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Geology of the Surat Basin in Queensland

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ABSTRACT

The Surat Basin of eastern Australia contains 2500 m of Jurassic and Cretaceous sediments, terrestrial during the Jurassic, but showing two marine incursions during the Early Cretaceous. The sequence is almost flat-lying; the gentle basinward dip is modified by a few drape or compaction folds and faults. Deposition during the Jurassic was dominantly fluviatile and consisted of fining-upward megacycles, each more than 100 m thick. Volcanic debris suggests contemporaneous volcanism in both the Jurassic and the Early Cretaceous.

Sedimentation gave way to erosion during the Late Cretaceous and Early Tertiary, and the rocks were deeply weathered. In the Oligocene and Miocene, basin volcanicity around the margins of the Basin accompanied epeirogenic basinward tilting; since then the basin has been stable.

Petroleum reserves in the basin in 1974 were estimated as 5½ billion m^3 of gas and 3½ million m^3 of oil. The Walloon Coal Measures hold considerable reserves of bituminous coal and some of oil shale.

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CONTENTS

APPENDICES

TABLES

ILLUSTRATIONS

FIGURES

PLATES

SUMMARY

The Jurassic-Cretaceous Surat Basin, which is elongated meridionally, covers 300 000 km^2 in eastern Australia, mostly in Queensland. It contains up to 2500 m of virtually flat-lying sedimentary rocks and interfingers westward across the Nebine Ridge with the Eromanga Basin, and eastward across the Kumbarilla Ridge with the Moreton Basin. Basement blocks consisting of the Central West Fold Belt and the New England Fold Belt limit the basin to the south, and the South Coastal Structural High limits it to the northeast. To the north the basin has been eroded. Dips seldom exceed 2°, and fault displacements of more than 200 m are rare.

The main part of the Permo-Triassic Bowen Basin, which covers in total an area of 200 000 km^2, lies to the north of the Surat Basin, but a southerly extension, the southern part of the Taroom Trough, unconformably underlies the Surat Basin. The southern part of the trough has an area of 50 000 km^2, and contains up to 9000 m of sedimentary rocks. The Taroom Trough is a meridional half-graben, bounded to the east by a line of faults along the margins of basement blocks. Dips seldom exceed 15°, but fault displacements are as much as 2000 m. The structures in the Bowen Basin are generally reflected in the overlying Surat Basin sequence.

In Early Permian time the marine Back Creek Group was laid down over most of the area, which was fairly flat except in the southwest, where basement was exposed until the Jurassic. In the Late Permian the sea withdrew and the coal measures of the Blackwater Group were deposited. The Permian sequence is over 3500 m thick in places.

In the Early Triassic the redbeds of the Rewan Group were laid down over much of the area. In the southeast the faults bounding the Taroom Trough had started to develop and the conglomeratic Cabawin Formation was deposited nearby.

Late in the Early Triassic and in the Middle Triassic normal stream sediments accumulated in the Taroom Trough. Initially they were also laid down in the northeast, but the faults bounding the trough in the north developed during this period. The Triassic sequence (Rewan and Clematis Groups and Moolayember Formation in the north, Rewan Group and Wandoan Formation in the south) is up to 5000 m thick.

Late Triassic erosion removed all the Triassic and most of the Permian sequence east of the fault zone. Important tectonic movements had ceased by the Jurassic, and most structures in the Surat Basin sequence are drapes over basement rises, and depressions due to the compaction of thick sedimentary sequences.

Deposition in the Surat Basin gradually extended, and even the basal sands extend beyond the Taroom Trough. The Jurassic to lowermost Cretaceous sediments are essentially terrestrial and cyclic; the sequence is up to 1700 m thick, and each of the five cycles is hundreds of metres thick. Each cycle generally began with the deposition of fairly coarse mature sand, which graded up into finer and more labile sand and silt, and ended with the deposition of labile sand, silt, mud, and coal. The cycles represent deposition by braided streams, followed by meandering streams, and finally by deposition in swamps, lakes, deltas and, in places, shallow seas. Andesitic volcanic debris is common in the Middle and Upper Jurassic sequence; it represents, in part at least, contemporaneous volcanism. Late Jurassic epeirogenic uplift gave the basin its present general configuration.

The sea entered the area in the Neocomian, probably initially from the east and later across the Nebine Ridge, and muds were being laid down below wave base by the late Aptian. There followed a regression during which sand, silt, and mud were deposited, another transgression marked by silt and mud, and a final regression during which sand and silt were deposited. The two transgressive muddy units and two regressive sandy units together form the Rolling Downs Group, whose deposition ceased in the late Albian. Andesitic debris derived from Early Cretaceous volcanism to the east is a major component of the sequence. The combined thickness of the Rolling Downs Group and the previous paralic unit (Bungil Formation) is up to 1200 m.

Steady erosion and pediplanation took place during the Late Cretaceous and Early Tertiary, and a deep-weathering profile was developed. In Oligocene-Miocene time basic volcanics were poured out around the Surat Basin and epeirogenic movements increased the basinward tilt. Thereafter the basin remained stable and its northern margin was extensively eroded.

By 1974 over 350 petroleum exploration wells had been drilled and over 30 gas fields and 2 significant oil fields discovered: the initial total reserves were estimated at 5463 million m^3 of gas and 3.608 million m^3 of oil. Production is mainly from the basal Jurassic Precipice Sandstone. Gas and oil pipelines have been laid to Brisbane and the oil reserves have already been heavily depleted. Future exploration will probably be concentrated on the Precipice Sandstone and the Permian sequence on and near the Roma Shelf. Another target warranting consideration is the Jurassic Hutton Sandstone in the Bollon area.

The Middle Jurassic Walloon Coal Measures could be open-cut for power generation and several prospects are currently being assessed.

INTRODUCTION

The Surat Basin is about 300 000 km^2 in area (Fig. 1); over half of it lies in Queensland, the remainder in New South Wales. It contains up to 2500 m of mainly Jurassic clastic continental sedimentary rocks and Lower Cretaceous marine beds. Dips are generally centripetal but low; the rocks in the central part of the basin are extensively obscured by Cainozoic alluvium. Hydrocarbons are being produced from a number of small fields, generally from reservoirs in Lower Jurassic sandstones.

The main roads, railways, and centres of population in the area studied are shown in Figure 2, and the general topography and the main drainage systems are outlined in Figure 3. The highest country is in the north and east (1000-300 m) and the lowest in

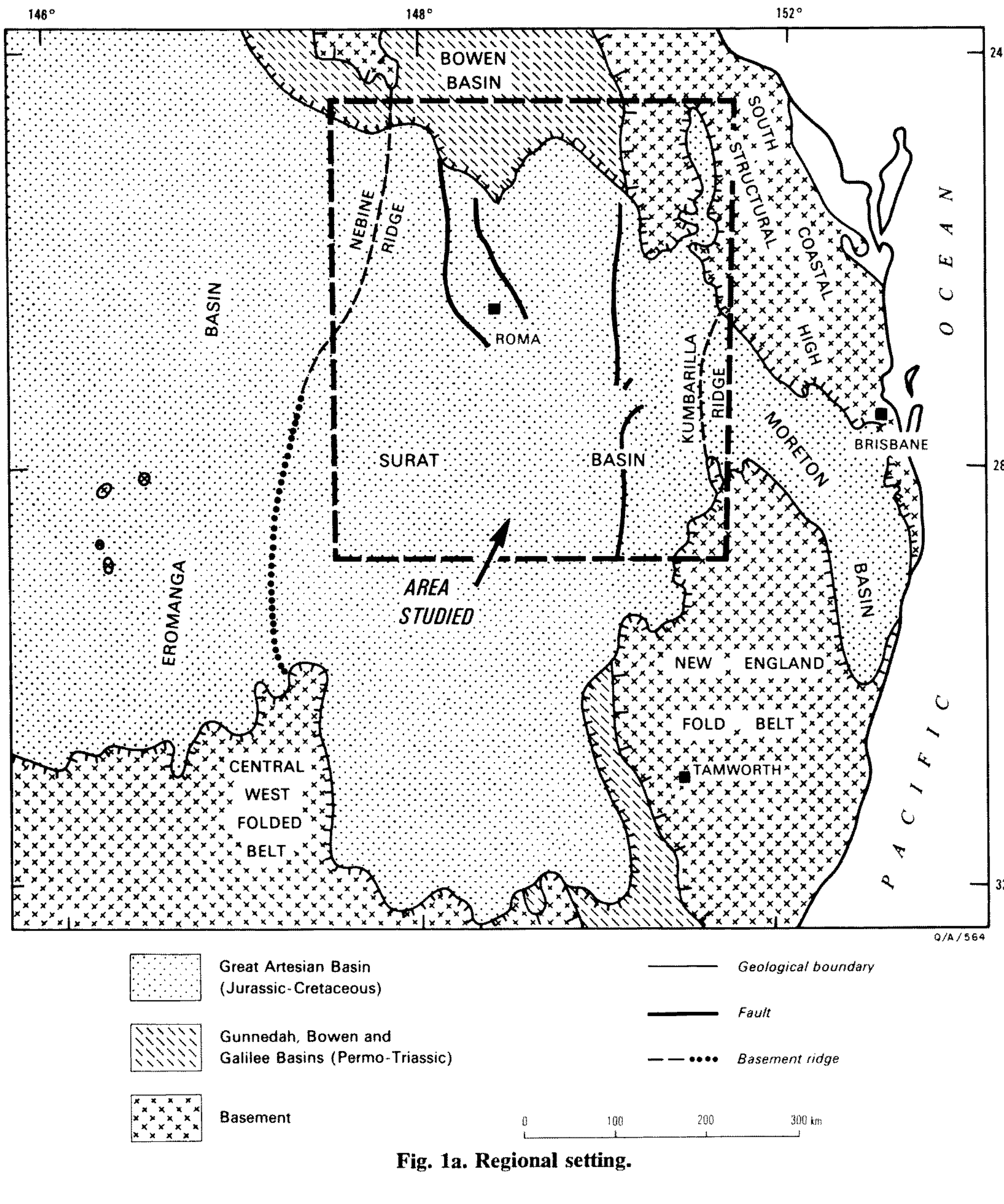


Fig. 1a. Regional setting.

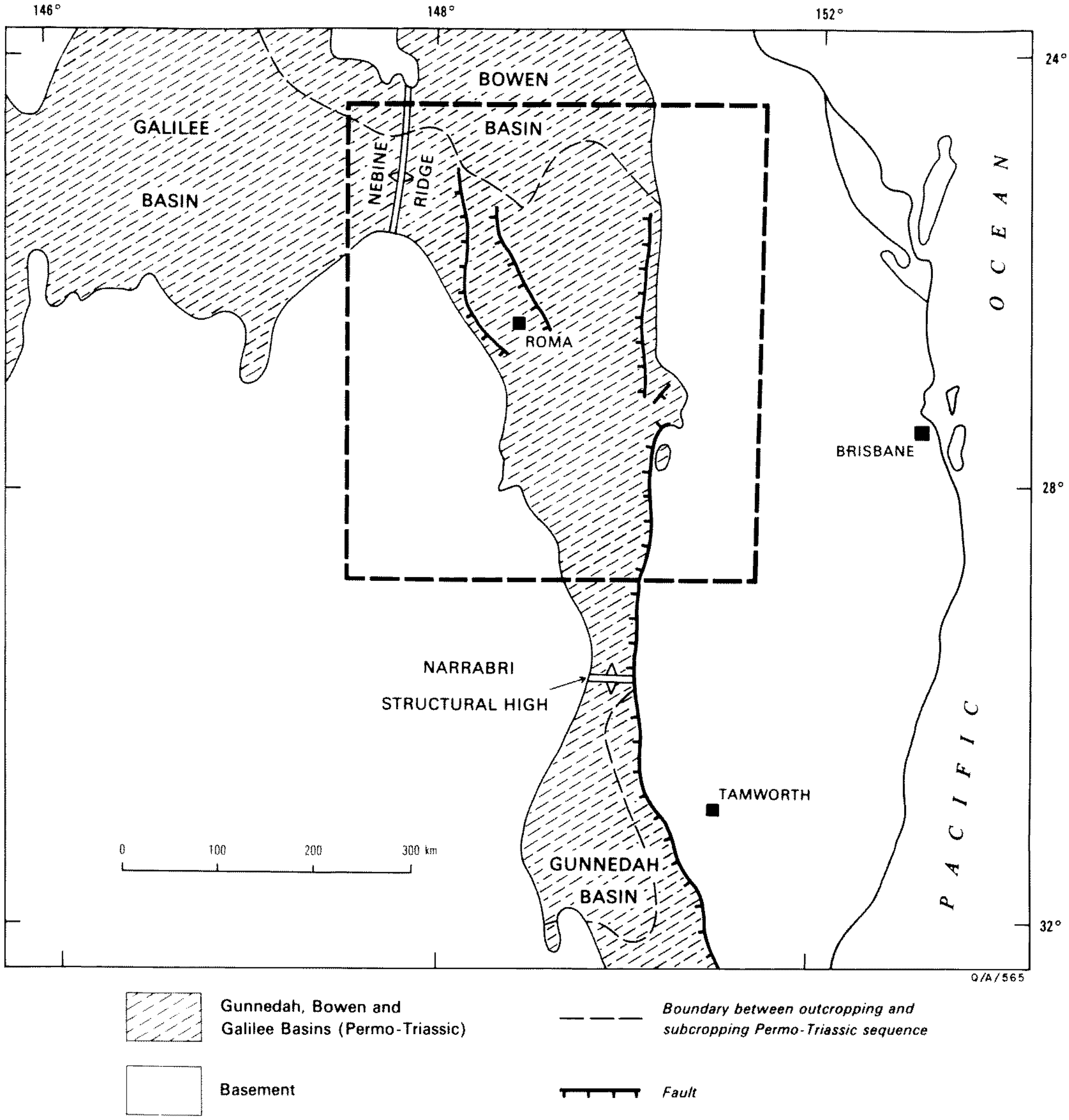


Fig. 1b. Regional setting.

the southwest (less than 200 m). The eastern edge of the basin lies less than 200 km from the Pacific coast, whereas the western edge is 500 km inland. The climate throughout the basin is subtropical, but the higher country nearer the coast is much cooler and wetter than the inland areas.

The annual average temperature varies across the area from 15°C to 21°C and the normal annual range is 0°C to 35°C. Temperatures higher than 45°C and lower than —5°C are uncommon. Frosts are common during winter nights. The annual rainfall ranges from 800 mm in the east to 350 mm in the southwest and the average annual runoff varies accordingly from 120 to less than 12.5 mm.

Drainage through virtually the entire area (Fig. 3) is to the southwest, joining the Darling system, which debouches eventually into the Southern Ocean. Gradients are initially high, but diminish rapidly to the southwest,

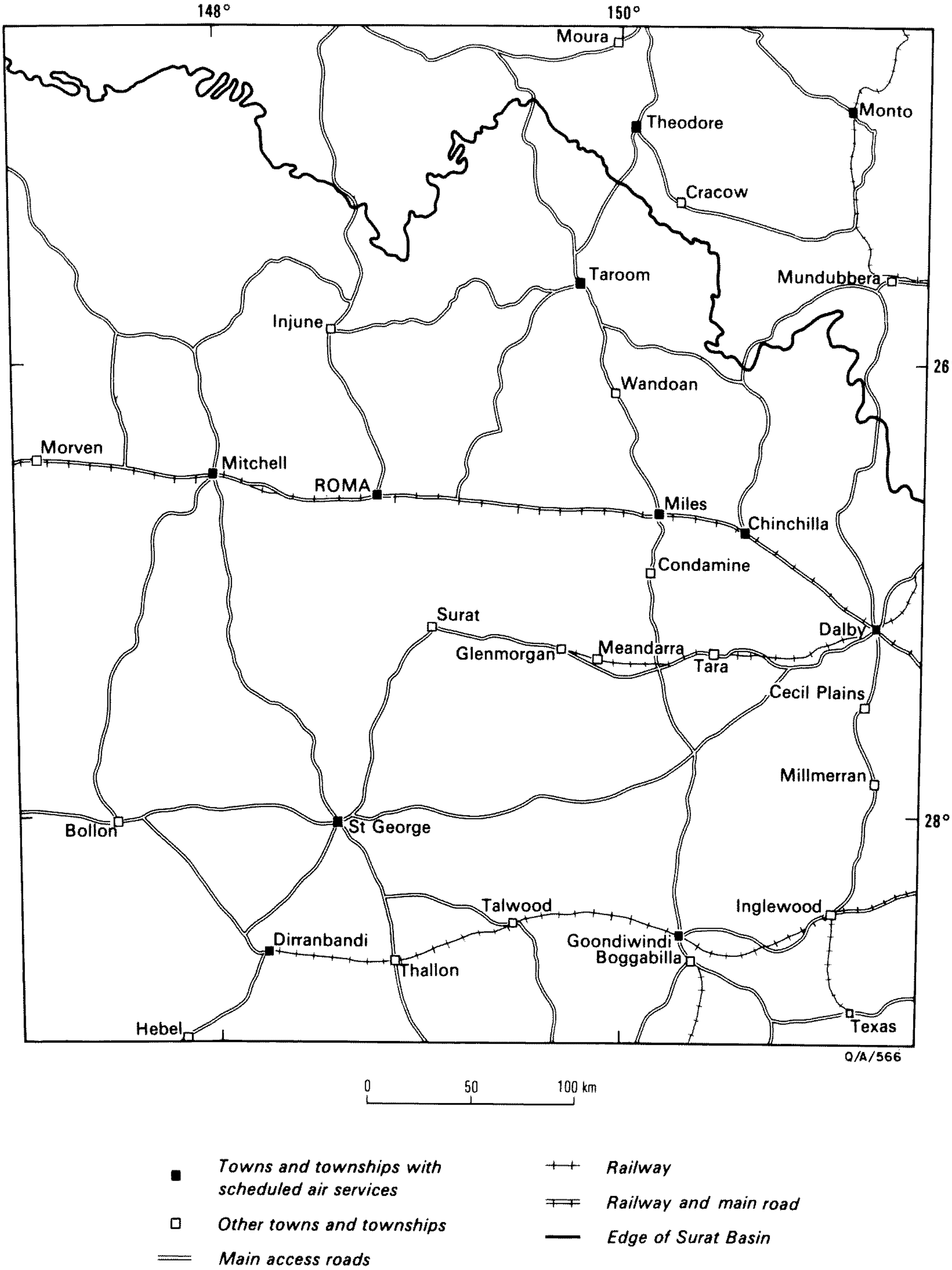


Fig. 2. Towns and access.

and are minimal on the alluvial tracts that make up one-third of the area (Fig. 4). There are no perennial streams in this area of little runoff and high summer temperatures.

The area is almost entirely devoted to agriculture, particularly on the good soils in the east, and the pastoral industry. The main centres of population are concentrated on the good clayey soils of the Injune Creek and Rolling Downs Groups and on Cainozoic alluvium (see Fig. 4); they include Dalby (pop. 9000), Roma (6000), Goondiwindi (3500), Chinchilla (3300), St George (2250), and Miles (1500). The total population of the area is about 50 000.

Cash crops such as wheat, oats and sorghum are concentrated east of Meandarra, particularly on the alluvial plains of the Condamine River, although cotton is grown on a large irrigated area near St George. Beef cattle are concentrated in the rougher or drier country in the north, centre, and east, and sheep are raised for wool in the southwest. Forestry is important on the sandy country north of Chinchilla, west of Cecil Plains and Millmerran, and around Inglewood.

Scheduled air services call at many of the larger centres (Fig. 2), and east-west rail links connect Brisbane with Charleville (west of Morven), Glenmorgan, and Dirranbandi. A well developed network of roads links all the major population centres and important farming areas. Sealed roads extend for some distance north and south of the Warrego Highway, which connects Brisbane and Charleville, but elsewhere are common only in the more densely populated eastern third of the area. Unsealed roads are generally passable in sandy country, but are impassable in clayey country after rain.

Physiography

Cainozoic stream systems have cut back into the sediments of the Bowen and Surat Basins from the north and the southwest, leaving the Great Dividing Range as a major erosional remnant (Fig. 3). The northerly-flowing streams have cut large drainage basins and it is estimated that the Comet River system, for example, has removed a thickness of about 1000 m of Mesozoic sedimentary rocks and Tertiary basalt, assuming that the early Cainozoic surface was relatively even.

In the Surat Basin proper, where the rainfall is smaller and where gradients of the streams are lower, the southwesterly-flowing streams have been less effective erosive agents than the northerly-flowing streams in the Bowen Basin. Regarding the Tertiary (Oligocene or older) land surface as a datum (Fig. 4), it is apparent that the southerly-flowing streams have seldom cut down more than 200 m. In wide areas, the old valleys have been filled with 100 m and more (cross-section of Fig. 4; Fig. 48) of Cainozoic sediments, and the present alluvial surface is only just below, or in places actually above, the remnants of the Tertiary surface. Much of the Cainozoic fill may be less than 15 000 years old and was deposited when run-off diminished after the last glacial epoch.

The physiographic units are shown in Figure 4.

The *basalt-capped mesas,* which range in elevation from 450 to 1200 m, are the remnants of formerly widespread flows that filled depressions in mid-Tertiary time. Their presence shows that the topography has been completely inverted in the last 25 million years in many areas.

The *dissected sandstone country with cuestas and mesas* has formed where resistant sandstone and less resistant interbeds crop out, and have been incised by active streams with considerable gradients. The unit is confined to the Lower Jurassic and the Upper Jurassic to Lower Cretaceous sandy sequences. In most of the basin, dips range from $\frac{1}{2}°$ to 2° and southerly-dipping cuestas have been formed, but in the east dips are even lower and mesas have been formed.

The *dissected tablelands,* representing the Early Tertiary land surface, are confined to the lower areas within the basin. The ferruginized and silicified land surface was more resistant to erosion than the unaltered Mesozoic rocks and is still being dissected.

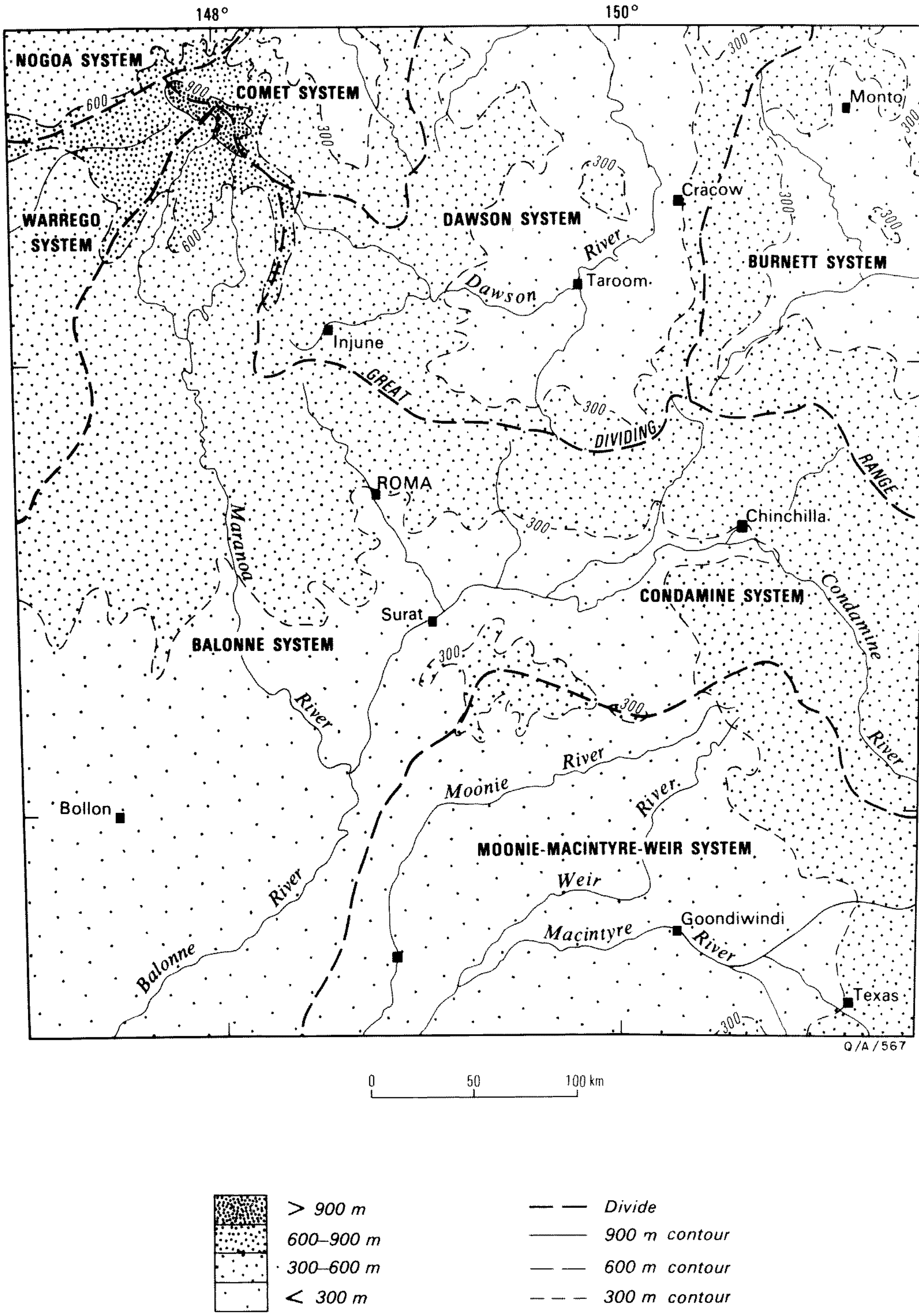


Fig. 3. Topography and drainage.

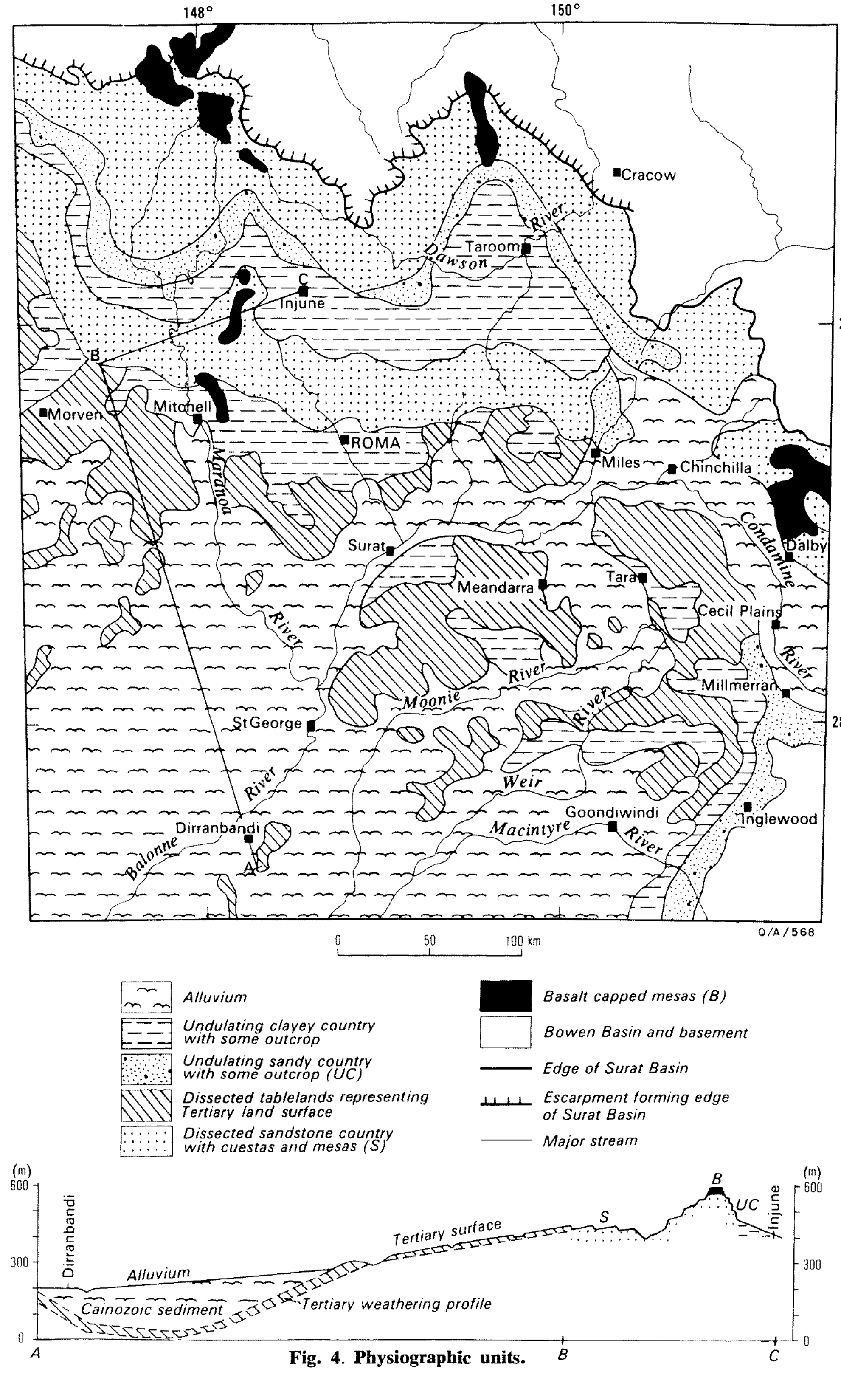


Fig. 4. Physiographic units.

Much of the basin was probably once capped by this surface, but it has been almost completely eroded in the higher areas. In places the surface is buried under Cainozoic alluvium.

Undulating sandy country, with some outcrop, has formed on the upper part of the Hutton Sandstone and on the sandstones flanking the Texas High in the northern part of the New England Fold Belt. Stream gradients are low and incision slight, and cuestas or mesas are only poorly developed.

Undulating clayey country, with some outcrop, has been developed on the unresistant mudstones, siltstones, and labile sandstones of the Injune Creek and Rolling Downs Groups, where the Tertiary surface has been stripped. Stream gradients are generally fairly low in these belts.

Alluvium, deposited by the major stream systems, has reduced the pre-existing relief in much of the basin. The history of this alluvium, which forms broad clayey plains whose gradient fits the streams, is complex and largely unknown.

Geological investigations

Geologists have worked in the Surat Basin for more than a century. The general geology is reviewed in the Explanatory Notes on the various 1:250 000 Sheet areas and in Day (1964); Day (1969) has summarized the history of palaeontological research; and the history of the search for petroleum is reviewed in Raggatt (1968). Since the early 1960s, intensive mapping programs by the Bureau of Mineral Resources (BMR) and Geological Survey of Queensland, and petroleum search activities by company geologists have completely revised our knowledge of the basin. Geologists who contributed substantially to the mapping programs included N. F. Exon, E. N. Milligan, B. R. Senior, B. M. Thomas, A. Mond, D. Burger, Danielle Senior, and Barbara Graham from BMR, and D. J. Casey and R. F. Reiser from the Geological Survey of Queensland.

Surface geology

Jack & Maitland (1895) mapped the intake areas of the Great Artesian Basin and from this work the 'Blythesdale Braystone' was recognized (Jack, 1895a, b). Reeves (1947) discussed the petroleum potential of the Roma area and produced the first detailed geological map; much of his nomenclature is still in use. Whitehouse (1954) made the first regional survey of the Great Artesian Basin and produced a map at a scale of 40 miles to an inch of the Mesozoic and Cainozoic rocks of Queensland, which was incorporated in the geological map of Queensland (Hill, 1953). Mack (1963) reviewed the surface and subsurface geology of the southern part of the Surat Basin, and presented a regional map of the area. Day (1964) mapped the Roma-Wallumbilla area in detail, and attempted to resolve the confused stratigraphic nomenclature current at that time.

The outcrop geology of the Surat Basin is now much better known because of the joint regional mapping program of BMR and the Geological Survey of Queensland (1965 to 1969; see map). This has been reported in detail in unpublished Records by Exon, Milligan, Casey, & Galloway (1967), Exon, Reiser, Jensen, Burger, & Thomas (1968), Thomas & Reiser (1968), and Exon, Mond, Reiser, & Burger (1972). All the 1:250 000 maps and Explanatory Notes covering the area have been published.

Senior (1971) has discussed the history of the Nebine Ridge, which bounds the Surat Basin to the west, and Exon, Langford-Smith, & McDougall (1970) have discussed the Early Tertiary period of deep weathering.

New nomenclature for the Jurassic Injune Creek Group was proposed by Exon (1966) and the Springbok Sandstone Lens within the group was elevated to formation status by Power & Devine (1968). New nomenclature for the marine Cretaceous was established by Vine, Day, Milligan, Casey, Galloway, & Exon (1967), who restricted Whitehouse's (1954) terms 'Roma' and 'Tambo' to the faunas alone. The Blythesdale Formation of Day (1964) has been replaced by the Mooga Sandstone and Bungil Formation of Exon & Vine (1970). Reiser (1970) proposed new nomenclature for the upper part of the Rolling Downs Group (marine Cretaceous) in the Surat area. Further subdivisions of the Injune Creek Group were made by Swarbrick, Gray, & Exon (1973). The outcrop nomenclature now in use, and its relation to older schemes are shown in Table 18.

A general review of the macrofauna and palaeogeography of the marine Cretaceous sequence in the Surat Basin is included in Day (1969).

Largely as a result of the surface mapping and because of the need to relate it to the subsurface geology, both BMR and the Geological Survey of Queensland carried out programs of stratigraphic drilling in the area.

The BMR drilling was carried out in conjunction with the mapping; the holes were up to 200 m deep, and cores were taken at selected intervals. The results have been reported in various BMR Records and also by Mond & Senior (1970) for the southwestern part of the basin and by Exon (1972a) for the northern and eastern parts of the basin.

The stratigraphic holes drilled by the Geological Survey of Queensland were up to 450 m deep, with a high proportion of coring. One project (see also Allen, 1971) was to provide representative material for the entire Surat Basin sequence; the results have been recorded by Gray (1968, 1972). Another project (Swarbrick, 1973) was to investigate the stratigraphy and economic potential of the Injune Creek Group.

Palaeontology

Palynology has proved to be the most useful stratigraphic tool for the basin as a whole. The Jurassic sequence was studied by de Jersey & Paten (1964), Paten (1967), and Reiser & Williams (1969). The Lower Cretaceous sequence has been intensively studied by Burger (1972, 1973, 1974, in prep.). Evans (1966) published a general review of Australian Mesozoic microfloras, including those from the Surat Basin. Lonergan (1973) reviewed the Triassic-Jurassic boundary in petroleum exploration wells in the southern part of the basin. Gould (1973) described fossil wood (*Osmundacaulis hoskingii*) from the upper part of the Injune Creek Group, and he also (Gould, 1974a) reviewed the entire fossil flora of the Walloon Coal Measures.

The study of marine Cretaceous shelly macrofossils has been outlined by Day (1964, 1969). Whitehouse (e.g. 1954) collected from the Roma area and established the existence of the characteristic Roma fauna. Day (1964) collected extensively from the Minmi Member of his 'Blythesdale Formation' and from the overlying Doncaster Member (his 'Roma Formation') and recognized similarities and differences between the two Aptian faunas. Day (1968) has described the Minmi fauna in considerable detail. Day (1969) presented faunal lists for four major faunas in the Surat Basin: the Nullawurt fauna of probable Neocomian age, the early Aptian Minmi fauna, the late Aptian Doncaster (=Roma) fauna, and the early Albian Coreena (=early Tambo) fauna. Day (1974) described most of the sparse Aptian ammonite fauna found in the Doncaster Member in the Surat Basin.

Haig (1973) produced the first broadly based study of the Early Cretaceous foraminifera of the Surat Basin.

Petroleum search

The search for petroleum is here divided into geophysical surveys, which were used to define most of the targets, and the subsequent drilling to assess the potential of these targets. Reports on selected geophysical surveys and petroleum exploration wells have been published (see Table 1).

BMR has carried out gravity surveys in the area since 1947, and the gravity contours are overprinted on the 1:1 000 000 scale geological map. The gravity contours are of considerable assistance in interpreting the distribution of the basement rocks.

Following early work by BMR (Dooley, 1950), which proved the value of the method, Union Oil Development Corp. made aeromagnetic surveys in the eastern part of the basin. The results were reported by Union & Adastra (1960), Kahanoff (1962), and Aero Service Corporation (1963). Our knowledge of the depth to basement in the deeper parts of the Bowen Basin depends entirely on these aeromagnetic data.

TABLE 1. RELEVANT PETROLEUM SEARCH SUBSIDY ACTS PUBLICATIONS

No. 22.	Associated Australian Oilfields N.L., 1964—AAO Pickanjinnie No. 1, Queensland, 36 pp.
No. 27.	Associated Australian Oilfields N.L., 1961—Eumamurrin (North Roma) seismic survey, 20 pp.
No. 34.	Associated Australian Oilfields N.L., 1962—South Roma seismic survey, Queensland, 1959, 12 pp.
No. 35.	Associated Australian Oilfields N.L., 1962—East Roma seismic survey, Queensland, 1959-1960, 18 pp.
No. 40.	J. E. Mack, Jr, Union Oil Development Corporation 1963—Reconnaissance geology of the Surat Basin, Queensland and New South Wales, 36 pp.
No. 43.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1964—UKA Cabawin No. 1, Queensland, 178 pp.
No. 44	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1964—UKA Cabwin East No. 1, Queensland, 56 pp.
No. 45.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation, 1964—UKA Moonie No. 1, Queensland, 94 pp.
No. 46.	Associated Australian Oilfields N.L., 1966—Summary of data and results, Surat Basin, Queensland: AAO Winnathoola No. 1, AAO Kooringa No. 1, AAO Pleasant Hills No. 1, 24 pp.
No. 51.	Associated Australian Oilfields N.L., 1964—AAO Combarngo No. 1, Queensland, 50 pp.
No. 53.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1964—Summary of data and results: Surat Basin, Queensland: UKA Wandoan No. 1, UKA Burunga No. 1, 20 pp.
No. 57.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1965—Summary of data and results: Surat Basin, Queensland: UKA Middle Creek No. 1, UKA Southwood No. 1, 18 pp.
No. 58.	Phillips Petroleum Company, Sunray DX Oil Company, and Queensland American Oil Company, 1965—Summary of data and results: Surat Basin, Queensland: PSQA Durabilla No. 1, PSQA Kogan No. 1, PSQA Kogan South No. 1, 30 pp.
No. 59.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1965—UKA Wandoan No. 1, Queensland, 58 pp.
No. 61.	Union Oil Development Corporation, Kern County Land Company, and Australian Oil and Gas Corporation Limited, 1965—Summary of data and results: Surat Basin, Queensland: UKA Flinton No. 1, UKA Coomrith No. 1, UKA Wunger No. 1, 26 pp.

The effectiveness of the seismic exploration method in this area was first shown by BMR surveys in the period of 1954 to 1960. Since then a great deal of reconnaissance and detailed seismic work has been done for the Associated Group in the Roma area, for Phillips Petroleum Co. in the Kogan-Cecil Plains area, and for Union Oil Development Corp. elsewhere in the basin (see relevant Explanatory Notes). Seismic surveys are now a normal prerequisite for all wildcat wells in the basin, and up to six persistent reflectors are present.

Successful exploration in the Surat Basin has been virtually confined to the Roma Shelf and to the Moonie and Alton areas. A general review of the main reservoirs in the Surat Basin is given by Hogetoorn (1968).

Various papers dealing with the Roma Shelf have been published by geologists of Mines Administration Pty Ltd; they include a review of exploration methods by Swindon (1965), a case history of fields and reservoirs by Swindon (1968), and a discussion of stratigraphic traps by Traves (1971). Sell, Brown, & Groves (1972) made a detailed study of hydrocarbon-producing Lower Jurassic sandstones, including their stratigraphy, lithology, and depositional environment. Detailed studies of selected gas fields have been carried out by Mines Administration and the Geological Survey of Queensland: the Bony Creek field by Power (1966), Pickanjinnie by Gray (1969), and Pine Ridge and Raslie by Hogetoorn (1970).

