathic silty sandstone, locally fine to coarse sandstone, both containing volcanic detritus, and thin beds of hard limestone and coquinite. 540 m thick; thins to 225 m in N	Top formation of Blenheim Subgp in most of Auburn Arch area	U. Permian marine fossils of Fauna IV in a few beds mainly

TABLE 10. ROCK UNITS OF THE BLENHEIM SUBGROUP (continued)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Barfield Formation (Pur)		Barfield homestead, Banana area (Derrington et al., 1959; Dear et al., 1971; Mollan et al., 1971)	Predominantly massive green to dark blue mudstone with interbedded grey and black calcareous concretions and glendonites; some blue-grey calcilutite and grey laminated mudstone, green and brown lithic sandstone and pebbly sandstone; lapilli tuff, agglomerate, andesite, and lithic arenite; includes thick lithic sandstone and interbedded sandstone/siltstone sequences in N. 900 m thick; much thicker between Banana and Biloela	As for Banana Fm and Flat Top Fm above. Dominant formation of Blenheim Subgp in Auburn Arch area, particularly in N. May be mainly lateral equivalent of Boomer Fm	Abundant U. Permian marine fossils of Fauna IV. Fossils and abundant glendonites suggest deposition in cold marine environment
Oxtrack Formation (Puo)		Oxtrack Cr 24 km NNW of Cracow (Derrington et al., 1959; Mollan et al., 1971; Dear et al., 1971)	Fossiliferous brown flaggy limestone grading laterally into calcareous siltstone, silicified limestone, fossiliferous calcareous mudstone grading into coquinite; hard white lithic sandstone interbedded with siltstone. 30-105 m thick	As for Banana Fm and Flat Top Fm above. Basal formation of Blenheim Subgp; disconformably overlies Buffel Fm and Camboon Andesite	Abundant early U. Permian marine fossils of Fauna IV. Deposited in shallow sea
Boomer Formation (Puu)	Discontinuous large outcrops throughout Gogango Overfolded Zone and N to Connors Arch and Strathmuir Synclinorium	Boomer Ra. Type section in Leura Cr 40 km SW of Marlborough (Malone et al., 1969)	Thin to medium interbeds of very fine to medium volcanolithic labile sandstone, dark blue siltstone and dark carbonaceous claystone; sandstone predominates in places, usually in thick beds, but absent elsewhere; in places siltstone contains wisps and balls of dark sandy claystone; locally abundant conglomerate. Max measured thickness 375 m; true thickness possibly 1500 m or more	Very tightly to moderately folded, faulted and cleaved; gentler dipping off SW flank of Connors Arch. Lateral equivalent of Barfield Fm and possibly Flat Top Fm. To E, lateral equivalents are thick and conglomeratic Moah Cr Beds and Dinner Cr Beds (Kirkegaard et al., 1970)	Poorly fossiliferous, but some marine fossils of Fauna IV; lateral equivalents all marine and contain Fauna IV fossils. Boomer Fm probably deposited in early U. Permian sea; only formation of Blenheim Subgp in this area

TABLE 11. PERMIAN ROCK UNITS OF THE EUNGELLA-CRACOW MOBILE BELT

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Rookwood Volcanics (Pr)	Separate blocks of outcrop in Gogango Overfolded Zone and near Goovigen	Along Melaleuca Cr, near Rookwood homestead, about 25 km NE of Duaringa (Malone et al., 1969)	Spilitic pillow lavas; minor agglomerate, volcanic breccia, silicified trachyte, keratophyre; chert, silicified sandstone and mudstone. Est thickness 900 m+	Thick lenses of volcanics generally unfolded; dips SW off flank of Craigilee Anticline. Interfingers with and overlain by Boomer Fm and Moah Cr Beds; unconformable on Youlambie Cgl and U. Carboniferous; rests unconformably on Rannes Beds in places, but elsewhere relationship uncertain	No fossils. U. Permian age based on stratigraphic relationships. Submarine basaltic extrusion possibly related to intrusion of ultrabasic differentiate in Marlborough area
Youlambie Conglomerate (Ply)	Small areas on SW margin of Craigilee Anticline. Main development E of map area	Youlambie Cr in Monto Sheet area (Dear et al., 1971; Malone et al., 1969; Kirkegaard et al., 1970)	Lithic and volcanolithic pebble conglomerate, thinly to thickly interbedded with feldspatholithic labile sandstone and siltstone, laminated cherty siltstone interbedded with sandstone; mudstone; silicified sandstone and siltstone; blue massive or laminated chert; andesite sills and flows. Thickness unknown; very thick to E	Dips SW off Craigilee Anticline and off block of Devonian to Carboniferous (D-Ca) at N end of anticline. Unconformably overlain by Rookwood Volc; in N, faulted? against Rannes Beds but relationship unknown. Unconformable on U. Carboniferous	*Noeggerathiopis hislopi* of L. Permian age; just E of area contains small marine microfauna of early L. Permian age. Local conglomeratic sedimentation in Yarrol Basin associated with local uplifts
Unnamed Lower Permian (Pl)	Quail Is and on mainland to S	(Kirkegaard et al., 1970)	Siltstone with ferruginous concretions, feldspathic sandstone, lithic conglomerate. 4500? m thick	Overlies Neerkol Fm; faulted? against L. Palaeozoic? metamorphics. Possible equivalent of Youlambie Cgl	L. Permian marine fauna

TABLE 12. ROCK UNITS OF THE BLACKWATER GROUP

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Blackwater Group (Puw)		Blackwater area (Malone et al., 1969; Jensen, 1968)	Blackwater area: consists of Rangal Coal Measures, Burngrove Fm, and Fair Hill Fm (see below). 435 m thick. Baralaba-Cracow area: consists of Baralaba Coal Measures and Gyranda Fm (see below). Up to 825 m thick. Elsewhere mapped as undifferentiated (see below)	Structure varies from area to area. Conformable or disconformable on Back Cr Gp; unconformably, disconformably, and conformably overlain by Rewan Fm in different places	Abundant *Glossopteris* flora of Permian to L. Triassic age, usually in particular beds. Permian on stratigraphic position, but may extend into L. Triassic
Undifferentiated (Puw)	N part of basin	(Malone et al., 1964, 1966; Veevers et al., 1964b; Jensen et al., 1966; Jensen, 1968)	Fine to coarse, usually well sorted, grey-green to brown calcareous lithic sandstone; grey and blue siltstone, dark carbonaceous mudstone; brown calcareous sublabile sandstone, sandy calcarenite; tuffaceous lithic sandstone, hematitic in places, tuffaceous siltstone; conglomerate; coal seams, especially near top but minor seams throughout; hard white cherty tuff and chert? Up to 2100 m thick	Moderately tightly folded in Nebo Synclinorium, but dip rarely more than 40°; gentler folding and regional E dips on Collinsville Shelf. Apparently conformable on Back Ck Gp and conformably overlain by Rewan Fm	No marine fossils. Deposited in fluvial, lacustrine, or paludal environments. Predominance of volcanic detritus contrasts with abundance of quartz in underlying Blenheim Subgp in N. Prominent fossil log horizons in places, usually associated with tuff or tuffaceous sediments. Contains probable late U. Permian spores, which are quite different from spore assemblage in overlying Rewan Fm
Undifferentiated (Puw)	Folded Zone	(Malone et al., 1969)	Lithic sandstone, siltstone, mudstone, coal, calcareous and tuffaceous sediments as above; also interbedded and intergrading lithic sandstone and siltstone. About 1200 m thick	Very tightly folded and steeply dipping; folding becomes less intense to W and N. Similar to sequence on Comet Ridge but much thicker. Top and bottom relationships as in N part of basin	As for Puw in N part of basin
Undifferentiated (Puw)	Denison Trough and W part of basin	(Mollan et al., 1969)	Thinly interbedded green, commonly calcareous, lithic sandstone, siltstone, dark carbonaceous mudstone, coal, oil shale, claystone, ferruginous siltstone. 60-90 m thick	Moderately folded in Denison Trough; dips gently S in W part of basin. Structurally conformable on Black Alley Sh, but possibly disconformable	As for Puw in N part of basin
Rangal Coal Measures (Puj)	E flank of Comet Ridge	Deep Cr 10 km SW of Blackwater (Malone et al., 1969)	Mudstone, carbonaceous mudstone, feldspathic and volcanolithic sandstone, calcareous sandstone, carbonaceous shale, coal seams. 210 m thick	Regional dip to E off Comet Ridge at low angles; some minor cross-folds and local folds, and minor faulting. Topmost unit of Blackwater Gp; conformably or disconformably overlain by Rewan Fm	U. Permian to L. Triassic? Probably deposited in paludal environment, less commonly lacustrine or fluvial. Fossil logs in one horizon
Burngrove Formation (Pug)	From 24 km S to 64 km N of Blackwater	Burngrove Cr W of Blackwater (Malone et al., 1969)	Green, yellow, grey, and white cherty mudstone, dark grey, blue, and brown hard siltstone, siliceous and possibly tuffaceous in part; interbedded to interlaminated siltstone and buff fine sandstone; dark grey to black shale, grey labile and calcareous	Structure as for Rangal Coal Measures. Conformable between Rangal Coal Measures above and Fair Hill Fm below	Abundant well preserved plants in thin cherty mudstone beds. Probably deposited in shallow lakes

TABLE 12. ROCK UNITS OF THE BLACKWATER GROUP (continued)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Fair Hill Formation (Pul)	As for above two units; also NW of Comet Ridge	E flank of Comet Ridge N of Blackwater (Malone et al., 1969)	Trough cross-stratified lithic and feldspathic labile sandstone, in places quartz-rich and approaching sublabile sandstone; siltstone, mudstone, interlaminated mudstone and fine sandstone; calcareous sandstone grading into sandy limestone; tuffaceous sandstone, volcanolithic pebble conglomerate, rare thin beds of green chert and white sandstone; minor carbonaceous mudstone; coal. 115-135 m thick	As above, and gently folded on NW flank of Comet Ridge. Basal formation of Blackwater Gp. Conformably overlies German Cr Coal Measures	U. Permian; abundant fossil logs in places. Probably deposited in fluvial environment; rarely paludal or lacustrine
Baralaba Coal Measures (Pul)	Baralaba to Cracow area	Baralaba (Reid, 1944, 1945d; Olgers et al., 1966; Dear et al., 1971; Mollan et al., 1969)	Carbonaceous mudstone and shale; medium to coarse trough cross-stratified feldspatholithic sandstone; minor lithic sublabile sandstone; coal; bands of calcareous sandstone nodules and concretionary ironstone. 210-360 m thick	Dips west at 10°-25° along flank of Auburn Arch with some minor folding and faulting. Tightly folded near Baralaba with dips up to 80° and many faults. Top formation of Blackwater Gp in Baralaba to Cracow area; probably equivalent to Rangal Coal Measures	Abundant *Glossopteris* flora. Probably deposited in part of widespread late Permian paludal environment
Gyranda Formation (Puy)	Baralaba to Cracow area	Back Cr near Cracow (Derrington et al., 1959; Mollan et al., 1969; Dear et al., 1971; Jensen, 1968)	Green trough cross-stratified lithic sandstone, partly tuffaceous; calcareous sandstone; hard thinly laminated green to brown mudstone; volcanolithic pebble conglomerate; upper part consists of hard white and brown fine cherty tuff and minor volcanic breccia. 480 m thick	As for Baralaba Coal Measures above. Conformable on Flat Top Fm. Upper tuffaceous member may be equivalent to Burngrove Fm	Abundant *Glossopteris* flora, particularly in upper member; tuffs from upper member give isotopic age of 240 m.y. (Webb & McDougall, 1967)

TABLE 13. DISTRIBUTION CHART OF PERMIAN SPECIES

	Fauna I	Fauna I? (Stanleigh Formation)	Fauna II	Fauna II (Sirius Shale)	Fauna IIIA	Fauna IIIB	Fauna IIIC	Fauna III (Ingelara and Catherine Formations)	Fauna III (Ingelara equivalent – Folded Zone)	Fauna IV (Oxtrack Formation)	Fauna IV
Pachymyonia cf. *etheridgei*	X										
Notospirifer sp. A	X										
Megadesmus cf. *antiquatus*	X	X									
Eurydesma hobartense	X	X	X								
Astartila cf. *gryphoides*	X	X	X		X	X	?		X[1]		
Warthia sp.	X	X	X		X	X	X	X			X
Aviculopecten sp.	X	X	X								X
Deltopecten limaeformis	X		X								
Chaenomya sp. nov. A	X		X								
Myonia cf. *davidis*	X		X								
Ingelarella profunda	X		X								
Notospirifer hillae plicata	X		X								
Merismopteria sp.	X		X			X					X
Pseudomyalina sp.		X									
Oriocrassatella queenslandica		X									
Megadesmus cf. *noblissimus*		X	X								
Stutchburia cf. *randsi*		X	X								
Cypricardinia? cf. *gregaria*		X	X								
Modiolus sp.		X	X								
Notospirifer extensus		cf	X	cf	X						
Chaenomya sp.		X	X								X
Notospirifer hillae			X								
Pseudosyrinx sp. nov.			X								
Spiriferellina sp.			X								
Keeneia sp.			X								
Terrakea pollex			X								
Taeniothaerus subquadratus			X								
Ingelarella denmeadi			X								
Streptorhynchus sp. nov.			X								
Ptychomphalina sp.			X								
Terrakea or *Cancrinella* sp.			X								
Strophalosia preovalis var. *warwicki*			X								
Strophalosia cf. *preovalis* or *jukesi*			X								
Strophalosia jukesi			X								
Strophalosia brittoni			X								
Taeniothaerus subquadratus var. *acanthophorus*			X								
Trigonotreta or *Pseudosyrinx* sp.			X								
Aviculopecten cf. *leniusculus*			X								
Aviculopecten cf. *comptus*			X								
Aviculopecten cf. *fittoni*			X								
Aviculopecten sp. nov.			X								
Deltopecten squamuliferus			X								
Deltopecten sp.			X								
Astartella sp. nov.			X								
Mourlonia (Mourlonia) sp. nov.			X								
Bembexia sp. nov. A			X								
Taeniothaerus sp.			X								
Schizodus sp. nov. A			X								
Pseudomyalina cf. *mingenewensis*			X								
Streplopteria cf. *englehardti*			X								
Parallelodon sp. nov. A			X								
Trigonotreta sp. A			X								
Gilledia sp. nov.			X								

TABLE 13. DISTRIBUTION CHART OF PERMIAN SPECIES (continued)

	Fauna I	Fauna I? (Stanleigh Formation)	Fauna II	Fauna II (Sirius Shale)	Fauna IIIA	Fauna IIIB	Fauna IIIC	Fauna III (Ingelara and Catherine Formations)	Fauna III (Ingelara equivalent – Folded Zone)	Fauna IV (Oxtrack Formation)	Fauna IV
Streblochondria? sp.			X								
Ingelarella ovata			X	X							
Ingelarella plana			X	X							
Ingelarella plica			X	X							
Cancrinella farleyensis			X	X							
Anidanthus springsurensis			X	X							
Strophalosia preovalis			X	X							
Neospirifer (Grantonia) cf. *hobartensis*			X	X							
Terrakea sp.			X	X	X			X			X
Glyptoleda reidi			cf		X			X			X
Cancrinella sp.			X	X	X						X
Neospirifer sp. A			X	X				X		X	X
Schizodus sp.			X		X						
Glyptoleda buarabae			cf		X			X			
Neospirifer sp.			X			X					X
Streblopteria sp.			X				X	X		X	X
Peruvispira sp.			X					X		X	
Lissochonetes sp.			X					X	X[2]		X
Atomodesma sp.			X								X
Plekonella sp.			X								X
Cancellospirifer sp.			X								X
Aviculopecten tenuicollis			X								X
Palaeosolen? sp.			X								X
Trigonotreta sp.				X							
Atomodesma cf. *mytiloides*					X						
Megadesmus sp. nov.					X						
Wilkingia? sp. nov.					X						
Pseudomonotis sp. nov.					X						
Ingelarella sp.					X						
Chaenomya sp. nov. B					X			X	X[1]		
Stutchburia costata					cf	cf	cf	X			X
Mourlonia (Platyteichum) costatum					X		X	X			
Ingelarella ingelarensis					cf		cf	X	X[2]		X
Pachymyonia sp. nov.					X			cf			
Parallelodon or *Cypricardinia*						X					
Volsellina? sp.						X					
Pelecypoda gen. et sp. nov.						X					
Bembexia sp. nov. B						X			X[2]		
Cypricardinia? sp.						X	X				
Aviculopecten cf. *subquinquelineatus*						X	X				
Schizodus sp. nov. B						X	?				
Notospirifer sp. C						cf	cf	X			
Notospirifer sp. B						?	X				X
Megadesmus sp.						?	X				X
Mourlonia (Walnichollsia)? sp.						X		X			X
Notomya or *Pyramus* sp.						X					X
Phestia sp.						X					X
Notomya? sp. nov.							X				
Astartidae gen. et sp. nov. A							X				
Ingelarella undulosa							X				
Mourlonia (Mourlonopsis) cf. *strzeleckiana*							X				X
Peruvispira sp. nov.							X				X
Stutchburia cuneata							X				X
Stutchburia cf. *compressa*							X				X
Atomodesma exaratum								X			
Elimata sp. nov.								X			
Spiriferellina? sp.								X			
Pseudosyrinx? sp.								X			
Plekonella acuta								X	X[2]		