Similar studies of the Moonie and Alton areas were made by geologists of Union Oil Development Corp.; they include early reports on the Moonie oil strike by Graves (1963) and Moran & Gussow (1963), a report on the development of the field by

TABLE 2. RELEVANT UNION OIL DEVELOPMENT CORPORATION UNPUBLISHED GEOLOGICAL REPORTS
(Available in Geological Survey of Queensland library)

No. 2.	KELLER, A. S., 1960—Geology of the Cabawin Trend, Queensland, Australia.
No. 3.	McGARRY, D. J., 1960—Review of Mesozoic and Permian stratigraphy, related to the Bowen and Artesian Basin.
No. 5.	MACK, J. E., 1961—The geology of the Bowen and Surat Basins, Queensland.
No. 6.	WORIES, H., 1961—Subsurface correlations in Springsure-Roma area, and Bowen Basin, Queensland, Australia.
No. 7.	MACK, J. E., 1961—The geology of the southern part of the Surat Basin, Queensland and New South Wales.
No. 8.	MACK, J. E., 1962—Reconnaissance geology of the Surat Basin, Queensland and New South Wales, Australia.*
No. 9A.	KELLER, A. S., and WORIES, H., 1963—Relinquishment of a portion of Authority to Prospect 57P.
No. 11.	MACK, J. E., 1964—Subsurface geology of the Moonie Trend, ATP 57P, Queensland, Australia.
No. 13.	MACK, J. E., 1964—Subsurface geology of the Crowder-Weir Trend, ATP 57P, Queensland.
No. 16.	MACK, J. E., 1964—Subsurface geology of the Undulla Nose, ATP 57P, Queensland.
No. 17.	MACK, J. E., 1965—Geologic report on subsidised drilling operations: UKA Giligulgul No. 1, UKA Gurulmundi No. 1, UKA Weringa No. 1, Miles-Wandoan district, Bowen-Surat Basin.
No. 19.	KELLER, A. S., and BURROUGH, H., 1965—Relinquishment of a portion of Authority to Prospect 57P, Queensland, Australia.
No. 22.	HERRMANN, F. A., and KELLER, A. S., 1966—Relinquishment of a portion of Authority to Prospect 57P, Queensland, Australia.
No. 25.	CAREY, A. R., and KURASH, G. E., 1969—Relinquishment of a portion of Authority to Prospect 145P, Queensland, Australia.

* Published as Petroleum Search Subsidy Acts (PSSA) volume No. 40.

Pyle & Buckley (1965), and a discussion of reservoir conditions by Pyle (1967). Buckley, Bradley, & Zehnder (1969) have given case histories of the Moonie and Alton Oil Fields. Important unpublished geological reports by company geologists, which have been released, are listed in Table 2.

Possible oil migration paths in the Surat Basin have been discussed by Erickson (1965), Conybeare (1970), and Senior (1970. A study of correlations and lithofacies of the Jurassic sediments in the Cecil Plains/Ipswich area was carried out by Meyers (1970). Power & Devine (1970) have published the results of an important study of the subsurface stratigraphy, geological history, and petroleum accumulations in the Surat Basin, illustrated by a series of isopach maps. Exon (1974) has done the same for the Permo-Triassic sequence below the Surat Basin and the overlying Lower Jurassic sequence.

The present study

This study is an attempt to synthesize knowledge gained over the years during the surface mapping program with the great amount of information available from company geophysical and drilling activities. Several regional gravity and aeromagnetic surveys and scores of regional and detailed seismic surveys have been carried out, and almost 500 wells have been drilled since the late 1950s.

Many of these operations have been subsidized under the Commonwealth Petroleum Search Subsidy Acts, and the results are public. Many more were carried out in areas which have since been relinquished, and final reports are now obtainable from the Queensland Department of Mines. Some exploration companies have generously made available unsubsidized and confidential material for this study.

The petroleum exploration wells are concentrated in areas where success has been

TABLE 3. SOURCE OF GEOPHYSICAL DATA USED FOR STRUCTURE CONTOUR MAPS

Horizon	*Company*	*Report*	*Area*
Basement	UKA	Kahanoff* (1962)	Mimosa Syncline
	UKA	GR 19	Southwest
	UKA	GR 22	Southwest
	UKA	GR 25	Mimosa Syncline
	Minad	Not released	Roma Shelf
Permian 'S'	UKA	GR 25	Mimosa Syncline
Permian 'L'	UKA	GR 19	Northernmost part of Mimosa Syncline
	UKA	GR 22	Northern part of Mimosa Syncline
	UKA	GR 25	Mimosa Syncline
	Minad	Not released	North, including Mimosa Syncline
Evergreen 'G' and related horizons	UKA	GR 25	Mimosa Syncline and southwest
	Minad	Not released	North
	Phillips	Fjelstul & Beck (1963)	East
Walloon 'F'	UKA	United Geophysical Corp. (1963)	Southwest
	Minad	Not releasad	North

* This is an aeromagnetic survey, all others are seismic.
Note: GR = Union Oil Company geological report. These are relinquishment reports listed in Table 2.

achieved, particularly on the Roma Shelf and along the eastern hinge-line, but there are few wells in the middle of the Mimosa Syncline and in the western part of the basin. Fortunately, over 250 water bores have been wireline-logged in recent years as part of a continuing BMR program to provide hydrological and stratigraphic data in the Great Artesian Basin (see Appendix 5). These logs have been of great use, especially in areas where there are few petroleum exploration wells.

As a first step in this study, the best available seismic data for various horizons throughout the basin (Table 3) were reduced and generalized to provide structure contour maps; the main horizons involved were basement, the top of the Permian sequence, the Evergreen Formation Resistivity Marker, and the top of the Walloon Coal Measures.

Then several well correlation diagrams (Pls 2-8) were drawn up for the Jurassic-Cretaceous sequence and correlations were gradually established and modified until a coherent picture was obtained. Basically the correlation was lithological, with little emphasis on time-lines. Once these correlation lines had been established, other wells were correlated with those on the correlation lines, until some 260 wells had been correlated, giving as dense a coverage as was considered necessary. Then similar correlations were carried out using the wireline logs (gamma, neutron when available, and lithological) of 170 water-bores, and these were tied in with nearby petroleum exploration wells where possible.

This work has made use of additional (especially water-bore) data to that of Power & Devine (1970) and the intervals studied and conclusions arrived at vary significantly for parts of the sequence. Fewer data were available for the Permo-Triassic sequence and the correlations were mostly based on the checking of company picks, making use of the petrographic work and the correlations of the Institute Française du Petrole (Tissot, 1963; Fehr, 1965) and of BMR co-workers. Thus much less original work was involved than was the case with the Jurassic-Cretaceous sequence. It is considered that a full-scale study of the Permo-Triassic sequence would be very worthwhile.

Once well correlations and picks had been firmly established, seven structural maps at a scale of 1:1 000 000 were drawn (Pls 9-15), making use of the seismic compilations and the well and water-bore data. Isopach maps (e.g. Pls 16-21) were then drawn for selected intervals bounded by relatively distinctive horizons which could be traced basinwide and which were believed to be relatively time-synchronous. Finally, two palaeographic maps (Figs 17, 18) were drawn to show the sequence immediately above and below the pre-Jurassic unconformity, and the present structure of that unconformity.

The various correlation diagrams and maps form the basis for much of this Bulletin. The maps are not claimed to be accurate in detail, but are believed to present a coherent regional picture which was not previously available.

Acknowledgments

I most gratefully acknowledge my debt to the geologists of various companies for the great deal of help they have given me over the years—especially those of Mines Administration Pty Ltd, Union Oil Development Corp., Phillips Petroleum Co., and American Overseas Petroleum Pty Ltd. A close working relationship with the geologists of the Petroleum Section of the Geological Survey of Queensland has been of immense benefit.

Lithological nomenclature

Crook's (1960) classification of arenites is followed with slight modification. 'Arenite' is used as the generalized non-genetic term for sand-size clastic material. The generally accepted arbitrary figure of 75 percent matrix is taken as the division between arenite and mudstone. All the arenites described fall into Crook's genetic subdivision of 'sandstone'—traction current deposits. Sandstones in which quartz forms more than 90 percent of the clasts are called 'quartzose'; 75 to 90 percent, 'sublabile'; less than 75 percent, 'labile'; and less than 30 percent, 'very labile'. If the feldspar : lithic ratio is greater than 3:1, or less than 1:3 respectively, the qualifying terms 'feldspathic' or 'lithic' can be used with 'sublabile sandstone'; 'labile sandstone' can be 'feldspathic sandstone' or 'lithic sandstone'; and very labile sandstone can be 'very feldspathic' or 'very lithic'.

'Siltstone' is used as a grainsize term (1/16-1/56 mm). 'Mudstone' is used as a general term for non-fissile sediments of the lutite class, and 'shale' is defined as a fissile mudstone. 'Claystone' is used for sediment consisting dominantly of clay minerals.

The Wentworth Scale has been followed for grainsize terminology (Pettijohn, 1957).

STRUCTURE

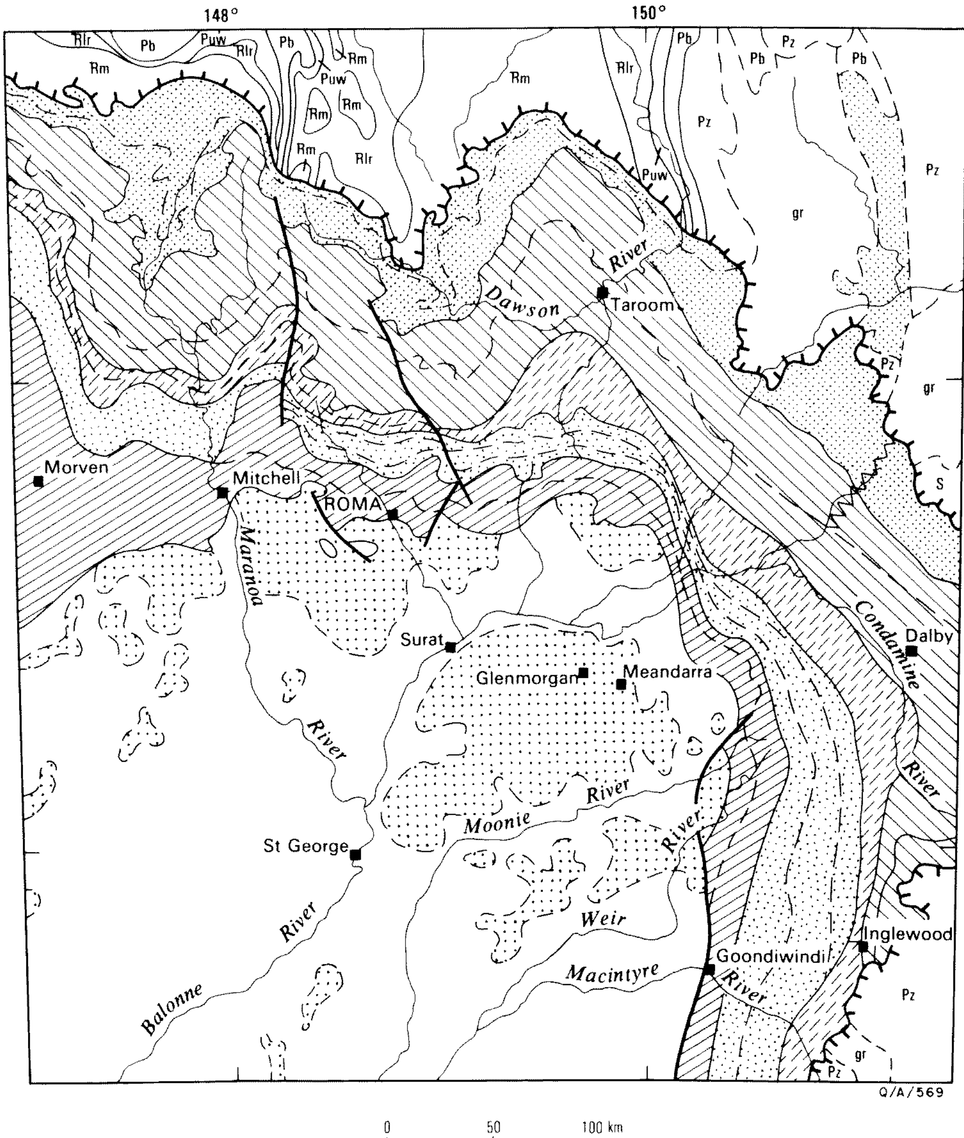
The relation of the Bowen and Surat Basins to the surrounding structures is shown in Figure 1; the solid geology of the area studied is outlined in Figure 5 and the main structural units in Figure 6.

The meridional Bowen Basin is bounded in the east by the line of thrust faults along the western edge of the South Coastal Structural High (Auburn Arch) and the New England Fold Belt, and in the southwest by the St George/Bollon Slope. It intertongues with the Galilee Basin across the Nebine Ridge and with the Gunnedah Basin across the Narrabri Structural High.

The Surat Basin is bounded in the east by the Auburn Arch and the New England Fold Belt; between these two basement blocks it intertongues with the Moreton Basin across the Kumbarilla Ridge. To the west it intertongues with the Eromanga Basin across the Nebine Ridge and its broad southerly extension, the Cunnamulla Shelf. In the south it is bounded by the Central West Folded Belt, and in the north it has been eroded.

By comparing Figures 6 and 7, the basis of the subdivision into structural units within the Surat Basin becomes apparent. The dominant feature of the structure contours of the basement surface* (Fig. 7) is the meridional Taroom Trough, bounded in the east by the Burunga-Leichhardt Fault Zone and the Goondiwindi-Moonie Fault Zone, both of which are thrusts, and in the west by

* 'Basement' is here regarded as the rocks which were present before Bowen Basin sedimentation began, together with Permo-Triassic batholiths.



Boundary of isopached intervals

Other geological boundaries

Cainozoic Alluvium

Rolling Downs Gp (younger than Kld)

Doncaster Mbr (Kld) and Bungil Fm (Kly)

Hooray Sst (J-Kh), Mooga Sst (Klm), Orallo Fm (Juo), Gubberamunda Sst (Jug)

Westbourne Fm (Juw), Adori Sst (Ja), Springbok Sst (Js), Pilliga Sst (Jp)

Walloon Coal Meas (Jw), Hutton Sst (Jlh), upper Marburg Sst (Jlm_1)

Evergreen Fm (Jle), Precipice Sst (Jlp), lower Marburg Sst (Jlm_2), Mulgildie sequence (Jm)

Base of Surat Basin

Fault

Rm — Moolayember Fm, Clematis Gp

Rlr — Rewan Gp

Puw — Blackwater Gp

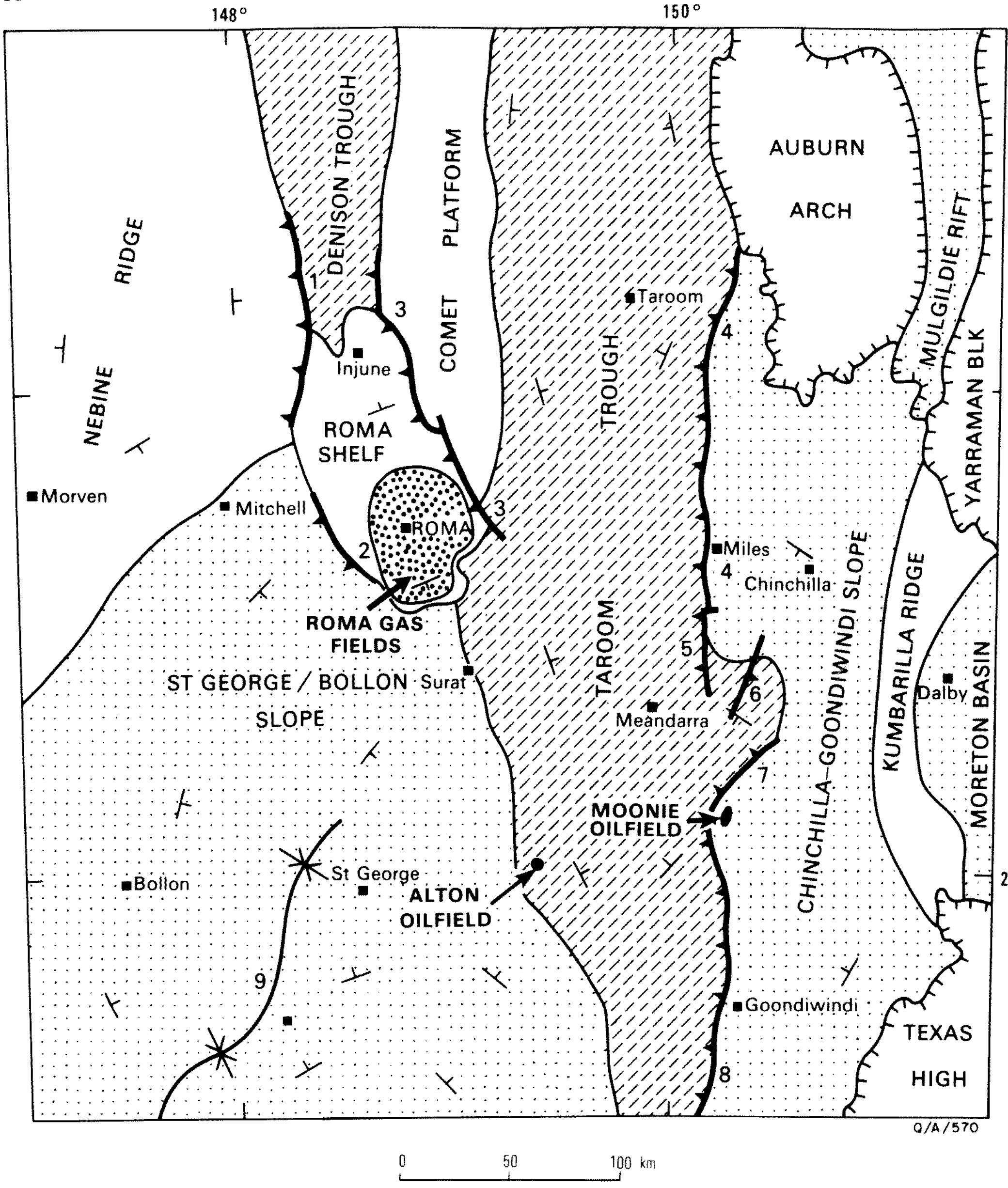
Pb — Back Creek Gp

Pz — Palaeozoic volcanics and sediments

gr — Granite

S — Schist and gneiss

Fig. 5. Solid geology.



1 *Merivale Fault zone*
2 *Abroath Fault zone*
3 *Hutton–Wallumbilla Fault zone*
4 *Burunga Fault zone*
5 *Leichhardt Fault*
6 *Undulla Fault*
7 *Moonie Fault*
8 *Goondiwindi Fault*
9 *Dirranbandi Syncline*

Outcrop boundary of structural unit
Subsurface boundary of structural unit
Fault (teeth on downthrow side)
Regional dip of basement surface

Fig. 6. Structural elements.

the Nebine Ridge, the Roma Shelf, and the St George/Bollon Slope. From a study of seismic and gravity data and ERTS imagery, Bourke (1974b) has concluded that the Goondiwindi Fault in the Warialda area of northern New South Wales is definitely a thrust and suggests that it may be continuous with the Hunter-Mooki Thrust system to the south. Between the Moonie and Undulla Faults is a northeasterly trending graben which may be an extension of the Mulgildie Rift, as suggested by Power & Devine (1970). Few data exist on the intervening region, although the Target Stockyard Creek No. 1 well has shown that there cannot be a large connecting graben. Between the Undulla and Macintyre Faults is the south-southwesterly-plunging Undulla Nose.

The Taroom Trough is 10 000 m deep in the north, shallowing to about 1600 m in the south. The thrust faults on the eastern margin give the trough the general appearance of a half-graben; the displacement on the faults decreases from over 2000 m in the north to less than 1000 m south of Moonie. The regional basement slope into the trough is about 15° in the northeast, but in the northwest the slope is more gradual except in the deeper part of the basin. In the south the regional slope is variable, but seldom exceeds 5° except near faults.

The St George/Bollon Slope and the Chinchilla-Goondiwindi Slope fall toward the Taroom Trough at less than 1°. A noteworthy feature of the St George/Bollon Slope is the northeasterly-falling depression that coincides in part with the Dirranbandi Syncline and is extensively faulted (United Geophysical Corp., 1963).

Two major fault systems are associated with the Roma Shelf. The Hutton-Wallumbilla Fault trends north-northwest and has a westerly downthrow of up to 800 m in the north. The Merivale and Arbroath Faults, which form the western limit of the Roma Shelf, may be separate structures on the same line of weakness. The maximum westerly downthrow on the northerly-trending Merivale Fault, which is probably a thrust, exceeds 1000 m; on the northwesterly-trending Arbroath Fault it is about 1200 m. Both faults are bounded in the west by narrow half-grabens filled with pre-Jurassic sediments—the Merivale and Arbroath Troughs.

The structure contours on the top of the Permian coal measures (Fig. 8) are subdued reflections of contours on the basement map, with dips generally only half as steep. They show that the Permian sequence is largely confined to the Taroom and Denison Troughs, although it is also present on the Roma Shelf and the northern part of the Nebine Ridge. The deepest area, some 6000 m below sea level, is near Taroom.

The structure contours on the top of the Evergreen Formation (Fig. 9), constructed on a Lower Jurassic (early Surat Basin) horizon, still show the marked influence of the basement topography. The axis of the Mimosa Syncline faithfully follows that of the Taroom Trough, but the basin is much broader and shallower than the trough. The deepest part of the basin has migrated to the south of Taroom, to near Meandarra, where it is 1800 m below sea level. Displacement on the major faults seldom exceeds 200 m.

The structure contours on the top of the Walloon Coal Measures (Fig. 10) at about the top of the Middle Jurassic show the declining influence of the Bowen Basin on the Surat Basin. Superimposed on the meridional structure of the Mimosa Syncline is a southwesterly-trending depression through St George and Dirranbandi that corresponds with a depression in the basement (Fig. 7). The deepest parts of the basin lie along this depression, and range from 1300 m below sea level near Meandarra to 1100 m near Dirranbandi. Dips are generally very gentle, and fault displacements are slight.

The structure contours on the top of the Mooga and Hooray Sandstones (Fig. 11) and the contours on the top of the Doncaster Member (Fig. 12) are essentially similar and not very different from the structure of the top of the Walloon Coal Measures (Fig. 10). Figure 11 shows that the deepest part of the basin, between Meandarra and Talwood, is 650 m below sea level. The southwesterly-trending depression through

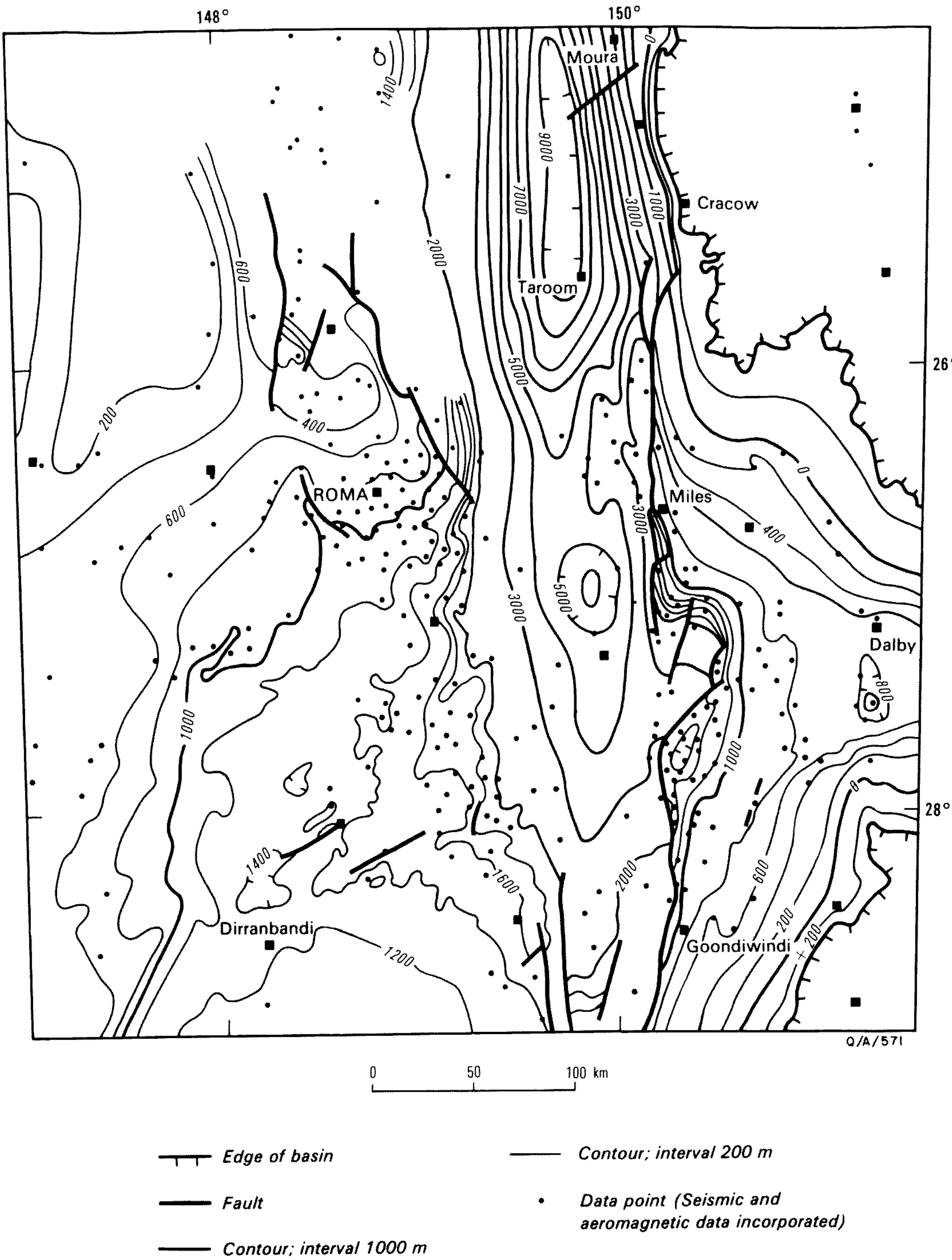
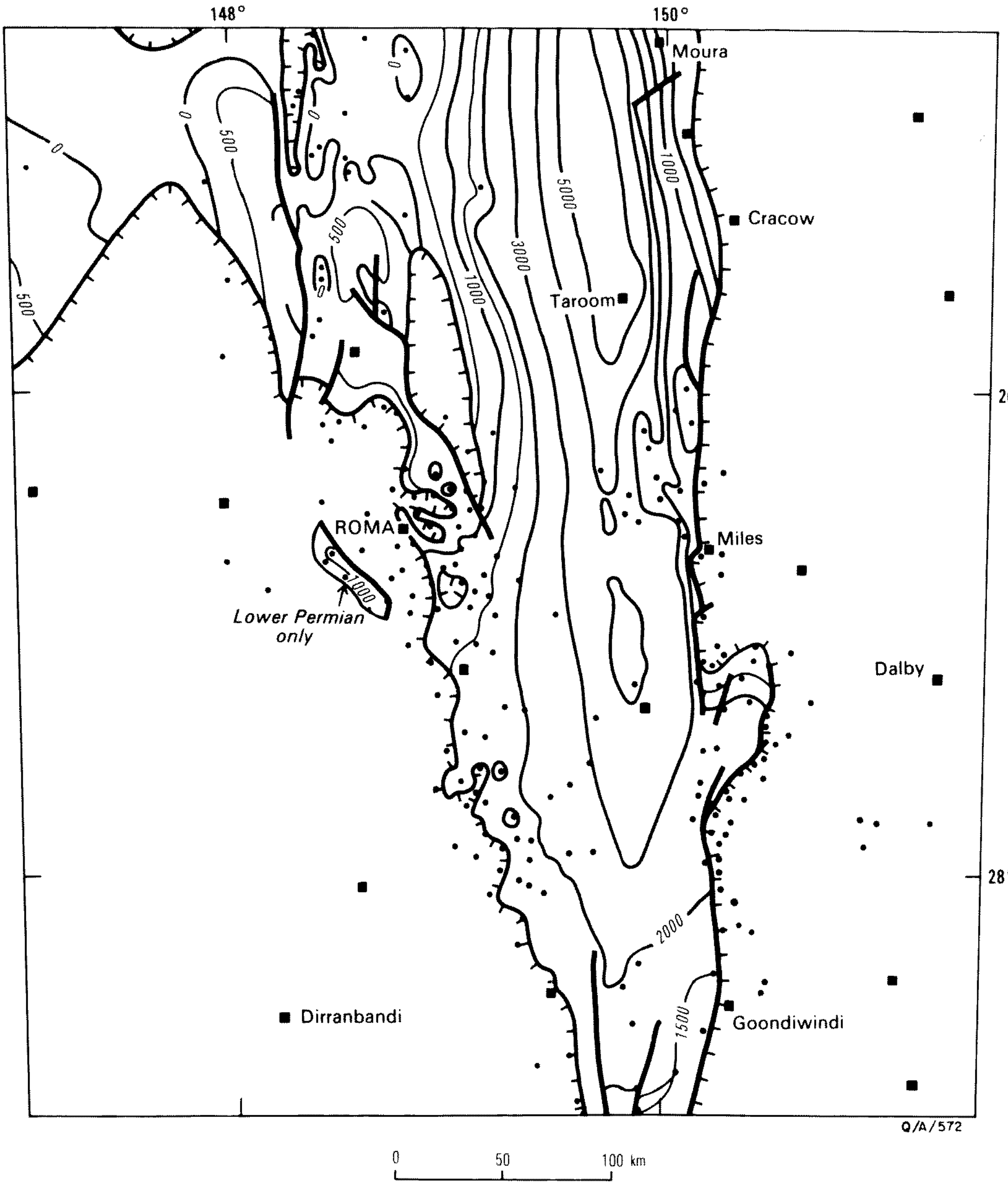


Fig. 7. Structure contours, top of basement, and basement rock types.



Limit of Upper Permian sequence

Fault

Data point (Seismic data incorporated)

Contour; interval 1000 m

Contour; interval 500 m

Fig. 8. Structure contours, top of Permian sequence.

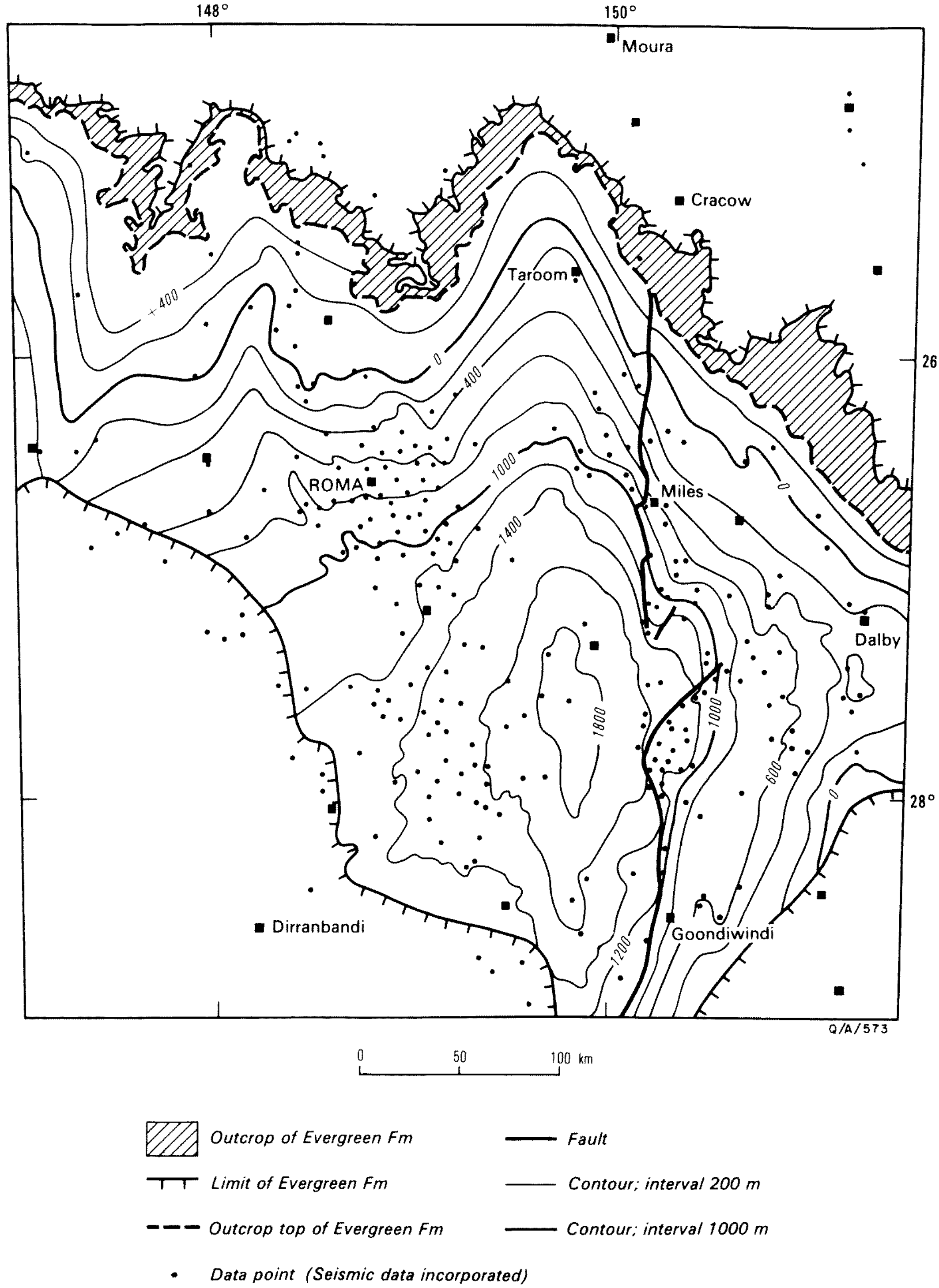


Fig. 9. Structure contours, top of Evergreen Formation.

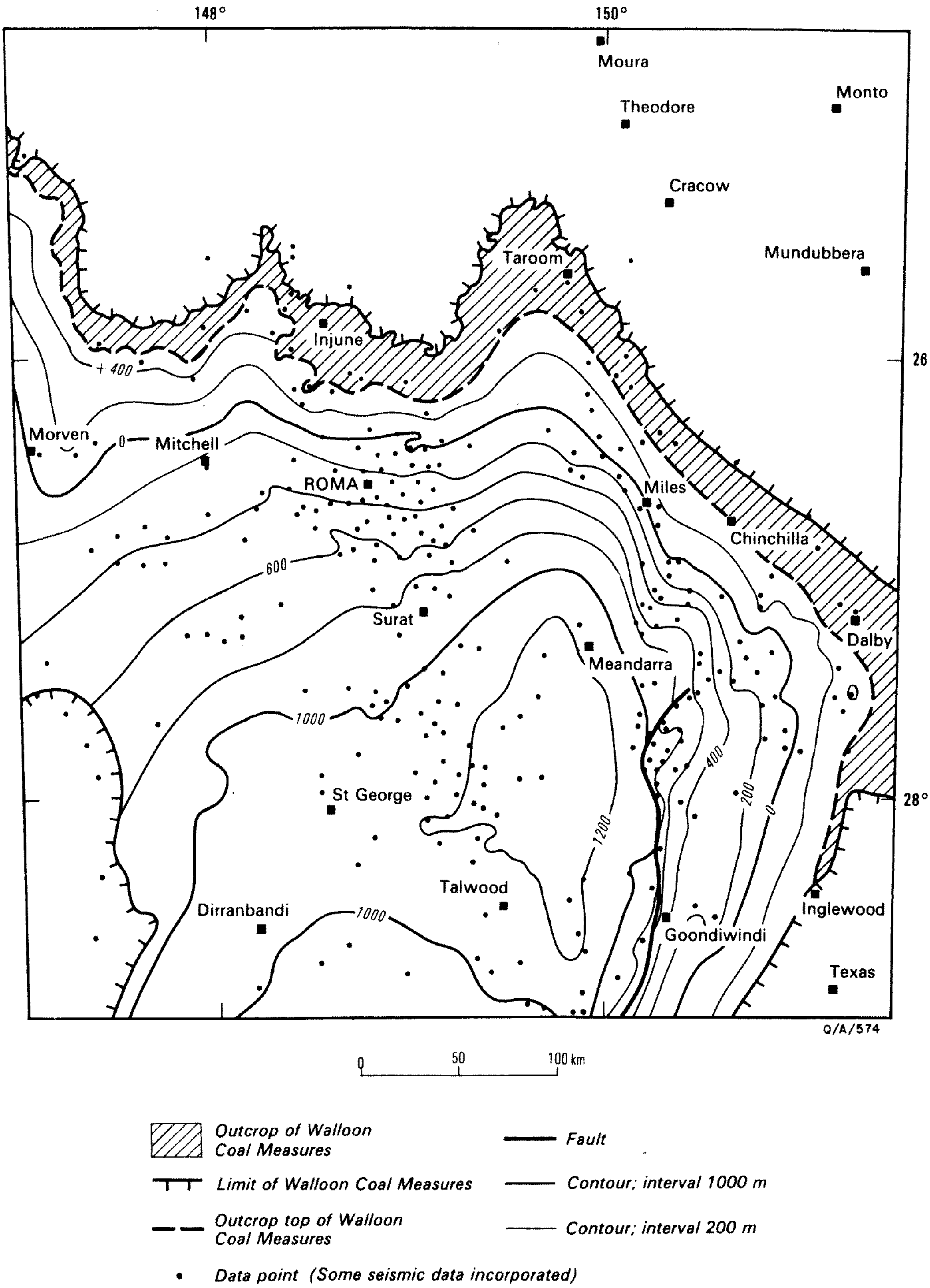


Fig. 10. Structure contours, top of Walloon Coal Measures.