TABLE 13. DISTRIBUTION CHART OF PERMIAN SPECIES (continued)

	Fauna I	Fauna I? (Stanleigh Formation)	Fauna II	Fauna II (Sirius Shale)	Fauna IIIA	Fauna IIIB	Fauna IIIC	Fauna III (Ingelara and Catherine Formations)	Fauna III (Ingelara equivalent – Folded Zone)	Fauna IV (Oxtrack Formation)	Fauna IV
Parallelodon sp. nov.								X	X[2]		
Conocardium sp.								X	X[2]	X	X
Plagiostoma? sp.								X		X	X
Cancrinella magniplica								X	X[2]	cf	cf
Volsellina? mytiliformis									cf	X	X
Ingelarella mantuanensis								X		X	X
Pyramus? sp.								X			X
Strophalosia sp.								X	X[2]		X
Strophalosia cf. *typica*								X			X
Ingelarella angulata								X	X[1]		X
Anthraconeilo sp.								X			X
Glyptoleda glomerata								X			X
Atomodesma (Aphanaia) sp.									X[2]	X	X
Parallelodon sp. nov. B										X	X
Attenuatella sp.									X[2]		X
Nuculopsis (Nuculopsis) sp.									X[1]		X
Neospirifer sp. B										X	X
Terrakea solida										X	X
Strophalosia clarkei										X	X
Strophalosia clarkei var. *minima*										X	X
Strophalosia ovalis										X	X
Cleiothyridina sp.											X
Thamnopora sp.											X
Cladochonus sp.											X
Calceolispongia sp. nov.											X
Ingelarella cf. *isbelli*											X
Ingelarella magna											X
Ingelarella cf. *magna* or *mantuanensis*											X
Ingelarella havilensis											X
Ingelarella sp.											X
Chaenomya? cf. *carinata*											X
Myonia carinata											X
Myonia cf. *corrugata*											X
Licharewia sp. nov.											X
Mourlonia (Platyteichum) coniforme											X
Mourlonia (Walnichollsia) subcancellata											X
Atomodesma bisulcatum											X
Nuculopsis (Nuculanella) sp.											X
Quadratonucula sp.											X
Pyramus sp.											X
Pseudomonotis? sp.											X
Cyrtorostra? sp.											X
Schizodus sp. nov. C											X
Stachella sp.											X
"Martinia" sp.											X
Notospirifer minutus											X
Streptorhynchus pelicanensis											X
Productidae, gen. et sp. nov.											X
Astartila cf. *cytherea*											X
Astartila sp.											X
Astartidae gen. et. sp. nov. B											X
Aviculopecten sp. A											X
Megadesmus grandis											X
Strophalosia cf. *brittoni* var. *gattoni*											X
"Solemya" edelfeti											X
Trigonotreta sp. B											X

[1] Basal sandstone
[2] Siltstone overlying sandstone

Compiled by H.M. Doyle from species distribution charts in BMR Reports 100, 123, and 142, modified from later collections and other work.

TABLE 14. ROCK UNITS OF THE MIMOSA GROUP

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Moolayember Formation (TRm)	On Redcliffe Tableland; between Carborough Ra and Kerlong Ra; in Mimosa Syncline and to W; strip extending across W part of basin	Along Injune-Rolleston road near Moolayember Cr (Reeves, 1947; Olgers et al., 1966; Mollan et al., 1969, 1971; as Teviot Fm, a synonym of Moolayember Fm: Malone et al., 1964)	Green to brown mudstone and labile, rarely sublabile, sandstone. Beds commonly calcareous; contain green-brown altered biotite? Sandstone consists mainly of fragments of volcanic rock and minor feldspar; finer-grained to W. Thick beds of volcanolithic pebble to cobble conglomerate near base in E; some beds of quartzose sandstone in transition zone from Clematis Sst. Minor carbonaceous shale and fine cherty tuff? Mainly calcareous micaceous lithic sandstone and siltstone in N. Max thickness of 1650 m in Mimosa Syncline; much thinner to N and W	Low S dips in W; dips up to 25° off flanks of Springsure Anticline; generally preserved in synclines, elsewhere dips about 10° or less. Transitional into overlying Clematis Sst, but may be disconformable in places near margin of basin; unconformably overlain by Precipice Sst	Plants, including species of *Dicroidium*, *Thinnfeldia?*, *Sphenopteris*, *Phyllopteris*. Spore assemblage indicates M. to U. Triassic age. Deposited in rapidly subsiding fluvio-lacustrine, probably reducing, environment; presence of acritarchs suggests occasional periods of brackish water
Clematis Sandstone (TRe)	Redcliffe Tableland, Carborough Ra, Kerlong Ra, and Burton Ra; thin ridge to broad range around Mimosa Syncline; S part of Denison Trough and across W part of basin	Gorge of Clematis Cr in Expedition Ra (Jensen, 1926a; Whitehouse, 1955; Olgers et al., 1966; Mollan et al., 1969, 1971; as Carborough Sst, a synonym of Clematis Sst: Malone et al., 1964, 1966; Malone et al., 1969)	Fine to very coarse and pebbly thick-bedded cross-stratified lithic and feldspathic sublabile sandstone and quartzose sandstone, with interbeds of reddish brown micaceous mudstone and grey-white siltstone. Volcanolithic labile sandstone and conglomerate common in SE. Sandstone generally contains large proportion of argillaceous or micaceous matrix. Max thickness of 300 m in Mimosa Syncline, thinner to W; possibly 450 m in Carborough Ra area	Preserved in synclines in N with limbs dipping at up to 15°; dips at up to 15° in Mimosa Syncline and synclines to W and up to 25° off Springsure Anticline; low S dip in W part of basin. Middle unit of Mimosa Gp. Transitional on Rewan Fm in N and in E limb of Mimosa Syncline, but disconformable on or locally overlaps Rewan Fm to S and W	Plants include species of *Dicroidium*, *Cladophlebis*, *Sphenopteris*, and *Neocalamites*. Spore assemblage suggests L. to M. Triassic age. Deposited in slowly subsiding fluvial environment, possibly mainly in river channels rather than floodplains
Rewan Formation (TRr)	Poorly exposed between Clematis Sst and Blackwater Gp throughout most of basin. Also crops out in Folded Zone and on E flank of Comet Ridge	Small tributary of Consuelo Cr 6 km N of Rewan homestead (Mollan et al., 1969, 1971; Olgers et al., 1966; as part of U. Bowen Coal Measures: Malone et al., 1964, 1966; Malone et al., 1969)	Red-brown and green massive mudstone, red ferruginous claystone; green to brown fine to very coarse and pebbly labile and volcanolithic sandstone, commonly calcareous; volcanolithic pebble conglomerate; sublabile sandstone near top in places. Grainsize and proportion of volcanic detritus decreases from E to W and from bottom to top. Coarser-grained or sandy basal unit generally overlain by mudstone unit. Max thickness of 3600 m in Mimosa Syncline, much thinner to W; up to 1050 m in N part of basin	Structure generally similar to that of overlying Clematis Sst. Tightly folded in Folded Zone; dips gently E off Comet Ridge. Basal unit of Mimosa Gp. Disconformable, or in places unconformable, on Blackwater Gp; possibly transitional on Blackwater Gp in N part of basin. May include slight angular unconformity near base in SW	Occasional poorly preserved fossil plants. Contains mainly L. Triassic spore assemblage, though deposition may have started near end of U. Permian. Deposited in rapidly subsiding shallow lacustrine and partly fluvial oxidizing? environment

TABLE 14. ROCK UNITS OF THE MIMOSA GROUP (continued)

Rock Unit (map symbol)	Distribution	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Sagittarius Sandstone Member (TRs)	E flank of Comet Ridge for 32 km S and N of Blackwater	Sagittarius Cr 1.5 km N of Blackwater (Malone et al., 1969)	Green or grey-green fine to medium, rarely coarse and pebbly, festoon-bedded feldspathic and lithic labile sandstone; grey, greenish grey, or light green fine silty sandstone, siltstone, and mudstone; rare carbonaceous mudstone and plant-bearing dark siltstone; thin pebble conglomerate bands; red-brown mudstone interbeds more common near top; shale-pebble conglomerate and thin cone-in-cone limestone lenses near base in places. Up to 450 m thick	Regional dip to E at low angles, but folded into many low-amplitude ripple folds. Basal member of Rewan Fm in Blackwater area. Member readily distinguished from upper part of formation in which red-brown mudstone predominates. May be equivalent to lower part of Rewan Fm in type area. Locally disconformable on Blackwater Gp, but in places may be transitional	No marine faunas or diagnostic floras known. *Conchostrichons* in thin limestone bands. Spore assemblages suggest mainly L. Triassic age, but may be partly U. Permian. Deposited in rapidly subsiding fluvial environment
Brumby Sandstone Member (TRb)	Arcadia Cr area; present but not delineated on flanks of S Springsure Anticline	Brumby Mt, near Arcadia Cr, 65 km NNW of Injune (Mollan et al., 1969, 1971)	Poorly sorted dense tough lustre-mottled very coarse pebbly sandstone with fragments of volcanic rocks and grains of green chert. Generally forms ridges. 4.5-9 m thick	Dips at up to 25° off flanks of Springsure Anticline and at lower angles off Arcadia Anticline. Member near base of Rewan Fm. Locally unconformable on Blackwater Gp or on thin basal sequence of Rewan Fm	Fluvial sedimentation. L. Triassic age based on spore assemblages in adjacent rocks

TABLE 15. ROCK UNITS OF THE GREAT ARTESIAN BASIN SEQUENCE

Rock Unit (map symbol)	Distribution and Topography	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Roma Formation (Klr)	SW corner of map area; subdued topography, mainly covered by Cainozoic sediments	Along Wallumbilla Cr for 19 km S of Wallumbilla township (Day, 1964; Vine et al., 1967)	Grey laminated siltstone and mudstone, weathering yellow-brown; hard thin-bedded nodular calcareous fine sandstone and mudstone, ferruginized in outcrop; gritty, locally glauconitic, sublabile sandstone near base. 60 m thick; thicker to S	Conformable and possibly transitional on Hooray Sst; unconformably overlain by lateritized Tertiary sediments in map area	No fossils known in map area; elsewhere contains marine Aptian macrofauna. Deposited during widespread marine transgression; thin-bedding and fine grainsize suggest mainly low-energy depositional environment
Blythesdale Formation (Klb)	S margin of map area, about 40 km SW of Injune; forms low sand-covered scarps.	Along Blyth Cr in Roma Sheet area (Day, 1964)	White to brown fine to medium porous quartzose sandstone with quartz pebbles and bands of claystone clasts; small-scale cross-bedding, rare ripple marks, numerous worm casts; minor siltstone and mudstone beds containing plant debris in places. 9-24 m thick	Local member (Claravale Sst Mbr, Mollan et al., 1971) of Blythesdale Fm. Possibly disconformable on Orallo Fm. At top of sequence in map area	Unstudied macroflora and microflora. Correlated with units regarded as L. Cretaceous on palynological data. Fluvio-lacustrine or possibly paralic
Orallo Formation (Juo) (= Southlands Formation; Mollan et al., 1971)	S margin of map area, about 40 km SW of Injune; generally low relief	Type section of Southlands Fm: 38 km WSW of Injune	Upper part: thinly bedded mudstone, siltstone, and very fine quartzose to sublabile sandstone, locally calcareous; rare beds of gritty coarse sandstone. Locally, 15-cm ironstone band at top Lower part: thick-bedded cross-bedded, medium and rarely fine-grained, calcareous argillaceous labile to sublabile sandstone, with pebble bands. 120-150 m thick	Conformably overlies Gubberamunda Sst. Laterally equivalent to Orallo Fm plus lower members of Blythesdale Fm in Roma area, and to part of Hooray Sst to W	Unstudied macroflora and microflora. Correlated with units containing U. Jurassic to L. Cretaceous spore assemblages (Evans, 1966b). Fluvial and later lacustrine
Gubberamunda Sandstone (Jug)	SW of Injune near S margin of map area; forms low rises and cuestas	Roma-Injune road from 32-38 km N of Roma (Reeves, 1947; Day, 1964)	Medium to thick-bedded cross-bedded fine to coarse pebbly argillaceous porous quartzose to lithic sublabile sandstone, with abundant plant impressions and clay clasts in some beds; quartz-pebble conglomerate with sandstone matrix as above; minor grey-green thin-bedded to laminated siltstone and claystone. 60-75 m thick	Conformable, probably transitional, on Westbourne Fm. Laterally equivalent to lower part of Hooray Sst to W	U. Jurassic spore assemblage. Large-scale cross bedding and coarse grainsize suggest fluvial environment; possibly derived from S or SE
Hooray Sandstone (J-Kh)	N-trending belt in SW part of map area; forms dissected plateaux with steep scarps and rare cuestas	Hooray Cr 19 km ENE of Tambo (Exon, 1966)	White medium to thick-bedded cross-bedded coarse argillaceous sublabile sandstone containing scattered pebbles, glauconite, and some worm tubes; thick-bedded cross-bedded pebble conglomerate with sandy matrix as above; some beds of feldspathic sublabile and quartzose sandstone, white mudstone, and claystone. 120 m thick	Conformable on Westbourne Fm, but locally basal sands have scoured tops of siltstone units in Westbourne Fm. Contains unconformity of unknown magnitude	No flora or fauna known. Correlated with U. Jurassic to L. Cretaceous units. Possibly fluvial

TABLE 15. ROCK UNITS OF THE GREAT ARTESIAN BASIN SEQUENCE (continued)

Rock Unit (map symbol)	Distribution and Topography	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Westbourne Formation (Juw)	SW corner of map area and W of Injune along S edge of map area; low relief with rare cuestas	From 1279-1651 ft (389.8-503.2 m) in Westbourne 1 (Gerrard, 1964; Exon, 1966)	Grey thin-bedded to laminated carbonaceous, micaceous, and in places calcareous, siltstone and mudstone with ferruginous (after calcite?) discoidal concretions in places; thin to thick-bedded fine to very fine sublabile to rarely quartzose sandstone, calcareous in places, usually interbedded with siltstone; thin beds of hard calcareous siltstone and sandstone. Low-angle cross-bedding and small-scale slumping common, abundant poorly preserved plants. 105-120 m thick in W, up to 300? m in syncline W of Injune	Top formation of Injune Cr Gp. Conformable on Adori Sst in W; or possibly disconformable on Birkhead Fm E of Maranoa Anticline. Recognizable throughout large area in subsurface by high gamma-ray readings on logs	U. Jurassic spores and acritarchs. Probably mainly lacustrine; cross-bedded sandstone units may have been deposited in small deltas; presence of acritarchs and traces of glauconite suggest occasional marine incursions
Adori Sandstone (Ja)	N-trending belt in SW part of map area; forms low cuestas and strike ridges	Adori Hill 35 km ENE of Tambo (Woolley, 1941; Exon, 1966)	Medium to very thick-bedded cross-bedded white argillaceous sublabile sandstone with pebbly sandstone bands, worm casts and tubes, plant impressions, and clay clasts; minor interbeds of thin-bedded grey to buff siltstone and white claystone; some minor erosion surfaces in formation. 60 m thick; lenses out to SE	Middle formation of Injune Cr Gp in W; lenses out to SE near axis of Maranoa Anticline. Conformable on Birkhead Fm	Indeterminate plants only. Conformable between units containing M. Jurassic spore assemblage below and U. Jurassic assemblage above. Possibly fluvial; cross-bed azimuths suggest N or NE provenance
Birkhead Formation (Jmb)	S part of Mimosa Syncline; extends W to Billin Cr and then NNW; mainly low relief with some low cuestas	Along Birkhead Cr near Tambo-Alpha road. Type section from 1880-2244 ft (573.0-684.0 m) in Westbourne 1 (Exon, 1966; Gerrard, 1964)	SW part of area: grey carbonaceous siltstone and mudstone, fine to medium lithic sandstone, thin coal seams, rare thin beds of cone-in-cone limestone (120 m) underlain by medium-grained sublabile sandstone with calcareous concretions, gritty and quartz-rich in places in basal 6 m Injune to Billin Cr area: as above with additional 45 m of fine to coarse cross-bedded labile sandstone (Springbok Sst Mbr: Mollan et al., 1971) at top Mimosa Syncline: poorly exposed alternating mudstone and sandstone, with many coal seams up to 1.5 m thick (90 m), underlain by medium to coarse cross-bedded argillaceous calcareous lithic sublabile to labile sandstone, locally conglomeratic near base. 30-60 m thick	Basal formation of Injune Cr Gp. Conformable or locally disconformable on Hutton Sst. Springbok Sst Mbr of Injune/Billin Cr area may be equivalent of Adori Sst. Increase in proportion of calcite in lower unit and coal in upper unit from W and E probably reflects changes in depositional environment	M. Jurassic microflora; probably Jurassic macroflora. Fluvio-lacustrine changing to lacustrine-paludal in E; mainly fluvial and lacustrine, and rarely paludal, in W