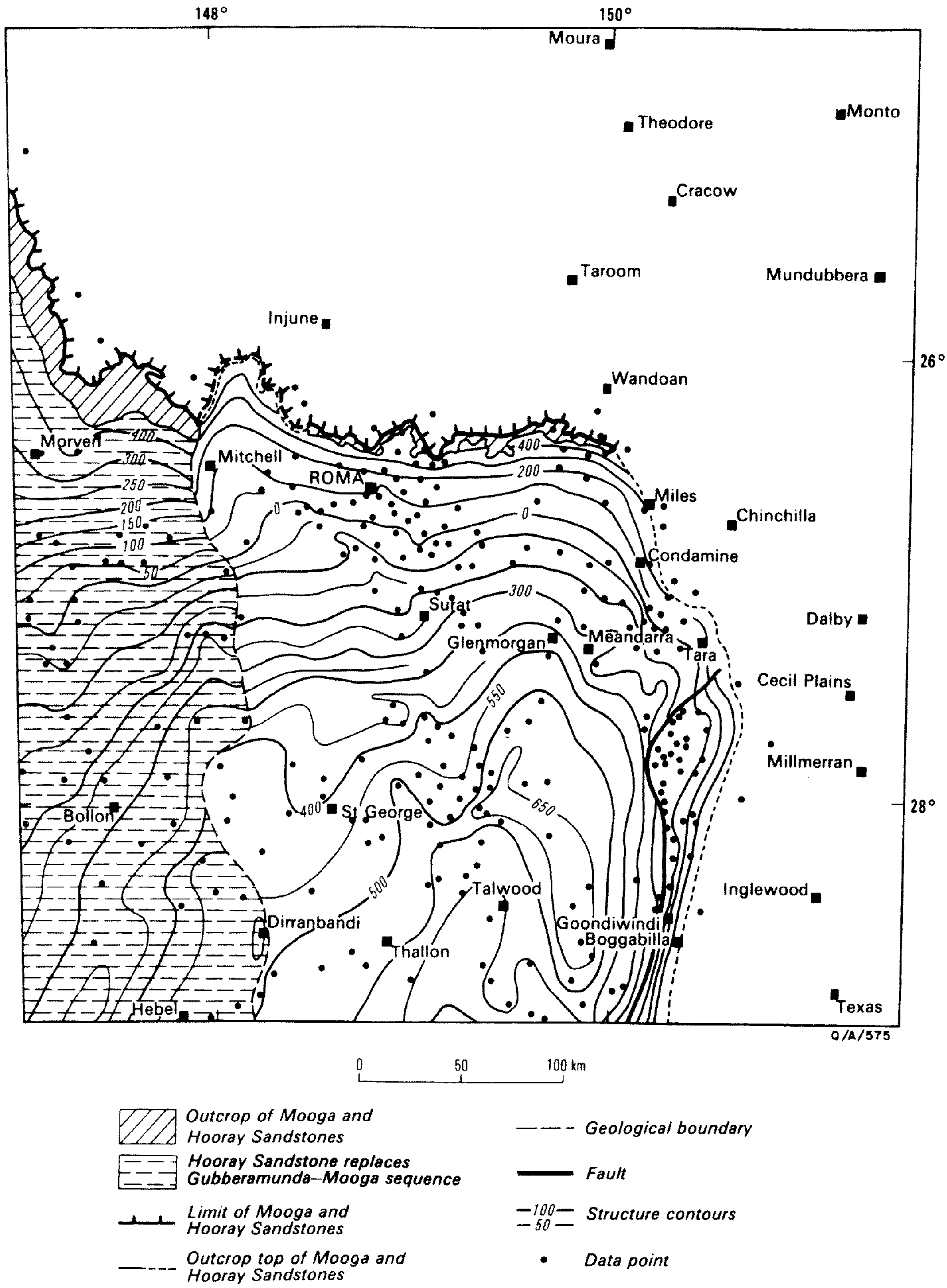


Fig. 11. Structure contours, top of Mooga and Hooray Sandstones.

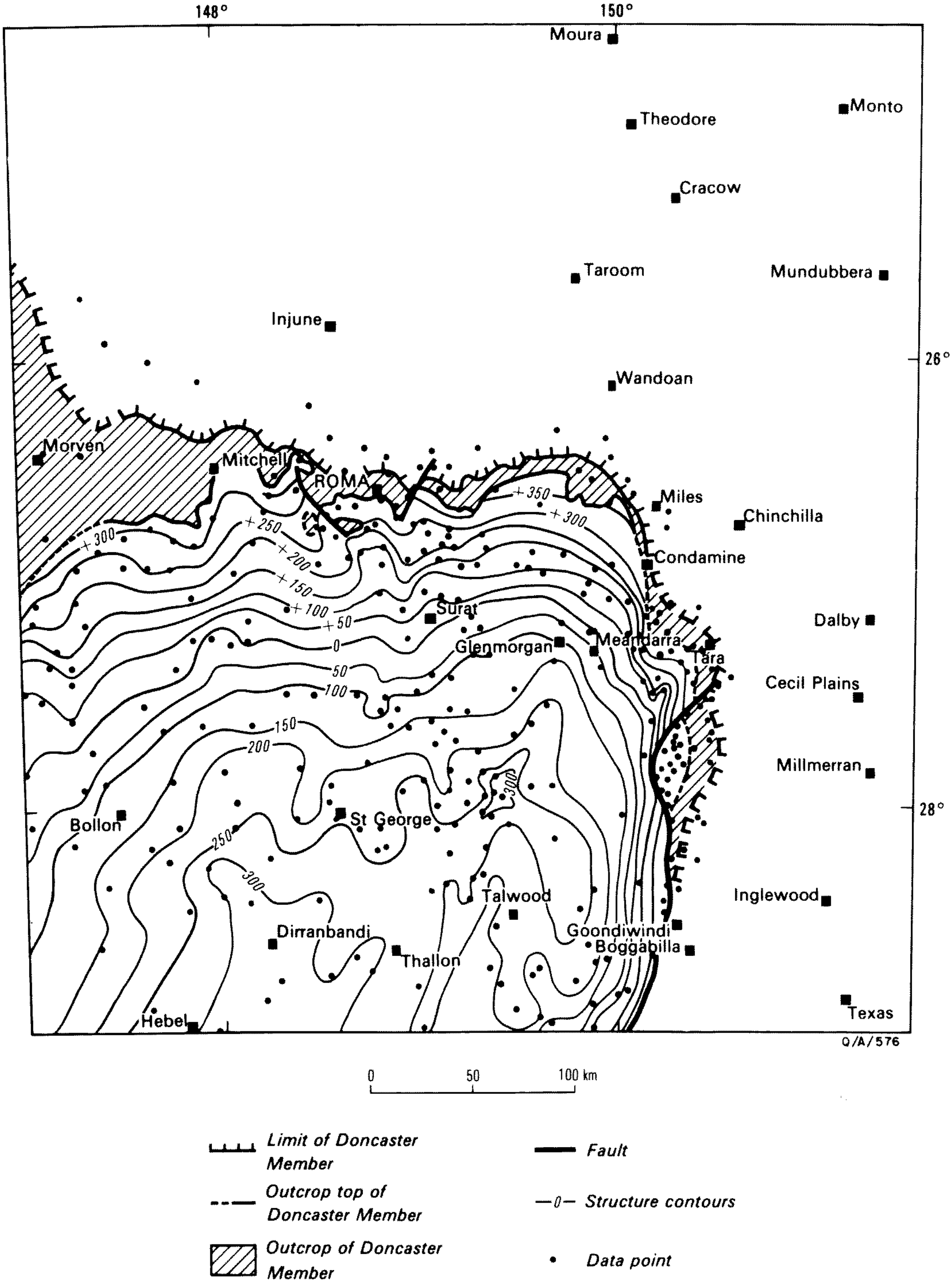


Fig. 12. Structure contours, top of Doncaster Member.

TABLE 4. GENERAL STRATIGRAPHY

	Unit	*Maximum Thickness* (m)	*Environment of Deposition and Lithology*
Albian	Griman Creek Formation	480	Paralic and freshwater: sandstone, siltstone, mudstone
	Surat Siltstone	150	Marine: siltstone, mudstone, sandstone
	Coreena Member (Wallumbilla Formation)	210	Paralic and freshwater: siltstone, mudstone, sandstone
U. Aptian	Doncaster Mudstone (Wallumbilla Formation)	270	Marine: mudstone, some siltstone
Neocomian to L. Aptian	Bungil Formation	270	Freshwater and paralic: mudstone, siltstone, sandstone
Neocomian	Mooga Sandstone	300	Freshwater: sandstone, some siltstone and mudstone
U. Jurassic	Orallo Formation	270	Freshwater: labile sandstone, siltstone, mudstone, coal
	Gubberamunda Sandstone	300	Freshwater: sandstone, some silstone and conglomerate
	Westbourne Formation	200	Freshwater and possibly paralic: siltstone, mudstone, sandstone
M.-U. Jurassic	Springbok Sandstone	250	Freshwater: labile sandstone, siltstone, mudstone
M. Jurassic	Walloon Coal Measures	650	Coal measures: labile sandstone, siltstone, mudstone, coal
	Eurombah Formation	100	Freshwater sandstone, some conglomerate, siltstone and mudstone
L. Jurassic	Hutton Sandstone	250	Freshwater: sandstone, some siltstone and mudstone
	Evergreen Formation	260	Freshwater and paralic: siltstone, mudstone, sandstone
Unconformity	Precipice Sandstone	150	Freshwater: quartzose sandstone, some siltstone and mudstone
Youngest L. Triassic -M. Triassic	Wandoan Formation (= Clematis Gp + Moolayember Fm)	1800	Freshwater: sandstone, siltstone, shale, conglomerate
L. Triassic	Rewan Group (= Cabawin Fm)	3500	Redbeds: mudstone, siltstone, multicoloured sandstone
U. Permian	Blackwater Group	700	Coal measures: shale, siltstone, sandstone, coal
L.-U. Permian	Back Creek Group	3000	Marine and paralic: shale, siltstone, sandstone, conglomerate
L. Permian	Reids Dome Beds	2500	Freshwater: conglomerate, sandstone, siltstone, shale, coal

Dirranbandi is a prominent feature and a meridional rise between Talwood and Mungindi is a new feature.

Figure 12 still shows the reflection of the old trends but the results of the Late Jurassic and Tertiary epeirogenic movements are predominant. There is a general southerly tilt in much of the basin, and the deepest areas, 300 m below sea level, are around Dirranbandi and in a small depression north of Talwood. The meridional rise west of Talwood is almost joined to a rise extending south of Surat, giving the basin a bilobate appearance. Displacement on the Goondiwindi-Moonie Fault and the various faults around Roma does not exceed 100 m.

In general, tectonic movement in the area took the form of thrusting and asymmetrical folding in the Late Permian and Triassic and of normal faulting and related folding thereafter. In Permo-Triassic time uplift and intrusion in the east combined with east-west compression gave rise to the eastern zone of thrust faulting. The Merivale Fault is probably a thrust which developed in response to the east-west compressive stress but in contrast, the Arbroath Fault is an older (Early Permian) normal fault that developed before compression. Post-Triassic movements seem to have been related to isostatic readjustment, with limited movements on old fault lines, downwarping in areas of sediment accumulation, and draping over basement rises.

The epeirogenic movements of the Late Jurassic and mid-Tertiary led to broad tilting to the south and west, and slight movements on the old faults. The Tertiary epeirogenic movements were associated with widespread intrusion and extrusion of basic rocks. Together the two periods of epeirogenic movement led to uplift of over 1000 m in the north and somewhat less in the east.

GEOLOGICAL EVOLUTION

The general stratigraphy of the area is summarized in Table 4 and more detailed stratigraphic information is provided on pages 66 *et seq*. An outline of the evolution of the stratigraphic nomenclature for the Bowen Basin is given in Table 13 and for the Surat Basin in Table 18.

The rocks which existed in this area before sedimentation began in the Bowen Basin in the Early Permian, as well as the Permo-Triassic batholiths, are regarded as basement. Their distribution is shown in Figure 7. The Devonian Timbury Hills Formation, which consists of indurated and deformed sediments and metasediments, underlies most of the western half of the area, and the Carboniferous to Permian sedimentary rocks and volcanics of the 'Kuttung Formation' occupy most of the eastern half.

The Timbury Hills Formation is composed mainly of terrestrial rocks that were deformed during the Carboniferous Kanimblan Orogeny, when the Roma granites (and possibly the granites near Talwood and south of Mungallala) were intruded. The large area of schist and gneiss south of Morven, and the smaller area near St George may be related to this period of intrusion, or could be older.

The 'Kuttung Formation' is marine in part and was laid down in Late Carboniferous and Early Permian time. It was folded and intruded by the Auburn granite during the same general time span, and was further deformed and intruded by the granites of the Yarraman Complex during the Permo-Triassic Hunter-Bowen Orogeny.

Bowen Basin

By Early Permian time, the area described comprised an exposed stable western block composed of sediments and metasediments of the Timbury Hills Formation buttressed by bodies of schist, gneiss, and granite and a less stable eastern area consisting of Carboniferous and Permian volcanics and sediments, which formed the floor of a shallow sea. As a result of subsidence during the Permian, as much as 4000 m of sediment accumulated (Fig. 13).

While the Lower Permian Camboon Andesite and its equivalents were being extruded, and some of the Auburn granites were being intruded, the thick coal measures of the Reids Dome Beds were laid down in the newly formed half-graben west of the Arbroath Fault, and farther north in the Denison Trough.

In Early Permian (Artinskian) time, volcanism declined and the predominantly marine sediments of the Back Creek Group were laid down north and east of the emergent basement block. This steady thickening to the northeast, from a veneer near Roma to 3000 m north of Taroom, suggests that subsidence took place to the east of a hinge-line along the western side of the present-day Taroom Trough. Marine micro-organisms and terrestrial plant debris are abundant in the sediments, which accumulated at a rate probably as high as 15 cm per 1000 years*. Transgressions and regressions took place in some areas.

The sea withdrew in the Late Permian and the basin was filled with sediment, which

* All rates of subsidence refer to compacted sediment.

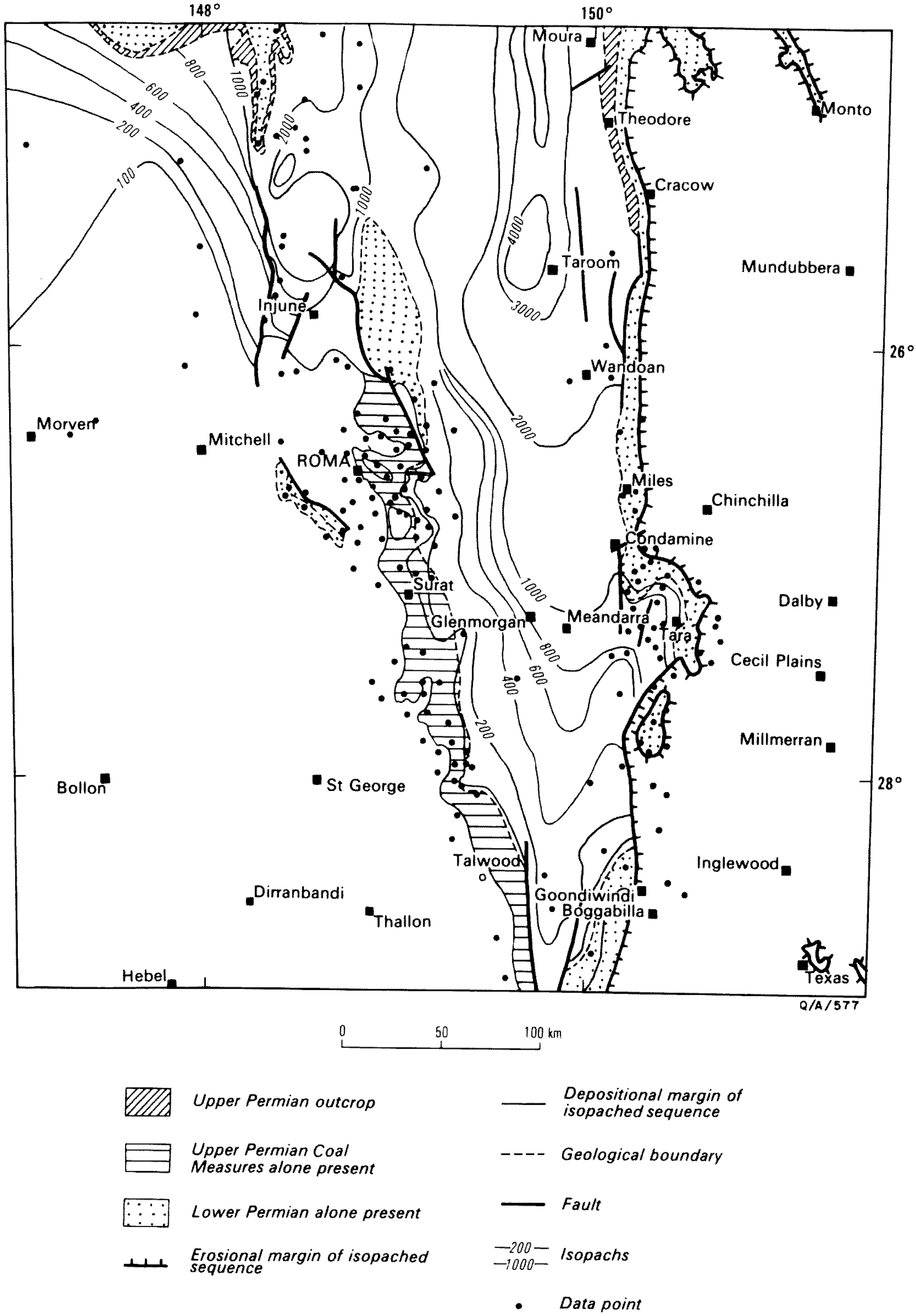
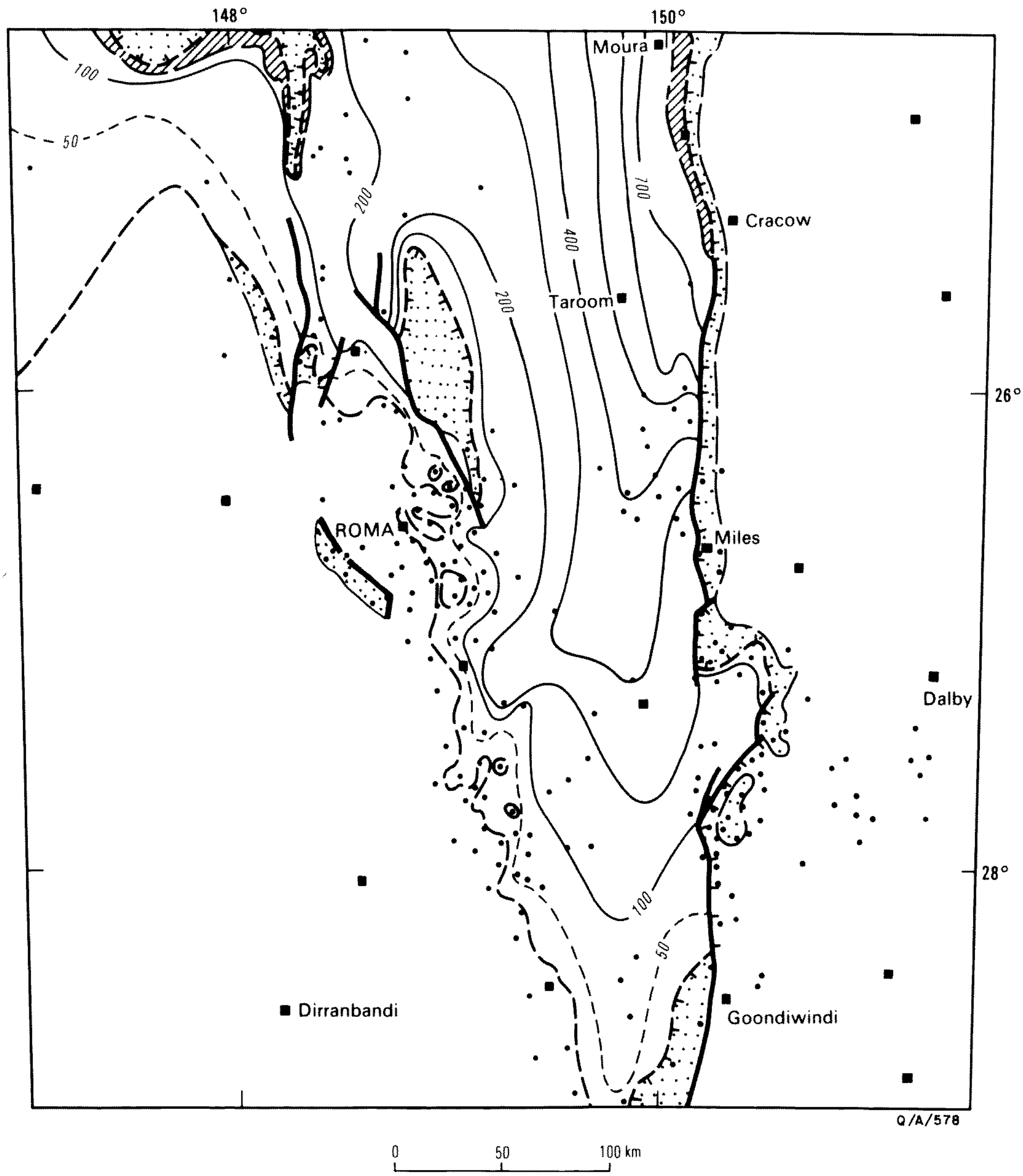


Fig. 13. Thickness of Permian sequence.



Back Creek Group (L to U Permian) only

Blackwater Group (U Permian) outcrop

Erosional margin

Data point

Depositional margin

Other geological boundary

Fault

Isopach; interval 100 m

Isopach; interval 50 m

Fig. 14. Thickness of Blackwater Group.

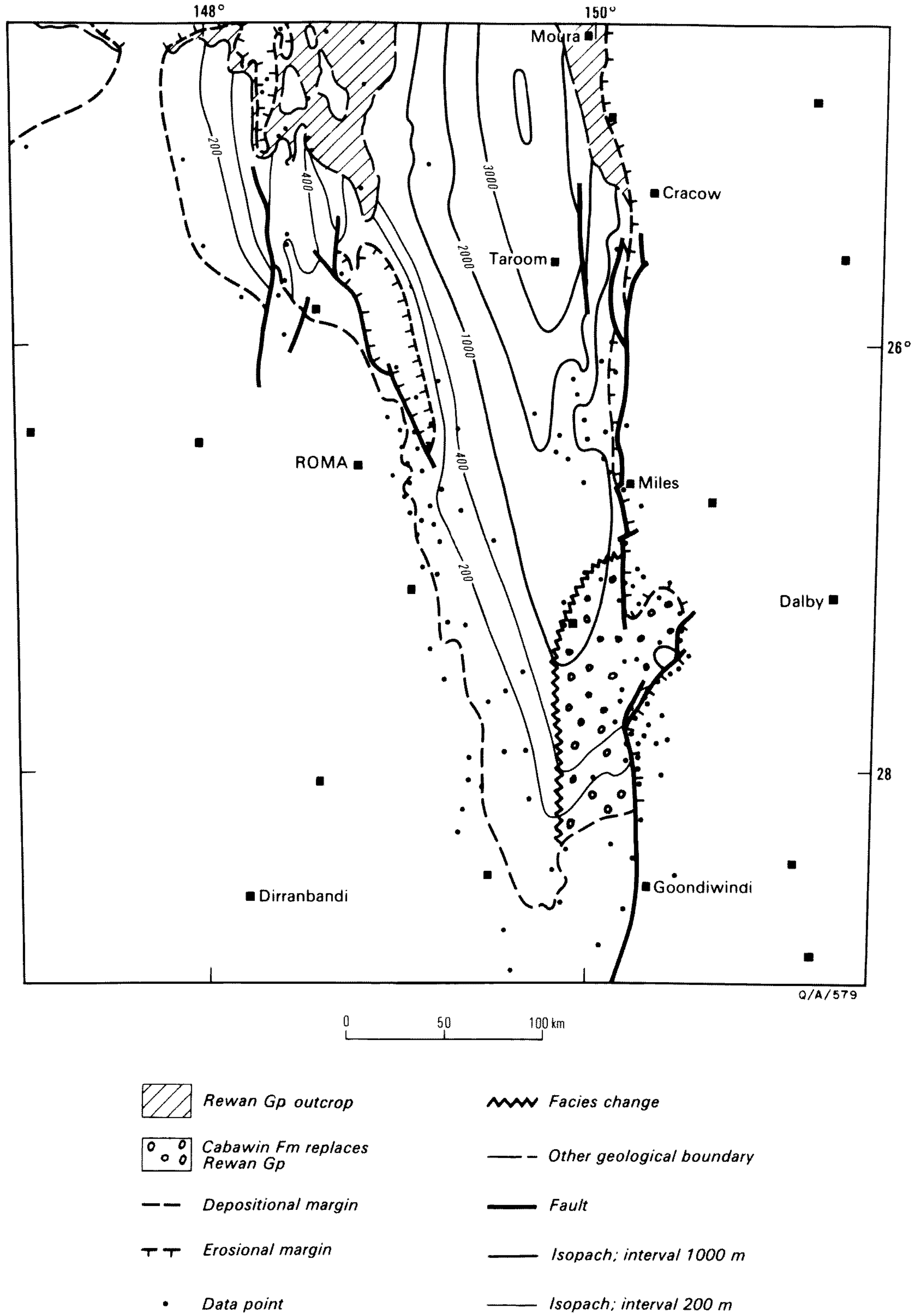


Fig. 15. Thickness of Rewan Group and Cabawin Formation.

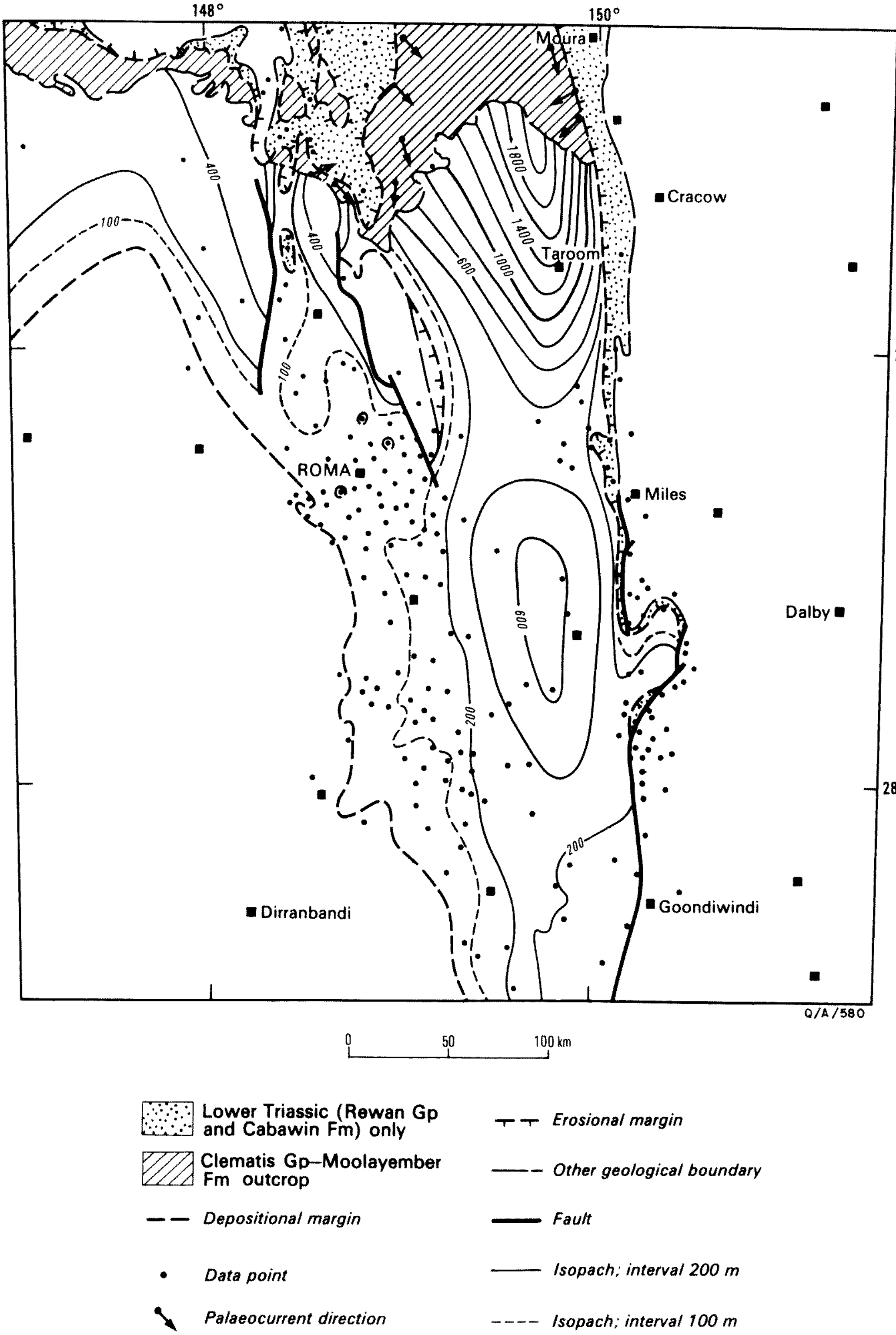


Fig. 16. Thickness of Wandoan Formation.

lapped onto the southwestern block. Coal accumulated in swamps on an extensive coastal plain, but the rate of sedimentation was lower, at about 7 cm per 1000 years. Toward the end of the Late Permian, widespread granite emplacement took place in the east, and uplift of the Texas High began in the southeast. These movements were associated with compression and overthrusting from the east. The basinward thickening evident in the south in the Late Permian (see Fig. 14) suggests that the Taroom Trough was beginning to form. In the north, however, where the sequence thickens to the east, it appears that the eastern side of the trough had not yet been developed, or that its axis lay farther east.

In Early Triassic time, the coal swamps dried up and the fine-grained terrestrial redbeds (derived from red soils on nearby uplands) of the Rewan Group were laid down in a more restricted area than the coal measures (Fig. 15). South of Miles, Triassic sediments lapped against the coal measures which were being tilted and uplifted to form the present structural basin. The Goondiwindi-Moonie and Leichhardt Faults were formed during the emplacement of the Triassic granites in the southeast. Along the margins of the faults massive conglomerates of the Cabawin Formation, derived from the Permo-Carboniferous terrain, were deposited South of Goondiwindi redbeds are absent.

North of Roma the Triassic sequence is generally conformable with the coal measures, except where movements on the Hutton-Wallumbilla and Merivale Faults led to the stripping of any coal measures on upthrown blocks. The thickening of the sequence to the northeast from Roma to beyond Taroom (Fig. 15) shows that there the eastern margin of the Taroom Trough had still not been formed, and the Rewan Group was laid down conformably on the coal measures. In the northeast, the rate of deposition of the Rewan Group may have exceeded 30 cm per 1000 years.

From the late Early Triassic onwards other terrestrial sediments gradually replaced the redbeds, and the Wandoan Formation (mainly Middle Triassic) was laid down (Fig. 16). It lapped much farther onto the southwesterly basement block than any of the earlier units. The Wandoan Formation is generally conformable on the Rewan Group and Cabawin Formation but in the south and on parts of the Wandoan Axis (the anticline on which UKA Wandoan No. 1 was drilled) it is unconformable on the Permian coal measures. Further movements on the Hutton-Wallumbilla and Merivale Faults meant that upthrown blocks covered with Permian and Rewan Group sediments were exposed during the deposition of the Wandoan Formation. The thinning of the sequence towards the fault zone to the east of Taroom (see Fig. 16) indicates that the thrust-faults bounding the Taroom Trough to the northeast, including the Burunga Fault, had begun to develop. The maximum rate of deposition of about 20 cm per 1000 years occurs along the axis of the trough north of Taroom.

At the close of the Middle Triassic the southwest basement block was still exposed, but extensive plains underlain by sediments of the Wandoan Formation extended across the Taroom Trough between the basement block and the uplifted block to the east of the Burunga - Moonie - Goondiwindi Fault Zone.

In the Late Triassic the compressional forces declined, and movement on the thrust faults bounding the Taroom Trough ended, deposition ceased, and widespread erosion took place. The sediment liberated during this period of erosion may have been deposited in and beyond the Moreton Basin, and most of the intrusions, which are now exposed in the basement, were exhumed during this erosional period.

Thus deposition in the Bowen Basin was fairly rapid, with sedimentation rates averaging 20 cm per 1000 years. The gross sequence of events was: marine deposition, followed by the deposition of coal measures, redbeds, and other terrestrial beds, and finally, erosion. The thrust-faulting associated with the development of the Taroom Trough began in the Early Triassic in the south and ended in the Middle or Late

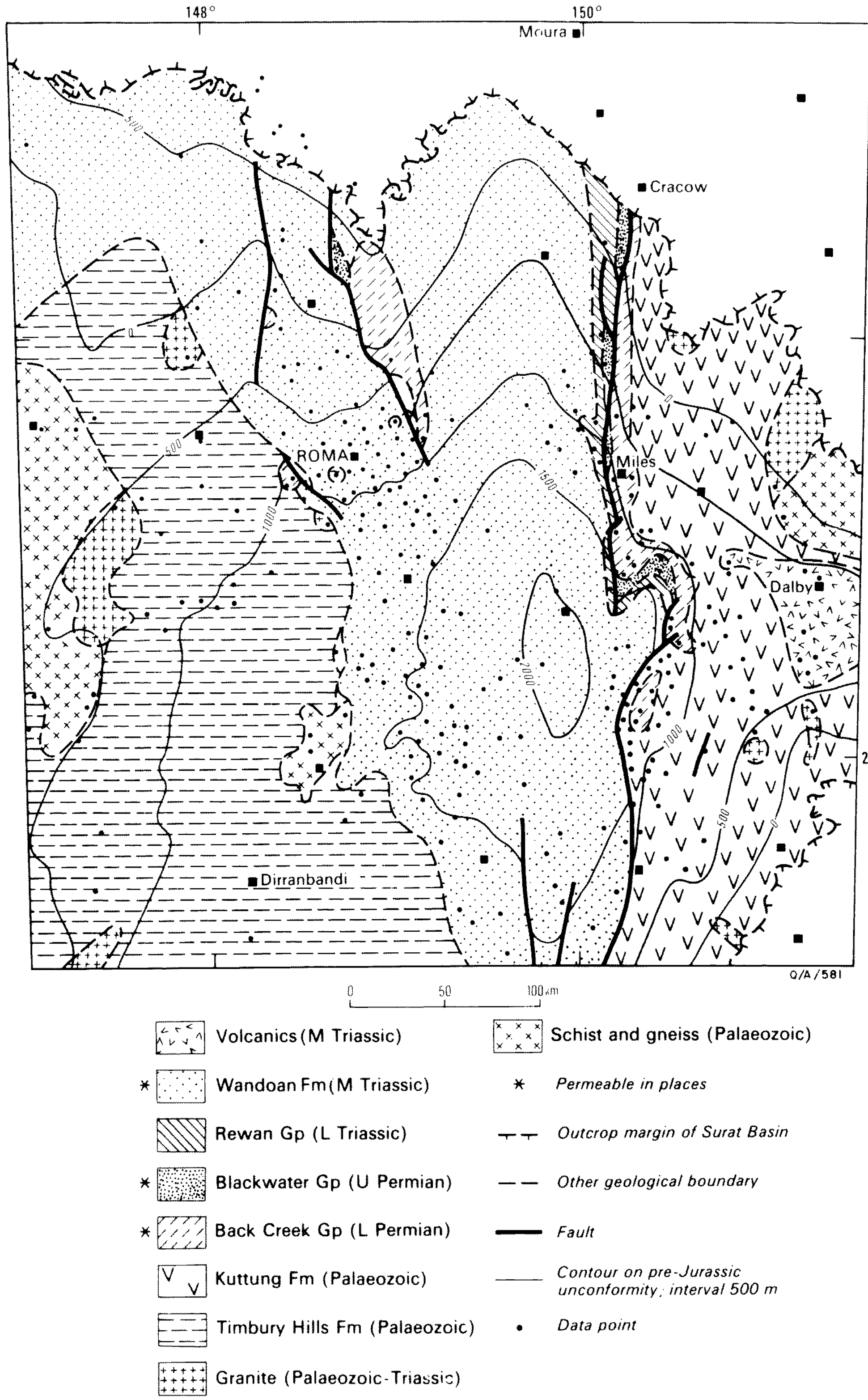


Fig. 17. Units immediately below the Surat Basin.

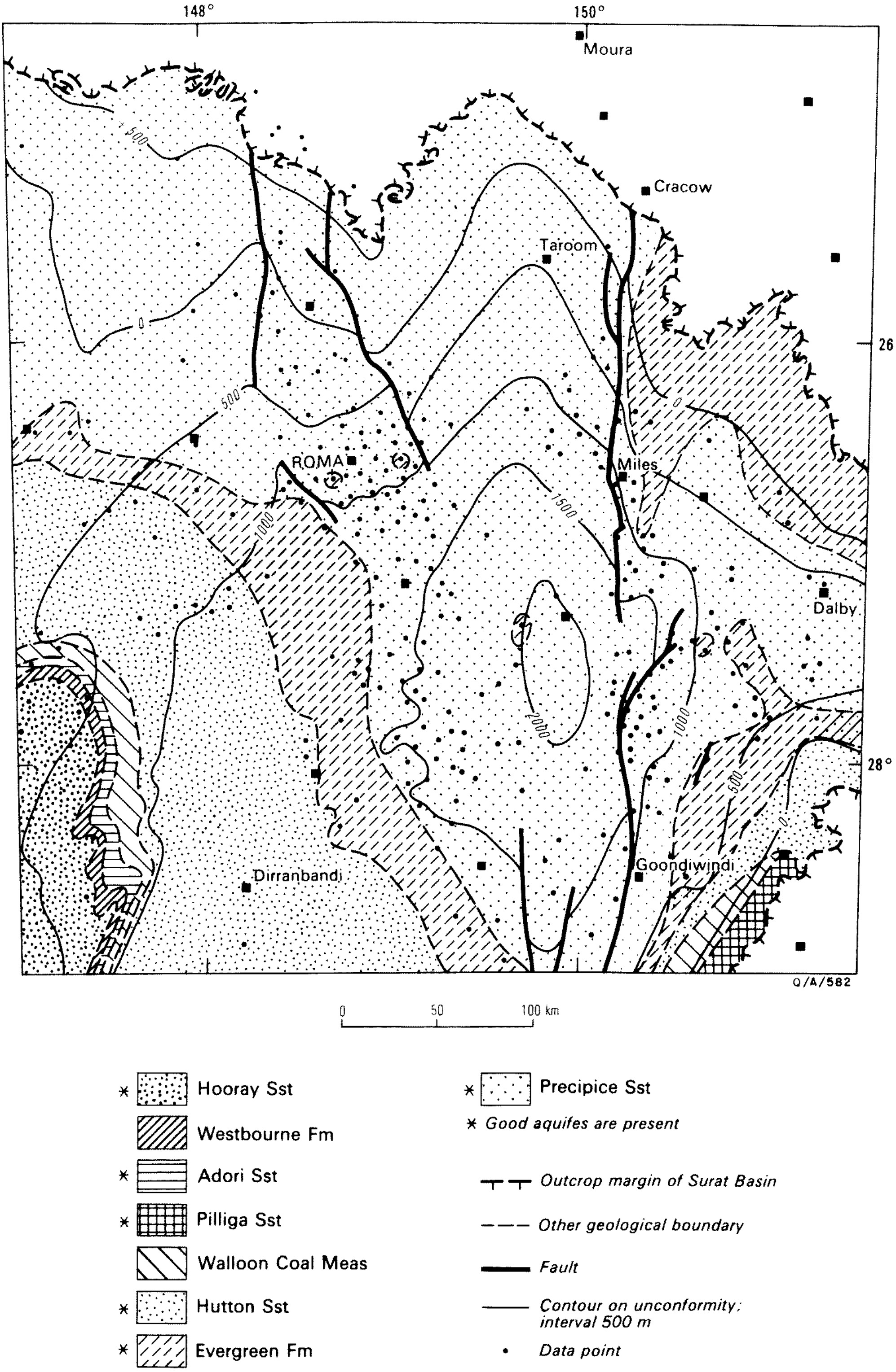


Fig. 18. Units immediately above the pre-Jurassic unconformity.