TABLE 15. ROCK UNITS OF THE GREAT ARTESIAN BASIN SEQUENCE (continued)

Rock Unit (map symbol)	Distribution and Topography	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Hutton Sandstone (Jlh)	Broad sinuous belt across S part of map area; forms low sandy plains and rounded hills	Near Hutton Cr 19 km ENE of Injune (Reeves, 1947; Whitehouse, 1955)	Medium-grained poorly sorted cross-bedded feldspathic? argillaceous sublabile sandstone grading up into mainly fine thick-bedded massive well sorted quartzose sandstone; minor beds of siltstone, mudstone, and pebble conglomerate; mudgalls common in sandstone, particularly near base; thin bedded sandstone and mudstone near top. 120-225 m thick	Conformable on Evergreen Fm. Thickest in synclines and thinnest over structural highs where lower sandstone is generally richer in quartz	Plants, logs, and one species of pelecypod in one bed of unknown affinities. Palynological data suggest mainly L. Jurassic age, but may extend into M. Jurassic, Fluviatile? or brackish?; more reworking in upper part
Evergreen Formation (Undifferentiated) (Jle)	Broad sinuous belt across S part of map area to W margin; mainly soil-covered plains and scarps on sandstone members	Type area and section in outcrop and boreholes 40 km NNE of Injune	Fine to medium light grey flaggy micaceous feldspathic? labile to sublabile sandstone grading up into green massive lithic sandstone, locally ripple-marked, cross-bedded, and/or calcareous; thin-bedded and fissile siltstone and mudstone; hard white flaggy micaceous argillite; thin coal seams; thin beds of concretionary limonite; calcareous mudstone. Includes 3 members described below. Max thickness of 168 m in E; 144 m in type area; 120 m in W	Conformable on Precipice Sst; locally overlaps Precipice Sst in E. One member E of Mimosa Syncline and two members to W. To NW, Boxvale Sst Mbr thickens and eventually is sole representative of formation	Rare freshwater? pelecypods, abundant plant remains, spores, and acritarchs, which indicate L. Jurassic age. Acritarchs associated with oolite member and Westgrove Ironstone Mbr. Most of Evergreen Fm deposited in freshwater lake. Lower part of Boxvale Sst Mbr possibly deposited in streams or deltas around W margin of lake Middle and upper parts (Westgrove Ironstone Mbr) and oolite member possibly deposited during short-lived marine incursion. Lensing out of Westgrove Ironstone and oolite member to N suggests easterly connexion to open sea
Oolite Member (Jlo)	Sinuous thin belt along E limb of Mimosa Syncline; low distinct scarps and soil-covered slopes	Informal unit. Best exposures 38 km SW of Cracow	Chamositic mudstone, as in Westgrove Ironstone Mbr, in beds 5 cm-1 m thick; thin-bedded ferruginous sublabile sandstone; grey fissile and massive red-brown ferruginous mudstone; ironstone beds produced by ferruginization of thin-bedded sediments. 6-12 m thick	Member near top of Evergreen Fm in E limb of Mimosa Syncline. Probably equivalent to upper part of Boxvale Sst and Westgrove Ironstone Mbr	

TABLE 15. ROCK UNITS OF THE GREAT ARTESIAN BASIN SEQUENCE (continued)

Rock Unit (map symbol)	Distribution and Topography	Type Area and Main References	Lithology and Thickness	Structure and Relationships	General Remarks
Boxvale Sandstone Member (Jlb)	Broad sinuous belt in SW from W margin to axis of Mimosa Syncline; forms prominent scarps and plateaux	Along Dawson R, N to NE of Injune (Reeves, 1947)	Ripple-marked thin-bedded flaggy and micaceous very fine quartzose sandstone, with worm tubes and interbeds of grey micaceous siltstone, predominant in upper part; thick-bedded cross-bedded poorly sorted argillaceous quartzose sandstone dominant in lower part; middle part includes thinly bedded siltstone, fine sublabile and quartzose sandstone, coal, green labile sandstone, and bedded ironstone (possible altered chamositic mudstone). Max thickness 90 m; lenses out to E	Member in Evergreen Fm, which is conformably overlain by Westgrove Ironstone Mbr. Middle and upper units may be time equivalents of lower part of oolite member. In NW conformable between Precipice Sst and Hutton Sst	
Precipice Sandstone (Jlp)	Wide to thin sinuous belt along margin of Great Artesian Basin and outlier to N near Bluff; forms cliffs, scarps, gorges, buttes, plateaux, and mesas with sandy soil cover	In Precipice Cr and adjacent tributaries of Dawson R (Whitehouse, 1952, 1955)	Thick-bedded cross-bedded poorly sorted quartzose sandstone with muscovite flakes, plant impressions, quartz-pebble bands; very coarse sandstone to fine conglomerate particularly near base; thin-bedded lithic sublabile sandstone, laminated micaceous siltstone and white flaggy argillite, thin coal seams and carbonaceous shale near top in SE; includes more lutite in subsurface to S. Thickness ranges from 30 m in SE to 150 m in NW; thinner on anticlines than in synclines	Unconformable on Permian and Triassic units, angular unconformity in E and centre and disconformity in W; grades up into Evergreen Fm. Outliers to N indicate original depositional area extended well N of present margin of Great Artesian Basin	L. Jurassic spore assemblage in carbonaceous interbeds. Mainly fluviatile; cross-bedding measurements indicate mainly E transport; thinning and local cross-bedding directions suggest depositional area bounded to E
Westgrove Ironstone Member (Jlw)	Crops out in thin sinuous belts between Boxvale Sst and Hutton Sst from W limb of Mimosa Syncline to near W margin of map area; forms low scarps and soil-covered slopes	Type section in shallow boreholes beside Carnarvon Developmental Road, 40 km NNE of Injune (Mollan et al., 1971)	Concretionary ironstone, oolitic in places, chamositic? mudstone, mudstone, siltstone. 9-24 m thick; lenses out to N	Member at top of Evergreen Fm W of Mimosa Syncline	

TABLE 16. IGNEOUS ROCKS

Rock Unit (map symbol)	Distribution and Topography	Lithology and Main References	Geological Age	Isotopic Age* (approx.)	Relationships
(Tb)	Widespread sheets and outliers in SE part of Clermont Stable Block, Denison Trough, N part of Bowen Basin, and Mimosa Syncline; scattered outcrops elsewhere. Forms plateaux and grassy downs	Mainly flood basalts: tholeiitic and alkalic olivine basalt and rare trachyandesite and hawaiite flows; mostly fine-grained, slightly porphyritic, rarely vesicular; remainder vesicular with amygdales of zeolites, calcite, and chalcedony. Plugs, dykes, and rare sills of basalt, gabbro, diorite, olivine teschenite, and analcite basanite. Minor tuff, volcanic conglomerate, and freshwater sediments. (Malone et al., 1964, 1966, 1969; Veevers et al., 1964a,b; Olgers et al., 1966; Jensen et al., 1966; Mollan et al., 1969, 1971)	Tertiary. No accurate stratigraphic control. Some probable Tertiary plants in underlying sediments in places	33-20 m.y. (Probably many separate intrusions and extrusions)	Interbedded with, overlain by, or overlying Tertiary sediments in places. Basalts of Clermont Stable Block and Denison Trough genetically related to Peak Ra Volc, Minerva Volc, and Hoy Basalt. Intrusive into or unconformable on pre-Tertiary rocks
Hoy Basalt (Th)	Scattered plugs NW of Anakie crop out as prominent conical hills; general NNE alignment	Columnar-jointed porphyritic olivine basalt, minor olivine dolerite and gabbro, generally containing inclusions of anorthosite, peridotite, gabbro, pyroxenite, acid plutonic rocks, corundum, spinel, pyroxene, and feldspar. Remnants of associated basalt flows. (Veevers et al., 1964a)	Tertiary		Probably related to flood basalts. Intrudes Retreat Granite, Anakie Metamorphics, and Drummond Gp
(Tv)	Isolated areas in N part of basin, mainly near W margin of Connors Arch and E of arch, and at Cape Hillsborough. Form plateaux with vertical cliffs, high mountainous country, and rounded or conical hills	Mainly acid to intermediate flows, pyroclastics, plugs, and dykes. Fine-grained porphyritic, rarely non-porphyritic, rhyolite with contorted flow laminae, interbedded with rhyolite breccia, tuff, and agglomerate; flow-banded porphyritic trachyte and soda-trachyte flows and sills; dacite flows with columnar jointing in places; sodic microgranite plug; basaltic and andesitic volcanics; welded tuff. Minor shale and sandstone interbedded with pyroclastics at Cape Hillsborough. (Malone et al., 1966; Jensen et al., 1966)	Tertiary spores and dicotyledonous leaves at Cape Hillsborough		Overlie Tertiary basalt and Tertiary sediments. Intrusive into or unconformable on pre-Tertiary rocks
Peak Range Volcanics (Tp)	Peak Ra NE and E of Clermont. Form prominent steep hills and mountains	Trachyte, quartz trachyte, peralkaline rhyolite plugs, dykes and flows in S part of Peak Ra; rhyolite plugs, flows, and dykes, some plugs with pitchstone selvages, rare phonolite plugs in N part of Peak Ra (Mollan, 1965)	Tertiary		Acid to intermediate differentiates of alkali basalt flows of Peak Ra area

*Approximate isotopic ages based on data supplied by A.W. Webb.

TABLE 16. IGNEOUS ROCKS (continued)

Rock Unit (map symbol)	Distribution and Topography	Lithology and Main References	Geological Age	Isotopic Age* (approx.)	Relationships
Minerva Hills Volcanics (Tr)	N of Springsure. Form prominent peaks, ridges, mesas, and rounded hills with relief of up to 240 m	Plugs, domes, and dykes of porphyritic soda-rhyolite and quartz trachyte, flow-banded, autobrecciated, columnar-jointed; intruding but comagmatic with flows of basalt, trachyte, and trachybasalt, basaltic ash, pumice, scoria, acid agglomerate. (Veevers et al., 1964a; Mollan et al., 1969)	Tertiary	28-24 m.y. (Probably several periods of intrusion and extrusion)	Probably acid differentiates of basaltic magma, similar to parent magma of Peak Ra Volc
Tabor Gabbro (Tt)	150 km NW of Injune	Stocks and one sill of teschenitic olivine microgabbro. (Mollan et al., 1971)	Probably Tertiary		Intrudes Hutton Sst
(K/Tv)	On and W of Connors Ra and Broadsound Ra. On ranges: steep-sided dissected plateaux and hills. W of ranges: rugged broken hills, circular or elongate in plan	Fine and even-grained, rarely porphyritic, rhyolite with smooth or contorted flow banding, rhyolite autobreccia, agglomerate, and lapilli tuff; massive porphyritic, locally flow-banded, dacite and trachyte, minor toscanite flows and pyroclastics; includes plugs and dykes of same rock types in places. (Malone et al., 1969)	Cretaceous or Tertiary. Structural deformation and geomorphology suggest they may be pre-Tertiary		Unconformable on or intrusive into Carboniferous Permian and Triassic rocks. Possibly related to Cretaceous or Tertiary (K/Ti) intrusive activity
(Tv) (= K/Tv)	On Cape Conway and islands in NE part of map area. Mainly rugged cliff-bounded islands	Acid to intermediate waterlaid ash-fall tuff and agglomerate, well bedded in places; andesite and rhyolite flows and rhyolite flows; arkosic carbonaceous conglomeratic sediments. Intermediate to acid dykes. (Clarke et al., 1971)	Cretaceous. May include rocks of different ages	112 m.y. (sample from Cape Conway only)	Intruded by granites similar to some giving probable late L. Cretaceous isotopic ages
(K/Ti)	High hill 16 km SW of Baralaba	Massive fine to coarse trachyte stock, some dykes. (Olgers et al., 1966)	Cretaceous or Tertiary	70 m.y.	Intrudes Gyranda Fm
(K/Ti)	Long crescentic ridge 110 km E of Clermont	Medium-grained trachysyenite sill with associated trachyte dykes. (Malone et al., 1969)	Probably as above		Associated dykes intrude Blackwater Gp
(Mi)	Small to medium-sized intrusives near Mackay. Mainly subdued topography, but some of smaller bodies form high rugged hills	Mainly diorite, microdiorite, and microgranodiorite cut by many dark fine-grained dykes; coarse and medium-grained granite; granophyre with dolerite and rhyolite dykes. (Jensen et al., 1966)	May include rocks of several ages		Intrude Permian or Devono-Carboniferous rocks. Overlain by Tertiary volcanics

*Approximate isotopic ages based on data supplied by A.W. Webb.

TABLE 16. IGNEOUS ROCKS (continued)

Rock Unit (map symbol)	Distribution and Topography	Lithology and Main References	Geological Age	Isotopic Age* (approx.)	Relationships
(Ki)	Small intrusion near Cape Hillsborough	Coarse pink alkali granite with flat sheet jointing. (Clarke et al., 1971)	Late L. Cretaceous	110 m.y.	Intrudes Campwyn Beds
(Ti) (= K/Ti)	On some islands in NE part of map area	Massive medium-grained pink or grey granite cut by thick acid dykes and thin irregular basic dykes; flat sheet jointing common. (Clarke et al., 1971)	Probably late L. Cretaceous		Correlated with Cape Hillsborough granite on lithology
(Ki)	Small to medium-sized intrusions in Nebo Synclinorium and N part of Collinsville Shelf. Mainly subdued topography surrounded by high hills of metamorphosed sediments	Plutons up to 9 km across, laccoliths, sills, and dykes; possibly members of differentiated suite; mainly fine-grained porphyritic hornblende granodiorite, alkali granite, microgranodiorite, syenite, leucodiorite, leucocratic anorthite gabbro, and dolerite dykes. (Malone et al., 1964, 1966)	Early L. Cretaceous. Probably intruded during folding of Nebo Synclinorium	130-120 m.y. (Probably more than one intrusive event)	One body intrudes Carborough Sst; others intrude U. Permian Blackwater Gp. Generally concordant; low-grade but extensive contact metamorphism
Mount Barker Granodiorite (Kgm)	83 km W of Mackay. Mainly forms upland valley; some high hills capped by metamorphics	N-trending biotite-hornblende granodiorite; some high-grade contact metamorphic rocks preserved on top of hill of granodiorite in one place. (Malone et al., 1964; Isbell, 1955)	Early L. Cretaceous	125 m.y.	Intrudes Lizzie Cr Volc and Connors Volc. Probably related to Cretaceous intrusives (Ki) of Nebo Synclinorium
Bundarra Granodiorite (Kgb)	130 km NE of Clermont. Occupies area of low relief surrounded by hills of metamorphosed sediments	Leucocratic granodiorite grading into alkali granite and syenite with increase of hornblende. (Malone et al., 1964, 1969; Veevers et al., 1964b; Jensen et al., 1966)	Early L. Cretaceous		Occupies core of dome in Back Cr Gp and Blackwater Gp. Correlated with and possibly genetically related to Cretaceous intrusives (Ki) of 130-120 m.y. age
(P-Mi)	13 km SE of Collinsville	Small hornblende granodiorite to diorite stock intruding Lizzie Cr Volc. (Malone et al., 1966)	Post-L. Permian		Probably related to early L. Cretaceous intrusions
(P-Mi)	Several small intrusions between Broad Sound and Mackenzie R and Fitzroy R	Gabbro stocks intruding serpentinite; gabbro stocks and sill intruding Rookwood Volc and Rannes Beds; diorite intruding Back Cr Gp; granite stocks intruding L. Palaeozoic? metamorphics. (Malone et al., 1969)	Permian or younger	240 m.y. (sample from one intrusion only; age of recrystallization, probably)	Probably mainly related to U. Permian intrusive activity; some may be younger
(C-Mi)	29 km NE of St Lawrence	4 small intrusions ranging from adamellite to granodiorite; probably intrude Carmila Beds. (Malone et al., 1969)	Permian? or younger		Lithologically like L. Cretaceous part of Urannah Complex

*Approximate isotopic ages based on data supplied by A.W. Webb.