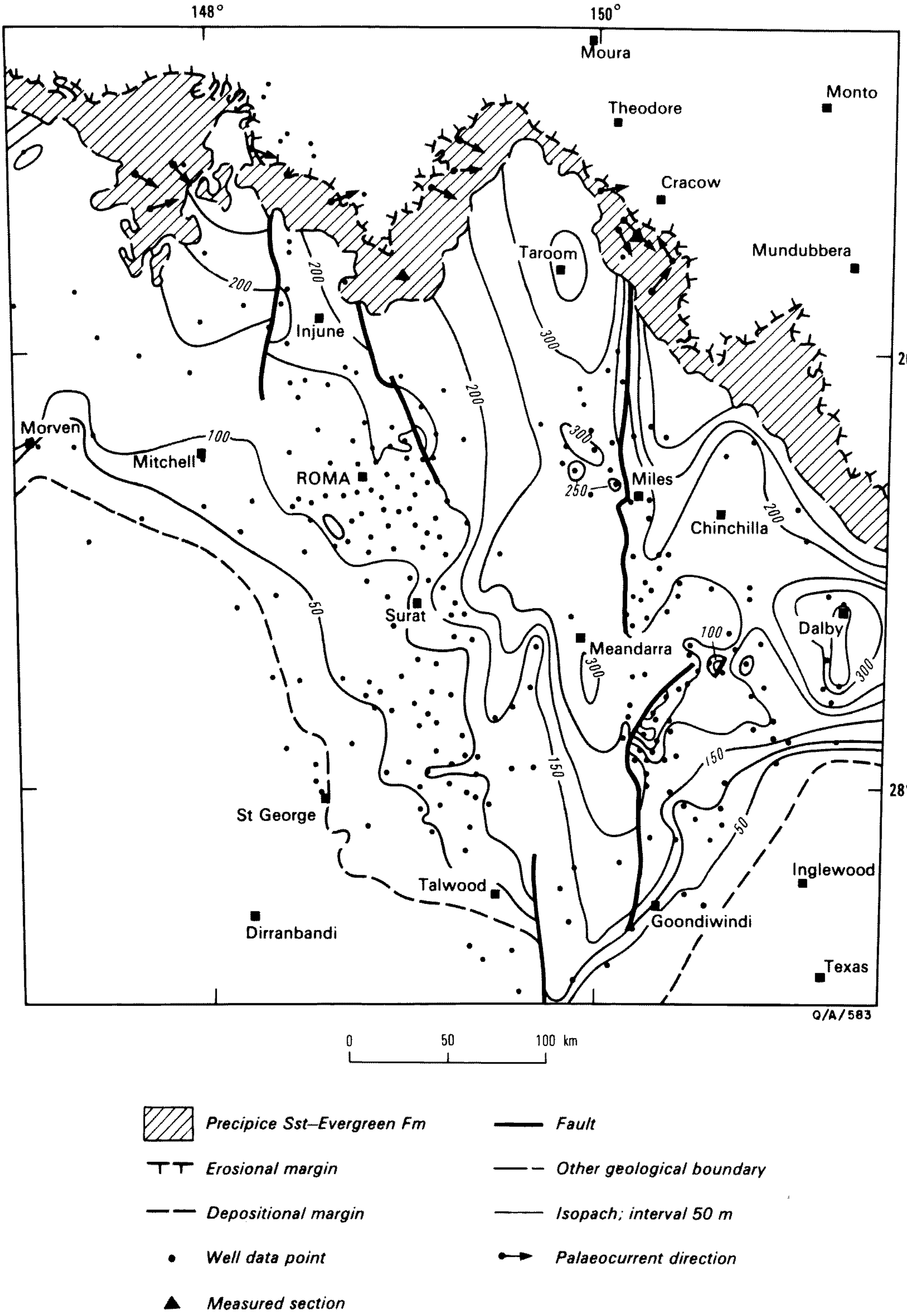


Fig. 19. Thickness of Precipice Sandstone and Evergreen Formation.

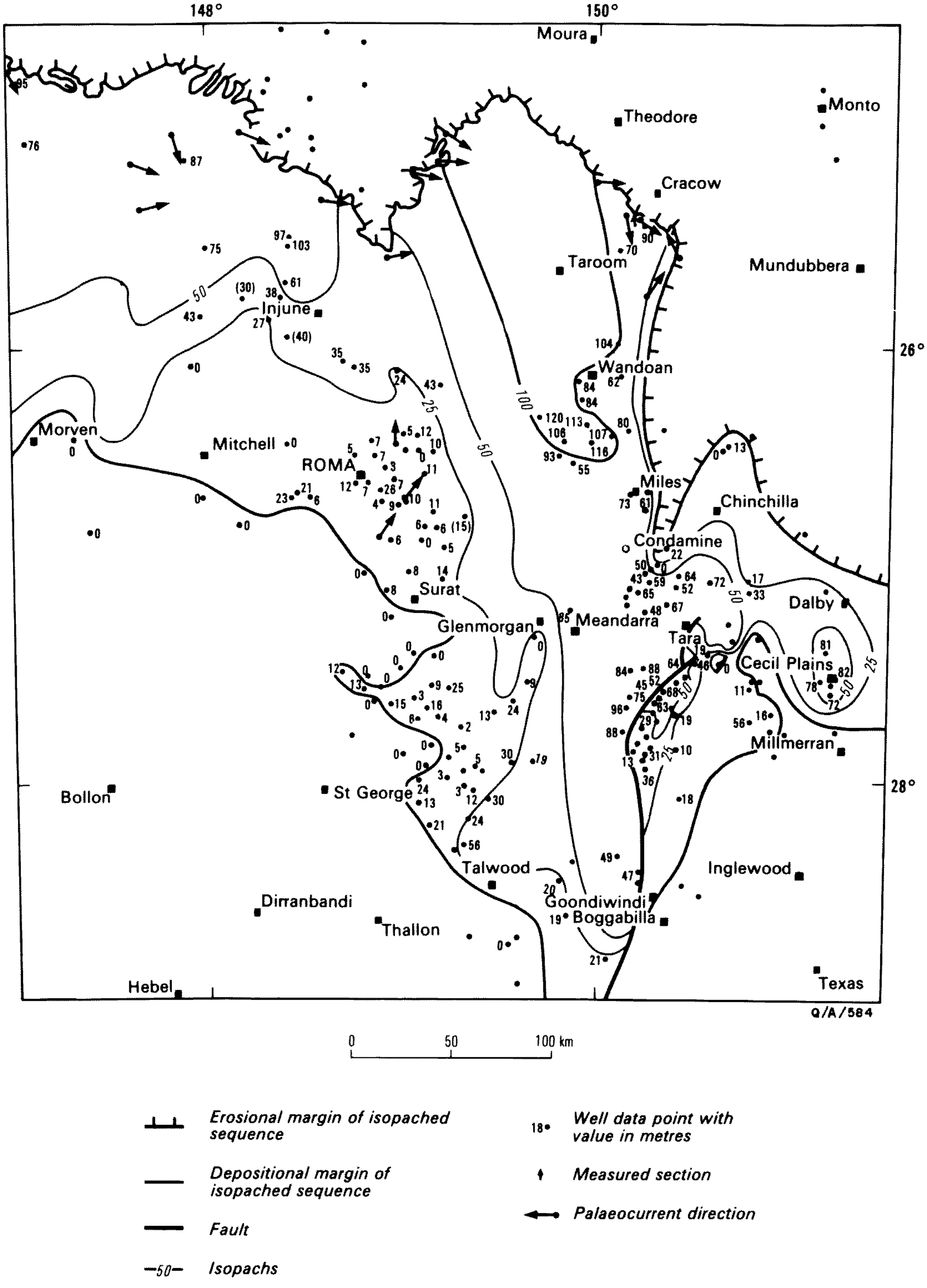


Fig. 20. Thickness of lower part of Precipice Sandstone.

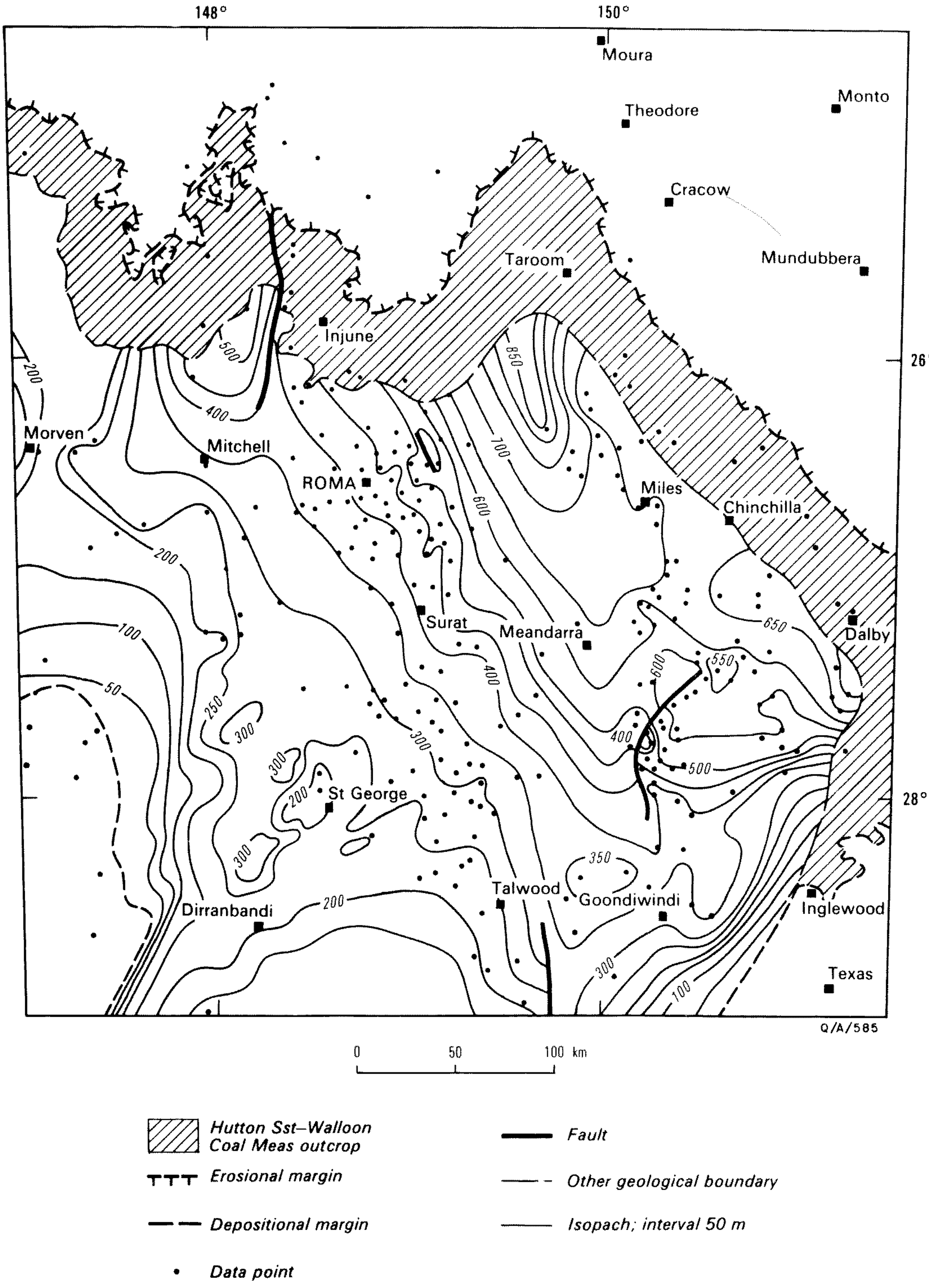


Fig. 21. Thickness of Hutton Sandstone and Walloon Coal Measures.

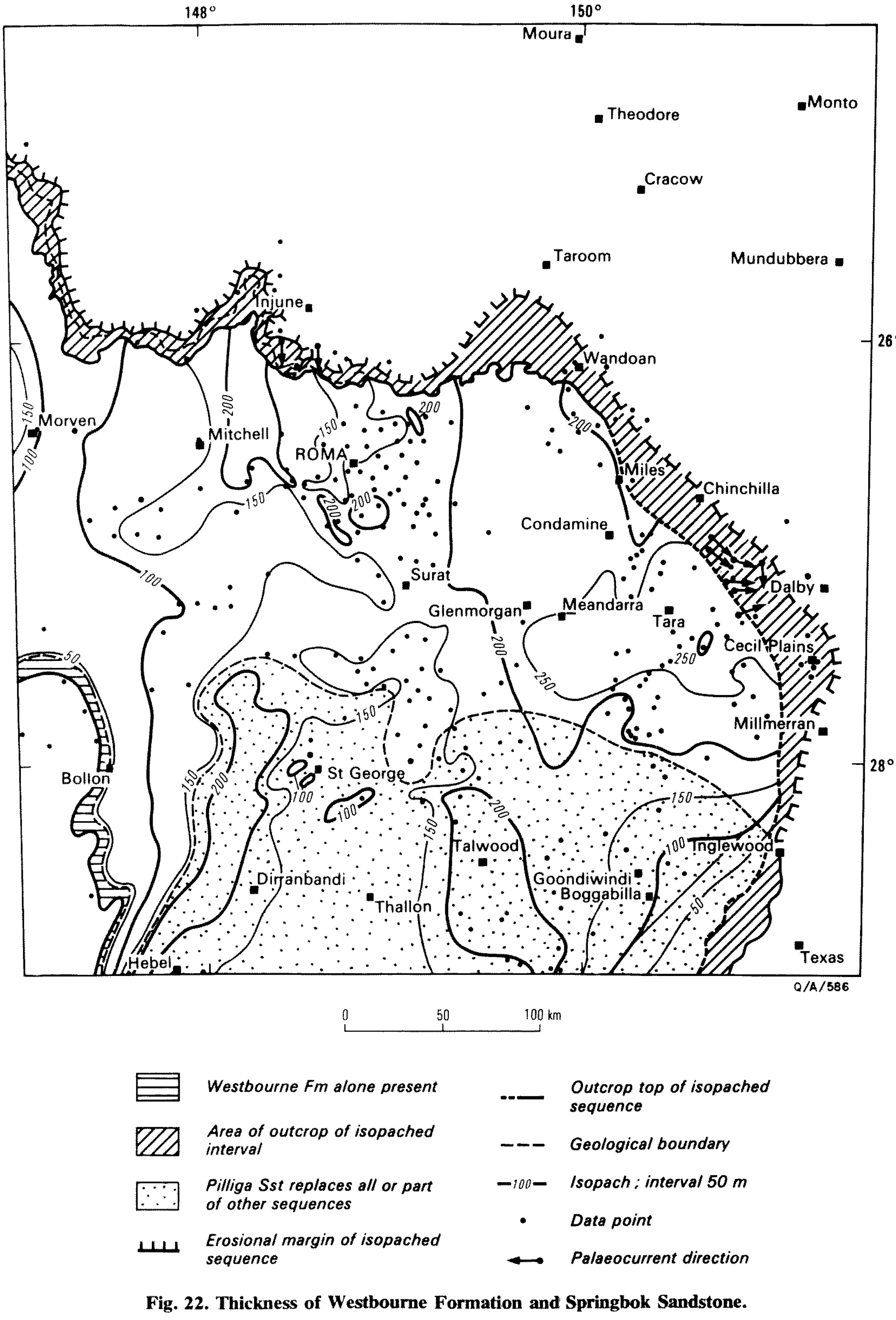


Fig. 22. Thickness of Westbourne Formation and Springbok Sandstone.

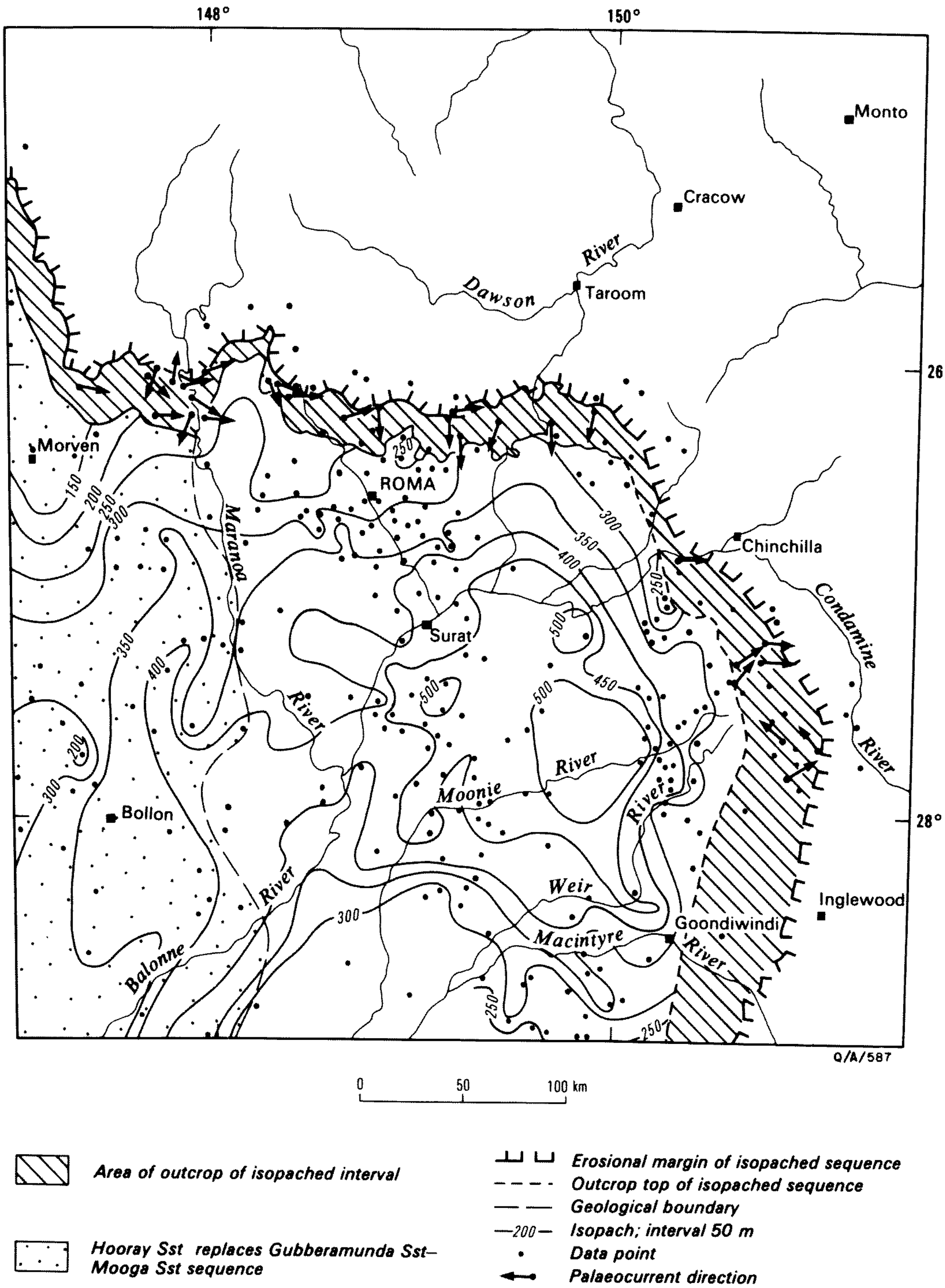


Fig. 23. Thickness of Gubberamunda Sandstone/Mooga Sandstone interval.

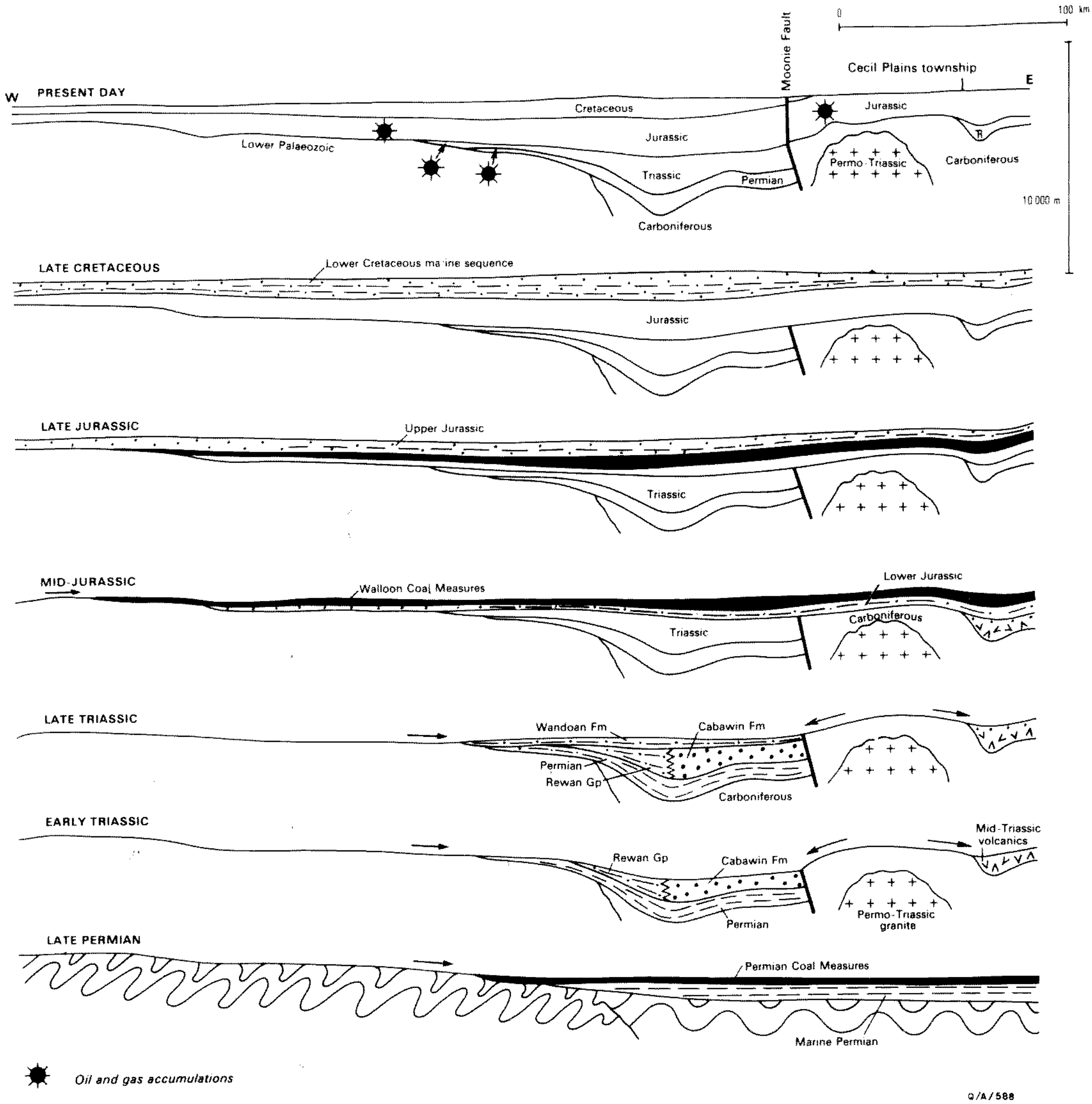


Fig. 24. Cross-sections showing evolution of Bowen and Surat Basins.

Triassic in the north. Deposition east of the trough ceased as faulting and uplift began. Intrusion occurred east of the Taroom Trough from Carboniferous to Early Triassic time, with the loci of intrusion moving slowly eastward.

Surat Basin

The Early Jurassic land surface (Fig. 17) consisted of elevated basement blocks in the southwest, northeast (Auburn Arch and Yarraman Block), and southeast (Texas High). Relatively low-lying areas included the central plains underlain by Triassic sediments, and an area east of the Taroom Trough underlain by Permo-Carboniferous volcanics and sediments.

Most of the low-lying areas were eroded only during the period immediately before deposition began in the Surat Basin, as they were soon covered by sand (Precipice Sandstone); thereafter deposition spread steadily over widening areas (Fig. 18).

The main source areas in the Jurassic were: the southwestern block, composed of

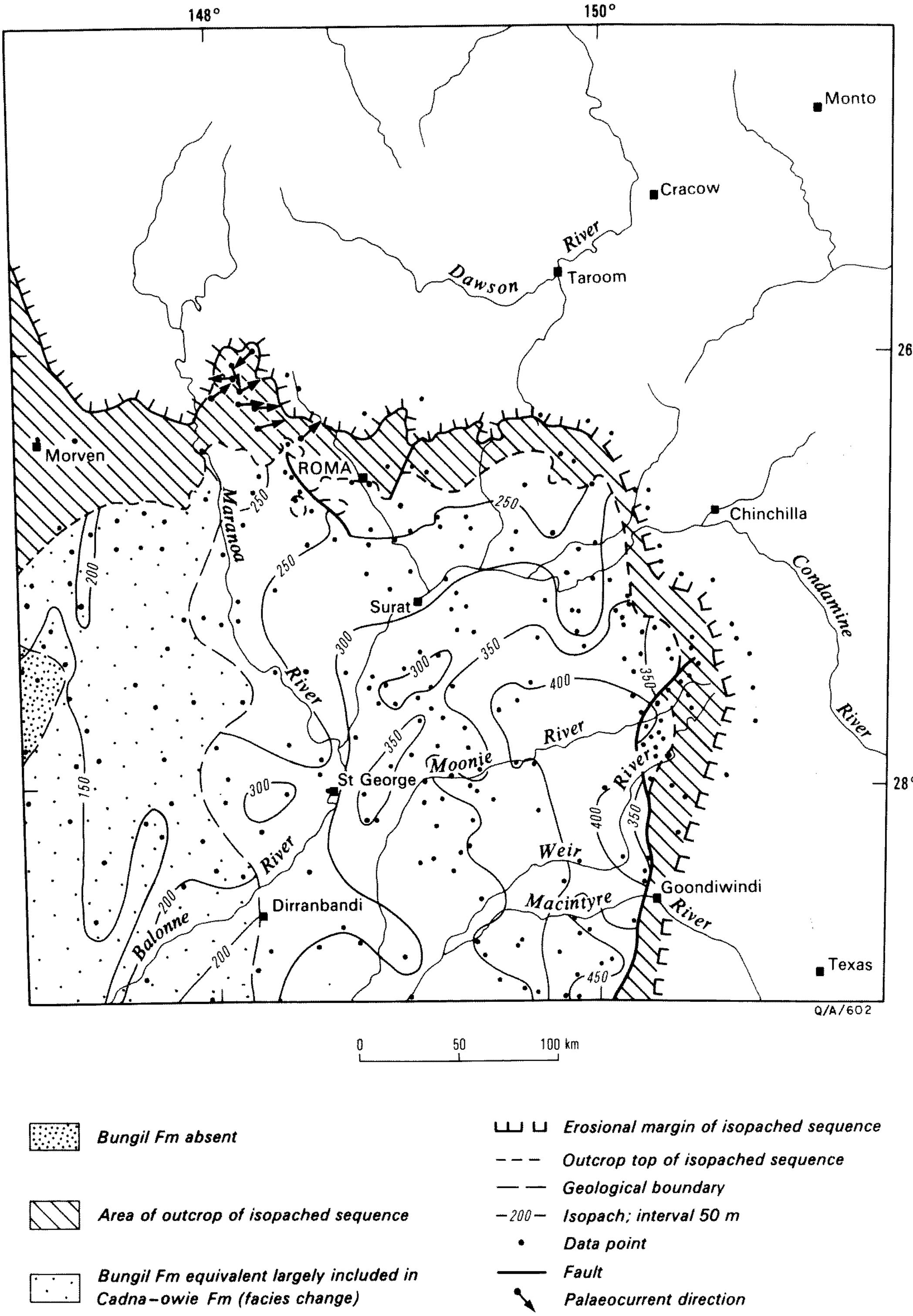


Fig. 25. Thickness of Bungil Formation and Doncaster Member.

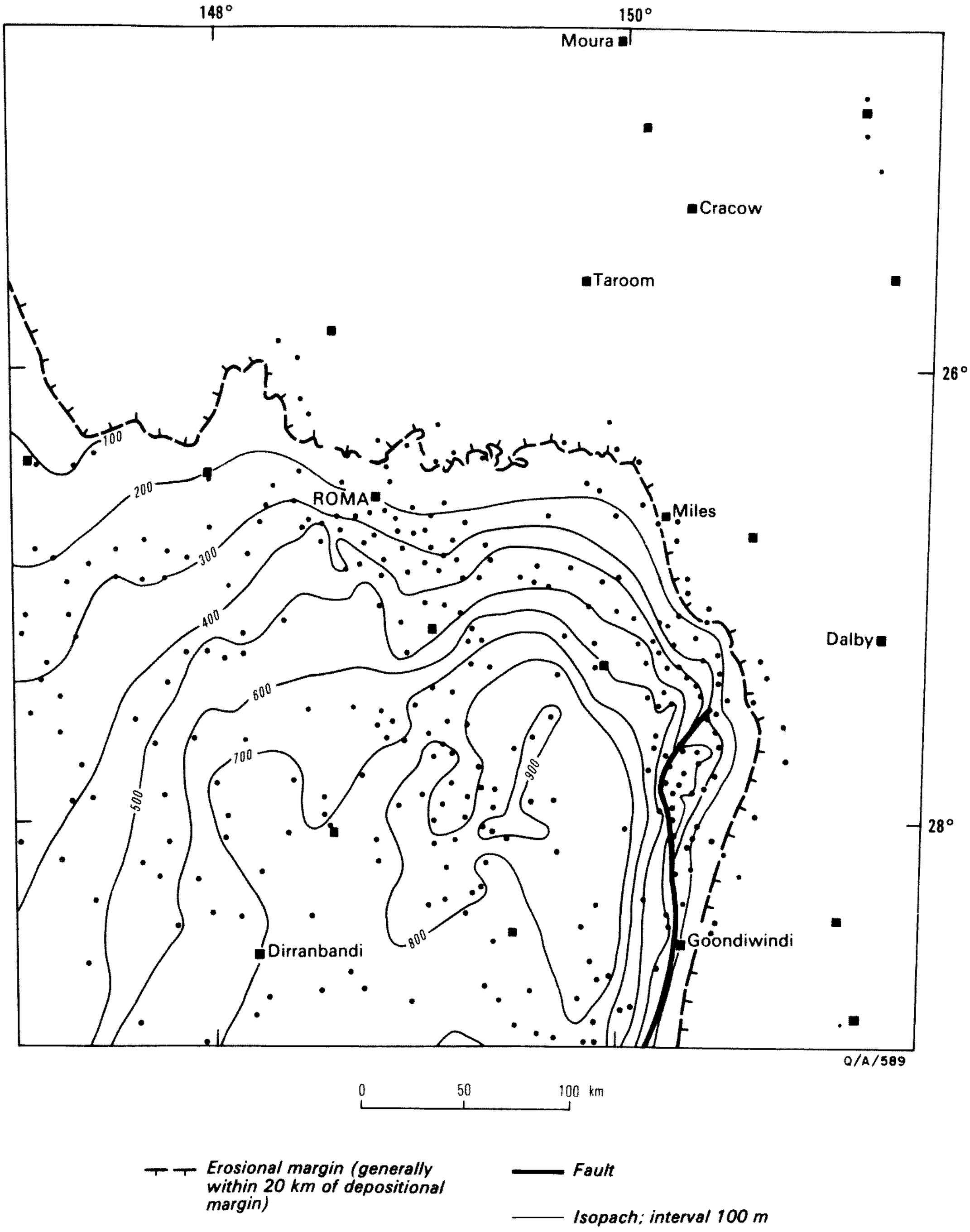


Fig. 26. Thickness of marine Cretaceous sequence.

siliceous sedimentary rocks, metasediments, schists, gneisses, and granites; the Auburn Arch and Yarraman Block, consisting largely of granite and gneiss; and the New England Fold Belt, composed mainly of indurated fine-grained sediments. The source areas for the marine Cretaceous sediments were different because the southwestern basement block was no longer exposed, although the eastern blocks were, and because all the basinal sediments north of Roma were being eroded. During the Cretaceous andesitic volcanism farther east provided most of the sediment laid down.

Major faulting and folding had ceased by earliest Jurassic time and, apart from slight movement on older faults, the development of structures in the Jurassic and Cretaceous was largely caused by draping over basement rises, and sinking of areas overlying thick Permo-Triassic sequences as they compacted.

Jurassic sedimentation was essentially cyclic. The cyclothems are hundreds of metres thick, and typical cycles generally began with coarse quartzose to sublabile sand, grading upwards into finer-grained more labile sand and silt, and ended with labile sand, silt, mud, and some coal. Each cycle represented deposition in turn from braided streams, from meandering streams, and finally from swamps, lakes, and deltas. Marine influence appears to have been confined to the later stages of each cycle. The cyclic deposition was related to periodic changes in climatic, tectonic, or eustatic conditions. The maximum rate of sedimentation for the Jurassic sequence was only 4 cm per 1000 years.

During the first cycle the Lower Jurassic *Precipice Sandstone* and *Evergreen Formation* (Fig. 19) were laid down. The sands in the lower part of the Precipice Sandstone were deposited by a braided stream flowing to the southeast in the north (Mollan, Forbes, Jensen, Exon, & Gregory, 1972), and to the northeast in the south (Sell *et al.*, 1972). The outlet to the system may have been to the north in the Cracow-Moura area, or to the east through the Moreton Basin area.

The porous and permeable lower part of the Precipice Sandstone, which is the main petroleum producer in the Surat Basin, is thickest (Fig. 20) where the total Evergreen Formation/Precipice Sandstone sequence (Fig. 19) is thickest. It is over 50 m thick in the northwest and in the Mimosa Syncline north of Goondiwindi, and exceeds 100 m in the northern part of the Mimosa Syncline around Taroom. The fine-grained upper part, which was laid down by meandering streams, is generally thinner than the lower part, and the total thickness of the Precipice Sandstone does not exceed 150 m.

The Evergreen Formation transgressed farther onto the basement blocks than the upper part of the Precipice Sandstone, which itself had transgressed farther than the lower part (Figs 19, 20).

The lower part of the Evergreen Formation consists of stream sediments, but the upper part was partly marine. Thus the Boxvale Sandstone Member (Table 19), which is underlain and overlain in places by beds containing swarms of acritarchs, may well contain marine beds. The finer-grained sandstone facies of the Boxvale Sandstone Member probably represents beach sands. The overlying oolitic ironstone beds, which are confined to the northern part of the basin and which have counterparts in the Moreton Basin (Allen, 1971), have long been regarded as marine.

In the second cycle of sedimentation, the Lower Jurassic *Hutton Sandstone* and the Middle Jurassic *Walloon Coal Measures* were deposited. Depositional conditions were less energetic than during the Precipice Sandstone/Evergreen Formation cycle, with braided streams relatively unimportant and coal swamps much more important. The Hutton Sandstone, which contains excellent aquifers, transgressed far over the southwestern basement block (Fig. 21) and was overlapped by the Walloon Coal Measures both in the southwest and southeast. Like the Precipice Sandstone/Evergreen Formation interval, the sequence attains its maximum thickness (Fig. 21) in the Taroom Trough and in the Moreton Basin. Most of the pre-Precipice Sandstone topographic irregularities had been smoothed out before deposition of the Hutton Sandstone began, and local variations in thickness are therefore smaller. The Walloon Coal Measures vary much more in thickness than the Hutton Sandstone. The gradual uplift of the Nebine Ridge is shown by the thinning of the Evergreen Formation, Hutton Sandstone, and Walloon Coal Measures over it, in contrast to the Precipice Sandstone pattern.

The third cycle of sedimentation consists of the Middle to Upper Jurassic *Springbok Sandstone* and *Westbourne Formation,* which intertongue with the Pilliga Sandstone in the south. The presence of considerable andesitic debris and bentonitic tuff in the Springbok Sandstone and Westbourne Formation, presumably derived from the north and east, indicates contemporaneous volcanism. The Springbok Sandstone was deposited by meandering streams on coastal plains, and the Westbourne Formation was laid down in backswamps, lakes, and deltas. The well sorted Pilliga Sandstone on the other hand was deposited by northerly-flowing braided streams. Although the variation in thickness of the sequence tends to parallel that of the Hutton Sandstone/Walloon Coal Measures interval, the range is much less (Fig. 22). The thinning towards the north and northwest indicates that uplift had begun in these areas. The Nebine Ridge persisted. The Dirranbandi Syncline had developed into a prominent feature and was virtually cut off from the Mimosa Syncline by a ridge between Roma and St George.

During the next sedimentary cycle the Upper Jurassic *Gubberamunda Sandstone* and *Orallo Formation* were laid down to the east of the Nebine Ridge. The Gubberamunda Sandstone consists mainly of sands deposited by braided and meandering streams, but the Orallo Formation consists principally of finer-grained overbank and swamp deposits. Andesitic volcanism appears to have provided much of the debris in the Orallo Formation, and bentonitic tuff is common.

The Orallo Formation is not present on the Nebine Ridge, where the Mooga Sandstone rests directly on the Gubberamunda Sandstone. On the ridge it is not possible to distinguish between the Mooga and Gubberamunda Sandstones, and the term Hooray Sandstone is used for the entire sequence. The thinning of the sequence to the north and east in Late Jurassic time (see Fig. 23) indicates epeirogenic uplift in these areas; the Kumbarilla Ridge was an important feature from then onward. The Dirranbandi Syncline area remained a centre of deposition.

The final cycle of deposition involved the Lower Cretaceous Mooga Sandstone and Bungil Formation. The Mooga Sandstone was laid down by meandering streams and grades upward into the Bungil Formation, which consists of fine-grained coastal plain and marginal marine deposits. The incoming of the sea in Neocomian and early Aptian time ended the era of fluvial cycles.

To summarize the tectonic events (see Fig. 24), the decrease in the rate of subsidence of the Mimosa Syncline, the corresponding increase in importance of the Dirranbandi Syncline, and the uplift of the Nebine Ridge occurred in Middle Jurassic time, whereas uplift of the northern area and of the Kumbarilla Ridge took place in Late Jurassic time, mainly during the deposition of the Westbourne Formation. The widespread distribution of bentonitic tuffs in the Middle and Upper Jurassic sequences of the Surat Basin (e.g. Exon, 1971; Swarbrick, 1973) shows that this epeirogenic period coincided with a period of volcanism.

The general shape of the Surat Basin in the Late Jurassic (Fig. 23) was similar to that of the present-day basin (e.g. Fig. 10) with the southwesterly-trending depression of the Dirranbandi Syncline superimposed on the meridional depression of the Mimosa Syncline.

The Early Cretaceous marine transgression, which began in the Neocomian with the deposition of the Bungil Formation and ended in the Albian with the Griman Creek Formation, was the last great sedimentary episode in the basin. The maximum rate of deposition for the entire period of 15 cm per 1000 years was much higher than during the Jurassic. The accelerated deposition was probably due partly to active coastal erosion, but was due mainly to the vast increase of stream-borne detritus derived from andesitic volcanic outbursts along the present east coast of Queensland.

The Cretaceous sea first entered the basin in late Neocomian time, when the paralic sediments of the Bungil Formation were laid down. The sea deepened during deposition of the Aptian Doncaster Member, and the isopach map of the *Bungil Formation/Doncaster Member* interval (Fig. 25) shows that the greatest thickness of sediment accumulated in the southeast, and continued to do so throughout the whole period of marine Cretaceous deposition (see Fig. 26). The sea may have entered from the west over the Nebine Ridge, in which case the depression to the east was rapidly inundated and deep-water marine muds were deposited almost directly on the freshwater sediments, except around the margins of the basin. More probably, the sea came first from the east via the Moreton Basin, which was later uplifted; a seaway to the Gulf of Carpentaria was formed in the Aptian.

In early Albian time there was a regression (Coreena Member) followed by another transgression (Surat Siltstone). The change from a littoral to freshwater environment in the Griman Creek Formation marks the withdrawal of the sea in the middle Albian.

During the Late Cretaceous and Early Tertiary there was steady erosion and pediplanation, and the development of a deep-weathering profile. In Oligocene-Miocene times basic volcanics were poured out to the north and east of the Surat Basin. The volcanism was associated with epeirogenic movements which increased the basinward tilt first developed in the Late Jurassic. Thereafter, and until the present day, the basin has been very stable, although as much as 200 m of Cainozoic sediment is present in places.

PETROLEUM GEOLOGY

Petroleum exploration in the Surat Basin, and the underlying Bowen Basin has a comparatively long history and has been moderately successful. An account of the early exploration, well histories, and drilling has been compiled by the Geological Survey of Queensland (1960), and later information is available from a variety of sources as outlined below.