TABLE 16. IGNEOUS ROCKS (continued)

Rock Unit (map symbol)	Distribution and Topography	Lithology and Main References	Geological Age	Isotopic Age* (approx.)	Relationships
(C-Mi)	In Connors Ra and Broadsound Ra	Granodiorite, adamellite, alkali granite, granite, monzonite, gabbro; trachyte and dolerite dykes; some intrusions are complex, others consist of one rock type. All intrude Connors Volcanics. (Malone et al., 1969)	Carboniferous to Mesozoic	305 m.y. (sample from one intrusion only; possibly includes other ages of intrusion)	Similar to and probably connected with Urannah Complex; probably includes intrusions of similar ages
(C-Mi)	East of N-flowing Fitzroy R	Large adamellite stock intruding Carboniferous and older sediments	Post-Carboniferous		
(C-Mi)	32 km S of Marlborough	Isolated granodiorite which may be connected with large Permian intrusions to E. (Malone et al., 1969; Kirkegaard et al., 1970)	Unknown		Possibly emplaced during extensive U. Permian period of intrusive activity
(C-Mi)	Poorly exposed area E of Broad Sound	Acid plutonic rocks probably related to Polygon Granite to E. (Kirkegaard et al., 1970)	Unknown		
Urannah Complex (C-Mr)	Occupies bulk of Connors Arch from N boundary of map area to lat 22° S. Varied topography mainly rugged, with many upland valleys	Fine to very coarse massive or foliated to gneissic, locally porphyritic and/or xenolithic, diorite; adamellite and granodiorite; large amphibolite xenoliths in diorite and granodiorite; porphyritic, graphic, and leucocratic granite and pegmatite, aplite dykes; dacite, acid porphyry dykes; stocks up to 1.5 km across of gabbro grading into hornblendite; green porphyritic andesite and microdiorite dykes up to 6 m across; basalt and dolerite dykes. (Malone et al., 1964, 1966; Jensen et al., 1966)	Ranges from Carboniferous or older? to Cretaceous	311-290 m.y. (see text). Probably includes younger intrusions	Complex probably mainly Carboniferous, but some of plutonic rocks and most of dykes younger. Oldest rocks intrude Connors Volc
(C-Mr)	Not delineated within complex	Hornblende-biotite adamellite (see Thunderbold Granite, Paine et al., 1970)	L. Permian	265 m.y.	Probably discrete bodies within complex
		Hornblende-biotite adamellite and granodiorite, microgranite. (In part Hecate Granite, see Paine et al., 1970)	L. Cretaceous	125 m.y.	Probably discrete bodies within complex
Auburn Complex (C-Ma)	Core of Auburn Arch in SE part of map area. Poorly lateritized in places	Fine to medium-grained granodiorite, locally porphyritic, microgranodiorite, minor diorite and monzonite; dykes of dacite, andesite, and aplite. (Mollan et al., 1971)	Mainly Carboniferous in map area	311 m.y.	Includes intrusives of U. Permian age E of map area. Oldest rocks intrude pre-Permian part of Camboon Andesite
(C-Rv)	SW of Rannes	Quartz porphyry, rhyolite, aplite.	Unknown		Mainly intrusive
	E of Theodore	Part of pre-Permian Camboon Andesite	Carboniferous or older		

*Approximate isotopic ages based on data supplied by A.W. Webb.

TABLE 16. IGNEOUS ROCKS (continued)

Rock Unit (map symbol)	Distribution and Topography	Lithology and Main References	Geological Age	Isotopic Age* (approx.)	Relationships
(Pui)**	Around Marlborough	Biotite adamellite and granodiorite with basic xènoliths	U. Permian	235 m.y.	Intrudes serpentinite (Pzs) and metamorphics (Pzl)
(Pui)**	N of Marlborough	Diorite, quartz diorite, microdiorite, gabbro, hornblende gabbro, granite	U. Permian	248-240 m.y.	Intrudes Carmila Beds; basic intrusion followed by more acid intrusion
(Pui)**	72 km S of Marlborough	Adamellite, minor diorite	U. Permian	240 m.y.	Intrudes Rookwood Volc
(Pzs)	Large area around Marlborough. High rugged topography	Massive serpentinite, schistose near fault contacts, contains blocks of microdioite. (Malone et al., 1969; Kirkegaard et al., 1970)	Permian		Intrudes metamorphics (Pzl) and L. Permian sediments E of map area. Intruded by U. Permian plutonic rocks
(Plx)	W to SW of Eungella. High prominent rounded ridges	Diorite, microdiorite, gabbro, and microgabbro sills or laccoliths. (Malone et al., 1964)	L. Permian		Intruded into and possibly intrusive equivalents of Lizzie Cr Volc
(Ci)	In NW part of map area. Mainly occupy valleys	Granite, granodiorite, adamellite, xenolithic in places, cut by aplite and other fine-grained acid dykes. (Malone et al., 1966; Paine et al., 1970)	U. Carboniferous	285 m.y.	Intrudes Bulgonunna Volc and unconformably overlain by Lizzie Cr Volc
(D/Ci)	In NW part of map area, near lat 21°S	Adamellite, biotite-hornblende adamellite and granodiorite, hornblende granodiorite and tonalite; diorite; jointed, faulted, xenolithic, contain many large roof pendants of contact metamorphosed sediments. (Malone et al., 1964, 1966; Paine et al., 1970)	Devonian or Carboniferous	330; 295-290 m.y. (see text)	Intrudes Ukalunda Beds; may be unconformable beneath Drummond Basin sequence
Retreat Granite (Dgr)	Large area NE of Emerald. Mainly subdued topography	Granodiorite to adamellite, minor granite and monzonite; a little gabbro, diorite, quartz diorite, andesite, and tonalite. (Veevers et al., 1964a,b)	Devonian	365 m.y.	Intrudes Anakie Metamorphics. Unconformably overlain by Silver Hills Volc
(Pzg)	Small area 45 km W of Springsure	Poorly exposed granite. (Mollan, et al., 1969)		450 m.y.	Intrudes? Anakie Metamorphics
(Pzr)	Near Maranoa R 100 km NW of Injune	Sheared diallage-rich gabbro cut by tremolite and chlorite veins; associated with tremolite and chlorite rock. (Mollan et al., 1971)	Ordovician or older		Unconformably overlain by Precipice Sst
Ravenswood Granodiorite (Pzi)	NW corner of map area	Hornblende-biotite granodiorite, adamellite, microgranodiorite, some microgranite. (Paine et al., 1970)	Silurian		Intrudes Mt Windsor Volc. Part of N basement to Drummond Basin

* Approximate isotopic ages based on data supplied by A.W. Webb.

**These intrusions are related to extensive U. Permian igneous activity mainly centred to E and SE of map area (Malone et al., 1969; Kirkegaard et al., 1970).

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SOLID GEOLOGY
BOWEN BASIN
QUEENSLAND
1972

PLATE 1

Scale 1 : 1,000,000

10 0 10 20 30 40 50 60 80 KILOMETRES

10 0 10 20 30 40 50 MILES

REFERENCE

Quaternary, some Tertiary sediments and volcanics omitted

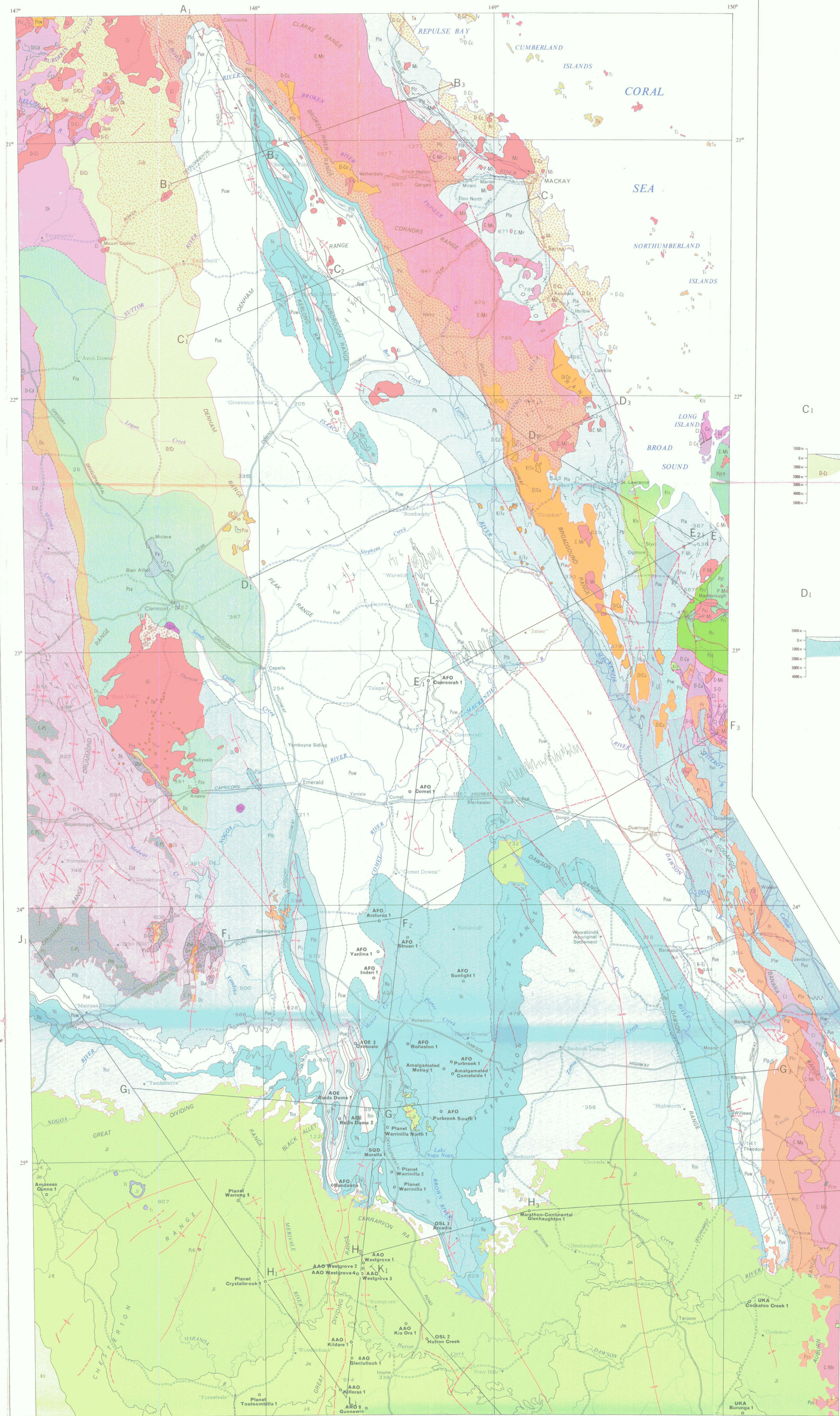
CAINOZOIC	TERTIARY		Ta	Claystone, siltstone, sandstone, pebbly sandstone, conglomerate, sandstone erosion breccia
			Tv	Rhyolite, dacite, trachyte, basalt flows and pyroclastics; minor intrusives
		Peak Range Volcanics	Tp	Rhyolite and trachyte flows and plugs
		Minerva Hills Volcanics	Tr	Alkaline trachyte and rhyolite flows, plugs, domes and dykes
		Hoy Basalt	Th	Olivine basalt plugs, with inclusions
		Tabor Gabbro	Tt	Olivine gabbro sill and stocks
	CRETACEOUS TO TERTIARY		K/Tv	Trachyte, rhyolite, dacite, andesite flows and pyroclastics; plugs and dykes
MESOZOIC	JURASSIC TO LOWER CRETACEOUS (GREAT ARTESIAN BASIN SEQUENCE)	Styx Coal Measures	Kls	Quartz sandstone, conglomerate, siltstone, carbonaceous shale, coal
		Roma Formation	Klr	Siltstone, sublabile sandstone, shale
		Gubberamunda, Orallo and Blythesdale Formations	J/K	Quartzose and sublabile sandstone, conglomerate, siltstone, claystone
		Injune Creek Group	Jm	Sublabile and lithic sandstone, siltstone, mudstone, claystone, thin coal seams, cone-in-cone limestone, concretions
		Precipice, Evergreen and Hutton Formations	Jl	Quartzose and sublabile sandstone, siltstone, mudstone, thin coal seams, conglomerate, chamositic mudstone and oolite
	CARBONIFEROUS TO MESOZOIC	Auburn Complex	C-Ma	Granodiorite; dacite dykes
		Urannah Complex	C-Mr	Granodiorite, granite, diorite, gabbro, amphibolite, rhyolite, porphyry; andesite and basalt dykes
	TRIASSIC	Moolayember Formation	Rm	Labile sandstone, calcareous in part, siltstone, shale, conglomerate
		Clematis Sandstone	Re	Cross-bedded, pebbly quartzose sandstone, red silty mudstone
		Rewan Formation	Rr	Red and green mudstone, green labile and sublabile sandstone, siltstone, volcanic pebble conglomerate
PALAEOZOIC			Pzs	Serpentinite
	PERMIAN (BOWEN BASIN SEQUENCE)	Blackwater Group	Puw	Volcanolithic and feldspathic sandstone, conglomerate, mudstone and carbonaceous mudstone and shale, siliceous siltstone, chert, tuff, coal seams
		Rookwood Volcanics	Pr	Basaltic and spilitic pillow lava and agglomerate chert sediments
		Blair Athol Coal Measures	Pa	Coal, siltstone, sandstone
		Back Creek Group	Pb	Sandstone, siltstone, fossiliferous limestone and calcareous sandstone tuff, volcanolithic sandstone, sheared siltstone, phyllite
		Blenheim Sub-group	Pue	Quartzose sublabile and labile sandstone, conglomerate, siltstone, mudstone, shale, limestone, tuff, andesite, coal seams
		Boomer Formation	Puo	Interbedded volcanolithic sandstone and siltstone, sheared siltstone, conglomerate, mudstone
		Gebbie Sub-group	Plb	Quartzose, and sublabile sandstone, fossiliferous calcareous siltstone and sandstone, conglomerate, coal seams
		Collinsville Coal Measures	Plc	Quartzose and sublabile sandstone; conglomerate, siltstone, carbonaceous shale, coal
		Calen Coal Measures	Ple	Quartzose sandstone, siltstone, claystone, minor coal
		Tiverton Sub-group	Plp	Quartzose and sublabile sandstone, mudstone, siltstone, calcareous sandstone, limestone, coquinite
		Lizzie Creek Volcanics	Plz	Andesite, basalt, trachyte and minor acid flows and pyroclastics, conglomerate, greywacke, tuffaceous sandstone, siltstone
		Carmila Beds	Pla	Conglomerate, lithic greywacke, acid to intermediate flows and crystal and lithic tuffs, siltstone, mudstone
		Reids Dome Beds	Plj	Sandstone, siltstone, mudstone, carbonaceous shale, coal, conglomerate
	LOWER PERMIAN AND OLDER	Rannes Beds	Plw	Shale, siltstone, limestone, sheared siltstone, phyllite, slate, labile sandstone, lenses of acid to intermediate volcanics, chert, volcanics
		Camboon Andesite	Pln / Pzn	Andesite, basalt, crystal tuff, tuff, agglomerate, limestone
	CARBONIFEROUS TO PERMIAN	Torsdale Beds	Ct	Lithic sandstone, conglomerate, siltstone, acid and intermediate lava, tuff, agglomerate
		Joe Joe Formation	C-Pj	Lithic conglomerate, lithic sublabile sandstone, siltstone, minor shale
	UPPER CARBONIFEROUS	Bulgonunna Volcanics	Cub	Porphyritic rhyolite and dacite flows, crystal tuff, agglomerate, breccia, welded tuff, lithic sandstone, siltstone
	UPPER DEVONIAN TO LOWER CARBONIFEROUS (DRUMMOND BASIN SEQUENCE)	Drummond Group and Upper Devonian Units	D/Cd	Quartz sandstone, siltstone, claystone, rhyolite flows and agglomerate
		Drummond Group	Cld	Quartzose and lithic sandstone, conglomerate, siltstone, mudstone, shale, tuff, algal and oolitic limestone
		Telemon Formation	Dut	Lithic conglomerate, lithic sandstone, multicoloured tuffaceous siltstone and shale, algal limestone
		Silver Hills Volcanics	Ds	Rhyolite, trachyte, andesite and basic flows and agglomerate; conglomerate, sandstone, shale
		Mt. Rankin Beds	D/Cr	Rhyolite, dacite flows, acid and intermediate pyroclastics, conglomerate, volcano-lithic sandstone, greywacke, siltstone
		Mt. Wyatt Beds	Dom	Lithic sandstone, siltstone, conglomerate
	MIDDLE DEVONIAN TO LOWER PERMIAN (YARROL BASIN SEQUENCE)		D-Ca	Limestone, mudstone, siltstone, sandstone, conglomerate
		Youlambie Conglomerate	Pr / Ply	Conglomerate, lithic and feldspathic sandstone, conglomeratic mudstone, siltstone; acid lava and tuff
		Neerkol Formation	Cu	Calcareous siltstone and sandstone, fossiliferous in part, conglomerate, mudstone
			Cl	Oolitic limestone, siltstone, mudstone, sandstone, chert
		Campwyn Beds	D-Cc	Intermediate, basic and acid volcanics, siltstone, sandstone, conglomerate, limestone
	DEVONIAN TO CARBONIFEROUS	Connors Volcanics	D/Co	Rhyolite, dacite, trachyte, andesite flows and pyroclastics, tuffaceous sandstone and volcanic conglomerate, jointed and quartz-veined
	SILURIAN ? TO DEVONIAN		S-D	Fossiliferous limestone; intermediate to basic flows and pyroclastics; chert
		Ukalunda Beds	Dk	Lithic and quartzose sandstone, shale, conglomerate, silicified limestone, chert, fossiliferous limestone lenses; some metamorphism
		Dunstable Volcanics	Dn	Green andesite flows and pyroclastics, coralline limestone lenses, cherty shale
			Dm	Micaceous siltstone, pebbly sandstone, shale, coralline limestone, volcanics
		Theresa Creek Volcanics	Dt	Andesite, trachyandesite, rhyolite, dacite flows, crystal and lithic tuffs, arkose, lithic greywacke, siltstone
	LOWER TO MIDDLE PALAEOZOIC		Pzm	Metasediments
		Anakie Metamorphics	Pza	Quartz-mica schist, knotted schist, slate quartzite, crystalline limestone, sandstone, abundantly quartz-veined
		Mt. Windsor Volcanics	Pzw	Dacite, rhyolite, some andesite flows and pyroclastics and interbedded labile sediments; minor schist, gneiss and hornfels
			Pzl	Quartz-mica schist, phyllite, amphibolite, talc schist, quartzite, hornfelsed quartz-mica schist, pyroxenite
			i	Intrusive. Age indicated by letter symbol

Geological boundary
Where location of boundaries is approximate, line is broken; where inferred, queried
Structural boundary
Anticline
Syncline
Monocline
Fault

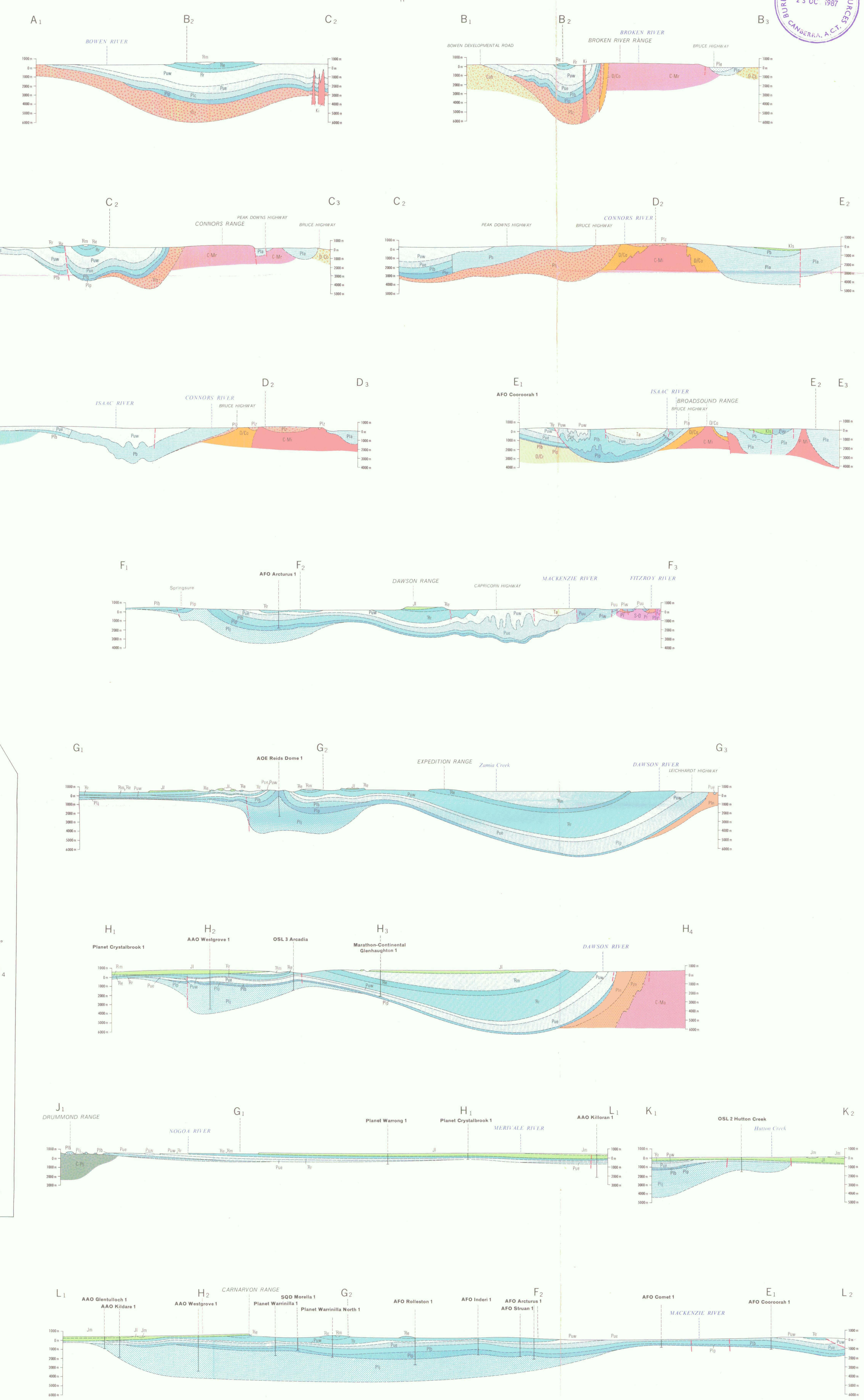
Prevailing strike and dip of strata
Prevailing strike and dip of overturned strata
Trend lines

Oil well

Main road
Road
Railway
Town
Settlement
"Collaroy" Homestead
133 Elevation in metres, approximate



Sections
Scale: $\frac{V}{H} = 4$



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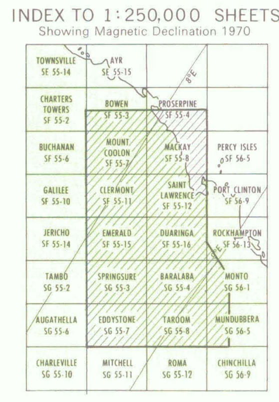
Lambert Conformal Conic Projection

INDEX TO 1:250,000 SHEETS
Showing Magnetic Declination 1970



Geology, to 1965, based on regional mapping of constituent 1 : 250,000 sheet areas, by E. J. Malone, A. R. Jensen, R. G. Mollan, F. Olgers, C. M. Gregory, J. J. Veevers, N. F. Exon, M. A. Randal, D. W. P. Corbett, J. A. J. Smit, A. W. Webb, J. M. Dickins (B.M.R.); A. G. Kirkegaard, V. R. Forbes, J. F. Dear, R.J. Paten, B. A. Coxhead, P. E. Bock, L. G. Cuttler (G.S.Q.); E. A. Webb, C. E. Crapp (Bowen Consolidated Coal Mines Pty Ltd); D. King, P. Goscombe, L. Hansen (Utah Development Co.); S. S. Derrington, K. H. Morgan (Mines Administration Pty Ltd); W. C. White, G. A. Brown (Ampol Exploration Ltd); and P. McKenzie, J. Faulkner (Broken Hill Pty Ltd).
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Cartography by Geological Branch B.M.R.
Drawn by E. Hawkins, I. Chertok.
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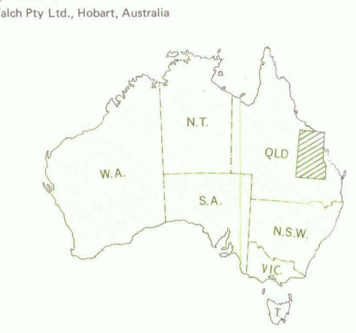

PLATE 2

BLOCK DIAGRAM

BOWEN BASIN

QUEENSLAND

1972

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Hon. R.W. Swartz, M.B.E., E.D. Minister for National Development. Base map compiled by the Bureau of Mineral Resources from air photographs, and information supplied by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force at 1 : 50,000 scale of Mt Coolon and Clermont 1 : 250,000 Sheet areas, and by Adastra Airways Pty Ltd at 1 : 85,000 scale of remainder of sheet; complete vertical coverage

Geology, to 1965, based on regional mapping of constituent 1 : 250,000 sheet areas, by E. J. Malone, A. R. Jensen, R. G. Mollan, F. Olgers, C. M. Gregory, J. J. Veevers, N. F. Exon, M. A. Randal, D. W. P. Corbett, J. A. J. Smit, A. W. Webb, J. M. Dickins (B.M.R.); A. G. Kirkegaard, V. R. Forbes, J. F. Dear, R.J. Paten B. A. Coxhead, P. E. Bock, L. G. Cuttler (G.S.Q.); E. A. Webb, C. E. Crapp (Bowen Consolidated Coal Mines Pty Ltd); D. King, P. Goscombe, L. Hansen (Utah Development Co.); S. S. Derrington, K. H. Morgan (Mines Administration Pty Ltd); W. C. White, G. A. Brown (Ampol Exploration Ltd); and P. McKenzie, J. Faulkner (Broken Hill Pty Ltd).

Cartography by: Geological Branch, B.M.R.

Drawn by E. Hawkins, I. Chertok.

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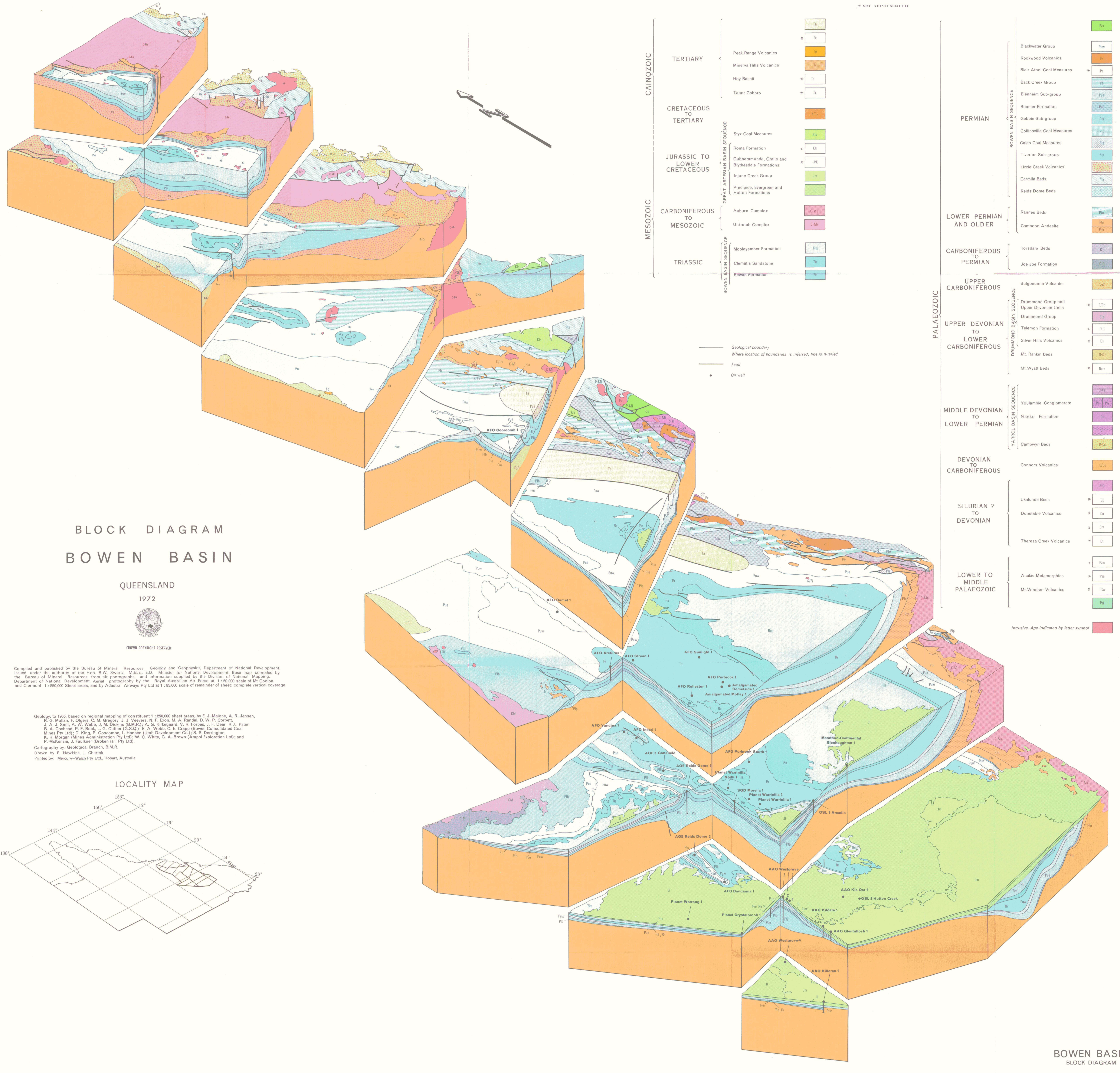
LOCALITY MAP



REFERENCE

* NOT REPRESENTED

CAINOZOIC	TERTIARY				Ta
				*	Tv
			Peak Range Volcanics		Tp
			Minerva Hills Volcanics		Tr
			Hoy Basalt	*	Th
			Tabor Gabbro	*	Tt
	CRETACEOUS TO TERTIARY				K/Tv
MESOZOIC	JURASSIC TO LOWER CRETACEOUS	GREAT ARTESIAN BASIN SEQUENCE	Styx Coal Measures		Kls
			Roma Formation	*	Klr
			Gubberamunda, Orallo and Blythesdale Formations	*	J/K
			Injune Creek Group		Jm
			Precipice, Evergreen and Hutton Formations		Jl
	CARBONIFEROUS TO MESOZOIC		Auburn Complex		C-Ma
			Urannah Complex		C-Mr
	TRIASSIC	BOWEN BASIN SEQUENCE	Moolayember Formation		Rm
			Clematis Sandstone		Re
			Rewan Formation		Rr
PALAEOZOIC	PERMIAN	BOWEN BASIN SEQUENCE			Pzs
			Blackwater Group		Puw
			Rookwood Volcanics		Pr
			Blair Athol Coal Measures	*	Pa
			Back Creek Group		Pb
			Blenheim Sub-group		Pue
			Boomer Formation		Puu
			Gebbie Sub-group		Plb
			Collinsville Coal Measures		Plc
			Calen Coal Measures		Ple
			Tiverton Sub-group		Plp
			Lizzie Creek Volcanics		Plz
			Carmila Beds		Pla
			Reids Dome Beds		Plj
	LOWER PERMIAN AND OLDER		Rannes Beds		Plw
			Camboon Andesite		Pln / Pzn
	CARBONIFEROUS TO PERMIAN		Torsdale Beds		C1
			Joe Joe Formation		C-Pj
	UPPER CARBONIFEROUS		Bulgonunna Volcanics		Cub
	UPPER DEVONIAN TO LOWER CARBONIFEROUS	DRUMMOND BASIN SEQUENCE	Drummond Group and Upper Devonian Units	*	D/Cd
			Drummond Group		Cld
			Telemon Formation	*	Dut
			Silver Hills Volcanics	*	Ds
			Mt. Rankin Beds		D/Cr
			Mt. Wyatt Beds	*	Dum
	MIDDLE DEVONIAN TO LOWER PERMIAN	YARROL BASIN SEQUENCE			D-Ca
			Youlambie Conglomerate		Plj / Ply
			Neerkol Formation		Cu
					Cl
			Campwyn Beds		D-Cc
	DEVONIAN TO CARBONIFEROUS		Connors Volcanics		D/Co
	SILURIAN ? TO DEVONIAN				S-D
			Ukalunda Beds	*	Dk
			Dunstable Volcanics	*	Dn
				*	Dm
			Theresa Creek Volcanics	*	Dt
	LOWER TO MIDDLE PALAEOZOIC			*	Pzm
			Anakie Metamorphics	*	Pza
			Mt. Windsor Volcanics	*	Pzw
					Pzl

Intrusive. Age indicated by letter symbol — i

Geological boundary
Where location of boundaries is inferred, line is queried

Fault

Oil well

BOWEN BASIN
BLOCK DIAGRAM

PLATE 3

TECTONIC UNITS AND STRUCTURAL SUBDIVISIONS
(WITH AEROMAGNETIC AND GRAVITY DATA)