Petroliferous gas was struck in a Roma town water bore in 1900—the first recorded hydrocarbon show in the basin. The Queensland Government No. 2 water bore produced gas for several years, and in 1906 a gasometer was erected to supply Roma with gas; after 10 days the flow of gas suddenly stopped because of a blockage, and the scheme was abandoned. The small supplies, flooding and formation damage by water, and various technical difficulties hindered early exploration.

By 1960 44 exploration wells had been drilled in the Surat Basin, and 5 in the Bowen Basin, but despite encouraging oil and gas shows, none was commercially important; AAO No. 4 (Hospital Hill) struck gas in 1954, but this was not utilized until 1961. Exploration had virtually ceased by 1960, but was renewed when Commonwealth assistance was introduced under the Petroleum Search Subsidy Act. The development of new geophysical techniques, in this basin where lack of outcrop had long been a problem for well-siting, also caused renewed interest. The discovery of commercial gas at Pickanjinnie southeast of Roma, and subcommercial oil at Cabawin in the eastern part of the basin, both in 1961, further intensified exploration, and by 1965 numerous small gas fields in the Roma area and the Moonie and Alton Oil Fields had been discovered. Thereafter new gas fields were found in the Roma area, but exploration elsewhere was generally unsuccessful. The Moonie-Brisbane oil pipeline was completed for Union-Kern-AOG in 1964, and the Roma-Brisbane gas pipeline for the Associated Group in 1969; in 1972 the capacity of the gas pipeline was increased to 34 MMcf/d by the installation of a compressor at the start of the main transmission line.

By the end of 1973 some 375 exploration wells had been drilled in the Surat Basin and 32 in the Bowen Basin. For the Bowen and

TABLE 5. PROVED GAS RESERVES, SURAT BASIN
(At end of 1973)

Field	*Year Discovered*	*Reservoir*	*Initial Recoverable Reserves (millions m^3)*	*Cumulative Production (millions m^3)*	*Remaining Recoverable Reserves (millions m^3)*
Hospital Hill	1954	Precipice Sst	3	1	2
Timbury Hills	1960	Precipice Sst	105	34	71
Pickanjinnie	1961	Precipice Sst & Showgrounds Sst	337	176	161
Bony Creek	1963	Precipice Sst	798	261	537
Richmond	1963	Precipice Sst	385	176	209
Back Creek	1964	Precipice Sst	11	1	10
Beaufort	1964	Precipice Sst	116	1	115
Blyth Creek	1964	Precipice Sst	52	—	52
Duarran	1964	Precipice Sst	29	10	19
Lamen	1964	Precipice Sst	44	—	44
Raslie	1964	Precipice Sst	89	27	62
Snake Creek	1964	Showgrounds Sst	57	37	20
Yanalah	1964	Precipice Sst	169	9	160
Maffra	1965	Precipice Sst	79	—	79
*Major	1965	Wandoan Fm	89	—	89
Oberina	1965	Precipice Sst	54	—	54
Pine Ridge	1965	Precipice Sst	181	35	146
		Moolayember Fm	47	—	47
Tarrawonga	1965	Precipice Sst & Showgrounds Sst	137	75	62
Lyndon Caves	1966	Precipice Sst	55	—	55
Hope Creek	1967	Precipice Sst	67	—	67
Pringle Downs	1967	Precipice Sst	17	2	15
Wallumbilla S	1967	Back Creek Gp	110	41	69
Pleasant Hills	1968	Evergreen Fm, Precipice Sst & Showgrounds Sst	941	153	788
		Westbourne Fm	14	—	14
Grafton Range	1969	Evergreen Fm & Precipice Sst	354	58	296
*Kincora	1969	Evergreen Fm & Wandoan Fm	532	—	532
Mooga	1969	Precipice Sst	147	—	147
*Boxleigh	1970	Wandoan Fm	150	—	150
Euthulla	1970	Precipice Sst	156	—	156
*Noorindoo	1970	Blackwater Gp	111	—	111
Westlands	1970	Precipice Sst	27	—	27
Totals			5463	1097	4366

Note: All fields were discovered by Associated Group or Amalgamated Petroleum except those marked * which were discovered by Union Oil and associated companies south of Roma; the latter are a considerable distance from the Roma-Brisbane pipeline.

Surat Basins initial reserves of oil (essentially the Alton and Moonie fields) were 3.608 million m^3, which had been depleted by 84 percent (3.026 million m^3) by the end of 1973, and initial reserves of gas were 5463 million m^3, which have been depleted by 20 percent (1097 million m^3) (see Tables 5, 6). Oil production at Moonie was at the rate of 254 m^3 a day and at Alton 44 m^3 a day, and gas production from the Roma fields was at the rate of 7.35 million m^3 a day ('Petroleum Search in Australia' figures). More detailed statistics for the various Surat Basin fields up to the end of 1973, taken from the records of the Department of Mines, Queensland (DMQ, 1973), are given in Tables 5 and 6.

Table 5 shows the gas fields discovered between 1954 and 1970, and that the bulk of the gas has yet to be exploited. Kincora is the only major field not held by the Asociated Group, but it is reasonably near their pipeline network.

Union Oil and its associates discovered both the Moonie and Alton Oil Fields, both of which are nearing the ends of their com-

TABLE 6. PROVED OIL RESERVES, SURAT BASIN
(At end of 1973)

Field	*Year Discovered*	*Reservoir*	*Initial Recoverable Reserves (1000s m^3)*	*Cumulative Production (1000s m^3)*	*Remaining Recoverable Reserves (1000s m^3)*
*Cabawin	1961	Blackwater Gp	115	—	115
*Moonie	1961	Precipice Sst	2957	2746	211
†Richmond	1963	Precipice Sst	14	2	12
*Alton	1964	Evergreen Fm	305	259	46
*Bennett	1965	Precipice Sst	105	13	92
†Trinidad	1965	Precipice Sst	17	2	15
*Boxleigh	1970	Wandoan Fm	52	—	52
Other Roma fields*		Various	43	4	40
Total			3608	3026	582

* Discovered by Union Oil and associated companies outside the Roma area.
† Discovered by Associated Group or Amalgamated. Petroleum in the Roma area.

Note: Boxleigh is a condensate field.

mercial lives (Table 6). No substantial oil reserves have been discovered since 1965. In 1972 International Oils Exploration N.L. acquired Union Oil's share of the Union-Kern-AOG consortium's interests in the area.

By late 1974 the only area in the Surat Basin where major exploration was continuing was the Roma Shelf. Here the Associated Group* was unsuccessfully drilling Permian targets in the hope of finding major new gas reserves, as most of the obvious Jurassic targets had already been drilled. The ratio of success on the Roma Shelf has been about 20 percent for wildcat wells, and 40 percent for development wells. Success ratios elsewhere have been very much lower.

Lists of exploration wells, with basic statistics, are available in the published Explanatory Notes accompanying the 1:250 000 Sheet areas. Annual lists are provided by the Geological Survey of Queensland (GSQ, 1960-64) and the Department of Mines, Queensland (DMQ, 1965-74).

Source rocks

Possible petroleum source rocks include the marine Carboniferous and Permian sequences, the Permian coal measures, the Jurassic Evergreen Formation, and the marine Cretaceous sequence. The marine Carboniferous sequence (distribution shown in Fig. 17) underlies the Bowen and Surat Basin sequences near all the eastern petroleum discoveries but had been folded, uplifted, and eroded before deposition began in the Bowen Basin. Any petroleum generated would have been carbonized or would have escaped to the surface at that stage. The marine Cretaceous sequence has yielded traces of petroleum (e.g. Galloway & Duff, 1966), but generally insufficient depth of burial to generate hydrocarbons (everywhere less than 2000 m), and uncomplicated up-dip connexion of the possible reservoir sandstones to outcrop militate against the formation and trapping of oil. In any case Cretaceous oil could not have contributed to the accumulations in the Lower Jurassic and older rocks. Oil and gas were probably generated in both the Permian sequence and the Evergreen Formation, but the relative importance of their contributions to present-day accumulations is uncertain.

Several authors have considered the marine Permian sequence to be a potential source for petroleum in both the Permian sandstones and in younger reservoirs where they rest on the Permian. Recent papers supporting this view are those of Erickson (1965), Traves (1966), and Power (1967).

* The Associated Group consists of Associated Australian Resources NL (85%) and Interstate Oil Ltd (15%); the operational company is Mines Administration Pty Ltd.

TABLE 7. GEOTHERMAL GRADIENTS AND DEPTH OF POTENTIAL HYDROCARBON PRODUCTION

Area	*Number of Water Bore Readings*	*Heat Flow* (m/°C)	*Depth of Onset of Oil Production in metres* (95°C)	*Depth of Onset of Gas Production in metres* (135°C)
Nebine Ridge	6	15-20	1200-1500	1800-2400
Roma Shelf, and St George-Bollon Slope	30	20-30	1500-2300	2400-3500
Centre and eastern margin of basin	6	30-40	2300-3100	3500-4700

Assumptions: (1) Mean surface air temperature = 20°C; (2) Mean surface rock temperature = 20°—3°C = 17°C; (3) Oil is produced predominantly in the range 95°-135°C, gas in the range 135°-150°C.

Certainly the organic-rich marine muds in the Back Creek Group are suitable source rocks if historical factors were favourable.

Moran & Gussow (1963) have suggested that the Evergreen Formation, which is now widely regarded as partly marine, was a source of petroleum, because of the widespread shows within it, and because bubble-point pressures indicated Middle Jurassic accumulation. De Jersey & Allen (1966) have recorded Jurassic spores in oil from the Jurassic, Triassic, and Permian reservoirs, and concluded that the Jurassic sequence was the only significant source of oil discovered in the Surat and Bowen basins, although the Permian had yielded gas.

Recent geochemical studies have provided new data about the source of the petroleum. Mathews, Burns, & Johns (1971) studied the distribution of hydrocarbons in nine crude oils from the Precipice Sandstone and the Evergreen Formation in the Surat Basin, and also the distribution of hydrocarbons in solvent extracts from eight shale cores taken from strata adjacent to three of the oil reservoirs. The distribution of n-alkanes in the shales (dominantly long-chain alkanes) were typical of oils derived from land plants, but differed from the distribution in the oil reservoirs (dominantly short-chain alkanes). The authors suggested that at least oils in the Evergreen Formation were derived from the formation itself, and that the differences in distributions of n-alkanes were due to differential adsorption on silicates (e.g. clays) during migration.

Powell & McKirdy (1972) studied the chemistry of ten oils from the Bowen and Surat Basins. The samples were taken from reservoirs ranging from Devonian to Jurassic in age, and in location from the Roma Shelf to Alton, Moonie, and Conloi. With the exception of the oil from UKA Conloi No. 1, all the samples showed similarities in composition in the fractions boiling above 275°C, although the lower-boiling fractions showed considerable variation. The similarity in composition of the higher-boiling fractions suggests that they may have had a similar source and that the differences in composition of the lighter fractions were due to alteration during migration. The Conloi oil, which comes from within the Evergreen Formation, either had a different origin, or had been extensively altered during migration and incorporation in the reservoir.

Powell & McKirdy (1972, 1973) and others have shown that the ratio of the straight-chained alkanes, pristane and phytane, may indicate the origin of oils. High pristane/phytane ratios are believed to indicate derivation from land plants because high pristane values are favoured by aerobic decomposition of plant material, which is more likely on land. Partly decomposed material would then be swept into a reducing environment before oxidation was completed and eventually give rise to hydrocarbons. The rocks in which the organic material was entombed could be non-marine or marine themselves.

The pristane/phytane ratios of the oils from the Bowen and Surat Basins (generally 5.6-8.2, Conloi 3.2; Powell & McKirdy,

1972) are much higher than those recorded in a number of overseas oils which are regarded as marine (Powell & McKirdy, 1973). This strongly suggests that they are derived from land plants. Abundant plant material is preserved in the fine-grained rocks in both the Permian sequence and the Evergreen Formation (which include both non-marine and marine sediments), so the oil could have been derived from either.

Present-day geothermal gradients in 42 subartesian water bores in the Surat Basin have been calculated by Dr E. Polak (pers. comm.). The results are summarized in Table 7, which shows high gradients on the Nebine Ridge, moderate gradients on the Roma Shelf and the St George/Bollon Slope, and low gradients in the central and eastern parts of the basin.

Using certain widely accepted assumptions (Table 7), the depth of onset of oil production in these areas at present would lie between 1200 m on parts of the Nebine Ridge, and 3100 m in parts of the eastern side of the basin. As the area has been tectonically stable since the Triassic, these figures may well have applied since then, and possibly indicate the amount of cover necessary to develop oil and gas in the Evergreen Formation. In combination with the various isopach maps they suggest that development and migration of petroleum from the Evergreen Formation was unlikely until Cretaceous time in most of the basin.

Migration and entrapment

The regional directions of lateral migration of hydrocarbons at different periods in the history of the basin were outlined by Erickson (1965), and the present discussion and results, based on more detailed maps, are broadly similar. Erickson believed that major eastward migration could have started in the Early Triassic, whereas the present study suggests that it began in the Middle Triassic. He assumed that there were hydrocarbons and that 'they would migrate in an updip direction for some distance, often in spite of a very low dip'. He did not deal with 'less tangible factors such as the nature of migration, the time of lithification, the tendency of porosity to decrease basinwards, the timing of the earliest compaction and flushing of clays, etc.' It has here been assumed that a depth of cover of 2000 m is sufficient to generate hydrocarbons and start their migration.

The present study makes the same assumptions and uses the same methods as Erickson, who stated that 'the direction of regional migration is traced through geological time by making use of a series of isopach maps. If the upper marker bed is regarded as an approximate datum plane, the isopach contours become a structural map of the lower marker bed at the time the upper one was deposited. The degree of structural flexing of sedimentary beds between the marker beds increases gradually from the top to the bottom of the section involved. The direction of hydrocarbon migration is towards the thin areas shown on the isopach maps. The chosen direction of migration can be no better than the maps, and these in turn are no better than the markers themselves, which, of course, seldom formed a horizontal datum, or may have been subsequently subjected to erosion.'

Isopachs of the intervals of most interest are presented in Figure 27. The oldest sediments belong to the mainly Lower Permian Back Creek Group, and include a number of fossiliferous limestones, sandstones, siltstones, and mudstones. Regressive sand bodies such as the Catherine Sandstone, which yielded gas at Rolleston, are the only likely reservoir rocks. The isopachs (Fig. 27a) show that the sequence near Taroom is about 4000 m thick, and that it thins steadily to the west and south. The western limit is considered to be a depositional edge, and the eastern limit is erosional and faulted. The main directions of lateral migration are shown in Figure 27a. At the end of deposition of the group the dominant direction was southwesterly; the base of the group rose at about 40 m per km in the north, and at about 15 m per km in the south. Mack (1963) reported depositional thinning over the Cabawin Anticline, which would have directed local migration into that area.

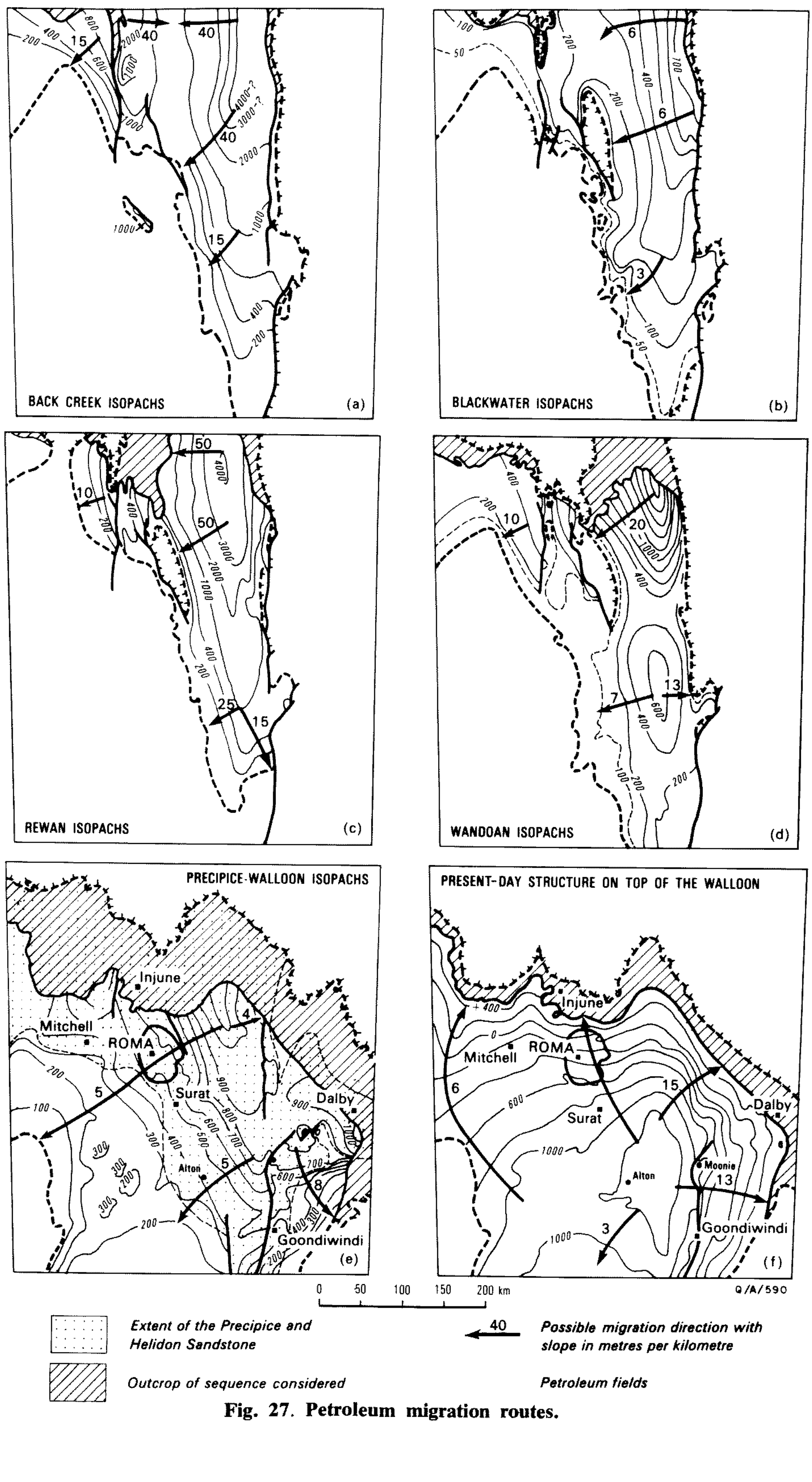


Fig. 27. Petroleum migration routes.

The Upper Permian Blackwater Group consists of non-marine lithic sandstone, siltstone, mudstone, and coal. No reservoir rocks are known within the group. The isopachs (Fig. 27b) show that the depositional and migrational patterns were similar to those of the Back Creek Group. After deposition of the Blackwater Group the base of the group rose at 3 to 6 m per km, generally to the west-southwest. Although hydrocarbons in the Blackwater Group would not have migrated at that stage, because the maximum thickness of the group is 700 m, any hydrocarbons in the middle of the Back Creek Group would probably have started to migrate.

The Lower Triassic Rewan Group, which is up to 4000 m thick (Fig. 27c) is a redbed sequence consisting of mudstone, lithic sandstone, and some conglomerate, especially in the Cabawin Formation. It contains no known source rocks or reservoirs. During the Early Triassic the eastern margin of the present-day Taroom Trough developed in the south with uplift of basement blocks along meridional faults; the Cabawin Formation consists of coarse detritus laid down in the newly formed basin. Changes in the shape of the basin led to some changes in direction of migration. When deposition of the Rewan Group had been completed the base of the group rose to the west-southwest at 50 m per km in the north and at 25 m per km in the south, and to the southeast at 15 m per km in the south; in the northeast an easterly component of migration may have started to develop. Most of the hydrocarbons from the Permian strata would have begun to migrate by the end of Rewan Group time. Some would have been trapped in Permian reservoirs, some would have been hindered in their migration by the numerous impermeable beds, and some would have escaped at the surface.

The mainly Middle Triassic Wandoan Formation, which is up to 2000 m thick (Fig. 27d), consists mainly of labile sandstone, siltstone, and mudstone, but the lower part contains quartzose sandstones which form reservoirs and potential reservoirs (Showgrounds and Clematis Sandstones). During the Middle Triassic the eastern margin of the Taroom Trough took up its modern configuration when uplift of the basement in the northeast was completed. By the time deposition of the Wandoan Formation had been completed, an easterly migration direction was firmly established in the east, where the base of the formation rose at 13 to 20 m per km. After deposition of the Wandoan Formation there was a long period of erosion and peneplanation.

By the Late Triassic the maximum loading on the potential source rocks of the Permian sequence was over 5000 m in the north, but less than 200 m west of Moonie. The sequence had been compressed and subjected to most of the tectonic movement which has occurred in the basin. Migration must have occurred from source rocks in most of the basin, but perhaps not in the south. Hydrocarbons were probably trapped in sandstones in the Back Creek Group at Rolleston and possibly in the Showgrounds Sandstone on the Roma Shelf. Considerable quantities of hydrocarbons must have escaped to the surface, especially along the eastern margin where the upturned Permian beds crop out extensively.

The main producer of hydrocarbons in the basin, the Lower Jurassic Precipice Sandstone, was now laid down unconformably on the older sediments. The porous and permeable lower part of the quartzose Precipice Sandstone is thickest in the north and east, but its distribution in the south and west is patchy (Fig. 20). The inter-relationship of the underlying units and the units resting on the unconformity surface (of which the most important is the Precipice Sandstone) is shown by the palaeogeological maps (Figs 17, 18). The Precipice Sandstone rests directly on all the older units along the eastern margin of the basin, and on the Back Creek Group in the southern part of the Comet Platform, but elsewhere it generally overlies the Wandoan Formation. To be found anywhere in the Jurassic sequence, hydrocarbons from Permian source rocks would, in almost all areas, have had first to make their way into the Precipice Sandstone.

During the Jurassic the basin was comparatively stable and each unit generally lapped over the previous one onto basement. Overlying the Precipice Sandstone is the Evergreen Formation, which consists mainly of mudstone, siltstone, and labile sandstone, but which also contains the quartzose Boxvale Sandstone that is a reservoir in some fields. The quartzose Hutton Sandstone above the Evergreen Formation is another potential reservoir. The Middle Jurassic Walloon Coal Measures, which consist of mudstone, siltstone, labile sandstone, and coal, overlapped the Hutton Sandstone in most of the basin, and formed an effective cap that would have prevented the escape of hydrocarbons from the older units in most areas. The Evergreen Formation is the youngest probable source rock for the hydrocarbons in the basin, so in most areas rocks younger than the Hutton Sandstone are unlikely to contain economic accumulations and they are therefore not discussed here.

By the end of the Walloon Coal Measures time, as much as 1000 m of Jurassic sediment had accumulated, not enough to free hydrocarbons in the Evergreen Formation, but enough to promote further migration of hydrocarbons in the pre-Jurassic rocks. Hydrocarbons could have moved into the Precipice Sandstone directly from the Permian and Triassic sequences along the eastern side of the basin, and on the southern part of the Comet Platform. Along the western margin of the basin, hydrocarbons could have migrated along the basal sands at the contact between the generally tight Wandoan Formation and the basement rocks, and up into the Precipice Sandstone.

After deposition of the Walloon Coal Measures had been completed, the slope on the lower Precipice Sandstone was still only between 4 and 8 m per km (Fig. 27e). Hydrocarbons escaping into the Precipice Sandstone along the eastern margin of the Taroom Trough would have either made their way southeastward in the south, where the Walloon Coal Measures seal was probably incomplete and they may have escaped to the surface, or have remained more or less in place in the north. Hydrocarbons escaping from the Permian rocks in the southern part of the Comet Platform would have migrated southwestward across the Roma Shelf. Hydrocarbons escaping along the southwestern edge of the Wandoan Formation would have entered either the fringe of the Precipice Sandstone, or the Evergreen Formation and, by moving through the sands resting on basement, could have moved up into the Hutton Sandstone and thence southwestward into the Bollon area, where they would have been trapped against the basement rise by the overlapping Walloon Coal Measures.

Structural and porosity/permeability traps in the Precipice Sandstone would have prevented extensive lateral migration of large quantities of hydrocarbons in many areas—especially along the eastern faulted zone, and on the Roma Shelf.

In summary, the only hydrocarbons likely to have been migrating until the Middle Jurassic would have been from the Permian sequence. Until the Middle Triassic migration would have been dominantly to the southeast and southwest and west. Thereafter migration would have been to the southeast and southwest towards the sides of the basin. The bulk of the hydrocarbons would have started to migrate in the Early Triassic and would thereafter have been committed to a southwesterly course. Most of the hydrocarbons which did migrate to the east in the Late Triassic would have escaped at the surface. Thus in the Middle Jurassic hydrocarbons would have been concentrated in Permian, Triassic, and Lower Jurassic reservoirs, mainly on the western side of the basin.

Later in the Jurassic, epeirogenic uplift in the north and east gave the basin its modern shape, and the migration directions shown in Figure 27f were established. Tertiary epeirogenic uplift in the same areas resulted in an increase in the tilt along the migration directions, which are now 3 to 15 m per km on the top of the Walloon Coal Measures, and somewhat more on the Precipice Sandstone.

The isopach map of the total Jurassic sequence (Pl. 21) suggests that it was not

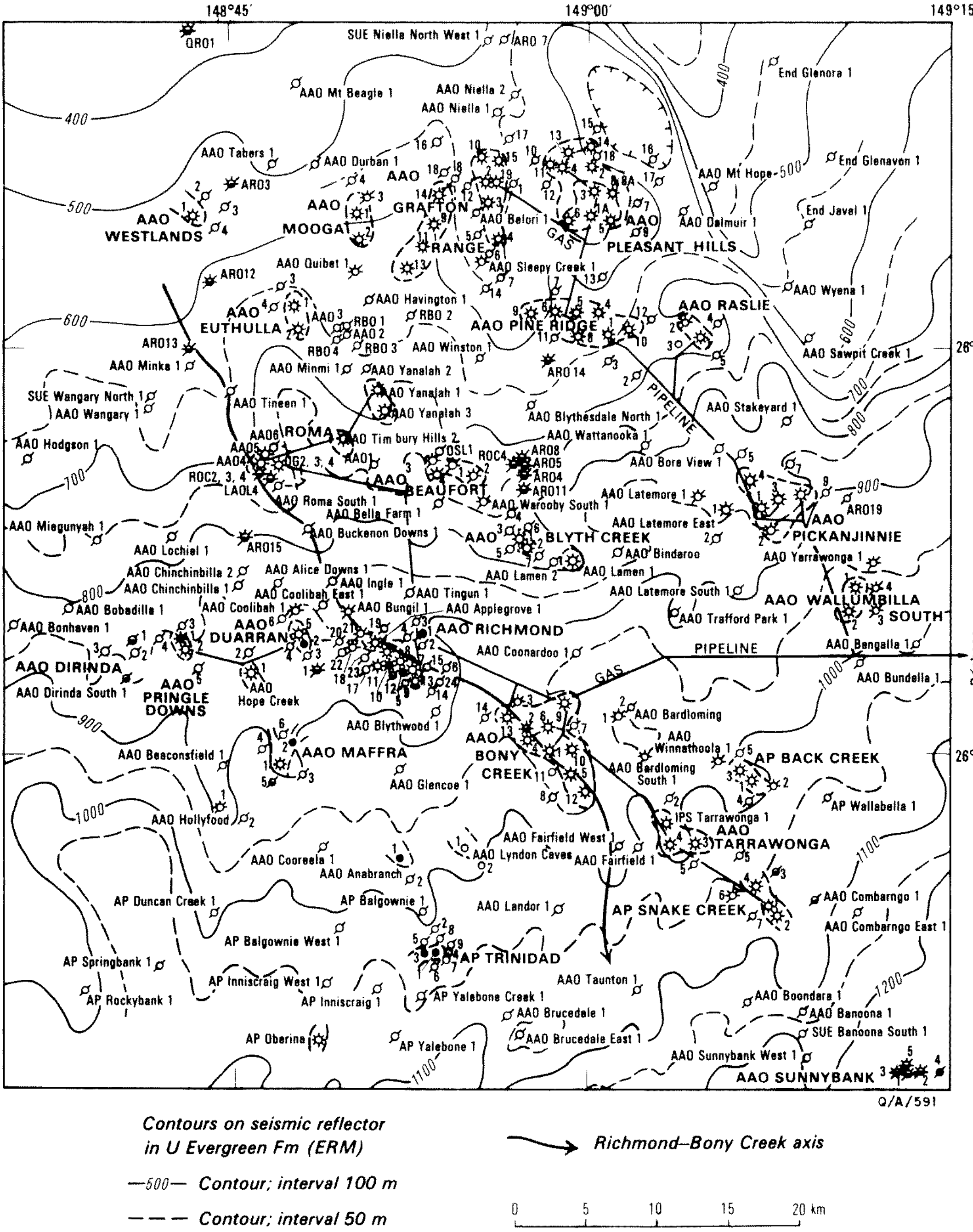


Fig. 28. Petroleum fields on Roma Shelf.

until well into the Early Cretaceous that the load on the Evergreen Formation approached that needed to mobilize hydrocarbons (cf. Table 7). By then the migration paths shown in Figure 27f were firmly established. Hydrocarbons from the Evergreen Formation would have moved radially, mainly to the north and the east. Because of the prevailing dip, they could have moved upward into the Hutton Sandstone, or laterally into the Precipice Sandstone. Lateral movements into still older units would have been possible where the structure was suitable. By the end of the Early Cretaceous the additional loading of generally more than 500 m of sediment (Fig. 26) would have ensured widespread migration of hydrocarbons out of the Evergreen Formation.

Thus in the Middle and Late Jurassic the only hydrocarbons capable of migrating were those from the Permian sequence. Those which escaped from the Permo-Triassic sequence would have migrated to the southwest and southeast in the Early Jurassic, mainly in the Precipice Sandstone, but quite probably also in the Hutton Sandstone. By the Middle Jurassic some would have entered stratigraphic and structural traps, but some would still be migrating. In the Late Jurassic, when the direction of migration changed, some of the old traps became ineffectual, and new traps developed. In the Early Cretaceous, hydrocarbons from the Evergreen Formation would have started to migrate to the north and east, that is, in the same direction as the older oil. From then on, the same directions of migration prevailed, and hydrocarbons from either source could have been moved vertically into younger units, or laterally through the unit they were in, or into older units. The loading of sedimentary cover rocks reached a maximum in the late Early Cretaceous, and thereafter declined as erosion predominated. In the mid-Tertiary increases in dip may have led to further migration.

Roma Shelf accumulations

Several papers have been published by geologists of Mines Administration Pty Ltd on various aspects of the Roma Shelf deposits; among the more important are a review of petroleum in the Roma-Springsure area (Traves, 1966), a case history of fields and reservoirs by Swindon (1968), a discussion of stratigraphic traps by Traves (1971), and an environmental study of hydrocarbon-producing Lower Jurassic sandstones by Sell *et al.* (1972). Á brief description of the Jurassic reservoirs was given by Hogetoorn (1968), and outlines of the Bony Creek gas field by Power (1966), of the Pickanjinnie gas field by Gray (1969), and of the Pine Ridge and Raslie gas fields by Hogetoorn (1970).

On the Roma Shelf there are a number of relatively small fields producing gas or oil, or both, from a variety of reservoirs (Tables 5, 6; Fig. 28). By far the most important product is gas, which is piped to Brisbane. Most of the gas produced is from the Lower Jurassic Precipice Sandstone, but it has also been recovered from the Permian Back Creek and Blackwater Groups, the Middle Triassic Showgrounds Sandstone and Moolayember Formation, and the Lower Jurassic Evergreen Formation. The two largest fields are Bony Creek and Pleasant Hills, in which the initial recoverable reserves were around 800 and 950 million m^3 respectively.

Commercial oil has been found only in the Precipice Sandstone, with the Trinidad field the largest (initial recoverable reserves 17 000 m^3), and it has been trucked to the Moonie oil pipeline. Other significant oil-bearing horizons include the Upper Permian Bandanna Formation, the Middle Triassic Showgrounds Sandstone and Moolayember Formation, and the Lower Jurassic Evergreen Formation.

Traps are generally stratigraphic, although structure is an important subsidiary factor in many fields. The following discussion of traps is drawn from Traves (1971) and Sell *et al.* (1972). The Wallumbilla South field produces at a depth of about 1750 m from a thin sand in the Permian Muggleton Formation, which may be a beach sand, and whose permeability is as high as 36 millidarcys. The Showgrounds Sandstone is an important producer in a number of fields. It is a sand deposited on the eastern part of the Roma Shelf by a series of southeasterly-flowing streams, and has porosity as high as 19 percent and permeability as high as 4 darcys. In most places the trapping mechanism is an up-dip pinch-out of the sand, which is seldom more than 10 m thick.

Twenty-four gas fields have been discov-

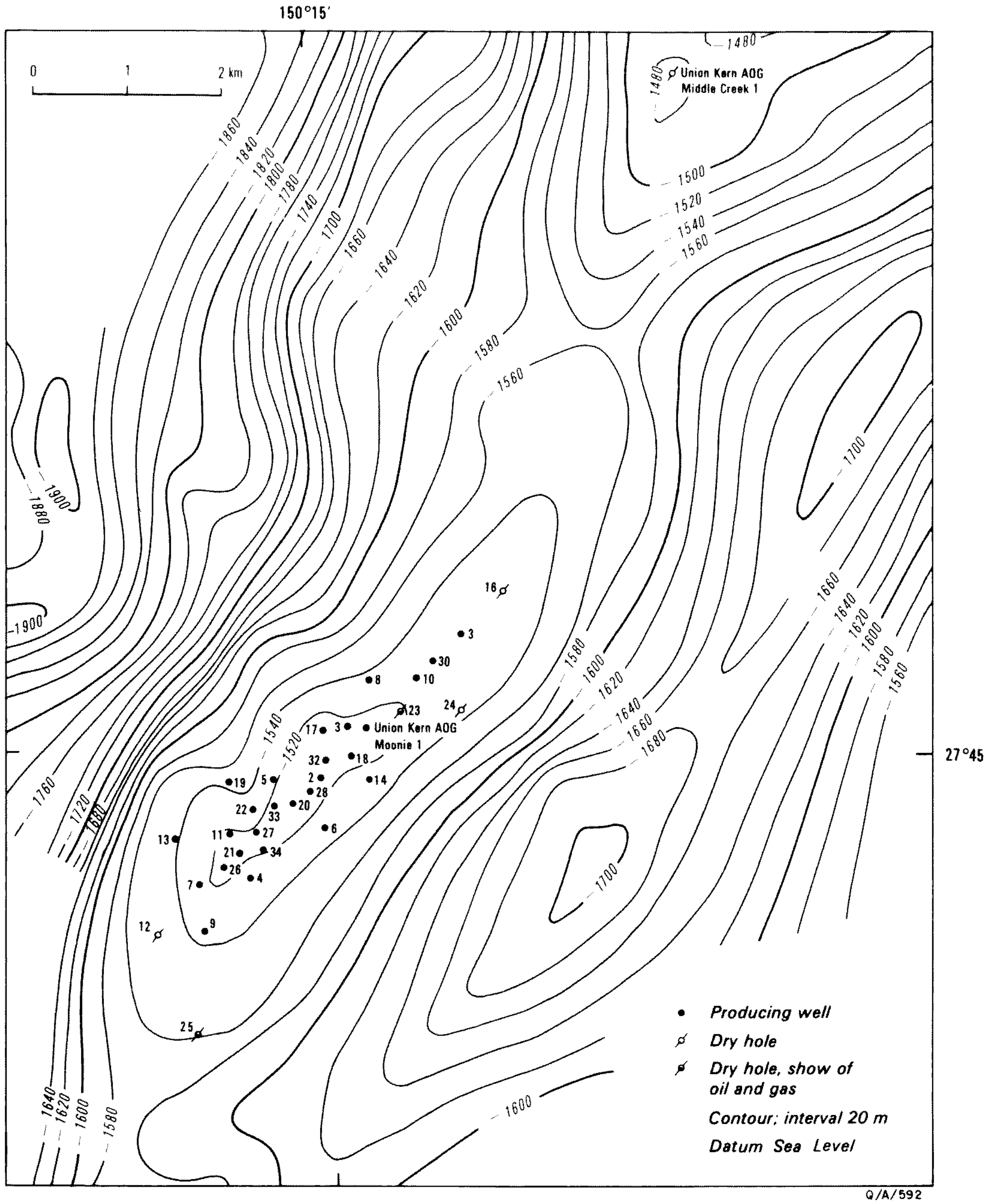


Fig. 29. Structure map of Moonie Oil Field.

ered in the Precipice Sandstone at depths ranging from 850 to 1350 m. The formation was deposited by streams flowing generally north-northeast. Sinuous bodies of porous sand, with an average porosity of 20 percent, and generally less than 5 km wide and 10 m thick, appear to have been originally deposited in shallow valleys where the initially clayey sands were extensively reworked by streams. Permeability in the channel sands is as high as 2 darcys, and most of the petroleum accumulations occur where

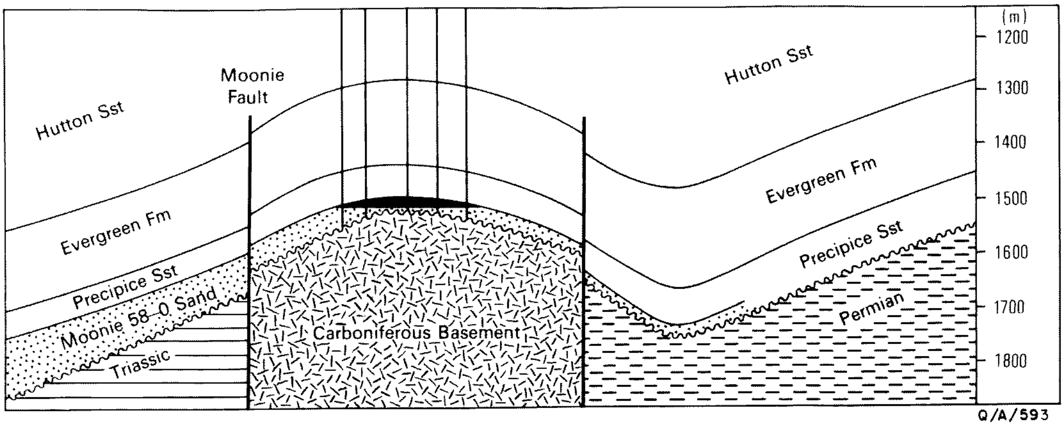


Fig. 30. Cross-section through Moonie Oil Field.

these northeasterly-trending belts of channel sands cross positive axes trending northwest. Some traps may consist of up-dip permeability barriers within belts of channel sands.

Several gas accumulations in the lower part of the Evergreen Formation are believed to be in shoreline sands enclosed in impermeable sandstone and shale. They normally occur on the flanks of basement ridges.

The general pattern of migration in the basin (see pp. 47-52) suggests that the hydrocarbons in the Jurassic sequence may have been derived from Permian sources in the Early and Middle Jurassic, when migration was to the west, or later, when migration was to the north. Hydrocarbons from the Evergreen Formation can only have moved in Early Cretaceous or later times, when migration was to the north. The trapping mechanism in the Precipice Sandstone would have worked equally well from the Early Jurassic to the Holocene, although the northwesterly-trending positive axes would have been subhorizontal in Early and Middle Jurassic times (their present southeasterly plunge was developed later).