BOWEN BASIN

QUEENSLAND
1972

Scale 1:1,000,000

20 0 20 40 60 80 100 KILOMETRES

20 0 20 40 60 MILES

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Hon. R.W. Swartz, M.B.E., E.D. Minister for National Development. Base map compiled by the Bureau of Mineral Resources from air photographs, and information supplied by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force at 1 : 50,000 scale of Mt Coolon and Clermont 1 : 250,000 Sheet areas, and by Adastra Airways Pty Ltd at 1 : 85,000 scale of remainder of sheet; complete vertical coverage
Lambert Conformal Conic Projection

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Geophysical data from Geophysical Branch B.M.R.
Compiled 1968 by: E. J. Malone
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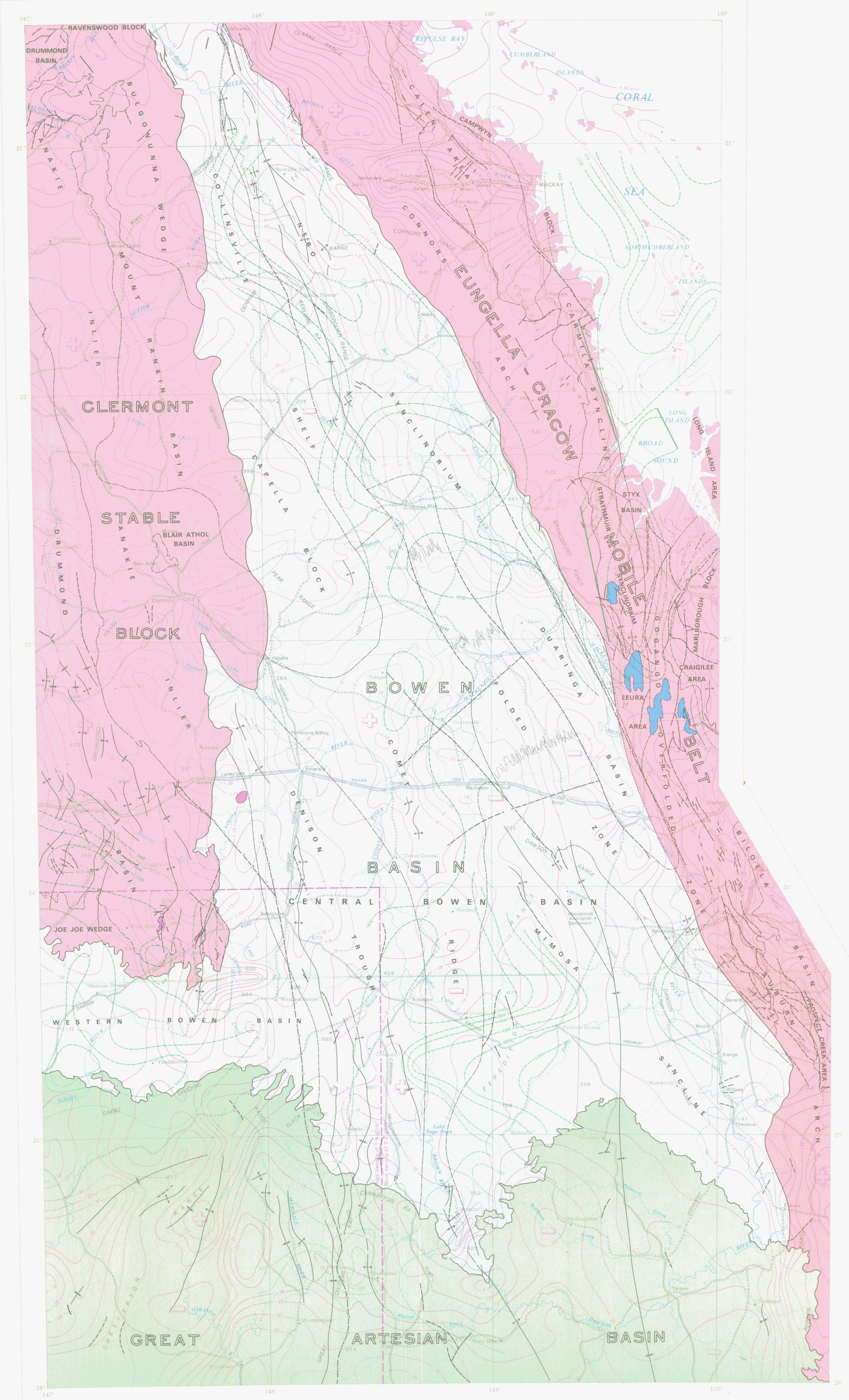
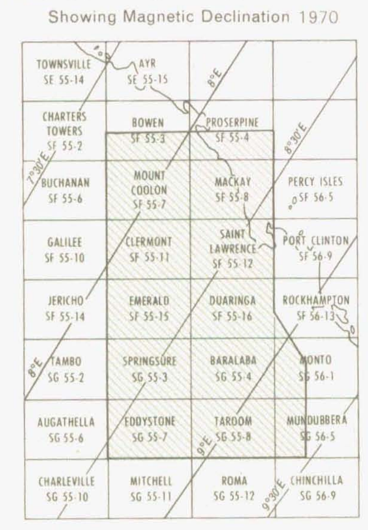


INDEX TO ADJOINING SHEETS
Showing Magnetic Declination 1970



Tectonic unit boundary
Structural unit boundary
Pre-Permian inliers
Middle Devonian or older inliers
Rock density boundary
Magnetic basement contour in metres
Anticline
Syncline
Monocline
Fault
Prevailing strike and dip of strata
Prevailing strike and dip of overturned strata
Trend lines (air-photo interpretation)
Possible fault
Isogals
Gravity anomaly — relative high
Gravity anomaly — relative low
Main road
Road
Railway
Town
Settlement
"Rewan" *Homestead*
610 *Elevation in metres, approximate*

Magnetic basement contours from Wells and Milsom (1966), Bureau of Mineral Resources, Geology and Geophysics.
Gravity reduced from 1 : 250,000 and 1 : 500,000 Series, Geophysical Branch, B.M.R.
Station Bouguer anomaly reliability: standard deviation <1 milligal
Rock density of 1·9 g/cm³ used for computations of Springsure and Eddystone 1 : 250,000 Sheet areas; 2·2 g/cm³ for remainder.

AEROMAGNETOMETER AND GRAVITY DATA
BOWEN BASIN

Plate 4, Figure 1. Drummond Group in Burdekin River, 6 km south-east of confluence with Suttor River.

Plate 4, Figure 2. Small thrust in Rannes Beds, road cutting in Gogango Range, 8 km west of Grantleigh siding.

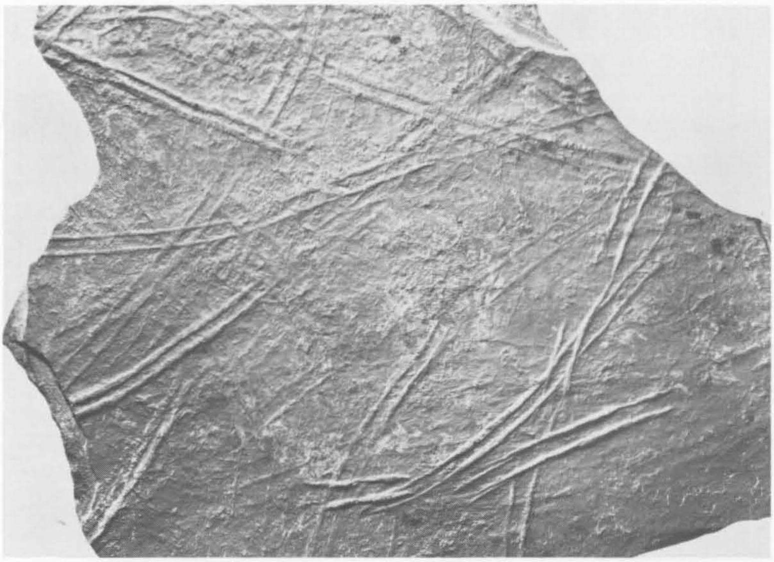


Plate 5, Figure 1. Animal tracks on lower surface of siltstone, Joe Joe Formation. (Slightly less than natural size.)

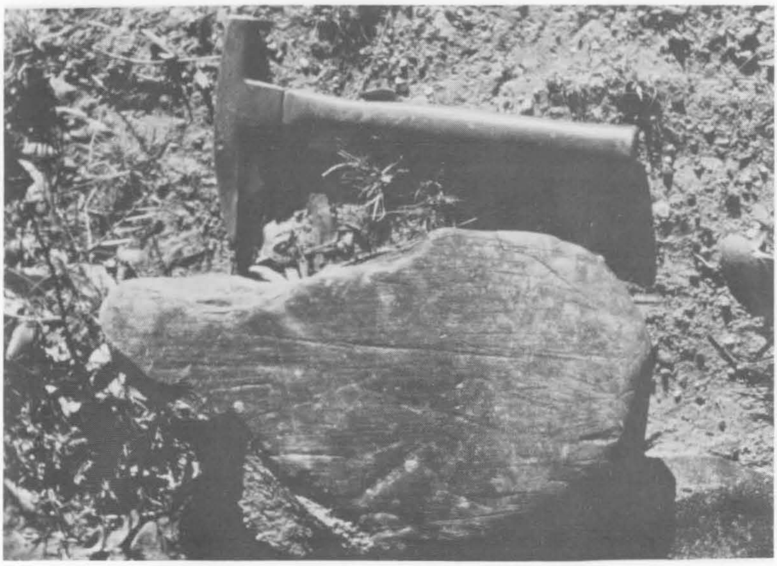


Plate 5, Figure 2. Striated and faceted boulder, Joe Joe Formation, 5 km north of Joe Joe homestead.

Plate 6, Figure 1. Staircase Sandstone in Staircase Creek.

Plate 6, Figure 2. Boulders in mudstone of Cattle Creek Formation, Cattle Creek, Reids Dome.

Plate 7, Figure 1. Oblique air-photograph of Permian rocks in Reids Dome (looking south).

Plate 7, Figure 2. Sandstone of Gebbie Subgroup in Parrot Creek.

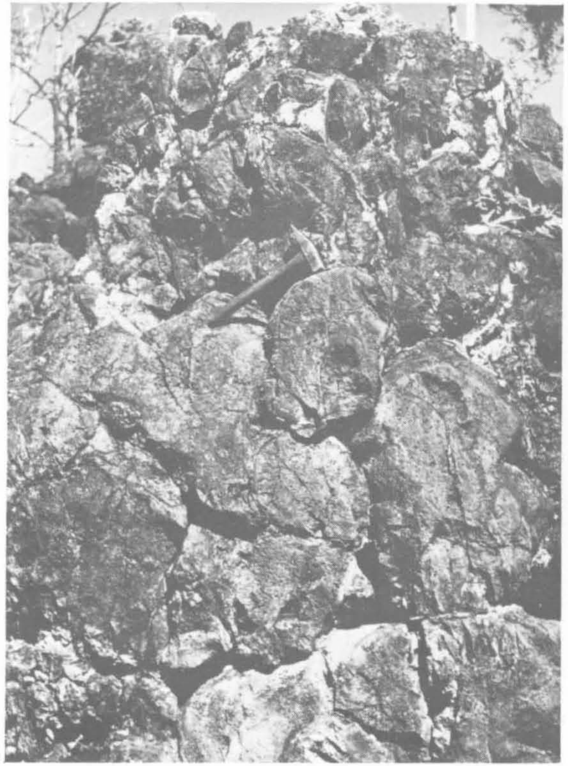


Plate 8, Figure 1. Pillow lava in Rookwood Volcanics, about 1 km northwest of Ohio homestead.

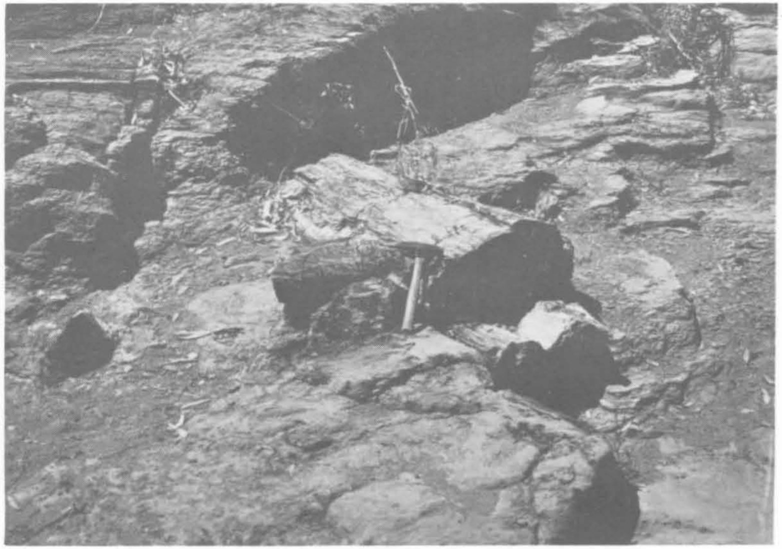


Plate 8, Figure 2. Fossil tree trunk in Blackwater Group, Cherwell Creek.

Plate 9, Figure 1. Animal markings in Burngrove Formation, Blackwater Group, 10 km north of Cooroorah homestead.

Plate 9, Figure 2. Fine lithic sandstone of Rewan Formation, near Moolayember Dip, Carnarvon Range.

Plate 10, Figure 1. Red mudstone of Rewan Formation, about 3 km southwest of Lake Elphinstone.

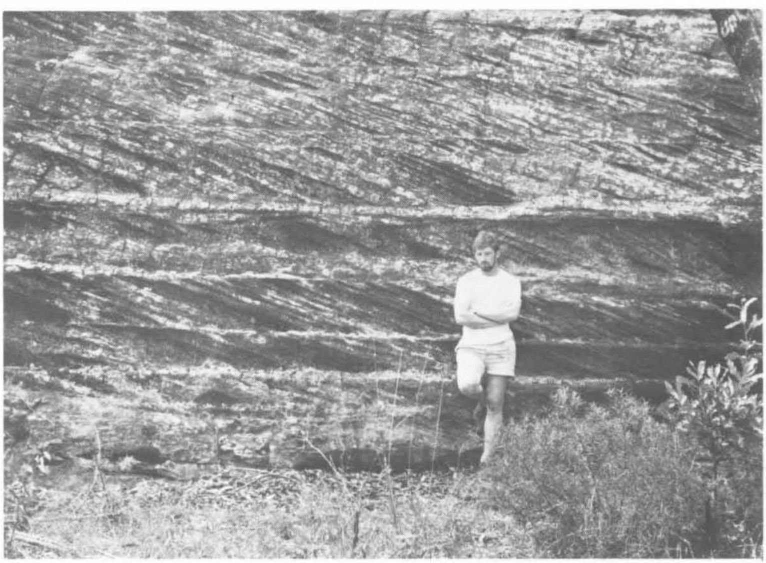


Plate 10, Figure 2. Clematis Sandstone, middle part of Planet Creek, Expedition Range.

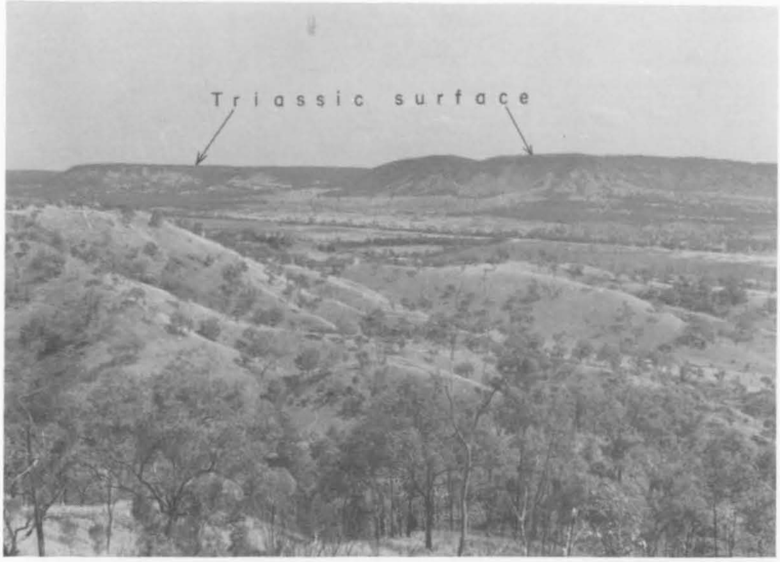


Plate 11, Figure 1. Exhumed Triassic surface in Permian strata dipping west at about 20° (looking southwest towards 'The Braes').

Plate 11, Figure 2. Natural arch in Precipice Sandstone, 6.5 km northwest of Mount Moffatt homestead.

Plate 12, Figure 1. Feldspathic sandstone of Evergreen Formation.