There are great difficulties in predicting the occurrence of such stratigraphic traps, as the seismic tool does not have sufficient resolving power to differentiate porous sandstone belts from non-porous belts. By 1973 most of the more easily identifiable targets on structural highs had been drilled, and the search was concentrated on the Permian sequence.

Moonie Oil Field

The Union-Kern-AOG Moonie No. 1 well flowed oil at 220 m^3 a day through a 1-inch choke in December 1961, but it was not until September 1962 that the Moonie field was declared commercial. This, the first commercial oil field in Australia, stimulated widespread exploration in the Surat Basin. Production reached a peak of 1600 m^3 per day in 1966 and had declined to less than 240 m^3 per day by 1974. The oil is water-driven, and water began to invade the peripheral wells in 1966. Thirty-four wells have been drilled, of which all but five were producers.

Union Oil Co. geologists have published papers on various aspects of the field, most of which have been summarized by Buckley *et al.* (1969), from whom most of the following discussion is drawn. The history of exploration in the Surat Basin and the geology of the Moonie field were outlined by Moran & Gussow (1963). There followed a discussion of production facilities and methods by Pyle & Buckley (1965) and of subsurface and reservoir conditions in the field by Pyle (1967).

The field is an anticline on a horst block and is about 7 km long by 2 km wide (Figs 29, 30); its initial recoverable reserves were estimated at 3 000 000 m^3 which had been depleted by 93 percent late in 1973. The main producing horizon is the basal sandstone member of the Lower Jurassic Precipice Sandstone, the '58-0 sand', which is 20 to 60 m thick and about 1800 m below surface. The productive limits of this reservoir are controlled by an oil/water interface. An upper sandstone member, the '56-4 sand', is separated from the main sand by 30 m of tight sand and silt and, although always present, is productive only in certain wells. Its productive limits are controlled by permeability barriers and an oil/water interface.

The '58-0 sand' is generally quartzose and consists of a number of lenticular sand bodies. The grainsize ranges from very fine to conglomeratic, but most of the sand is medium to very coarse-grained. Carbonaceous laminae and high-angled cross-bedding are common. The lower part of the sand body is generally less clayey and slightly coarser than the upper part. The average horizontal permeability is about 300 millidarcys, but the effective vertical permeability is zero in any one core because of the numerous tight streaks. Average porosity is 18 percent, and the initial water saturation was 47 percent. The reservoir fluid is considerably undersaturated with gas, and there are differences in the solution gas:oil ratio across the main producing horizon. The highest gas:oil ratio was 56:1, corresponding to a bubble point pressure of 1680 psig, and the average is 45:1.

Geologically this area is fairly typical of the Chinchilla-Goondiwindi Slope. By Late Triassic time the area, which lies on an upthrown block immediately east of the Moonie Fault on the eastern hinge-line of the basin, had been eroded to give a range of hills of the 'Kuttung Formation' flanked west of the fault by a low plain of Triassic sediments, and to the east by a plain of Permian sediments and tuffs. There was a general tilt to the north and, in the Early Jurassic, the '58-0 sand' was spread across the old surface by northerly and northeasterly flowing braided streams to form an extensive alluvial plain. The sand overlying the Permian sequence is more clayey and less permeable than that overlying the 'Kuttung Formation', and it appears that the coarser sediment was deposited on the slopes and the finer on the plains.

The history of entrapment of the oil has been outlined by Buckley *et al.* (1969). Between the deposition of the Precipice Sandstone and the close of Walloon Coal Measures (Middle Jurassic) time, oil entered the Precipice Sandstone, migrated to the southwest up the regional slope, and was trapped south of the present Moonie field by permeability barriers and areas of no sand deposition corresponding to basement highs. Soon after (Middle or Late Jurassic) the regional tilt was reversed. The plunge on the Moonie structure, which is a drape over a basement ridge, was also reversed and oil migrated northwestward until it reached the present closure, which was then at the lower end of a southwesterly-plunging regional nose. Movement on the faults bounding the anticline to the northwest and southeast increased the relief during the tilting episode. There was sufficient northeasterly closure to trap the oil migrating back up the nose.

If this reconstruction is correct, the oil at Moonie must have originated in the Permian sequence, as oil in the Evergreen Formation would not have been expelled until the loading upon it became adequate in the Early Cretaceous (see also pp. 45-52). That Permian oil was present in the vicinity is suggested by the nearby UKA Cabawin No. 1 accumulation in Permian sediments. The alternative that the oil migrated from the Evergreen Formation as suggested by Moran & Gussow (1963) remains viable, but the accumulation would have occurred later than is generally suggested. The mid-Tertiary epeirogenic movements increased the regional tilt, and may have caused renewed movement on the old fault lines, and perhaps renewed migration.

Alton Oil Field

The Alton field, which lies near the eastern edge of the St George/Bollon Slope (Fig. 6), was described by Buckley *et al.* (1969), and the following discussion is mainly based on this paper.

The Union-Kern-AOG Alton No. 1 well was drilled in 1964 on a seismically determined structure on the basin side of the St George/Bollon Slope, to test closure of Evergreen Formation/Precipice Sandstone

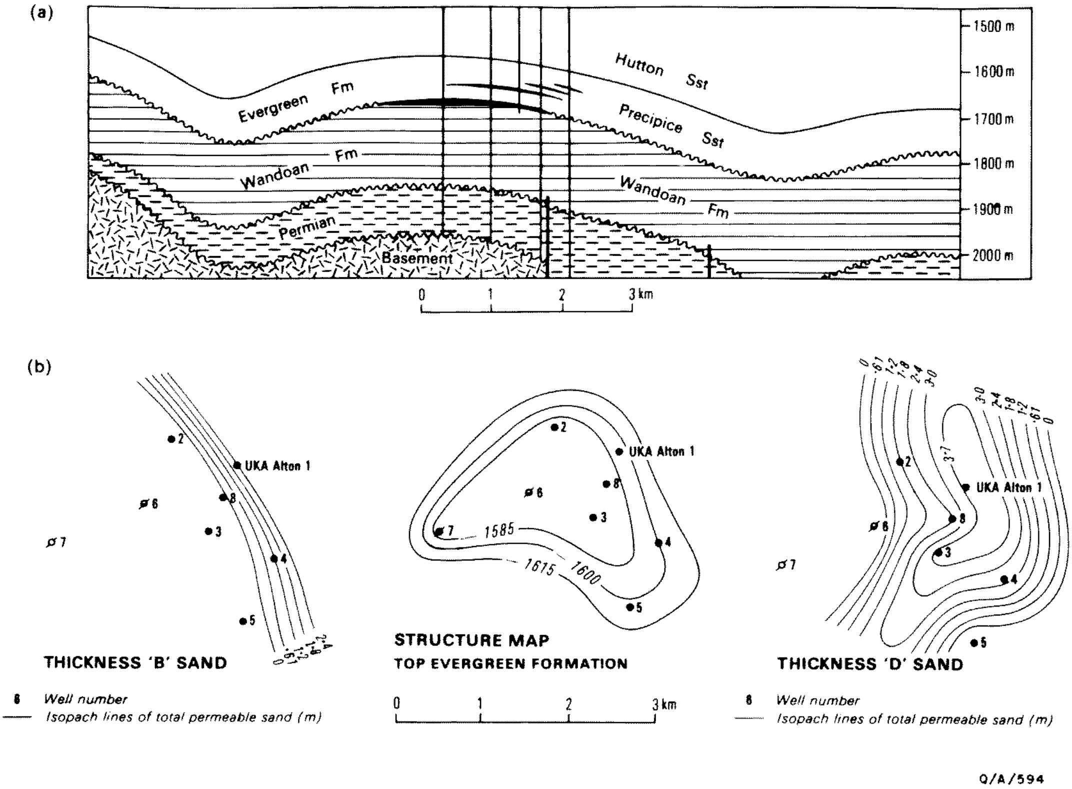


Fig. 31. Stucture of Alton Oil Field.

sands known to occur in the area. It produced 180 m³ a day through a ⅝-inch bottom hole choke from the interval 6060 to 6120 feet (1847-1865 m). Six more producing wells were drilled, and by January 1966 oil was being trucked to the Moonie pipeline. Production never exceeded 160 m³ a day, and by 1968 all the wells had to be pumped, with production around 110 m³ a day; by late 1973 production had declined to around 44 m³ a day. The producing horizons are about 1850 m below ground level.

Alton oil is of 54° API gravity, and has an average solution gas:oil ratio of 73:1, and bubble point pressure of 917 psig. Average reservoir porosity is 17 percent and permeability is 240 millidarcys. Initial water saturation was 45 percent. Although little water was produced until 1969, Buckley *et al.* have suggested that the producing mechanism was by partial water drive and fluid expulsion.

In the Alton field the traps are partly stratigraphic and partly structural (see Fig. 31b). The field is situated on a small anticline, and measures about 2.5 km by 1 km. Production is obtained from five separate sands designated A, B, C, D, and E within a sequence of shale, siltstone, and sandstone, 80 m thick, called the 'Evergreen-Precipice unit' by the Company. The sequence is probably equivalent to the Lower Jurassic Evergreen Formation, and directly overlies the Triassic Wandoan Formation which rests on a Permian sequence (Fig. 31). The wells were completed in different sands, but the A, C, and E sands are of very limited extent and most of the oil is contained in the B and D sands, neither of which exceeds 4 m in thickness (Fig. 31).

The Alton sands appear to be sinuous channel-like bodies that cross the eastern side of the structure. They represent only brief surges of current restricted to narrow channels. Probably because relief was lower and runoff was less, blanket sands like those of the Moonie area did not develop. The Alton sandstones are thicker to the south and east, where no suitable structural traps exist.

The available oil in each sand is limited by zero permeability lines, and an individual oil/water interface for each sand. Another factor is the thickness of sand, which is greatest near the centres of the channels.

The Alton structure is a drape over a faulted basement block. Oil entering the sands probably originated in the surrounding Evergreen Formation; it was expelled during the Early Cretaceous (see pp. 47-52), migrated up-dip, and was trapped within the channels on the anticline.

The Bollon area

One area which has been little explored, but which Exon (1974) has pointed out possibly has some economic potential, is an area around Bollon in the southwestern part of the basin. His maps were based on seismic maps compiled by United Geophysical Corp. (1963), and on well data and wireline-logged water-bores; most of them are reproduced here at a larger scale.

Basement in this area (Fig. 7) lies much higher than it does below the Mimosa Syncline, and parts of it were exposed throughout the whole of the Permo-Triassic. Jurassic sediments gradually lapped up onto the elevated basement blocks, and the Lower Jurassic stream sands of the Hutton Sandstone were deposited directly on basement over a wide area (Fig. 18). The Walloon Coal Measures are believed to overlap the Hutton Sandstone to the west, sealing it against the basement rise.

In the Early and Middle Jurassic (Fig. 27) the migration paths for most of any hydrocarbons from the Permian sequence in the Taroom Trough that had made their way into the Jurassic sequence led directly into this area. Such hydrocarbons would generally have migrated up-dip in the Precipice Sandstone until it pinched out against basement. They would then either have been trapped or have made their way via the basal sands of the Evergreen Formation up the basement surface and into the Hutton Sandstone. Once in the Hutton Sandstone, assuming it to have been already sealed by the Walloon Coal Measures, they would have made their way up-dip towards the thinner sediments shown by the isopach map of the Hutton Sandstone and Walloon Coal Measures (Fig. 21). West of Dirranbandi this would have been to the west, and south of Dirranbandi to the south, that is, out of the Dirranbandi Syncline. To the west any hydrocarbons would have been stopped by the Walloon Coal Measures seal against basement in the Bollon area, but to the south they would have migrated out of the area considered, unless trapped by permeability or structural barriers within the Hutton Sandstone.

In Late Jurassic and later times (Fig. 27f), when the regional dip changed in the Bollon area, the direction of migration was to the north, although it remained unchanged south of Dirranbandi. Hydrocarbons formerly trapped against basement would have tended to migrate northward, and some hydrocarbons in other traps could also have been freed.

The reconnaissance seismic surveys by United Geophysical Corp. (1963) used simple techniques and very widely spaced traverses. The complex structure outlined on the basement surface suggested that the structures in the overlying Hutton Sandstone would also be complex. Thus it is possible that some of the hydrocarbons that migrated into the area in the Early and Middle Jurassic were permanently trapped and could not migrate out of the area when the direction of migration changed to the north. Permeability traps elongated across the direction of migration probably developed in the fluvial sands that had been laid down by easterly-flowing streams on an irregular surface at the edge of the basin.

No wells have been drilled in the Hutton Sandstone in this area, which would appear to merit further examination. Although some of the faulting in the area is probably Cainozoic (Senior, 1970), by analogy with the rest of the basin it is likely that much of the basement relief is original (as is also sug-

TABLE 8. GAS SHOWS IN PERMIAN SEQUENCE SOUTH OF LATITUDE 24°30′S
(To late 1973)

Area	*Unit*	*Traps Drilled*	*Shows*	*Percentage Shows*	*Potential and Producing Fields*	*Percentage Fields*
West	Blackwater Group	64	8	12	2	4
	Back Creek Group	44	14	27	4	9
	Reids Dome Beds	15	4	27	0	0
East	Blackwater Group	16	2	12	0	0
	Back Creek Group	31	4	13	0	0
Total		96	23	24	6	6

TABLE 9. OIL SHOWS IN PERMIAN SEQUENCE SOUTH OF LATITUDE 24°30′S
(To late 1973)

Area	*Unit*	*Traps Drilled*	*Shows*	*Percentage Shows*	*Potential Fields*
West	Blackwater Group	64	2	3	0
	Back Creek Group	44	3	7	0
	Reids Dome Beds	15	2	13	0
East	Blackwater Group	16	1	6	0
	Back Creek Group	31	0	0	0
Total		96	7	7	0

gested by the isopachs of the Hutton Sandstone and Walloon Coal Measures), and that further movement on basement faults was associated with Middle and Late Jurassic epeirogenic movement.

In conclusion, it is probable that hydrocarbons migrated into this area in the Early and Middle Jurassic and were trapped. The later regional tilt to the north probably spilled many of these concentrations, but the area is complex and suitable stratigraphic and structural traps are probably present. A more intensive modern seismic survey might delineate targets which could be tested by drilling to depths of 1000 to 1500 m.

Conclusions

There is no doubt that substantial quantities of gas, and perhaps oil, will continue to be found in the Surat Basin. Major new finds are most likely to be found in the two sequences generally recognized as being the most prospective—the Permian beds and the basal part of the Jurassic Precipice Sandstone. Another unexplored possibility is the Lower Jurassic Hutton Sandstone in the southwestern part of the basin.

The Permian sequence remains prospective although, until the end of 1973, the results of drilling were rather disappointing, with some gas but no oil production (Tables 5, 6, 8, 9). There is no doubt that hydrocarbons were generated within the sequence, and any porous and pearmeable sand bodies would be possible reservoirs. To date the Permian sequence has been remarkably tight. The most prospective area around the margin of the Roma Shelf is up-dip of the likely source beds in the Taroom Trough, and has been throughout the history of the basin. Beach sands in the marine Permian sequence, sealed up-dip by fine-grained swamp sediments or pinching out against basement, are the most probable potential reservoirs (see Traves, 1971). Hydrocarbons have been recorded in a number of wells, but good reservoirs have yet to be found, despite the use of high-resolution seismic methods and considerable drilling in the Wallumbilla area.

Tables 8 and 9 show that gas has been recorded in the Permian sequence in some 25 percent of the wells which penetrated it, but oil in only 7 percent. They suggest that the Back Creek Group is the most prospective part of the Permian sequence, and that the western side of the basin is more prospective than the eastern side.

The Precipice Sandstone has been the target for most of the drilling in the basin and has produced both gas and oil. Where it forms a thick porous blanket sand the contained hydrocarbons have generally migrated laterally up-dip to escape at outcrop, or have been flushed out by water moving through this excellent aquifer. Only where such blanket sands are folded into a large anticline, as at Moonie, or where fault-traps are involved, is there much chance that hydrocarbons have escaped flushing. The most obvious structural traps have been drilled, and the eastern and southern parts of the basin must now be regarded as unprospective.

On the Roma Shelf, on the other hand, the widespread gas finds in the Precipice Sandstone have generally involved lateral porosity-permeability barriers within a relatively thin sandstone sequence. Sinuous bodies of permeable sand, which are interpreted as old channel-sand complexes, are limited laterally by impermeable sands. Most of the gas fields have been found where anticlines complete the trapping mechanism, and most of these anticlinal traps have been drilled.

Assuming that belts of permeable sand are surrounded by impermeable beds, it is possible that purely stratigraphic traps may exist well down the flanks of the anticlines, or in the synclines. Refined seismic techniques may help to define such targets, and a second phase of petroleum search on the Roma Shelf seems inevitable.

On the southwestern side of the basin further traps of the Alton type almost certainly exist—isolated thin sandstone reservoirs that represent stream channels within the impermeable Lower Jurassic Evergreen Formation. Small fields of this type may exist in any structural setting, but their prediction is difficult.

In the Bollon area, and indeed elsewere in the southwestern part of the basin, the Lower Jurassic Hutton Sandstone is virtually untested. Some of the sands in pinch-outs against basement highs, and permeable channel sands in impermeable sediments near the basement source areas may still contain some hydrocarbons, in spite of the fact that artesian water has probably flushed out any hydrocarbons from most of the Hutton Sandstone.

To summarize, the best prospects are the Precipice Sandstone on the Roma Shelf and the marine Permian sequence where it abuts on the Roma Shelf; the Hutton Sandstone in the southwest is less promising. Further small gas fields may be found in the Precipice Sandstone at a depth of about 1500 m. The Permian sandstones are thicker than those of the Precipice Sandstone, and if they were permeable they could yield much greater supplies of petroleum. Most of the wells would be less than 2000 m deep. Exploration of the Hutton Sandstone in the Bollon area would require good-quality seismic work to define targets, most of which would be less than 1000 m deep.

ECONOMIC GEOLOGY
(Excluding Petroleum)

Groundwater

The Surat Basin contains several pressure aquifers which flow to the surface in the deeper parts of the basin; water is drawn from numerous bores for stock and domestic use. Most of the aquifers lie in the Precipice, Hutton, Pilliga, Gubberamunda, and Hooray Sandstones, but less important aquifers occur within the Injune Creek Group, the Bungil Formation, and the Rolling Downs Group. The rates of flow have diminished over the years and many of the artesian bores have ceased to flow. Flows of over 4000 m^3 per day, which were once commonplace, are now rare.

The shallowest major aquifers in different areas are plotted in Figure 32; the oldest are nearest the margin of the basin, and show clearly the effect of the basinward dip. The depth to economic supplies of water seldom exceeds 300 m, except in the central part of the basin (see Fig. 32). In the central part of the basin, where abundant supplies of good water could be obtained at considerable depth from the Hooray Sandstone, water is pumped from the overlying Rolling Downs Group because it is so much shallower, although supplies are small and saline. Within the Rolling Downs Group the

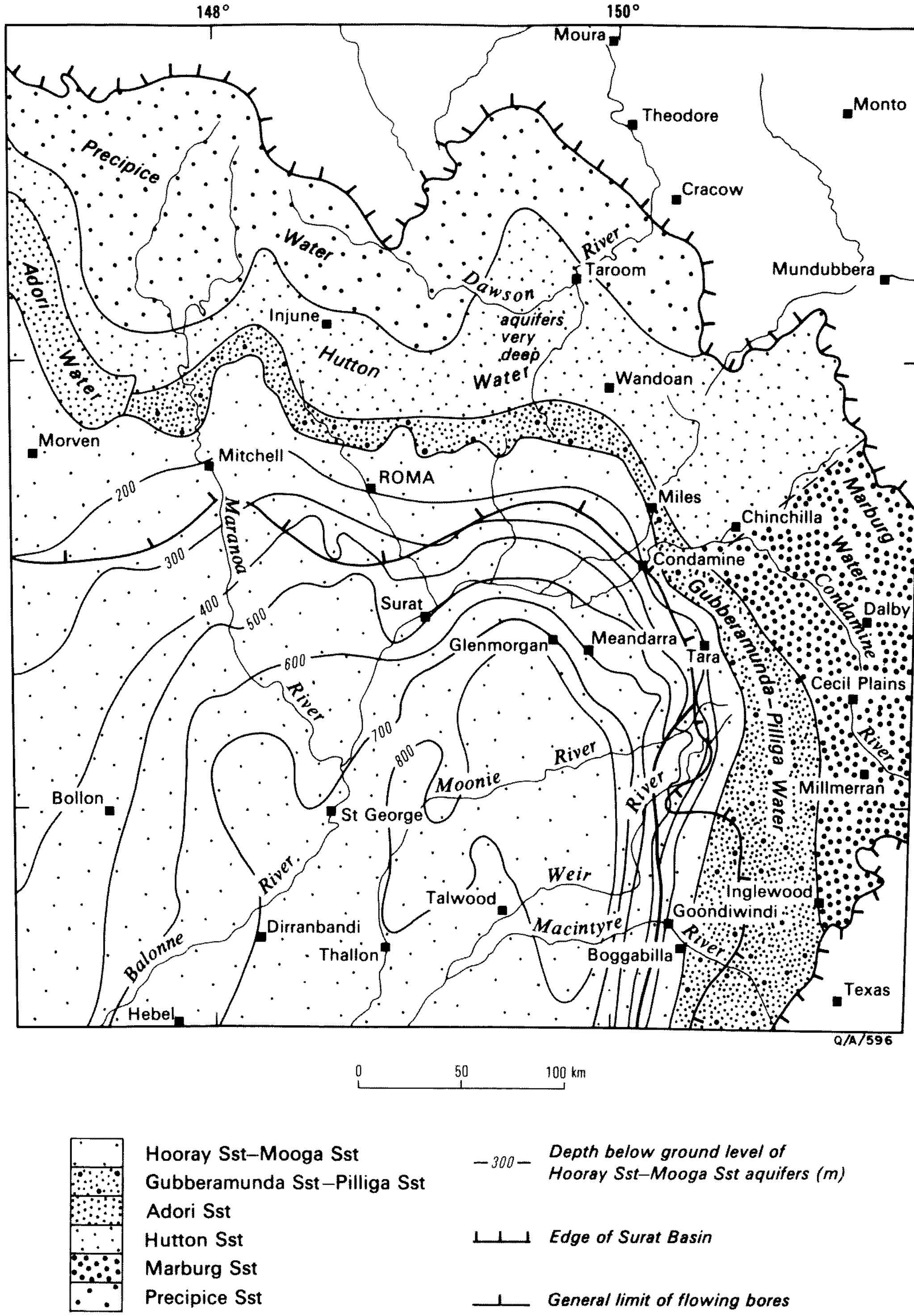


Fig. 32. Distribution of aquifers.

TABLE 10. CHEMISTRY OF MAJOR AQUIFERS

Aquifer	West of 149° E Number of Bores Sampled	West of 149° E Total Dissolved Solids (ppm)	West of 149° E HCO_3/Cl Ratio (equivalents)	East of 149° E Number of Bores Sampled	East of 149° E Total Dissolved Solids (ppm)	East of 149° E HCO_3/Cl Ratio (equivalents)
Hooray Sandstone	19	600-1650 (av. 1100)	0.05-5.3 (av. 2.5)			
Mooga Sandstone	5	600-1570 (av. 1100)	1.4-4.9 (av. 2)	23	1350-2200 (av. 1800)	0.8-17.6 (av. 4)
Gubberamunda Sandstone	5	650-900 (av. 800)	1.4-3.5 (av. 2)	17	850-2100 (av. 1300)	0.6-11 (av. 3)
Pilliga Sandstone				11	750-1750 (av. 900)	2.7-4.4 (av. 3.5)

major aquifers are the Coreena Member and the lower part of the Griman Creek Formation.

In all the aquifers most of the water is stored in the pore spaces between sand grains in sandstone. Fracture porosity is generally unimportant. There are recharge areas around the northern and eastern margins of the basin, and the water moves in a general southerly direction (Ogilvie, 1954). Recharge probably takes place from belts of alluvium and sandy soil overlying the aquifers, and also through joints in the sandstone outcrops.

The main aquifers generally contain bicarbonate water that is suitable for stock and in places for domestic use. According to the Groundwater Map of Australia (1972) the main aquifers west of an arc through Taroom, Roma, Surat, Talwood, and Goondiwindi contain an average of less than 1000 ppm total dissolved solids, whereas in most of the area to the east of the arc the values are between 1000 and 3000 ppm; values of less than 1000 ppm are also recorded in the Goondiwindi-Inglewood-Millmerran area around the Texas High. The salinity of the Precipice Sandstone varies in a complex manner from less than 1000 to over 4000 ppm (see, e.g., Conybeare, 1970).

Table 10 shows the results of analyses of water from major aquifers carried out by the Government Chemical Laboratories, Brisbane, for the BMR (see Appendix 5). The quality of the water is generally better on the western side of the basin than in the east, with total dissolved solids averaging 1000 ppm as against 1500 ppm. However, the Pilliga Sandstone in the east averages only 900 ppm total dissolved solids. The predominance of bicarbonate over chloride (the major ions present) is quite marked.

The aquifers in the Rolling Downs Group contain chloride water, some of which is suitable for stock, but little for human use. The salinity is nearly always greater than 1000 ppm, and exceeds 3000 ppm in the area to the west and south of Surat. The Injune Creek Group also contains highly saline chloride water in the Injune-Taroom area, with salinities ranging from 1000 to over 3000 ppm.

Many of the Cainozoic sands and sandstones contain subartesian water that ranges from fresh to saline, but the only supplies of importance are those obtained from the alluvium along the Condamine River system and in the area of the Dirranbandi Syncline. Lumsden (1966) has reported that the quality of the water in the alluvium along the Condamine River ranged from poor to excellent, and that supplies are adequate for small irrigation schemes near the river.

Surface water

Although the major rivers and streams flow only intermittently they contain permanent and semi-permanent waterholes. In the north and east, where there is some relief and where the annual rainfall is over 500 mm, large earth tanks and dams can be constructed on the clayey soils in and near creeks, gullies, and depressions. They are generally only used for watering stock, but a few of the larger dams have been used for irrigation of small areas.

Coal

The coals in the Walloon Coal Measures have been mined near Injune and Warra for use on the railways,but after the conversion to diesel locomotives in the 1960s the mines were closed. The coals are suitable for use in powerhouses, and for the production of petrochemicals and synthetic gas.

At the Maranoa Colliery near Injune (see Mollan *et al.,* 1972, pp. 89-90) 540 000 tonnes of coal were produced between 1933 and 1963. The main seam was up to 1.4 m thick and consisted of high-volatile weakly coking bituminous coal. W. Hawthorne* gave the following data for the main seam: fixed carbon, 42.6 to 51.1 percent; calorific value, 7528 to 8133 kcal per kg; and ash content, 13.1 to 22.3 percent.

Several holes drilled by the Queensland Department of Mines in the Injune Creek Group intersected coal in the Walloon Coal Measures between the Eurombah Anticline and Taroom (Swarbrick, 1973). Seams of perhydrous coal up to 3.6 m thick were intersected at various levels. The coal is black, has a greasy lustre, a conchoidal or subconchoidal fracture, and a poorly developed cleat. A typical proximate analysis (air-dried basis) is as follows: inherent moisture, 4.0 percent; volatile matter, 38.8 percent; fixed carbon, 35.2 percent; and ash, 22.0 percent. The calorific value ranged from 5500 to 6700 kcal per kg, and the sulphur content from 0.3 to 0.8 percent. Analyses of other coals from the Walloon Coal Measures show that high volumetric yields of fairly high calorific value gas, high tar yields, and low coke yields can be obtained.

Recently drilling has been carried out by private companies in the Millmerran, Wandoan, and Chinchilla areas to locate coal for on-field power stations. Lone Star Exploration NL in a press statement on 8 May 1973 announced that the Chinchilla area 'appears to have . . . two potential open cut areas with inferred reserves in excess of 100 million long tons of raw coal'. In the same statement the company announced that its Wandoan prospect has at least two areas of interest, one with inferred reserves of about 15 million tons of raw coal, and the other with inferred reserves of about 97 million tons.

Following the decline in production of the Ipswich fields because of damage caused by the 1974 floods, the management of the Swanbank powerhouse was considering the use of coal from the Millmerran area, where Millmerran Coal Pty Ltd has evaluated open cut and underground prospects, the best of which (Commodore prospect) has proven reserves of 126 million tonnes, of which 90 million tonnes could be open-cut (*The Australian Financial Review,* 14 Feb. 1974).

The Permian coal measures are outside the scope of this Bulletin (see Dickins & Malone, 1973, for general discussion). The thin coal seams in the Springbok Sandstone and Norwood Mudstone Member of the Westbourne Formation (Swarbrick, 1973), and in the Orallo Formation and Rolling Downs Group, are not of economic significance.

Bentonite

Bentonite is widespread in the Orallo Formation (Duff & Milligan, 1967; Exon & Duff, 1968) between Roma and Miles, and thin beds have also been reported in the Injune Creek Group (e.g. Swarbrick, 1973).

Duff & Milligan (1967) have reported the discovery of bentonite and bentonitic clay in beds up to 1 m thick in the Orallo Formation north of Yuleba. The surface and drill samples analysed show that the bentonite does not meet the API specifications for use in drilling muds, but that it could possibly be used, after alkaline treatment, for iron ore pelletizing.

A similar deposit (Figs 33, 34) was reported by Exon & Duff (1968) north of Miles, where beds up to 1.5 m thick crop out, and thinner beds of bentonite were intersected in shallow drill holes. Analyses have shown that this bentonite is sodium montmorillonite and has potential as a base for drilling mud, and possibly for iron ore pelletizing.

No attempt has been made by BMR to evaluate these deposits fully, but it is encouraging to note that the beds dip at a low angle, and that they could probably be worked by open-cut. The Miles deposit lies

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* Geological Survey of Queensland file note—Maranoa mine area, Injune, 16/7/56.

Fig. 33. Thick bed of bentonite overlying coal in the lowermost part of the Orallo Formation. Five beds crop out in a scarp immediately north of BMR Chinchilla Nos. 1 & 2 on the Miles-Wandoan road, 3 km north-northwest of Miles.

on the Miles-Wandoan railway, and is less than 350 km west of Brisbane.

Iron ore

Beds of oolitic limonite are present in the Westgrove Ironstone Member and an unnamed oolite member of the Evergreen Formation (Mollan *et al.,* 1972, p. 91). A limonite bed up to 3 m thick crops out in the oolite member in the Cockatoo Creek area east of Taroom, where ore reserves have been estimated at 140 million tonnes. The thickness of the ore averages 1.4 m, the overburden 1.8 m, and the average grade is 37.5 percent iron (Urquhart, 1962). Further deposits are present under thicker overburden, both in the Dawsonvale/Cockatoo Creek area and in the Pontypool-Geddesvale-Kilbeggan area.

The Westgrove Ironstone Member is generally thinner than the oolite member and contains less ironstone, but up to 3 m of oolitic ironstone is present in places in the Eddystone Sheet area (Mollan *et al.,* 1972).

Road metal and aggregate

The Tertiary basalts in the northern and eastern parts of the basin are quarried for road metal and aggregate. In the south and west, however, the only road metal and aggregate available are Cainozoic gravels, and toughened beds in the deep-weathering profile that are only marginally suitable.

The major basalt quarries near Amby and north of Roma and Dalby supply most of the needs in the north. Other quarries could be developed in any of the extensive basalts as the need arises. At the Amby quarry

Fig. 34. Close-up photograph of bentonite in Figure 33. The bentonite has been formed by the alteration of volcanic ash, which contains numerous glass shards.

54 000 m^3 of aggregate had been produced up to 1962 (Shipway, 1962), and good reserves exist to the north and south of the quarry. The intrusive basalt 30 km north of Roma has also been quarried for some years. Other quarries farther east include Kings Pit north of Bell, the Malakoff Quarry east of Jimbour, and several used and disused quarries north and east of Dalby. The basalts southwest of Millmerran and south of Goondiwindi have been used locally for road metal.

In the lightly populated areas of the south and west few of the roads are surfaced. Local deposits of Cainozoic gravel and sand and ferruginous layers in the deep-weathering profile are used for surfacing parts of the more important roads, and Cainozoic gravel is used for bitumen aggregate in the St George area.

Clay

A brickworks at Chinchilla uses clay from deeply weathered Jurassic sediments. Hueber & Holland (1952)* have reported that the clays are suitable for bricks, agricultural pipes, and pottery. Analyses of mudstones in the Doncaster Member near Roma (Allen, 1961) have shown that they are suitable for brickmaking. A 10-m bed of kaolinitic claystone in the Hooray Sandstone is exposed 32 km south of Mungallala on the Mount Elliott Homestead road (Exon *et al.*, 1967), and other clay prospects are discussed by Mollan *et al.* (1972).

* CSIRO report on clays in the Chinchilla area filed at the Geological Survey of Queensland, Brisbane.

Miscellaneous minerals

Opal was mined on Mamaree and Beechwood stations, some 60 km southeast of Surat, in the early years of the century. All the shafts are in the Griman Creek Formation, in which the opal is concentrated near the base of the deep-weathering profile. No official records are available, and it is doubtful whether much commercial opal was found.

Oil shale and kerosene shale have been reported from the Walloon Coal Measures in the Injune area, and distillation tests have yielded as much as 225 l of crude oil per tonne. The kerosene shale from the Orallo Formation near Orallo (Jensen, 1926) yielded 200 l of crude oil per tonne.

Various mineral deposits occur in the older rocks surrounding the Surat Basin. The Cracow Goldfield is discussed by Mollan *et al.* (1972), old copper and tin workings northeast of Chinchilla by Exon *et al.* (1968), and the tin, gold, copper, silver, lead, arsenic, manganese, molybdenite, limestone and gemstone occurrences of the Texas High by Olgers & Flood (1974).

ROCK UNITS OLDER THAN THE SURAT BASIN

Basement to the Bowen Basin

Basement in the area consists of indurated and deformed sediments, low-grade metasediments, acid igneous complexes, and volcanics, whose distribution and present relief are shown in Plate 9. In the deep parts of the Taroom Trough basement has not been reached by exploratory wells. The sediments, metasediments, and volcanics range in age from Devonian to Early Permian, and are intruded by granites ranging from possibly as old as Devonian to Early Triassic; the granites generally become younger to the east, in harmony with the eastward migration of the Tasman Geosyncline. The main basement rock units are summarized in Tables 11 and 12.

Timbury Hills Formation (Pzt)

The term 'Timbury Hills Formation' is commonly used for all the indurated sediments and metasediments that form the basement to the west of the Mimosa Syncline. Late Devonian plants have been recovered from two wells, but as the sequence probably includes rock units of different ages the validity of the name is doubtful. The oldest sediments overlying the basement are the Lower Permian Reids Dome Beds, which rest unconformably on the Timbury Hills Formation in the Arbroath Trough.

'Kuttung Formation' and equivalents (C-Pk)

All the volcanics and sediments of Carboniferous to Early Permian age are here included in the 'Kuttung Formation' of Mack (1963), despite the doubtful validity of the name. The age and relations of the rocks recovered in cores are uncertain, and it is not possible to identify separate units such as the Camboon Andesite and Combarngo Volcanics.

The outcrop equivalents of the 'Kuttung Formation' include the Camboon Andesite to the west of the Auburn Complex, the Yarrol Basin sequence east of the Auburn Complex, and the Texas Beds (Clt) in the Texas High.

Roma granites (Clg)

'Roma granites' is the term used by Houston (1964) for the granites penetrated by exploratory wells on the Roma Shelf. She maintained that they were probably part of the same intrusive body that underlies the other basement rocks on the shelf. The Roma granites consist mainly of adamellite; they intrude the Timbury Hills Formation, which is hornfelsed in some wells (Houston, 1964). The K-Ar ages obtained on samples from five AAO wells range from 298 to 350 m.y. (A. W. Webb, table 1 *in* Houston, 1964). All the samples are weathered, so the accuracy of the determinations is doubtful. The presence of arkosic sediments above the granites indicates a period of subaerial erosion.

Auburn Complex (Cug & P-TRg)

The Auburn Complex (see Mollan *et al.*, 1972) consists of granodiorite and minor diorite cut by dykes of dacite and andesite. The complex intrudes Palaeozoic metamorphics and the Lower Permian Camboon Andesite; the isotopic ages obtained on samples from the complex range from early Late Carboniferous to early Late Permian (311-240 m.y.). The results suggest that the complex consists of a western Carboniferous body (Cug) and an eastern Upper Permian to Triassic body (P-TRg) (Webb & McDougall, 1968) which were mapped by Whitaker, Murphy, & Rollason (1974). The complex is unconformably overlain by Lower Jurassic sediments.

Yarraman Complex (Pzm & P-TRg)

The Yarraman Complex (see Exon *et al.*, 1968) consists of foliated acid rocks (Pzm) in the south, and massive granodiorite (P-TRg) in the north.

The grade of metamorphism of the foliated acid rocks (Pzm) increases to the north. The schists and phyllites in the south give way to the north to banded gneisses and foliated granodiorite, which farther north grades into slightly banded biotite granodiorite with elongate biotite clots, and then into equigranular granodiorite (both of

TABLE 11. PRE-BOWEN BASIN STRATIGRAPHY

	Name (map symbol)	*Thickness* (m)	*Lithology*	*Fossils and Environment of Deposition*	*Relations*	*Main References*
Lower Permian	Camboon Andesite (Pln)	3000±	Andesitic and dacitic welded tuff and flows; minor basalt, rhyolite and agglomerate	Plants. Terrestrial and shallow marine	Intruded by Auburn Granite; conformably overlain by Permian sediments	Mollan et al. (1972, pp. 19-20), Whitaker et al. (1974, pp. 32-3)
Lower Carboniferous (possibly ranges into U. Devonian and U. Carboniferous)	Texas Beds (Clt)	Probably thousands of metres	Interbedded lithic sandstone and mudstone, shale, minor chert, jasper, fossiliferous limestone, andesite, intraformational conglomerate	Corals, brachiopods, bryozoans, crinoids. Shallow marine, below and above wave base	Intruded by Permo-Triassic granites; unconformably overlie L. Devonian sequence; unconformably overlain by Permian and Mesozoic sediments	Olgers & Flood (1974)
Devonian to Carboniferous	Yarrol Basin sequence (D, Cl, Cu)	1000+	Pyroclastics, lavas, sandstone, siltstone, shale, oolitic sandstone, calcarenite, recrystallized limestone, massive conglomerate	Corals, bryozoans, brachiopods. Shallow marine and possibly terrestrial	Intruded by Triassic granites; unconformably overlain by L. Jurassic sediments	Maxwell *in* Hill & Denmead (1960, pp. 160-2), Exon et al. (1968)
Carboniferous to Lower Permian	'Kuttung Formation' (C–Pk)	Probably thousands of metres	Tuff, andesite, dacite, siltstone, sandstone, conglomerate, shale	Shelly fossils. Shallow marine	Blanket term embracing subsurface Cracow Fm, Camboon Andesite, Combarngo Volc, Texas Beds, and Yarrol Basin sequence. Unconformably overlain by L. Jurassic sediments	Mack (1963)
Devonian at least	Timbury Hills Formation (Pzt)	Probably thousands of metres	Sandstone, siltstone, shale and their metamorphosed equivalents	Plants. Mainly terrestrial	Blanket term for all indurated subsurface sediments and metasediments in basement. Intruded by Roma granites; unconformably overlain by L. Permian and younger sediments	Derrington (1961), Traves (1966)

TABLE 12. PRE-BOWEN BASIN IGNEOUS AND METAMORPHIC ROCKS

	Name (map symbol)	*Location*	*Lithology*	*Relations*	*Main References*
Upper Permian to Lower Triassic (stratigraphic grounds)	(P-TRg)	Texas area (in SE part of map)	Massive granite and granodiorite	Intrudes Carboniferous Texas Beds; unconformably overlain by L. Jurassic strata	'Ashford granite' of Lucas *in* Hill & Denmead eds (1960, p. 233)
Upper Permian (isotopic grounds)	(P-TRg)	W of Proston (in E part of map)	Massive hornblende-biotite granite grading into granodiorite; acid to basic dykes	Part of Yarraman Block; genetic relations with contiguous metamorphic rocks (Pzm) unknown, although contact is generally gradational; intrudes Carboniferous rocks	Hill & Denmead eds (1960, pp. 245-9), Exon et al., (1968), Webb & McDougall (1968)
Upper Carboniferous to Lower Permian (isotopic and stratigraphic grounds	Auburn Granite (Cug, P-TRg)	Between Cracow and Eidsvold (in NE part of map)	Hornblende-biotite granite grading into granodiorite; acid to basic dykes	Part of Auburn Complex; intrudes Palaeozoic metamorphics and L. Permian Camboon Andesite to N; unconformably overlain by L. Jurassic strata	Mollan et al. (1972, pp. 74-6), Webb & McDougall (1968)
Lower Carboniferous (isotopic grounds)	Roma granites (Clg)	Roma area (subsurface)	Micaceous granite and adamellite in several discontinuous bodies	Intrude and thermally metamorphose L. Palaeozoic Timbury Hills Fm; unconformably overlain by M. Triassic and younger strata	Houston (1964)
Devonian?	(Dg)	Talwood area (in S part of map). (subsurface)	Granite, granodiorite, dolerite	Unconformably overlain by L. Jurassic sequence	
Mid-Palaeozoic	(Pzm)	SE of Durong (in E part of map)	Schist, gneiss, foliated granodiorite; minor phyllite, acid to basic dykes; grade of metamorphism increases to N	Part of Yarraman Block; generally gradational contact with P-TRg granite; unconformably overlain by L. Jurasisc sequence	Exon et al. (1968)
Lower Palaeozoic (stratigraphic grounds)	(Pzr)	Asbestos Gully (in NW part of map).	Mainly sheared gabbro; some altered ultrabasic rocks, chlorite rock, and tremolite veins	Unconformably overlain by Triassic (or older) rocks	Mollan et al. (1972, p. 12)
Palaeozoic	(Pzs)	S of Morven (in W part of map) and near St George (in SW part of map). (subsurface)	Schist, gneiss	Unconformably overlain by Jurassic sequence	

which are included in unit P-TRg). Thus the boundary between the units is gradational.

The granodiorites (P-TRg) intrude the Carboniferous volcanics and sediments of the Yarrol Basin sequence; copper mineralization is present near the contact. Acid igneous rocks belonging to the same suite of intrusions farther east were dated as Late Permian by Webb & McDougall (1968).

The relations between the massive granodiorites and the metamorphics is obscure. Although the contacts are generally gradational, some of the small granodiorite bodies in the metamorphics (Pzm) have sharp intrusive contacts. It is possible that the foliated acid rocks (Pzm) represent downfolded Lower Palaeozoic or mid-Palaeozoic rocks that were granitized and partly mobilized in the Permian to form the intrusives (P-TRg).

Texas High granite (P-TRg)

The Upper Permian to Triassic granites of the New England Batholith are intrusive into the Permo-Carboniferous sequence of the Texas High. The intrusives have been described in some detail by Robertson (1974), who assigns the granite west of Texas to the Late Permian or Early Triassic, and the granites south of Yuraraba to the Early Triassic. The PS Millmerran No. 1 well bottomed in granite that is also probably a northerly offshoot of the New England Batholith.

Other igneous intrusives

Other large bodies of granite (see Fig. 7) of uncertain age, which are presumed to be intrusives into the Timbury Hills or 'Kuttung Formation', or both, form the basement near Talwood (Dg), south of Mungallala, and north of Mitchell. The Mungallala granite is flanked by schist and gneiss; schists and gneisses also form basement at St George.

A small body of sheared gabbro and pyroxenite (Pzr), which crops out at Asbestos Gully on the Nebine Ridge, may be intrusive into the Timbury Hills Formation. It is unconformably overlain by pre-Jurassic sediments, and plagioclase from the gabbro has yielded an Early Palaeozoic K-Ar age (A. Webb, pers comm.). A zone of sharp magnetic anomalies along the crest of the Nebine Ridge is probably due to a continuation of these basic and ultrabasic rocks in the subsurface (Magellan Petroleum Corp., 1963, p. 13).

BOWEN BASIN ROCKS

The Permian and Triassic rocks cropping out in the Bowen Basin have been described by Mollan, Dickins, Exon, & Kirkegaard (1969), Mollan *et al.* (1972), and Dickins & Malone (1973). A summary of the nomenclature used in various areas and the preferred correlations from area to area are given in Table 13, and brief descriptions of the various units in Tables 14 and 17.

Four thousand metres of Permian sediments (mainly marine) and 5500 m of Triassic rocks (mainly freshwater) were laid down in the Taroom Trough, and a thick sequence of Permian rocks was also deposited in the Denison Trough. The 4000 m of Permian sediments and 5500 m of Triassic sediments represent accumulation rates of 13 and 27 cm per 1000 years respectively (Table 15), which indicate fairly rapid subsidence in these troughs throughout the Permo-Triassic period.

PERMIAN SEQUENCE NORTH OF SURAT BASIN

The Permian sequence in the *Denison Trough* (Table 14) consists of 2500 m of Lower Permian (Sakmarian) stream and swamp deposits (Reids Dome Beds), up to 2000 m of Lower to Upper Permian marine sediments (Back Creek Group), and 150 m of Upper Permian (Tartarian) coal measures (Blackwater Group). The Back Creek Group has been subdivided into the Tiverton (750 m) and Gebbie (700 m) Sub-groups and the relatively thin Blenheim Sub-group (300 m).

Farther east in the *Taroom Trough* near Cracow, over 1000 m of Sakmarian terrestial volcanic rocks of the Camboon Andesite are overlain by some 2000 m of Lower to Upper Permian marine sediments of the Back Creek Group and 800 m of the Tartarian Blackwater Group coal measures. The Tiverton and Gebbie Sub-groups of the Back Creek Group are relatively thin (200 m and negligible) in the Cracow area, whereas the

TABLE 13. NOMENCLATURE AND CORRELATES, SOUTHERN PART OF BOWEN BASIN

Mollan et al. (1972) *SE part of Bowen Basin* (e.g. Theodore-Cracow area)	*Jensen* (in press) *SE part of Bowen Basin* (Theodore-Cracow area)		*Union/Kern/AOG Southern part of Taroom Trough* (beneath Surat Basin)	*This Bulletin Southern part of Taroom Trough* (beneath Surat Basin)	*This Bulletin Roma Shelf*	*Mines Administration Pty Ltd Roma Shelf*	*Mollan et al.* (1972) *SW part of Bowen Basin* (e.g. Denison Trough)		
Moolayember Formation	Moolayember Formation		Wandoan	Wandoan	Moolayember Formation	Moolayember Formation	Moolayember Formation		Middle Triassic
Clematis Sandstone	Expedition* Sandstone	Clematis			Showgrounds Sandstone	Showgrounds Sandstone	Clematis		
——D——D——			Formation	Formation	u-u-u-u-u-u-u-u-u-u	u-u-u-u-u-u-u-u-u-u			
Rewan	Glenidal Formation	Group			No deposits	No deposits	Sandstone		
			u-u-u-u-u-u-u-u-u-u	u-u-u-u-u-u-u-u-u-u	u-u-u-u-u-u-u-u-u-u	u-u-u-u-u-u	D——D——D		Lower Triassic
	Arcadia Formation	Rewan	Cabawin Formation	Rewan Group (=Cabawin Formation)	Rewan Group	Rewan Formation	Rewan Formation		
Formation	Sagittarius Sandstone	Group							
					u-u-u-u-u-u-u-u-u	u-u-u-u-u-u			
Baralaba Coal Measures			Kianga Formation	Blackwater Group	Blackwater Group	Bandana Formation	Blackwater Group		Upper Permian
Gyranda Formation									
Back			Back	Back	Back	Black Alley Shale	Black Alley Shale	Blenheim	
Creek			Creek	Creek	Creek	Tinowon Formation	Peawaddy Formation	Sub-Group	
Group			Group	Group	Group	Muggleton Formation	Catherine Sst -Ingelara Formation	Gebbie	Lower Permian
					u-u-u-u-u-u-u-u-u	u-u-u-u-u-u-u-u-u-u	Aldebaran Sandstone	Sub-Group	
							Cattle Creek Formation	Tiverton Sub-Group	
							Reids Dome Beds		

* In this area probably the Dawson Range Sandstone of Reid (1945).
D = disconformity
u = unconformity

TABLE 14. PERMIAN STRATIGRAPHY, BOWEN BASIN

	Name (map symbol)	Maximum Thickness (m)	Lithology	Fossils	Environment of Deposition	Relations	Main References
Upper Permian	Blackwater Group (Puw)	800 in Taroom Trough, 250 beneath Surat Basin, 150 in Denison Trough area	Carbonaceous shale, siltstone, lithic to lithic sublabile sandstone, coal; some tuff in S	*Glossopteris* flora and spores (acritarchs at base in some areas)	Mainly terrestrial: streams, lakes, and coal swamps	Equivalent to Barralaba Coal Meas and Gyranda Fm in far N. Not readily divisible beneath Surat Basin. Minad's Bandanna Fm of Roma Shelf. Union's Kianga Fm in S	Malone, Olgers, & Kirkegaard (1969), Mollan et al. (1972), Dickins & Malone (1973)
Lower to Upper Permian	Back Creek Group (Pb)	2000 in Denison Trough, and beneath N part of Surat Basin	Shale, siltstone, sandstone, conglomerate, coal; some tuff in S. Minor limestone	Shelly faunas II, III, and IV, *Glossopteris* flora, spores and acritarchs	Dominantly shallow marine, grading into coastal plain and deltaic	Conformably overlies Reids Dome Beds in Dension and Arbroath Troughs. Unconformably overlies older units beneath Surat Basin, where it is not readily divisible	Derrington, Glover, & Morgan (1959), Dickins & Malone (1973)
Upper Permian	Blenheim Sub-Group	1500 in Baralaba area, 300 in Denison Trough area	Shale, siltstone, lithic sublabile sandstone; some clay, bentonite, tuff, and coquinite	Shelly fauna IV, *Glossopteris* flora, spores and acritarchs, rare fish scales	Swamps, coastal plains, shallow seas; marine influence diminished as time went on	Uppermost sub-gp of Back Creek Gp. Split into Black Alley Sh and Tinowan Fm on Roma Shelf by Minad. Conformable on older Permian sediments	Dickins & Malone (1973)
	Gebbie Sub-Group	700 in Denison Trough. Absent in Cracow area	Sandstone, siltstone, mudstone; some tuff, coquinite, and coal	Shelly fauna III, *Glossopteris* flora, spores	Moderately deep marine to coastal plain; dominantly shallow marine. Cold water; some ice rafting of cobbles and boulders. Some explosive volcanism	Middle sub-gp of Back Creek Gp. Represented by Minad's Muggleton Fm on Roma Shelf. Conformable on older Permian sediments, unconformable on basement	Mollan et al. (1969), Dickins & Malone (1973)
Lower Permian	Cattle Creek Formation (= Tiverton Sub-Group)	500 (Cattle Creek), 750 (Tiverton Sub-Gp) in Denison Trough. 200 (Tiverton Sub-Gp) in Cracow area	Conglomeratic siltstone, sandy mudstone, sandstone, coquinitic limestone	Shelly fauna II, characterized by *Eurydesma; Glossopteris* flora	Marine, somewhat restricted. Very cold water; ice rafting of cobbles and boulders	Only representative of Tiverton Sub-Gp in this area (lowest sub-gp of Back Creek Group). Confined to Denison Trough. Conformable on Reids Dome Beds	Mollan et al. (1969)
	Reids Dome Beds (Plj)	2500 in Denison Trough, 1100 in Arbroath Trough	Polymictic conglomerate, sandstone, siltstone, shale; some coal	*Glossopteris* flora, spores	Streams, lakes, and coal swamps	Virtually confined to Denison and Arbroath Troughs. Unconformable on basement rocks	Mollan et al. (1969)

TABLE 15. MAXIMUM RATES OF SEDIMENT ACCUMULATION FOR VARIOUS STRATIGRAPHIC INTERVALS

Sequence	*Age*	*Environment of Deposition*	*Time Span* (m.y.)	*Maximum Thickness* (m)	*Maximum Rate of Accumulation of Consolidated sediment* (m/m.y.)	(cm/1000 y.)
Cainozoic sediments	Cainozoic	Streams	65?	250	4?	0.4?
No sediments preserved	Late Cretaceous		38		0	0
Coreena Member and Griman Creek Fm	Early Cretaceous	Marine and streams	4	850	210	21
Doncaster Member		Marine	4	270*	70	7
Minmi Member		Shallow marine	2?	80	40?	4?
Mooga Sst and Nullawurt Sst		Streams	24?	430	18?	1.8?
Springbrook Sst and Orallo Fm	Jurassic	Streams and swamps	24	1000	40	4
Walloon Coal Measures		Swamps and streams	10	650*	65	6.5
U. part of Evergreen Fm, and Hutton Sst		Streams and deltas	10	370	40	4
Precipe Sst and L. part of Evergreen Fm		Streams and deltas	19	390	20	2
No sediments preserved	Late Triassic		20		0	0
Clematis Gp and Moolayember Fm	E-M Triassic	Streams and deltas	10	2000	200	20
Rewan Group		Streams	10	3500	350	35
Blackwater Group	Permian	Swamps and streams	10	700*	70	7
Back Creek Group		Marine	20	3500?	170?	17?
Reids Dome Beds		Streams	5	2500	500	50
MAJOR SUBDIVISIONS						
Cainozoic		Streams	65?	250	4?	0.4?
Marine Cretaceous		Marine and streams	8	1200*	150	15
Freshwater Cretaceous		Streams	24?	430	18?	2?
Jurassic		Streams and deltas	60	2400	40	4
Total Surat Basin	Jurassic-Cretaceous	Varied	95	4000	40	4
Triassic		Streams	20	5500	270	27
post-volcanic Permian		Marine and coal measures	30	4000?	130?	13?
Total Bowen Basin	Permian-Triassic	Varied	50	9500	190	19

* Compaction greater than normal.

TABLE 16. PERMIAN BACK CREEK GROUP STRATIGRAPHY, ROMA SHELF.

Unit	*Maximum observed Thickness* (m)	*Depositional Environment*	*Lithology*
BLACK ALLEY	60	LACUSTRINE	DARK CARBONACEOUS AND TUFFACEOUS SHALE AND SILTSTONE
Winnathoola Coal Mbr	20	TO Paludal	THIN TUFF BANDS; Black and brown coal, carbonaceous shale and siltstone
SHALE		MARINE	AND MINOR SANDSTONE
Mantuan *Productus* Bed	30	Marine	Coquinitic shale, siltstone and sandstone
TINOWON	124	PARALIC	GREY TUFFACEOUS SHALE AND SILTSTONE, MINOR SANDSTONE, THIN TUFF BANDS
Wallabella Coal Mbr	31	Paludal	Black coal, carbonaceous shale and siltstone
FORMATION			RARE COAL SEAMS MARINE FOSSILS COMMON
MUGGLETON	148	PARALIC	GREY SHALE, SILTSTONE AND SANDSTONE, FEW COQUINITES,
Lorelle Sandstone Mbr	62	TO Marine	Coarse-grained quartzose sandstone
FORMATION		MARINE	TUFF BANDS, AND COAL SEAMS

Blenheim Sub-group is relatively thick (1700 m).

These figures are based on the correlations of Mollan *et al.* (1972) and Dickins & Malone (1973), which differ from those of Anderson (1971), who maintains that the upper part of the Back Creek Group as defined by the BMR in the Denison Trough is the lower part of the type Blackwater Group in the Taroom Trough. The standard BMR correlations are as shown in Table 10.

Comparison of the sequences in the two areas shows that the area of maximum Permian deposition moved eastward from the Denison Trough in Blenheim Sub-group time.

Farther south, beneath the Surat Basin, the Permian sequence on the Roma Shelf and the Taroom Trough is thinner.

Permian Sequence on Roma Shelf

On the Roma Shelf, where the sequence consists of the Reids Dome Beds, the upper part of the Back Creek Group, and the Blackwater Group, the stratigraphy has been studied in detail by geologists of Mines Administration Pty Ltd. The results have been published in summary form by Traves (1966, 1971) and Swindon (1968), on which the following description is mainly based.

Reids Dome Beds

The Lower Permian Reids Dome Beds are preserved only in the half-graben of the Arbroath Trough, where they are about 1100 m thick. The Arbroath Fault does not cut the unconformably-overlying Lower Jurassic sediments, and is therefore of pre-Jurassic age. The absence of Triassic and post-Sakmarian Permian sediments in the trough suggests that active movement on the fault and subsidence of the half-graben were restricted to the Early Permian.

The Reids Dome Beds consist of coal measures that contain detrital sediments ranging from polymictic conglomerate to shale. The measures were probably laid down rapidly at the foot of a scarp where the velocity of the streams was suddenly reduced as they debouched from high country onto a swampy plain. While movement continued on the Merivale-Arbroath Fault to the east, the plain sank, and rapid deposition continued. After movement stopped, a thin sequence of Permo-Triassic sediments may have been laid down, but if so it was removed during the long period of Late Triassic erosion.

Back Creek Group

A thin sequence of marine beds representing the Back Creek Group was laid down in drowned river channels cut in the pre-Permian metamorphics and granite along the eastern margin of the Roma Shelf, most of which was well above sea level (e.g. Traves, 1971). With time the sea transgressed farther onto the shelf, so that the younger units overlap the older. The sub-divisions of the Back Creek Group on the Roma Shelf (after Paten & Groves, 1974) are summarized in Table 16.

Blackwater Group

The Blackwater Group (called Bandanna Formation by Mines Administration geologists) consists of up to 150 m of lake and swamp deposits that filled broad valleys in the basement and in the plains of older Permian sediments. It laps 5 to 15 km across the basement west of the Back Creek Group, generally to the longitude of Roma town (Fig. 13). The group consists mainly of brown and black carbonaceous shale and siltstone, with numerous thin coal seams and a little sandstone.

PERMIAN SEQUENCES IN TAROOM TROUGH BENEATH SURAT BASIN

The Permian sequence in the Taroom Trough has been extensively investigated by seismic surveys and drilling by the Union Oil Development Corp. and their associates, but no regional syntheses have been published by them. The following brief description and the structural and isopach maps (Figs 8, 13, 14) are based on data supplied to the Commonwealth Government under the terms of the Petroleum Search Subsidy Acts, and to the Queensland Department of Mines on relinquishment of various parts of their leases (see Tables 1, 2, 3).

A twofold subdivision into the marine Back Creek Group and the non-marine Blackwater Group (Kianga Formation of Union Oil Development Corp.) is readily made and sustained throughout the trough. Although it is probable that all three subgroups of the Back Creek Group, as known in outcrop, are present in this area, detailed studies of cores and well data would be needed to subdivide the sequence further.

The top of the Permian sequence is 4000 m below sea level near Meandarra in the axis of the Taroom Trough (Fig. 8). The trough shallows steadily to the south, and southwest of Goondiwindi its axis is 1400 m below sea level. The Permian sequence thins from 1000 m near Meandarra to 200 m near Goondiwindi, and the two groups within it also thin in the same direction.

Back Creek Group

The Back Creek Group consists of up to 700 m of shallow-marine deposits, and laps onto the basement west of the Taroom Trough. East of the fault zone along the eastern side of the trough it is preserved only in the depression east of Moonie; its equivalents (Plt) are preserved in small grabens on the Texas High. The original extent of marine Permian sedimentary rocks east of the fault zone is unknown, but on the west side of the trough their present extent probably coincides roughly with the original area of deposition.

The sequence in UKA Cabawin No. 1, where it is nearly 400 m thick, is probably representative for most of the area. The lower part consists of dark grey pyritic carbonaceous and silty shale, siltstone with carbonaceous partings, and silicified lithic sandstone. The upper part consists of interbedded blue-grey calcareous siltstone and shale, and lithic sandstone.

The fauna consists mainly of brachiopods and crinoids, and the environment of deposition ranged from moderately deep marine (depth of water less than 100 m) to coastal swamps. The tuffaceous material in the rock may have been derived from older volcanics, or it may represent contemporaneous volcanism.

The shelly fossils, plants, and microfossils all confirm the Permian age of the group.

Blackwater Group

The Blackwater Group consists of 300 m or less of coal measures. It overlaps the Back Creek Group on the west side of the Taroom Trough, where it rests directly on basement rocks, by as much as 20 km (Fig. 13). The present boundary of the group in the west probably coincides roughly with the western limit of the depositional basin. The group is not present to the east of the fault zone on the east side of the trough, and its original easterly extent is unknown. In the far south, where the sequence consists of interbedded coal, shale, siltstone, sandstone, tuff, and conglomerate, the maximum thickness is less than 50 m. The tuffs are micaceous and carbonaceous, and many of the coaly beds contain some volcanic ash. The sandstones range from lithic to quartzose.

The beds were deposited in swampy lowlands, and although they contain no marine macrofossils, they do contain a Late Permian microflora (de Jersey and Evans *in* PSSA Publication 43, UKA Cabawin No. 1 well completion report—see Table 1).

Lower Triassic Bowen Basin Sequence (Table 17)

Tissot (1963) has pointed out that the seismic and well data show that:
(i) in the central part of the basin, the Lower Triassic sequence is conformable on the Upper Permian coal measures; (ii) on both the eastern and western borders of the basin north of 26°30′S, the Lower Triassic sequence is conformable with the coal measures, both of which are truncated by the unconformably overlying Lower Jurassic sequence; and (iii) on both borders of the basin south of 26°30′S, the Lower Triassic sequence rests unconformably on the coal measures. The nearly horizontal Lower Triassic beds onlap against tilted coal measures that were rising to form the present structural basin.

Thus (after Tissot, 1963) we can suppose continuous subsidence and sedimentation in the central part of the Triassic basin. In the south both margins began to move, the western by gentle folding and the eastern by folding and faulting, in Late Permian to Early Triassic time, when the basin began to assume its present shape. Later in the Early Triassic, sedimentation started to lap over these border areas. In the north, on the other hand, sedimentation was continuous even on the present borders, and the folding and faulting took place later.

In most of the basin a sequence of fluvial and lacustrine varicoloured mud, silt, and sand was laid down, but near the southerly fault zone, and especially in the Moonie-Cabawin area, fluvial gravels predominated. The normal facies is assigned in this Bulletin to the Rewan Group (Jensen, 1975), and the conglomerate facies to the Cabawin Formation (Mack, 1963).

Rewan Group

The Rewan Formation (Isbell, 1955) has been upgraded to group status by Jensen (1975), who has divided the group into two formations—the Sagittarius Sandstone overlain by the Arcadia Formation—which have not yet been widely identified in the subsurface.

The type area of the Rewan Group (Isbell, 1955; Hill, 1957) is near Rewan hometsead in the Springsure Sheet area, where it is 500 m thick (Mollan *et al.*, 1969). Its nature and relation to the Cabawin Formation have been investigated by detailed petrological studies by Tissot (1963), Fehr (1965), and Bastian (1965a, c).

In outcrop (Jensen, 1975), the Sagittarius Sandstone consists of interbedded lithic sandstone, siltstone, and mudstone. The sandstone ranges from fine to coarse-grained, is calcareous in part, and contains scattered mud clasts and plant fragments. The siltstone and mudstone are green, brown, or grey, and in the subsurface are mottled in places. The contact with the underlying coal measures of the Blackwater Group is taken at the top of the youngest coal seam, and the same criterion is used throughout the basin in the subsurface.

The Arcadia Formation (Jensen, 1975) comprises all but the lowest 50 m of the

TABLE 17. TRIASSIC STRATIGRAPHY, BOWEN AND IPSWICH-MORETON BASINS

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Main References*
Upper Triassic	Raceview Formation (TRs)	70	Impermeable sandstone, siltstone and shale, minor coal	Uppermost Triassic spores. Plants comparable to those of Ipswich Coal Meas	Terrestrial: streams, swamps, lakes	Moreton Basin unit; conformable on Aberdare Congl. Pinches out to W against Kumbarilla Ridge	Staines (1964), de Jersey (1970a)
	Aberdare Conglomerate (TRs)	380	Polymictic conglomerate, grey, green, or red shale, minor coal	Uppermost Triassic spores	Fluviatile: channel and overbank deposition	Basal Moreton Basin unit; unconformable on older Triassic sequence. In this area confined to deeper part of Cecil Plains Syncline	Staines (1964), de Jersey (1970a)
?Middle Triassic	Volcanics (TRs)	Drilled 260±; seismic, 750	Interbedded gently dipping acid lavas and tuffs; greenish, massive, crystalline, siliceous, dense, hard	None	Terrestrial volcanics	Ipswich Basin unit; unconformable on Palaeozoic sequence. Deeper part of Cecil Plains Syncline. Probable equivalent of Neara Volc	Mellins (1971)
Middle Triassic	Moolayember Formation (TRm)	1500	Siltstone, mudstone, lithic and lithic sublabile sandstone; calcareous in part	Plants, spores, acritarchs, extremely rare freshwater pelecypods	Fluviatile channel and overbank deposition; deltaic grading possibly into shallow marine in axis of Taroom Trough	Bowen Basin unit; conformable on Clematis Gp in much of basin, but laps onto Permian and older rocks on W side	Mollan et al. (1972), de Jersey & Hamilton (1967)
Lower to Middle Triassic	Clematis Group (TRe)	300	Quartzose to sublabile sandstone, minor conglomerate, siltstone, and shale	Plants, spores	Fluviatile channel and overbank deposition	Bowen Basin unit; generally conformable on Rewan Gp. Showgrounds Sst of Roma Shelf is upper part of Clematis Gp	Mollan et al. (1972), de Jersey (1968), Jensen (1975)
	'Wandoan Formation' (TRw)	400	Quartzose to lithic sandstone, conglomerate, siltstone, shale	Plants, spores	Fluviatile channel and overbank deposition; deltaic grading possibly into shallow marine in axis of Taroom Trough	Subsurface Bowen Basin unit equivalent to Clematis Gp and Moolayember Fm. Generally conformable on Rewan Gp	Union (1964), de Jersey & Hamilton (1969)
Lower Triassic	Rewan Group (TRlr)	3500	Reddish brown and green mudstone, siltstone, lithic to lithic sublabile sandstone, conglomerate	Rather rare plant debris and spores	Terrestrial: fluviatile channel and overbank deposition, soils. Possibly aeolian in part	Bowen Basin unit; conformable or disconformable on Permian sediments in much of basin, unconformable around S margins. Union's subsurface 'Cabawin Formation' in S	Mollan et al. (1972), de Jersey (1970b), Jensen (1975)

type section of the Rewan Formation as measured by Mollan *et al.* (1969). The Arcadia Formation is characterized by thick sequences of red-brown mudstone, and is readily eroded. Red-brown mudstone and silty mudstone, with thin beds of green siltstone and very fine sandstone, are interbedded with thick beds of fine to medium-grained cross-bedded green sandstone. The sandstone is calcareous in places.

The thickness cropping out reaches a maximum of 3500 to 4000 m west of Theodore (Fig. 15). Jensen has shown that the beds were laid down by a system of meandering and anastomosing channels, and that the red colour of the mudstone is due to the presence of finely divided hematite derived from red soils in the source area.

On the Roma Shelf, where the Rewan Group is generally less than 200 m thick, Fehr & Bastian (1963) and Bastian (1965a) have shown that sandstone and mudstone predominate. The sandstone is mainly green and lithic, and the mudstone red-brown and green.

Detailed petrological work by Fehr (see Tissot, 1963) has shown that deposition of the Rewan Group sequence began at different times, with different sediments, in different areas. Thus, in AAO Meeleebee No. 1 a lower member (S_0), which seems to correlate with the lower part of the type section of the Cabawin Formation, is present. The sequence consists of very thickly bedded conglomerate and sandstone, which contain pebbles of tuff and some tuffaceous matrix. On most of the Roma Shelf, however, the finer-grained sediments resting on the pre-Triassic rocks are presumed to be younger. They consist of fine-grained green sandstone grading into green, grey, and brown siltstone, and varicoloured mudstone.

In the subsurface on the eastern side of the basin, in the Miles-Taroom area, the group consists of a thick monotonous sequence of mudstone, siltstone, and sandstone, containing a considerable proportion of tuffaceous debris. In UKA Wandoan No. 1, for example (Union, 1965), the group is 1379 m thick. The mudstone and siltstone are mottled green, red, and brown, with streaks and laminae of macerated carbonaceous matter at some levels. The sandstone is greenish white to green, lithic, and contains an abundant clay matrix. Conglomerate is generally rare in this area.

The palynological evidence outlined in the completion reports on the numerous petroleum exploration wells in the Rewan Group and the equivalent Cabawin Formation attests to the Early Triassic age of the group (see also de Jersey, 1970b).

Cabawin Formation

The Cabawin Formation was defined by Mack (1963), with its type section between 7640 and 9835 feet (2329-2998 m) in the UKA Cabawin No. 1 well. The sequence consists mainly of conglomeratic sandstone and conglomerate, with some varicoloured mudstone. The conglomerate beds consist of pebbles and cobbles of quartz, chert, quartzite, and tuff set in a clayey tuffaceous matrix. The mudstone is reddish brown, mustard-coloured, or grey, and grades into siltstone.

In the subsurface the distinctive conglomeratic facies can be traced only as far north as UKA Davidson No. 1 and as far south as UKA Sussex Downs No. 1. Thus the formation is confined to the Taroom Trough, where it flanks the Moonie-Goondiwindi fault system. It does not extend as far north as Miles, or as far south as Goondiwindi; nor does it occur west of the axis of the trough (e.g. in UKA Kinkabilla No. 1).

Thus the massive conglomerates can be related to movements on the Moonie-Goondiwindi fault system in the southern part of the Taroom Trough; they were probably deposited as fanglomerates near a fault scarp, and were mainly derived from Permian and Carboniferous volcanics on the upthrown eastern side of the fault system. To the west and north they interfinger with finer-grained sediments of the Rewan Group, and to the south they were either not deposited or have been removed by erosion. Similar conglomerates occur in the lower part of the Rewan Group in places, but they do not predominate.

The maximum thickness of the Cabawin Formation is probably about 1000 m near Meandarra (Fig. 15). Part of the formation may be older than the Rewan Group, although the pollens are indistinguishable from those in the Rewan Group.

MIDDLE TRIASSIC BOWEN BASIN SEQUENCE

In outcrop the Middle Triassic sequence is represented by the Clematis Group and the overlying Moolayember Formation (Table 17); the same units are recognizable on the Roma Shelf, although they are much thinner. In most of the subsurface these subdivisions are not easily recognizable, and the entire Middle Triassic sequence is here assigned to the Wandoan Formation (see also cross-sections on map).

Seismic and well data show that sedimentation and subsidence were continuous in the deepest part of the basin during the Early and Middle Triassic (see also Tissot, 1963). In a few areas along the northern margin of the basin, such as on the Wandoan axis on which the UKA Wandoan No. 1 well lies, folding started in Middle Triassic time, with the result that the Middle Triassic beds rest directly on the Upper Permian coal measures. In the western and southern parts of the basin the Middle Triassic beds lapped onto pre-Triassic rocks, but in the east they do not appear to have transgressed beyond the Burunga-Moonie-Goondiwindi zone of faulting.

In Middle Triassic time (Fig. 16) the basin was a half-graben in which there was rapid sinking and thick sedimentation in the east. The maximum thickness of the succession in the north, west of Theodore, is about 2000 m, but it thins rapidly to the south to about 300 m southwest of Wandoan. In a depression near Glenmorgan the sequence is 600 m thick, but to the south the maximum thickness decreases steadily to about 200 m west of Goondiwindi.

Clematis Group

The Clematis Sandstone (Jensen, 1926) was named after Clematis Creek in the Expedition Range, where it consists mainly of quartzose sandstone with minor siltstone towards the top. The unit has been upgraded by Jensen (1975) to group status, and now comprises the Glenidal Formation and Expedition Sandstone.

The Glenidal Formation conformably overlies the Rewan Group, and consists of mudstone, some of which is red, siltstone, and sandstone. The type section is in the Carnarvon Ranges (25°11′S; 148°35′E). The lower boundary is taken at the change from labile sandstone to sublabile sandstone, which corresponds with a decrease in the amount of mudstone. The Expedition Sandstone consists predominantly of quartzose to sublabile sandstone, with some lenses of grey or red siltstone and muddy siltstone. The type section, which is about 145 m thick, is in the hills immediately east of Serocold homestead in the Springsure Sheet area (see Mollan *et al.,* 1969, Sect. S29). The sandstone grades into pebbly sandstone and conglomerate in places, and is cross-bedded.

In outcrop the Clematis Group thickens to the east from about 100 m on the Springsure Shelf west of the Denison Trough to several hundred metres in the Expedition Range and to about 800 m in the Dawson Range. A system of braided and meandering channels spread sand southward (Fig. 16), and in some areas, especially early in Clematis Group time, soils were developed.

The hydrocarbon-bearing Showgrounds Sandstone of the Roma Shelf was named by Traves & Thralls (1960), and has been alluded to in many Mines Administration Pty Ltd publications since. Swindon (1968) equated it with the upper part of the Clematis Sandstone. It is a white quartzose sandstone that was derived from the quartz-veined Timbury Hills Formation and the Roma granite. It was deposited by streams either unconformably on basement rocks or conformably on the Rewan Group. Traves (1971) stated that it 'has medium porosity (14-19%) and high permeability (up to 4 darcys). The sand is coarse-grained, subangular, with fair to good sorting.' The thickness of the formation averages only 5 m, but is over 15 m along the eastern side of the Roma Shelf.

Moolayember Formation

The Moolayember Formation was first named the Moolayember Shale by Reeves (1947) after Moolayember Creek in the

Carnarvon Ranges. The name was amended to Moolayember Formation by Mollan *et al.* (1972), who described the type section. In the type area the formation consists of green-brown lithic sandstone interbedded with green-brown mudstone. In the Expedition Range farther east, mudstone predominates, and there is also a little conglomerate. In the Dawson Range in the east the sequence consists mainly of mudstone interbedded with conglomerate, tuff, and sandstone.

The formation thickens from about 300 m on the Springsure Shelf to over 1500 m in the middle of the Taroom Trough. On plant evidence its age is Triassic or Early Jurassic (M. White, appendix 3 *in* Mollan *et al.*, 1972). The spores are of Middle Triassic age (de Jersey & Hamilton, 1967).

Mollan *et al.* (1972) stated that 'The abundance of plant material and lack of marine fossils suggest that the Moolayember Formation is mainly terrestrial. The abundance of conglomerate in the east and the presence of trough cross-bedded sandstone throughout the sequence point to a fluvial environment, although it is not impossible that some of the deposition took place in lakes. There are some indications, especially in the east, of contemporaneous vulcanism, and certainly the sediments in the east were largely derived from a volcanic terrain.'

On the Roma Shelf the formation consists of grey to brown carbonaceous shale, siltstone, and grey lithic sandstone. It is generally less than 100 m thick, but reaches 300 m on the eastern edge of the shelf. It overlaps the Showgrounds Sandstone to the west, where it rests directly on basement rocks.

Wandoan Formation

The section from 3530 to 4817 feet (1076-1468 m) in the UKA Wandoan No 1 well was defined as the type section of the Wandoan Formation (Union, 1964). Detailed petrological studies of outcrops, and of samples from UKA Wandoan No. 1 and other wells by Fehr & Bastian (1963), Fehr (1965), Bastian (1965a), and Bastian & Arman (1965), have shown that the formation is equivalent to the Clematis Group and Moolayember Formation. This interpretation is supported by various palynological studies (e.g. Evans, appendix 2 *in* Union, 1965; de Jersey & Hamilton, 1969). In this Bulletin the term Wandoan Formation is used for the Middle Triassic sequence below the Surat Basin, except on the Roma Shelf.

In UKA Wandoan No. 1 the formation consists of sandstone, carbonaceous shale, and siltstone. Bastian & Arman (1965) have described a twofold subdivision in this well:

(a) Between 1310 and 1468 m the sequence mainly consists of fine to medium-grained clayey sublabile to labile sandstone in which the grains are angular to subangular and of moderate sphericity. In most of the sandstones the quartz content ranges from 50 to 80 percent, and there is up to 10 percent feldspar, 15 percent chert, and 15 percent mica and chlorite; tourmaline and zircon are common accessories. The sandstone grades into conglomerate in the upper 12 m, and brown to grey siltstone and shale are common below 1322 m (Union, 1965).

(b) Between 1076 and 1310 m the unit consists of fine sandstone, siltstone, and shale, with siltstone and shale predominant toward the base. The sandstones contain 10 to 40 percent quartz, 10 to 15 percent feldspar, up to 10 percent chert, 5 to 15 percent mica (predominantly biotite), and 15 to 30 percent matrix. Calcite is rather rare in contrast to the unit in outcrop. The upper part of this unit contains less quartz and more feldspar than the lower part, and chamosite pellets are fairly common in the upper part.

The white chert clasts in the formation appear to be devitrified tuff and were presumably derived from the Permian and basement rocks east of the major fault zone.

Fehr (1965) recognized several widespread lithological subunits which 'are significantly thinner in marginal parts of the basin' in the Surat Basin, and were defined by Fehr & Bastian (1963):

Subunit T5, the youngest subunit, is found only in the middle of the basin, and consists of two sandstone sequences separated by a shaly sequence. It is 109 m thick in UKA Coomrith No. 1.

Subunit T4 consists of alternating dark grey shale and thin sandstone, and is up to 100 m thick.

Subunit T3 consists of a lower porous grey sandstone part and an upper tighter shaly-silty-sandy part; it is up to 80 m thick.

Subunit T2 consists of a lower part of very fine to fine quartz sandstone and an upper more shaly and tuffaceous part; it is up to 60 m thick.

Subunit T1, the lowest subunit, is composed of a lower sandy part and a very consistent shaly upper part; it is up to 100 m thick.

Fehr (1965) equated the lower sandy part of subunit T1 with the Showgrounds Sandstone; the upper shaly part, and the remaining T units would then equate with the Moolayember Formation, the Showgrounds Sandstone being regarded as the upper part of the Clematis Group. Fehr's upper shaly part of subunit T1 was named the Snake Creek Mudstone Member of the Moolayember Formation by Hogetoorn (1970), who states that it is a widespread marker horizon in the southwestern and south-central parts of the Bowen Basin.

From the studies of Fehr & Bastian (1963) and Fehr (1965) it is apparent that most of the Wandoan Formation can be correlated with the Moolayember Formation, with generally less than 100 m of the sequence correlating with the Clematis Sandstone. Fehr (1965) considers that most of the sequence was laid down in fresh water, with local marine incursions in subunit T4. Subsidence was renewed during deposition of subunit T4, when polygenetic feldspathic and tuffaceous sands were laid down.