Plate 12, Figure 2. Urannah Complex diorite cut by (i) acid porphyry dyke (foreground), (ii) microdiorite (left hand side), and (iii) dolerite (right hand side).

Plate 13, Figure 1. Syenite intrusion doming Blackwater Group, near Daunhia homestead.

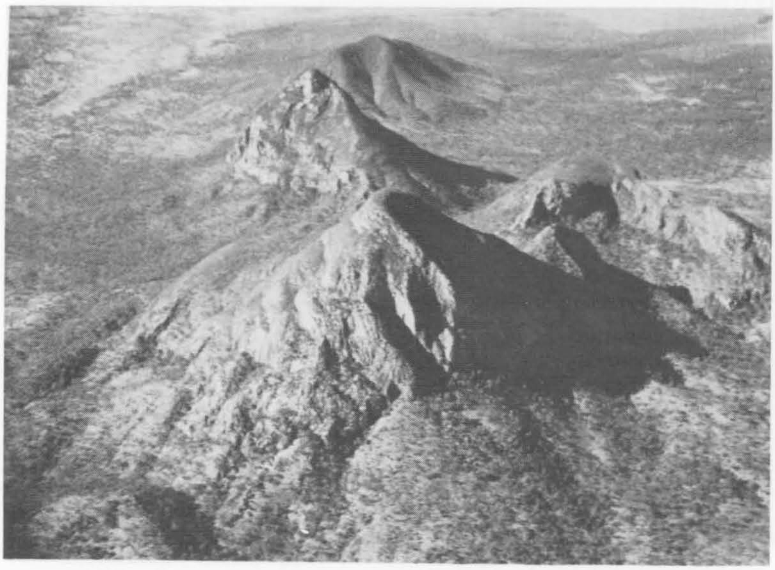


Plate 13, Figure 2. Peak Range Volcanics, air-photograph of Scott Peak, Roper Peak, and Malvern Hill (looking south).

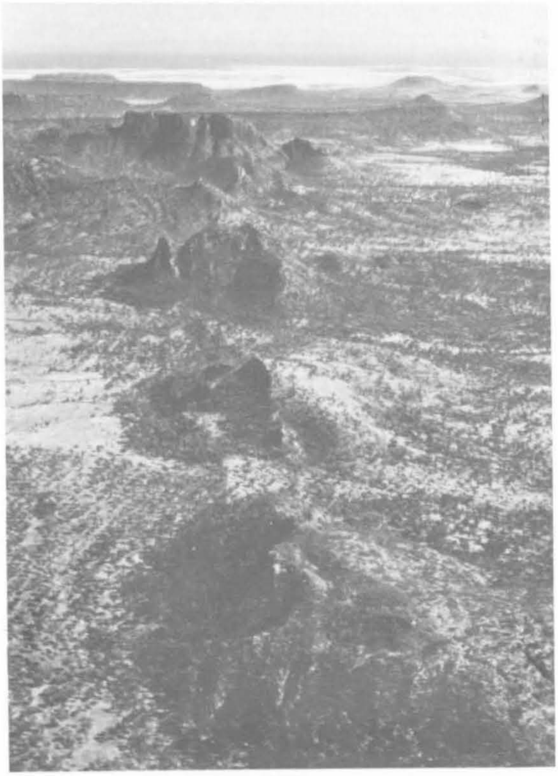


Plate 14, Figure 1. Major fault defined by Minerva Hills Volcanics. St Peter in centre background (looking northwest).

Plate 14, Figure 2. Moura open cut, 1964.

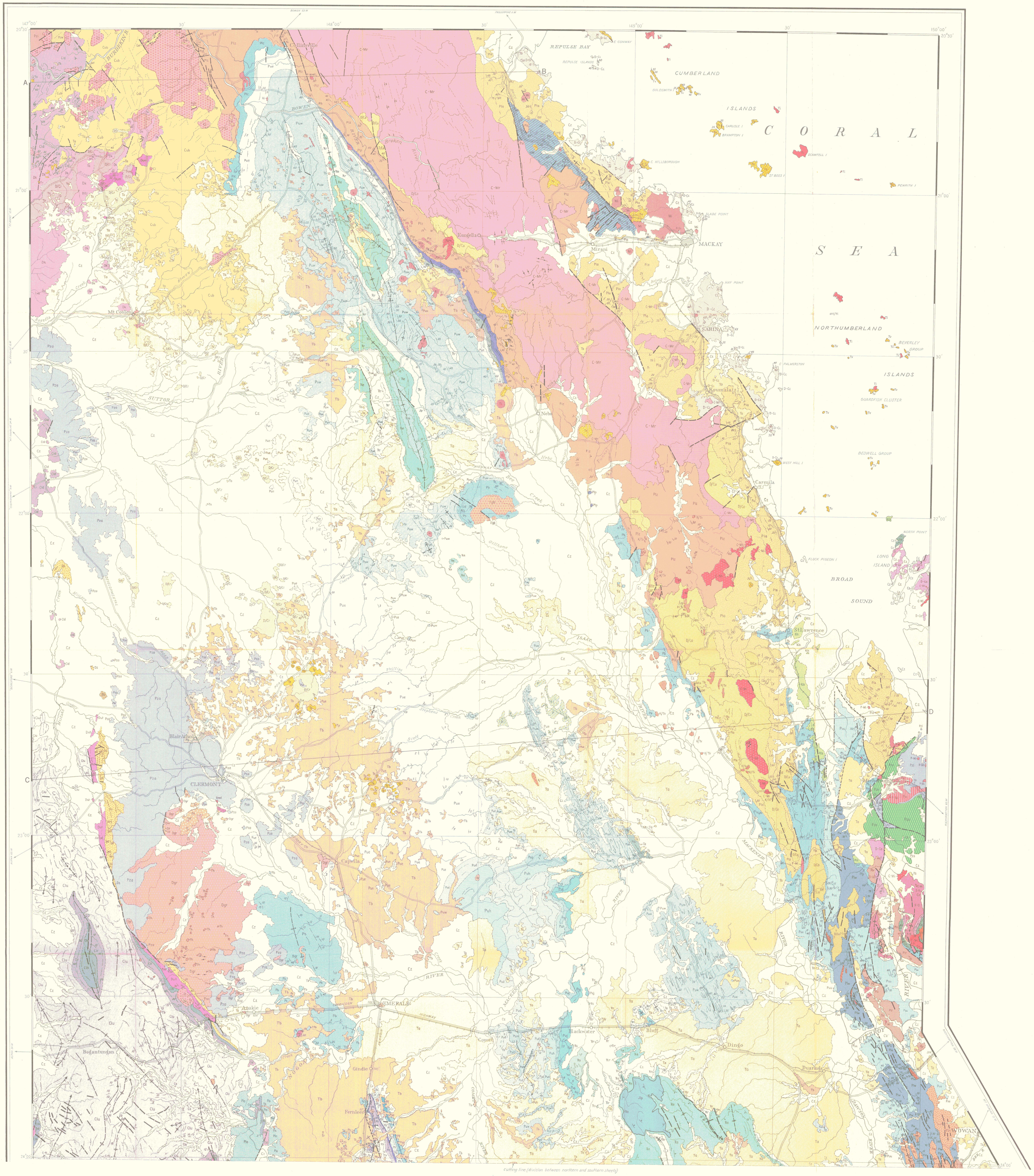
GEOLOGICAL MAP
BOWEN BASIN
QUEENSLAND

Compiled, 1965, by E. J. Malone, F. Olgers, R. G. Mollan, A. R. Jensen.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
1967

Scale 1 : 500 000

10 0 10 20 30 MILES
10 0 10 20 30 40 50 KILOMETRES

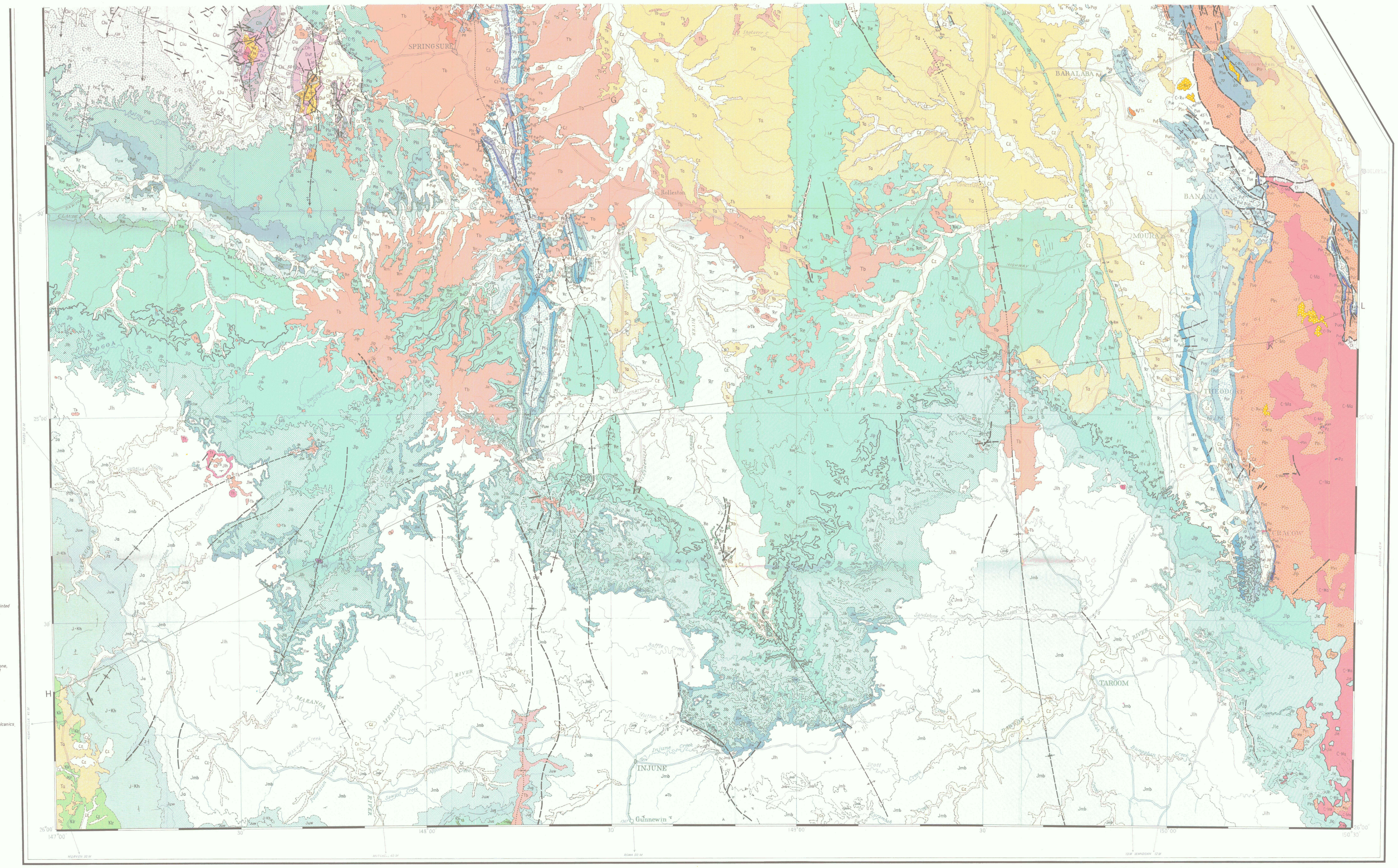


Reference

	UNDIFFERENTIATED		Cz	Alluvium, soil, sand, gravel
CAINOZOIC	TERTIARY		Ta	Claystone, clay, siltstone, sandstone, pebbly sandstone, conglomerate, sandstone erosion breccia
			Tb	Basalt; gabbro and dolerite plugs and stocks
		Peak Range Volcanics	Tp	Rhyolite and trachyte flows and plugs
		Minerva Hills Volcanics	Tr	Alkaline trachyte and rhyolite flows, plugs, domes and dykes
		Hoy Basalt	Th	Olivine basalt plugs, with inclusions
		Tabor Gabbro	Tt	Olivine gabbro sill and stocks
			Ti	Granite, granophyre, syenite, diorite
			Tv	Rhyolite, dacite, trachyte, basalt flows and pyroclastics; and minor intrusives
	CRETACEOUS TO TERTIARY		K/Ti	Trachyte plugs and dykes
			K/Tv	Trachyte, rhyolite, dacite, andesite flows and pyroclastics; plugs and dykes
	CARBONIFEROUS TO TERTIARY		C/Tv	Rhyolite, trachyte flows and pyroclastics
MESOZOIC	UNDIFFERENTIATED		Mi	Diorite, microdiorite, granite
	CRETACEOUS		Ki	Granodiorite, diorite, hornblende microdiorite, gabbro, syenite
		Mount Barker Granodiorite	Kgm	Hornblende biotite granodiorite
		Bundarra Granodiorite	Kgb	Leucocratic granodiorite, granite
		Roma Formation	Klr	Siltstone, sublabile sandstone, shale
		Blythesdale Formation	Klb	Quartzose and sublabile sandstone, pebbly in places, minor siltstone
		Styx Coal Measures	Kls	Quartz sandstone, conglomerate, siltstone, carbonaceous shale, coal
	JURASSIC TO CRETACEOUS	Hooray Sandstone	J-Kh	Quartzose to feldspathic sandstone, pebbly in part, siltstone, claystone
	JURASSIC	Orallo Formation	Juo	Siltstone, mudstone, quartzose sandstone, minor limestone
		Gubberamunda Sandstone	Jug	Quartzose and sublabile sandstone, pebbly in part
		Injune Creek Group: Westbourne Formation	Juw	Siltstone, mudstone, very fine grained quartzose to sublabile sandstone
		Injune Creek Group: Adori Sandstone	Ja	Feldspathic to sublabile sandstone, pebbly in part, siltstone, claystone
		Injune Creek Group: Birkhead Formation	Jmb	Sublabile to labile sandstone, in part calcareous, carbonaceous siltstone and mudstone, coal seams
		Hutton Sandstone	Jlh	Quartzose and sublabile sandstone
		Evergreen Formation	Jle	Labile and sublabile sandstone, siltstone, mudstone, carbonaceous shale, minor coal
		Westgrove Ironstone Member	Jlw	Concretionary chamositic ironstone, oolitic in places, mudstone, sandstone
		Oolite Member	Jlo	Concretionary chamositic ironstone, oolitic in places, mudstone, sandstone
		Boxvale Sandstone Member	Jlb	Quartzose sandstone, commonly micaceous, minor siltstone and coal
		Precipice Sandstone	Jlp	Cross-bedded, pebbly, quartzose sandstone
	TRIASSIC	Mimosa Group: Moolayember Formation	Rm	Labile sandstone, calcareous in part, siltstone, shale, conglomerate
		Mimosa Group: Clematis Sandstone	Re	Cross-bedded, pebbly quartzose sandstone, red silty mudstone
		Rewan Formation	Rr	Red and green mudstone, green labile and sublabile sandstone, siltstone, volcanic pebble conglomerate
		Sagittarius Sandstone Member	Rs	Green labile and sublabile sandstone, minor red and green mudstone
		Brumby Sandstone Member	Rb	Pebbly labile and sublabile sandstone
	PRE – JURASSIC		pJs	Ferruginous and calcareous sandstone, siltstone and altered sediments
	PERMIAN TO MESOZOIC		P-Mi	Hornblende granodiorite, diorite, granodiorite, gabbro
	CARBONIFEROUS TO MESOZOIC		C-Mi	Granite, adamellite, granodiorite
		Urannah Complex	C-Mr	Granodiorite, granite, diorite, gabbro, amphibolite, rhyolite, porphyry; andesite and basalt dykes
		Auburn Complex	C-Ma	Granodiorite; dacite dykes
	CARBONIFEROUS TO TRIASSIC		C-Rv	Rhyolite; trachyte, crystal tuff, quartz porphyry
	UNDIFFERENTIATED		Pz	Granulite, meta-quartzite
			Pzs	Serpentinite
	PERMIAN	Undifferentiated	P	Sandstone, siltstone, conglomerate
		Blair Athol Coal Measures	Pa	Coal, siltstone, sandstone
	UPPER PERMIAN	Blackwater Group: Undifferentiated	Puw	Labile sandstone, calcareous in part, siltstone, siliceous ashstone, carbonaceous shale, coal
		Blackwater Group: Rangal Coal Measures	Puj	Mudstone, carbonaceous shale, coal, labile sandstone
		Blackwater Group: Burngrove Formation	Pug	Mudstone, siltstone, siliceous ashstone, labile sandstone, calcareous labile sandstone
		Blackwater Group: Fair Hill Formation	Puh	Labile sandstone, calcareous in part, commonly pebbly, volcanic pebble conglomerate, siltstone, carbonaceous shale, coal
		Blackwater Group: Baralaba Coal Measures	Pul	Labile sandstone, conglomerate, coal, shale, siltstone
		Blackwater Group: Gyranda Formation	Puy	Labile sandstone, siltstone, mudstone, minor conglomerate, tuff
			Pui	Granodiorite, granite, gabbro
	LOWER TO UPPER PERMIAN	Back Creek Group: Undifferentiated	Pb	Sandstone, siltstone, fossiliferous limestone and calcareous sandstone, tuff, lithic (volcanic) sandstone, sheared siltstone, phyllite
		Back Creek Group: Boomer Formation	Puu	Interbedded lithic (volcanic) sandstone and siltstone; sheared siltstone, conglomerate, mudstone
		Blenheim Sub-Group: Undifferentiated	Pue	Labile, sublabile, and quartzose sandstone, fossiliferous limestone and sandy coquinite, mudstone, siltstone, conglomerate
		Blenheim Sub-Group: Banana Formation	Pun	Mudstone, siltstone
		Blenheim Sub-Group: Flat Top Formation	Puf	Siltstone, mudstone, sandy siltstone, minor conglomerate, limestone, coquinite
		Blenheim Sub-Group: Barfield Formation	Pur	Mudstone, siltstone, fossiliferous concretionary limestone, labile sandstone, greywacke, conglomerate, tuff, volcanic conglomerate, vesicular keratophyre
		Blenheim Sub-Group: Oxtrack Formation	Puo	Siltstone, calcareous mudstone, limestone, coquinite, calcarenite, silicified limestone
		Blenheim Sub-Group: Black Alley Shale	Puc	Dark shale, claystone, tuff
		Blenheim Sub-Group: Peawaddy Formation	Pup	Carbonaceous sandy mudstone, siltstone, feldspatho-lithic sandstone, sandy coquinite
		Blenheim Sub-Group: German Creek Coal Measures	Pud	Sublabile and quartzose sandstone, siltstone, carbonaceous shale, coal, minor pebble conglomerate
		Blenheim Sub-Group: Maria Formation	Pum	Micaceous siltstone, mudstone, calcareous sublabile sandstone
		Gebbie Sub-Group: Undifferentiated	Plb	Quartzose and sublabile sandstone, siltstone, mudstone, calcareous sandstone and siltstone, conglomerate, coal
		Gebbie Sub-Group: Collinsville Coal Measures	Plc	Quartzose and sublabile sandstone; conglomerate, siltstone, carbonaceous shale, coal
		Gebbie Sub-Group: Catherine Sandstone	Plf	Feldspathic sublabile sandstone
		Gebbie Sub-Group: Ingelara Formation	Pli	Conglomeratic siltstone, sandy mudstone, calcareous concretions
		Gebbie Sub-Group: Aldebaran Sandstone	Plf	Cross-bedded conglomeratic quartzose sandstone, siltstone, minor coal
		Gebbie Sub-Group: Colinlea Sandstone	Plo	Cross-bedded conglomeratic quartzose sandstone, minor siltstone

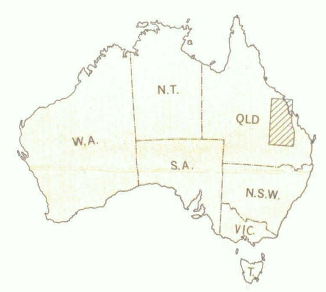
PALAEOZOIC

LOWER PERMIAN	Tiverton Sub-Group: Undifferentiated	Plp	Siltstone, mudstone, quartzose and sublabile sandstone, conglomerate, limestone, fossiliferous calcareous sandstone and siltstone
	Buffel Formation	Plu	Calcarenite, coquinite, calcareous mudstone, silicified limestone
	Sirius Formation	Pls	Pebbly siltstone, mudstone, sandstone
	Staircase Sandstone	Plt	Cross-bedded conglomeratic quartzose sandstone, siltstone, shale
	Stanleigh Formation	Plh	Sublabile sandstone, dark shale, siltstone, minor limestone
	Cattle Creek Formation	Plk	Mudstone, sandy in part, containing pebbles and boulders; sandstone, sandy coquinite, limestone
	Rookwood Volcanics	Plr	Basaltic and spilitic pillow lavas and agglomerate, chert, some tuffaceous sediments
	Youlambie Conglomerate	Ply	Sandstone, pebbly sandstone, siltstone, volcanic pebble conglomerate
	Calen Coal Measures	Ple	Quartzose sandstone, siltstone, claystone, minor coal
	Carmila Beds	Pla	Conglomerate, lithic greywacke, acid to intermediate flows and crystal and lithic tuffs, siltstone, mudstone
	Lizzie Creek Volcanics	Plz	Andesite, basalt, trachyte and minor acid flows and pyroclastics, conglomerate, greywacke, tuffaceous sandstone, siltstone
		Plx	Diorite and micro-diorite sills
	Reids Dome Beds	Plj	Sandstone, siltstone, mudstone, carbonaceous shale, coal, conglomerate
	Orion Formation	Plg	Sublabile sandstone, siltstone, carbonaceous shale
LOWER PERMIAN AND OLDER	Rannes Beds	Plw	Shale, siltstone, limestone, sheared siltstone, phyllite, slate, labile sandstone, lenses of acid to intermediate volcanics, chert Volcanics
	Camboon Andesite	Pln	Andesite, basalt, crystal tuff, tuff, agglomerate, limestone
CARBONIFEROUS TO PERMIAN	Joe Joe Formation	C-Pj	Lithic conglomerate, lithic sublabile sandstone, siltstone, minor shale
CARBONIFEROUS		Ci	Granodiorite, adamellite, granite, aplite
	Torsdale Beds	Ct	Conglomerate, lithic sandstone, siltstone, mudstone, chert, andesite, rhyolite, acid tuff, agglomerate
UPPER CARBONIFEROUS	Bulgonunna Volcanics	Cub	Porphyritic rhyolite and dacite flows, crystal tuff, agglomerate, auto-breccia, welded tuffs, lithic sandstone, siltstone
LOWER CARBONIFEROUS	Drummond Group: Undifferentiated	Cld	Sandstone, tuffaceous sandstone, siltstone, conglomerate, siliceous siltstone, acid volcanics, rare algal limestone lenses
	Ducabrook Formation	Clu	Lithic sandstone, siltstone, red and green shale, tuff, minor algal limestone
	Raymond Sandstone	Clr	Flaggy quartzose sandstone, minor siltstone
	Mount Hall Conglomerate	Clh	Cross-bedded, conglomeratic quartzose sandstone and quartz pebble conglomerate
	Telemon Formation	Dut	Lithic conglomerate, lithic sandstone, multicoloured tuffaceous siltstone and shale, algal limestone
UPPER(?) DEVONIAN	Silver Hills Volcanics	Ds	Rhyolite, trachyte, andesite and basic flows and agglomerate; conglomerate, sandstone, shale
	Theresa Creek Volcanics	Dt	Andesite, trachyandesite, rhyolite, dacite flows, crystal and lithic tuffs, arkose, lithic greywacke, siltstone
UPPER DEVONIAN TO LOWER CARBONIFEROUS	Mount Rankin Beds	D/Cr	Rhyolite, dacite flows, acid and intermediate pyroclastics, conglomerate, lithic (volcanic) sandstone, greywacke, siltstone
	Mount Wyatt Beds	Dum	Lithic sandstone, siltstone, conglomerate
DEVONIAN TO CARBONIFEROUS	Yarrol Basin Sequence: Neerkol Formation	Cu	Calcareous siltstone and sandstone, fossiliferous in part, conglomerate, mudstone
		Cl	Oolitic limestone, siltstone, mudstone, sandstone, chert
		D-Ca	Limestone, mudstone, siltstone, sandstone, conglomerate
	Campwyn Beds	D-Cc	Intermediate, basic and acid volcanics, siltstone, sandstone, conglomerate, limestone
DEVONIAN OR CARBONIFEROUS	Connors Volcanics	D/Co	Rhyolite, dacite, trachyte, andesite flows and pyroclastics, silicified, jointed and quartz veined; tuffaceous sandstone and volcanic conglomerate, jointed and quartz veined
		D/Ci	Granodiorite, very jointed, with numerous roof pendants
DEVONIAN	Retreat Granite	Dgr	Granite, granodiorite, adamellite, monzonite
LOWER TO MIDDLE DEVONIAN	Ukalunda Beds	Dk	Lithic and quartzose sandstone, shale, conglomerate, silicified limestone, chert, fossiliferous limestone lenses; quartz veining, silicification and some metamorphism
	Dunstable Volcanics	Dn	Tough green andesite lavas and pyroclastics, coralline limestone lenses, cherty shale
	Douglas Creek Limestone	Dmd	Coralline and stromatoporoid limestone
		Dm	Micaceous siltstone, pebbly sandstone, shale, coralline limestone, volcanics
SILURIAN TO MIDDLE DEVONIAN	Undifferentiated	S-D	Fossiliferous limestone; intermediate to basic flows and pyroclastics; chert
LOWER(?) PALAEOZOIC		Pzg	Granite
	Anakie Metamorphics	Pza	Quartz-mica schist, knotted schist, slate, quartzite, crystalline limestone, sandstone; abundantly quartz veined
		Pzl	Quartz-mica schist, phyllite, amphibolite, talc schist, quartzite, hornfelsed quartz-mica schist, pyroxenite
		Pzr	Gabbro and ultrabasic plutonic rocks
	Ravenswood Granodiorite	Pzi	Granodiorite
	Mount Windsor Volcanics	Pzw	Dacitic, rhyolitic, some andesitic flows and pyroclastics and interbedded labile sediments; minor schist, gneiss and hornfels

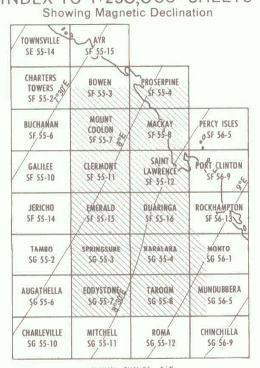


Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled by the Bureau of Mineral Resources from air photographs, and information supplied by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force at 1 : 50,000 scale of Mt Coolon and Clermont 1 : 250,000 Sheet areas, and by Adastra Airways Pty Ltd at 1 : 85,000 scale of remainder of sheet; complete vertical coverage
Transverse Mercator Projection.

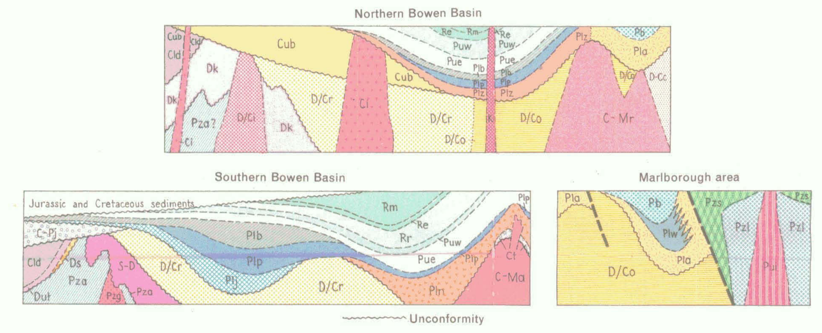
Geology, to 1965, based on regional mapping of constituent 1 : 250,000 sheet areas, by E. J. Malone, A. R. Jensen, R. G. Mollan, F. Olgers, C. M. Gregory, J. J. Veevers, N. F. Exon, M. A. Randal, D. W. P. Corbett, J. A. J. Smit, A. W. Webb, J. M. Dickins (B.M.R.); A. G. Kirkegaard, V. R. Forbes, J. F. Dear, R. J. Paton, B. A. Coxhead, P. E. Bock, L. G. Cuttler (G.S.Q.); E. A. Webb, C. E. Crapp (Bowen Consolidated Coal Mines Pty Ltd); D. King, P. Goscombe, L. Hansen (Utah Development Co.); S. S. Derrington, K. H. Morgan (Mines Administration Pty Ltd); W. C. White, G. A. Brown (Ampol Exploration Ltd); and P. McKenzie, J. Faulkner (Broken Hill Pty Ltd).
Drawn by E. H. J. Feeken.



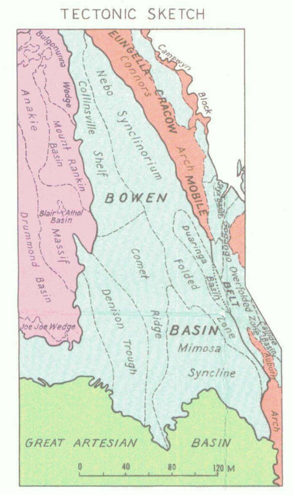
INDEX TO 1:250,000 SHEETS
Showing Magnetic Declination

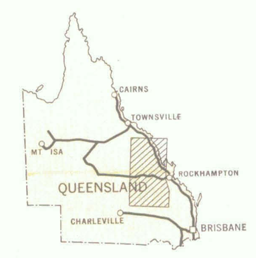


DIAGRAMMATIC RELATIONSHIP OF MAIN ROCK UNITS



TECTONIC SKETCH



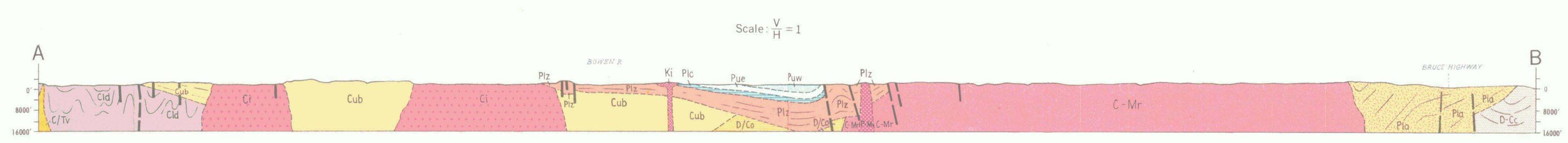


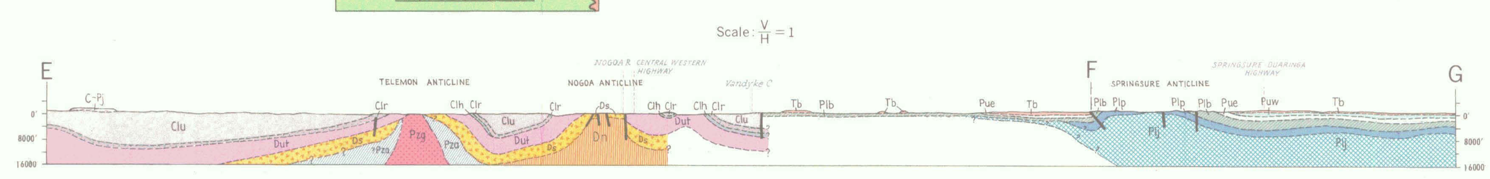
Geological boundary
Unconformity at base of Jurassic sequence
Syncline
Anticline
Monocline
Plunge of fold axes
Fault (D, U indicate relative movement down, up)
Where location of boundaries, folds and faults is approximate, line is broken, where inferred, queried; where concealed boundaries and folds are dotted, faults are shown by short dashes

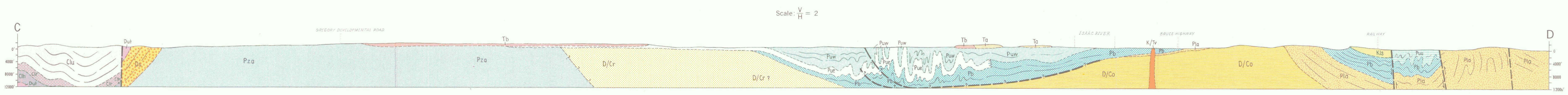
Strike and dip of strata
Vertical strata
Horizontal strata
Strike and dip of overturned strata
Dip <15°
Dip 15°–45°
Dip >45°
Trend lines showing dip
Joint pattern
(air-photo interpretation: Dip <15° to Joint pattern)
Strike and dip of foliation
Dyke: b basalt, an andesite, rh rhyolite, tr trachyte, gr granite

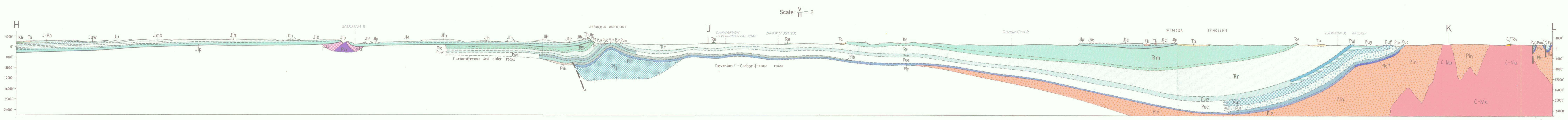
Main road
Railway
Town
Settlement
Spot elevation, instrument levelled; datum: mean sea level

Sections
(Folding partly diagrammatic)









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GEOLOGICAL MAP BOWEN BASIN QUEENSLAND

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T., or the Geological Survey of Queensland, Brisbane, Qld.