Triassic and Jurassic Rocks Confined to Ipswich-Moreton Basin (Table 17)

Regional setting

A Triassic sequence is present in the subsurface in the Cecil Plains Syncline (see cross-section EF on map), which lies east of the Kumbarilla Ridge and is an embayment of the Ipswich-Moreton Basin. In this area the Upper Triassic Raceview Formation (Staines, 1964) generally rests directly on the pre-Triassic basement rocks, but in a small area east of Cecil Plains township there is a depression containing faulted sediments of the Upper Triassic Aberdare Conglomerate (see Staines, 1964) and volcanics that may be equivalents of the Middle Triassic Neara Volcanics (Mellins, 1971). The Triassic sequences penetrated were 380 m thick in Phillips Cecil Plains No. 1 and 257 m thick in the A.P. Horrane No. 1 well; neither of the wells reached basement. Seismic data (Mellins, 1971) suggest that more than 900 m of Triassic rocks occurs in the middle of the Cecil Plains Syncline. The Triassic sequence is overlain by up to 600 m of Lower Jurassic sediments—the Helidon and Marburg Sandstones— which intertongue with Surat Basin formations in the vicinity of the Kumbarilla Ridge (see Table 18 for correlations). These are overlain by the Walloon Coal Measures, which are common to the Ipswich-Moreton and Surat Basins, and are treated with the latter.

Triassic volcanics

The oldest Triassic rocks yet penetrated in the Cecil Plains syncline are the volcanics in A.P. Horrane No. 1 (Mellins, 1971), which are regarded as probable equivalents of the Neara Volcanics of the Esk Rift. They consist of a series of interbedded relatively flat-lying acid lavas and tuffs, which are greenish, massive, crystalline, siliceous, dense, and hard. The thickness penetrated in A.P. Horrane No. 1 was 257 m (3518-4362 ft), but seismic data (Mellins, 1971) suggest that in the Horrane area there is over 750 m of Triassic volcanics resting unconformably on the Permo-Carboniferous basement.

If these volcanics are equivalent to the Neara Volcanics, then they are older than the Ipswich Coal Measures and are of Middle Triassic age.

Aberdare Conglomerate

The Aberdare Conglomerate is named after Aberdare Colliery in the Ipswich Sheet area (Staines, 1964), where it consists mainly of polymictic cobble and pebble conglomerates, sandstone, siltstone, and thin beds of carbonaceous shale. Beds of ferruginous shale are a distinctive feature in the type area.

TABLE 18. JURASSIC-CRETACEOUS NOMENCLATURE IN SURAT AND ADJACENT BASINS

	Eromanga Basin Formal Nomenclature	*Surat Basin Formal Nomenclature* (Surat Roma area)	*Roma Area* (Day, 1964)	*Surat Basin* (Whitehouse, 1954)	*Roma Area* (Reeves, 1947)	*Moreton Basin* (GSQ nomenclature)
Rolling Downs Group	Winton Formation	Griman Creek Formation (—?—?—?—)				
Rolling Downs Group	Mackunda Formation					
Rolling Downs Group	Allaru Mudstone					
Rolling Downs Group	Toolebuc Limestone					
Rolling Downs Group	Wallumbilla Formation: Coreena Member	Surat Siltstone				
Rolling Downs Group		Wallumbilla Formation: Coreena Member				
Rolling Downs Group	Wallumbilla Formation: Doncaster Member	Wallumbilla Formation: Doncaster Member	Roma Formation	Roma Formation	Rolling Downs Formation	
	Cadna-owie Formation	Bungil Formtaion	Blythesdale Formation: Minmi Member; Nullawurt Sst Member; Kingull Member	Blythesdale Group: Transition Beds	Transition Stage	
	Hooray Sandstone	Mooga Sandstone	Blythesdale Formation: Mooga Sst Member	Blythesdale Group: Mooga Sandstone	Mooga Sandstone	
		Orallo Formation	Orallo Formation	Blythesdale Group: Fossil Wood Beds	Fossil Wood Stage	
		Gubberamunda Sandstone	Gubberamunda Sandstone	Blythesdale Group: Gubberamunda Sandstone	Gubberamunda Sandstone	
Injune Creek Group	Westbourne Formation	Injune Creek Group: Westbourne Formation	Injune Creek Beds	Walloon Coal Measures	Lower Walloon Coal Measures	
Injune Creek Group	Adori Sandstone	Injune Creek Group: Springbok Sandstone				-u-u-u-u-u-u-u-u-u-u-u-u-u-
Injune Creek Group	Birkhead Formation	Injune Creek Group: Walloon Coal Measures; Eurombah Formation				Walloon Coal Measures
	Hutton Sandstone	Hutton Sandstone		Bundamba Group: Marburg Formation	Hutton Sandstone	—?—?—?—?— Bundamba Group: Marburg Formation
	Evergreen Formation	Evergreen Formation: Boxvale Sandstone Member		Bundamba Group: Boxvale Sandstones	Boxvale Sandstone	
				Bundamba Group: Evergreen Shales	Shale	Bundamba Group: Helidon Sandstone
	Precipice Sandstone	Precipice Sandstone		Bundamba Group: Precipice Sandstone	Bundamba Sandstone	
	-u-u-u-u-u-u-u-u-u-	-u-u-u-u-u-u-u-u-u-		-u-u-u-u-u-u-u-u-u-	-u-u-u-u-u-u-u-u-u-	
						Bundamba Group: Raceview Formation
						Bundamba Group: Aberdare Conglomerate

The Triassic sequence in the Phillips Cecil Plains No. 1 well was subdivided by Hogetoorn (appendix 1 *in* Meyers, 1970) into 49 m (4090-4252 ft) of Raceview Formation overlying 380 m (4252-5501 ft) of possible Ipswich Coal Measures. The lower sequence was regarded by Mellins (1971) as probable Aberdare Conglomerate, and this interpretation is preferred here.

The Aberdare Conglomerate, which in this area has so far been penetrated only in Cecil Plains No. 1, consists mainly of conglomerate with some shale. The conglomerate contains pebbles of shale, siltstone, sandstone, quartz, and quartzite. The shale is predominantly grey or green, but below 1590 m reddish hematitic shale is also present. Minor thin bands of coal are present in places.

Seismic and other evidence (Mellins, 1971) show that the formation is at least partly bounded by faults in this area, and that it extends only a few kilometres in any direction from Phillips Cecil Plains No. 1, except perhaps to the east. It probably rests disconformably on the Triassic volcanics at depth, as there is considerable time-break between the two units if the preferred age relations are correct. Its maximum thickness in the Cecil Plains Syncline may be as much as 1000 m.

The spores obtained from cores in the Phillips Cecil Plains well (de Jersey, Paten, & Hamilton, 1964) suggest an uppermost Triassic age, which makes it unlikely that this sequence equates with the Middle Triassic Ipswich Coal Measures.

Raceview Formation

The Raceview Formation (Staines, 1964) is named after Raceview in the Ipswich Sheet area, where it consists of interbedded sandstone, siltstone, shale (some carbonaceous), and a few thin seams of coal.

East of the Kumbarilla Ridge, a sequence of relatively impermeable sandstone, siltstone, and shale, which is commonly found below the Helidon Sandstone, contains spore assemblages that are transitional between typical Triassic and typical Jurassic assemblages. Recent lithological correlation (Hogetoorn, *in* Meyers, 1970), and increasing knowledge of the spore assemblage in the type area, has led various workers (e.g. Mellins, 1971) to call this sequence the Raceview Formation.

The Raceview Formation pinches out against the Kumbarilla Ridge in the west, and the Texas High in the south. It generally overlies the Permo-Carboniferous basement rocks unconformably, but in the central part of the Cecil Plains Syncline it rests conformably on the Aberdare Conglomerate, or disconformably on Triassic volcanics. It is apparently unaffected by the faulting which has displaced the underlying Triassic sequences.

The formation was deposited in still water, perhaps in lakes and backswamps. Its thickness reaches 67 m in ARO 20 (Dalby) and 49 m in Phillips Cecil Plains No. 1. Spore data suggest a Late Triassic, probably uppermost Triassic, age (de Jersey, 1970a).

Helidon Sandstone

In the Moreton Basin the Helidon Sandstone is the equivalent of the Precipice Sandstone, and is included within it in the isopach maps (e.g. Figs 19, 20). The names Helidon Series and Helidon Sandstone were used by Dunstan (1915) and Richards (1918) in their descriptions of the building stones near Helidon, east of Toowoomba. McTaggart (1963) mapped and defined the formation in the type area. The Helidon Sandstone is confined to the Moreton Basin, and crops out as far west as White Mountain (15 km north-northeast of Helidon) and as far east as Lowood.

Near Helidon it consists of 250 m of medium to very thickly bedded cross-bedded white feldspathic sublabile sandstone, and lesser siltstone. The sandstone weathers brown, and contains yellowish clayey rock fragments and considerable clay matrix. McTaggart (1963) reported the presence of a persistent basal conglomerate, and noted that the sandstone becomes finer-grained, more massive, and paler upwards.

The formation is present in the subsurface east of the Kumbarilla Ridge and north of Millmerran, where the name Helidon Sandstone is preferable to the name Precipice Sandstone commonly used by oil exploration companies. Meyers (1970) has suggested that the lower parts of the Helidon Sandstone (most of Meyers' 'Lower Precipice') and Precipice Sandstone do not link up across the Kumbarilla Ridge, and that the upper parts join only north of Kumbarilla.

According to Meyers (1970), who made a detailed study of well data, the formation is divisible into a lower shaly part, a middle sandstone part, and an upper sandstone-shale part. The lower shaly sequence is interpreted by Hogetoorn (*in* Meyers, 1970), and the author, as Raceview Formation. This interpretation agrees with the spore evidence (e.g. de Jersey *et al.*, 1964) and means that deposition of the Helidon Sandstone began with sand, as in the type area.

Thus there is a lower sandstone sequence and an upper sandstone-shale sequence in this area. The lower sequence consists (see Meyers, 1970) largely of porous coarse-grained quartzose to sublabile sandstone, with a few grey shaly interbeds. The sandstone contains subangular quartz grains and some quartz pebbles, and generally has a siliceous cement and a clay matrix. The upper sequence consists of sandstone and shale in roughly equal proportions. The sandstone is sublabile, light grey, and generally fine to medium-grained; the clasts consist of sub-rounded quartz, minor lithic grains and feldspar, and rare red garnet. The rock has a clay matrix and it is generally non-porous, and is characterized (as in the type area) by the presence of numerous orange to yellow weathered grains. The greyish shaly beds contain 'black oolites' in Phillips Wilkie No. 1 and Cecil Plains No. 1.

The Helidon Sandstone rests disconformably on the Raceview Formation in much of the area described in this Bulletin, and unconformably overlies the Permo-Carboniferous basement rocks on the Kumbarilla Ridge. To the west it gives way to the more quartzose Precipice Sandstone, and to the east to the Ripley Road Sandstone at the West Ipswich Disturbance.

The sequence is thickest in the Cecil Plains Syncline, where 146 m is recorded in the Phillips Cecil Plains No. 1 well. Meyers (1970) has suggested that the main source area was to the east, and that it consisted of metamorphic and possibly igneous rocks. The beds were laid down mainly by streams, and consist of point-bar and channel sands grading up into overbank deposits. The presence of oolites high in the sequence suggests shallow-marine incursions.

The miospore assemblages (de Jersey, 1971) indicate that the Helidon Sandstone is of Jurassic age, whereas the apparently laterally continuous Ripley Road Sandstone is mainly Rhaetic (uppermost Triassic) age. Thus deposition of the Ripley Road Sandstone in the east began before the Helidon and Precipice Sandstone were laid down in the west.

Marburg Sandstone

The Marburg Sandstone has been studied by numerous authors, many of whom preferred the name Marburg Formation; the nomenclatural problem has yet to be resolved.

Reid (1921) subdivided the Walloon Coal measures into the Marburg and Rosewood Stages. In the type area near Marburg the formation consists of torrentially cross-bedded calcareous sandstone with some shale, silty sandstone, grit, and conglomerate. Swindon (1960) used the term Marburg Sandstone in his description of the sandstone in the type area. McTaggart (1963) divided the Marburg Formation in the Lockyer-Marburg area into two parts: a lower sequence consisting of calcareous lithic sandstone, siltstone, and mudstone, with lesser conglomerate, and an upper sequence (Heifer Creek Sandstone) composed of 200 m of 'coarse ferruginous siliceous sandstone with minor shale and flaggy sandstone beds.' Casey, Gray, & Reiser (1968) have suggested that the Marburg Sandstone cannot be subdivided on a regional basis, and recent work in the Ipswich-Moreton Basin has shown that even in the type area it is difficult to distinguish individual members.

In the Surat Basin the Marburg Sandstone crops out east of Chinchilla around the Yarraman Block and to the north of Inglewood near the Texas High. East of Chinchilla (Exon *et al.*, 1968, pp. 48-51) the formation consists of interbedded sandstone and siltstone, with minor mudstone and local lenses of conglomerate. Most of the sandstone is fine to medium-grained and, where fresh, lithic to lithic sublabile, clayey, and commonly calcareous; the weathered sandstone appears to be porous and quartzose. The lithic grains consist mainly of chert and quartzite, with some feldspar, muscovite, biotite, and zircon. The sandstone is generally well bedded and thin to medium-bedded; low-angled cross-bedding and ripple marks are present in some beds. Thick-bedded, coarser-grained sandstone with high-angled cross-beds, which grades into grit and pebbly sandstone, is also common. The subordinate siltstone, which grades into sandstone, is grey, carbonaceous in some beds, and generally laminated to thin-bedded.

North of Inglewood the outcrops consist exclusively of sandstone, conglomerate, and breccia. The breccias rest on basement and consist mainly of quartz fragments, but in places rock fragments from the underlying cherty Palaeozoic rocks are abundant. These basal breccias grade up into coarse and medium - grained labile, sublabile, and quartzose sandstones. The sandstone is poorly sorted and consists of angular to subrounded grains. It is composed predominantly of quartz and matrix, with subordinate feldspar and rock fragments, and a little muscovite, biotite, zircon, and tourmaline. The sandstone cores from well below the weathering profile consist mainly of quartz and clay, and it appears that the labile constituents broke down to clay soon after deposition. The stratigraphic holes also show that the sequence contains appreciable amounts of siltstone and mudstone, which increase in relative abundance upward.

The Marburg Sandstone in the Moreton Basin is the equivalent of the Evergreen Formation and Hutton Sandstone in the Surat Basin. In the transitional area of the Cecil Plains Syncline the equivalents of the two Surat Basin units can be recognized in well logs, but they are here assigned to the Marburg Sandstone. Around the margins of the basin the typical Marburg Sandstone can be traced to the west of the Kumbarilla Ridge for some distance into the Surat Basin. These marginal beds are the coarser and more labile equivalents of the basinal Evergreen Formation and Hutton Sandstone.

The Marburg Sandstone conformably overlies the Helidon Sandstone in the Cecil Plains Syncline, but overlaps it and rests unconformably on basement to the north and south.

The formation was deposited by fast-flowing streams draining the Texas High and Yarraman Block. The coarse basal polymictic conglomerates near the Texas High were probably laid down during major floods, and most of them probably occupy stream valleys not far from the source areas. As the gradient decreased, progressively finer-grained sandstone and some siltstone were deposited. The attitude of the cross-bedding indicates northerly to northwesterly-flowing streams near the Texas High, and westerly flowing streams near the Yarraman Block. The thickness of the formation ranges from 200 to 300 m in the north and south to over 500 m in the Cecil Plains Syncline.

Fossils are rare, except for plant impressions, most of which are unidentifiable. Reid (1922) recorded the long-ranging plants *Taeniopteris spatulata* and *Cladophlebis australis* in the type area, and also the freshwater bivalves *Unio* and *Unionella?*. Various collections from the Talgai, Thane, and Durikai areas northwest of Warwick have yielded at least nine plant species that suggest an Early Jurassic age for the Marburg Sandstone (Gould, 1974b).

The microflora and the conformable relation with the overlying Walloon Coal Measures (de Jersey, 1963) provide strong evidence that the whole of the Marburg Sandstone is Jurassic. *Classopollis* occurs down to the lowest known outcrop of the formation at Lowood, and forms such as *Ischyosporites, Taurocusporites, Lycopodiumsporites rosewoodensis,* and *Laricoidites turbatus* are known from Jurassic sediments elsewhere, but have not been found in the Triassic. Comparison with Jurassic microfloras from Western Australia suggests that the formation is of Liassic age, but that it possibly extends into the Bajocian (de Jersey, 1963).

SURAT BASIN ROCK UNITS

Dominantly Non-Marine Jurassic to Lowermost Cretaceous Sequence

(Table 19)

Precipice Sandstone

The Precipice Sandstone, as the main producer of hydrocarbons in the Surat Basin, is of considerable ecnomic importance. It consists mainly of quartzose sandstone, with a coarser lower part and a finer upper part that contains some siltstone.

The name Precipice Sandstone was first used by Whitehouse (1952), who defined the type area (Whitehouse, 1954) as 'the sandstone cliffs in the gorge of Precipice Creek, a tributary of the Dawson River' in the Taroom Sheet area. The type section, which is 45 m thick, was measured in 1964 (Mollan, Exon, & Forbes, 1965) and is described and figured in Mollan *et al.* (1972). The section consists of fine to very coarse, thinly to very thickly bedded quartzose sandstone; there is no finer-grained upper part.

The Precipice Sandstone crops out in a sinuous east-west belt that terminates to the east against the Auburn Complex and defines the northern limit of the Surat Basin. The sandstone commonly crops out in a series of prominent cliffs. In the subsurface (Fig. 19) it terminates to the northeast against the Auburn and Yarraman Highs (see Fig. 6), to the southeast against the Texas High, and to the southwest against the St George/Bollon Slope; in the east it grades laterally into the Helidon Sandstone of the Moreton Basin, and in the northwest it persists across the Nebine Ridge into the Eromanga Basin.

The sandstone is generally white to grey when fresh, and is mostly quartzose, with minor lithic grains, feldspar, muscovite, mica, and coaly fragments. Red garnet is abundant in some horizons. In places it is pebbly, and interbeds of conglomerate may be present. The matrix consists of authigenic clay and silica, with a little calcite, siderite, or pyrite. The sandstone is generally thick-bedded and cross-stratified; the cross-beds are generally planar, although trough cross-bedding also occurs.

The upper part of the formation contains thinly bedded sandstone and siltstone in which ripple marks, worm trails, and leaf impressions are common. The siltstone is generally laminated and micaceous, and commonly carbonaceous. Thin seams of coal and carbonaceous shale are common, particularly in the Cracow area.

The Precipice Sandstone heralded a widespread fluvial transgression. It generally rests unconformably on rocks ranging from Devonian to Middle Triassic in age, but in the centre of the basin, where there was little Triassic movement, it disconformably overlies the Middle Triassic sequence.

The lack of marine fossils, the abundance of plant fossils, and the unidirectional cross-stratification indicate that the Precipice Sandstone is a stream deposit. Whitehouse (1952, p. 91) suggested that the sands were deposited by streams in large basins, and that the finer-grained sediment was transported beyond the basins to the sea. The presence of large planar cross-beds and the lack of fine material suggest deposition in a braided channel system similar to that of the 'channel-country' of central Australia, where Dr J. J. Veevers (pers. comm.) has found that sand greatly predominates, and noted that the only mud deposited is an ephemeral crust laid down during the waning stage of each flood; the mud crust is removed by the next flood. The reduction in grainsize toward the top of the formation may indicate a decrease in stream velocity as the gradient decreased. The excellent subsurface study of the Roma Shelf sequence by Sell *et al.* (1972) suggests that the Precipice Sandstone on the shelf was deposited by north-northeasterly flowing streams.

The isopach maps and palaeocurrent data (Figs 19, 20) indicate that the coarse porous lower part of the Precipice Sandstone was laid down by streams off the high areas, which probably drained to the northeast through the Moura area. Local rises were left bare, but the depressions were filled with sediment up to 100 m thick. The thickest deposits, which overlie the pre-Jurassic Taroom Trough, exceed 100 m in the Taroom area. Thick deposits were also laid

TABLE 19. DOMINANTLY NON-MARINE JURASSIC TO LOWER CRETACEOUS SEQUENCE

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Main References*
Lower Cretaceous (Neocomian)	Mooga Sandstone (Klm)	Outcrop, 30; subsurface, 300	Well bedded to cross-bedded quartzose to lithic sandstone, in part clayey, calcareous, and pebbly; siltstone and mudstone common in outcrop, less common farther into basin. Contains aquifers	Spores and pollen of Kla division, plants, *Unio*	Streams, including backswamps	Overlies Orallo Fm with regional conformity despite local scouring	Reeves (1947), Day (1964), Exon & Vine (1970), Gray (1972)
Upper Jurassic	Orallo Formation (Juo)	Outcrop, 140; subsurface, 270	Fine to medium cross-bedded very lithic to lithic sublabile sandstone, calcareous, clayey, and in places glauconitic?, grading into polymictic conglomerate; siltstone and mudstone, carbonaceous in part; coal; clay, some bentonitic	Spores and pollen of J6 division; abundant plant remains include stumps, logs, roots, and leaves	Streams, swamps, lakes, and possibly brackish coastal environments	Conformable on Orallo Fm	Day (1964), (Gray, 1972)
	Gubberamunda Sandstone (Jug)	Outcrop, 45; subsurface, 300	Cross-bedded quartzose to clayey lithic sandstone, some conglomerate siltstone and mudstone. Contains aquifers	Spores and pollen of J5 division, unidentifiable plant debris	Streams	Conformable on Westbourne Fm in most of basin, and on Pilliga Sst in S	Reeves (1947), (Gray, 1972)
Upper Jurassic to Lower Cretaceous	Hooray Sandstone (J-Kh)	Outcrop, 120; subsurface, 400	Quartzose to clayey labile sandstone, pebbly in part; siltstone and mudstone concentrated largely in upper part; conglomerate. Glauconie at some levels near Mungallala. Contains aquifers	Spores and pollen of J5, J6, K1a, and K1b divisions, acritarchs, plant debris	Streams, some brackish and shallow-marine environments later	Conformable on Westbourne Fm. W equivalent of Gubberamunda Sst, Orallo Fm, and Bungil Fm	Exon (1966), Mollan et al. (1972)
Middle to Upper Jurassic	Westbourne Formation (Juw)	Outcrop, 100; subsurface, 200 in Mimosa Syncline	Siltstone and mudstone, carbonaceous in part; very fine to fine quartzose to labile sandstone. Barite nodules in outcrop; glauconie in subsurface in the W and pyrite in E	Spores and pollen of J5 division, plant debris, acritarchs in places	Shallow marine, shoreline and coastal plain	Part of Injune Creek Gp. Conformable on Springbok Sst and Adori Sst; laterally equivalent to and intertongues with upper part of Pilliga Sst in S	Exon (1966), Mollan et al. (1972), Gray (1972), Swarbrick et al. (1973), Swarbrick (1973)
	Norwood Mudstone Member	50	Carbonaceous mudstone, bentonitic in part; lithic to lithic sublabile sandstone; minor siltstone and coal	Spores and pollen, plants	Swamps and streams; contemporaneous explosive volcanism	L. part of Westbourne Fm E of Mitchell. Mappable in subsurface only	Swarbrick et al. (1973), Swarbrick (1973)

TABLE 19. DOMINANTLY NON-MARINE JURASSIC TO LOWER CRETACEOUS SEQUENCE—*(cont.)*

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Main References*
Middle to Upper Jurassic	Adori Sandstone (Ja)	Outcrop, 60	Fine to medium clayey quartzose sandstone. Contains aquifers	Spores and pollen, plant debris	Streams	Part of Injune Creek Gp. Conformable on Birkhead Fm. Equivalent, W of Nebine Ridge, of Springbok Sst, with which it may intertongue in subsurface	Exon (1966), Exon, Galloway et al. (1972)
	Springbok Sandstone (Js)	Outcrop, 60; subsurface, 250 in Mimosa Syncline	Fine to coarse labile sandstone, calcareous in part, rare glauconie; siltstone, mudstone, some coal	Spores and pollen, plants	Streams, swamps, and brackish marine in deltas etc	Part of Injune Creek Gp. Conformable on Walloon Coal Meas; laterally equivalent to and intertongues with lower part of Pilliga Sst in S	Exon (1966), Power & Devine (1970), Mollan et al. (1972), Swarbrick (1973)
Middle Jurassic to Upper Cretaceous	Kumbarilla Beds (J-Kk)	600	Lithic to quartzose sandstone, clayey, calcareous in part, grading into conglomerate; siltstone and mudstone, carbonaceous in part. Contains aquifers	Spores and pollen, plant debris including wood	Streams, swamps, and lakes	Heavily weathered outcrop equivalent of subsurface Springbok Sst—Bungil Fm sequence on E side of basin	Exon & Vine (1970)
Middle to Upper Jurassic	Pilliga Sandstone (Jp)	250	Fine to coarse quartzose sandstone grading into conglomerate. Contains excellent aquifers	Spores and pollen, plant debris	Streams	Conformable on Walloon Coal Meas in this area and Purlawaugh Fm farther S, equivalent of Springbok Sst and Westbourne Fm	Hind & Helby (1969)
Middle Jurassic	Birkhead Formation	100	Mudstone, siltstone, labile sandstone; some calcareous, some carbonaceous. Minor coal	Spores and pollen of J4 and J5 divisions, plants	Lakes, swamps, and sluggish streams	Part of Injune Creek Gp. Conformable on Hutton Sst. NW equivalent of Walloon Coal Meas; confined to area near and W of Nebine Ridge	Exon (1966), Exon, Galloway et al. (1972)

TABLE 19. DOMINANTLY NON-MARINE JURASSIC TO LOWER CRETACEOUS SEQUENCE—*(cont.)*

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Main References*
Middle Jurassic	Walloon Coal Measures (Jw)	650	Lithic sublabile to very lithic sandstone, siltstone, carbonaceous mudstone, coal. Commonly calcareous and clayey (montmorillonite)	Spores and pollen of J4 and J5 divisions, plants	Swamps, lakes, and sluggish streams	Part of Injune Creek Gp. Conformable on Eurombah Fm; where Eurombah Fm is absent conformable on Hutton Sst or Marburg Sst. Surat Basin equivalent of Birkhead Fm	Cameron (1907), Reid (1921), Gould (1968), Gray (1972), Swarbrick (1973)
	Eurombah Formation	100	Fine to coarse clayey sublabile sandstone; some polymictic conglomerate, carbonaceous siltstone, and mudstone	Spores and pollen, plants	Sluggish streams and swamps	Part of Injune Creek Gp. Conformable on Hutton Sst; in N part of basin only. Lithology transitional between Hutton Sst and Walloon Coal Meas	Gray (1972), Swarbrick et al. (1973), Swarbrick (1973)
Lower Jurassic	Hutton Sandstone (Jlh)	250	Quartzose to sublabile sandstone, some siltstone and mudstone, commonly carbonaceous, minor conglomerate. Contains aquifers	Spores and pollen of J3 and J4 divisions, plants	Streams	Conformable on Evergreen Fm. Lateral equivalent of upper part of Marburg Sst	Reeves (1947), Mollan et al. (1972)
	Evergreen Formation	260	Siltstone, mudstone or shale, carbonaceous in part, lithic to quartzose sandstone, minor oolitic ironstone and coal	Spores and pollen of J1 and J2 divisions, acritarchs, plants, rare freshwater pelecypods	Streams, lakes, deltas; partly marine	Conformable on Precipice Sst. Lateral equivalent of lower part of Marburg Sst	Whitehouse (1952), Mollan et al. (1972)
	Westgrove Ironstone Member west of Mimosa Syncline axis, and Oolite Member east of axis	25	Chamositic ironstone, oolitic or pelletal in part, mudstone	Spores and pollen of J2 division, acritarchs, plants, rare freshwater pelecypods, plant stems and logs	Shallow-marine reducing environment, with gentle wave or tidal action	Within Evergreen Fm. Two oolitic horizons in subsurface in Mimosa Syncline. U. horizon may represent Westgrove Ironstone, lower, Oolite Mbr. Oolite Mbr overlies Boxvale Sst	Mollan et al. (1972)

TABLE 19. DOMINANTLY NON-MARINE JURASSIC TO LOWER CRETACEOUS SEQUENCE—*(cont.)*

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Main References*
Lower Jurassic	Boxvale Sandstone Member	90	Quartzose sandstone, minor siltstone and coal. Contains aquifers	Spores and pollen of J1 and J2 divisions, plants	Streams, deltas, and lakes	Within Evergreen Fm. Confined to area W of axis of Mimosa Syncline	Reeves (1947), Mollan et al. (1972)
	Marburg Sandstone (Jlm)	500	Clayey feldspathic to sublabile sandstone grading into conglomerate, siltstone, mudstone. Contains aquifers	Spores and pollen of J1 and J2 divisions, plants	Streams, deltas, and lakes	Equivalent of Hutton Sst and Evergreen Fm. Conformable on Helidon Sst, but laps onto basement	Reid (1921), Cameron et al. *in* Hill & Denmead (1960, pp. 288-291), de Jersey (1963), Staines (1964)
	Helidon Sandstone (Jll)	150	Clayey quartzose to sublabile sandstone, pebbly in part, mudstone or shale with some oolites	Spores and pollen of J1 division, plants	Streams, overbank deposition increased with time	Equivalent of Precipice Sst. Disconformable on Raceview Fm, but laps onto basement	Dunstan (1915), McTaggart (1963), Meyers (1970), de Jersey (1971)
	Precipice Sandstone (Jlp)	150	Quartzose sandstone and pebbly sandstone, some lithic sublabile sandstone, siltstone	Spores and pollen of J1 division, plants	Streams, overbank deposition increased with time	Unconformable on older units ranging from Devonian to M. Triassic	Whitehouse (1952), Mollan et al. (1972)

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down in the northwest, where the Nebine Ridge did not exist during the period when the Precipice Sandstone was laid down, and in the Triassic Cecil Plains Syncline, where the Helidon Sandstone occurs in place of the Precipice Sandstone. The finer-grained and thinner upper part of the Precipice Sandstone transgressed farther than the lower part, and few local rises were exposed at the end of Precipice Sandstone time.

About 70 percent of the Roma gas (e.g. Traves, 1971) and all the Moonie oil (e.g. Buckley *et al.,* 1969) occur within porous beds in the lower part of the Precipice Sandstone (see pp. 47-54). Along the northern margin of the basin the Precipice Sandstone is an important subartesian and artesian aquifer, but it is too deep to be of use elsewhere.

The total thickness of the formation varies in proportion to the thickness of the lower part (see Fig. 20), and is seldom more than one-third as much again. In the Mimosa Syncline and in the northwest the thickness generally exceeds 50 m, whereas on the Roma Shelf and St George/Bollon Slope, and east of the Goondiwindi-Moonie-Burunga Fault Zone, the sequence is generally thinner and decreases outwards.

The formation contains Mesozoic plants showing little evolutionary change, and accurate dating depends solely on palynology. Evans (1964) has reported Early Jurassic (Liassic) spores from outcrop, and there have been extensive reports of Early Jurassic spores from the subsurface (e.g. de Jersey & Paten, 1964; Reiser & Williams, 1969). Reiser & Williams (1969) include the Precipice Sandstone in their *Classopollis classoides* Zone in which *C. classoides* is predominant, although *Perinopollenites elatoides, Alisporites spp.,* and *Osmundacidites spp.* are also common. Microplankton have not been recorded.

Evergreen Formation

The Evergreen Formation, which contains some hydrocarbon reservoirs itself, is widely regarded as the source rock for much of the hydrocarbons in .the Surat Basin (see pp. 45-47). It consists mainly of siltstone, but shale and sandstone predominate at some horizons.

Whitehouse (1952, 1954) applied the name Evergreen Shales to the shaly section below the Boxvale Sandstone (Reeves, 1947) in the valley of the Dawson River immediately below Evergreen homestead. Later studies by Jensen, Gregory, & Forbes (1964) and Mollan *et al.* (1965), the results of which were published by Mollan *et al.* (1972), have shown that even in the type area there is another shaly sequence, which includes the Westgrove Ironstone Member and the upper part of the Evergreen Formation, above the Boxvale Sandstone.

The type section of the lower part of the Evergreen Formation and the Boxvale Sandstone has been described by Mollan *et al.* (1972): the lower part is 100 m thick, and consists mainly of fine to medium-grained sublabile to labile sandstone and weathered mudstone; the Boxvale Sandstone is 40 m thick, and consists, in contrast, of very fine to fine-grained quartzose sandstone.

The type sections of the Westgrove Ironstone Member and the overlying uppermost shaly part of the Evergreen Formation are in stratigraphic holes Taroom BMR Nos. 46 and 54 (Mollan *et al.,* 1972). The Westgrove Ironstone Member is 5 m thick, and consists of chamositic mudstone and pelletal ironstone, and the upper shaly part of the Evergreen Formation consists of 12 m of siltstone and mudstone.

The composite type section of the formation is about 160 m thick, and consists mainly of sandstone (slightly over 50%) and mudstone.

The Evergreen Formation crops out south of the Precipice Sandstone, but overlaps it to the east where, in the vicinity of the Yarraman Complex, it grades into the Marburg Sandstone; in the subsurface (Fig. 19) it extends farther southwest onto the St George/Bollon Slope, and farther southeast onto the Texas High.

Excluding its two members, the Evergreen Formation is fairly consistent in lithology. The sandstone is mainly fine-grained and contains abundant lithic and feldspar grains, some mica and carbonaceous grains, and garnet in places. Most of the sandstones are impermeable owing to the presence of an argillaceous matrix and the abundance of calcareous and ferruginous cements. The sandstone is generally thinly to medium-bedded and well bedded, with some small-scale cross-bedding and ripple marks. The siltstone and mudstone are carbonaceous and range from greenish grey to dark grey. Thin seams of coal occur in places.

The *Boxvale Sandstone Member,* which is confined to the northwestern part of the basin, generally west of the axis of the Mimosa Syncline, thickens rapidly to the west of the type section (see pl. 2 *in* Mollan et al., 1972). In the type section the topographic relief is fairly subdued, but farther west the member consists of upper and lower scarp-forming sandstones separated by a persistent poorly exposed soft sequence of siltstone, sandstone, coal, and ironstone. The more resistant sandstones are of two types. The first is thickly bedded, cross-bedded, poorly sorted, medium to coarse-grained, and quartzose, and commonly contains an argillaceous matrix. The second is thinly bedded, ripple-marked, well sorted, evenly and very fine-grained, and quartzose. It is micaceous and is interbedded with micaceous siltstone. Worm tracks are common.

The *Westgrove Ironstone Member,* in which the oolite member of Jensen *et al.* (1964) is here included, is more widespread than the Boxvale Sandstone Member, and extends right across the northern part of the basin. It seems to disappear on the Kumbarilla Ridge, but equivalent pelletal ironstones have been found in the Moreton Basin (Allen, 1971). The composition of the pellets and oolites is reported to range from chamosite to siderite, and possibly to glauconite, in different parts of the basin. In the east there are commonly two pelletal horizons separated by dark grey to purplish non-pelletal mudstone.

The Evergreen Formation generally rests conformably on the Precipice Sandstone, but laps onto older rocks near basement rises. In places the boundary between the Evergreen Formation and Precipice Sandstone is difficult to define as the upper finer-grained part of the Precipice Sandstone grades into the lowermost part of the Evergreen Formation in many wells. In practice the base of the lowest thick shaly sequence, which is generally over 5 m thick, is taken as the base of the Evergreen Formation. To the east, in the vicinity of the Kumbarilla Ridge, the Evergreen Formation grades into the lower part of the Marburg Sandstone, its equivalent in the Moreton Basin.

The degree of marine influence on the Evergreen Formation is uncertain. The lower part of the formation was probably laid down by meandering streams, mainly on coastal plains but possibly also in deltas. The coarse, thickbedded, cross-stratified sandstones within the lower part of the Boxvale Sandstone are stream deposits, but the very well sorted fine-grained quartzose sandstones in the upper part of the member may be beach deposits. They are thinly bedded and commonly laminated. The low-angle cross-bedding, asymmetrical ripple marks, and animal tracks lend some support to a beach origin, although no shelly marine fossils are present. Mollan *et al.* (1972) have suggested that the marked grain orientation, good primary porosity, and concentration of heavy minerals indicate reworking in a littoral zone, and concluded that the beds were laid down in lakes.

Mollan *et al.* (1972) state that 'the chamositic ironstone members seem to have been deposited on the bottom of a moderately shallow marine basin, in a reducing environment, remote from strong current action, but subjected to gentle wave or tidal action.' A source area of low relief with a marked variation in rainfall seems most likely. Most of the evidence presented in favour of this interpretation came from the oolites and their chemistry. The abundance of acritarchs in the Westgrove Ironstone Member (e.g. Evans, 1964; Reiser & Williams, 1969), and also just below the Boxvale Sandstone in some areas, certainly suggests a marine influence.

The lower and uppermost parts of the Evergreen Formation were probably laid down on a coastal plain, but the Boxvale Sandstone and Westgrove Ironstone Members were deposited during a marine transgression.

Oil is produced from Evergreen Formation sands in the Alton field (Buckley *et al.*, 1969), and gas (e.g. Traves, 1971) from sands on the Roma Shelf. Oil is also present in the Evergreen Formation in UKA Conloi No. 1 on the eastern side of the Mimosa Syncline, west of Miles.

The formation attains its maximum thickness of 260 m in the northern and central parts of the Mimosa Syncline, and in the south it is about 100 m thick. East of the Goondiwindi-Moonie-Burunga fault zone the formation thins only slightly away from the syncline until the basement outcrops are approached. On the Roma Shelf the thickness averages 100 m, but it decreases to the west and southwest.

The macrofossils include abundant Jurassic plants (e.g. White *in* Mollan *et al.*, 1972), and rare pelecypods from the oolite member, which Dr D. F. McMichael (Mollan *et al.*, 1972, p. 52) identified as a freshwater mussel, a unionid, and a marine or estuarine mytiloid.

Evans (1964) examined the pollens from shallow stratigraphic holes, and assigned the sequence below the oolite member to his division J1, and the oolite member and the overlying sequence to J2—both of which are of Early Jurassic age. Paten (1967) used the same divisions. Reiser & Williams (1969) formalized division J1 as the *Classopolis classoides* Zone, and replaced division J2 with an informal *Tsugaepollenites segmentatus/T. dampieri* 'Zone'. *Classopollis* is predominant in the lower zone (see Precipice Sandstone), but the more diverse assemblage in the upper zone contains a decreasing proportion of *Classopollis*, more *Lycopodiumsporites* spp. and *Osmundacidites* spp., and considerable numbers of *Araucaracites* spp., *Perinopollenites elatoides, Alisporites* spp., *Stereisporites* spp., *Cyathidites* spp., and *Baculatisporites* spp. Acritarchs are exceedingly abundant (over 50% of total spore, pollen, and acritarch grains) immediately above and below the Boxvale Sandstone in the north. Reiser & Williams (1969) have dated the upper part of the formation as late Liassic, and state that although the lower part is also probably Liassic it may possibly be as old as Rhaetic. The generally accepted age is Early Jurassic (Liassic).

Hutton Sandstone

The name Hutton Sandstone was first used by Reeves (1947) for sandstone near Westgrove Station in the Eddystone Sheet area. The type section is near Hutton Creek east-northeast of Injune (Mollan *et al.,* 1972). In the type area the formation is almost entirely composed of friable fine to medium-grained thick-bedded cross-bedded quartzose to sublabile sandstone.

The Hutton Sandstone crops out very poorly across the northern part of the area, and grades into the upper part of the Marburg Sandstone on the Kumbarilla Ridge. It is widespread subsurface, where it contains more siltstone and mudstone than is apparent in outcrop.

Detailed examination of the rock types cropping out was carried out by Mollan *et al.* (1972) and subsurface specimens were examined by Fehr (1965), Bastian (1965a), and Houston (1972). The sandstone consists predominantly of quartz; the quartz grains are more angular than those in the Precipice Sandstone. Some fragments of metamorphic and volcanic rocks and feldspar are also present. The sandstone is generally porous, although kaolinite forms a partial pore-filling; chlorite is common in some beds. The presence of coarse flakes of muscovite, and in places biotite and minor garnet, suggests a metamorphic source area. Calcite cement is fairly common in the subsurface. The gritty and conglomeratic sandstones contain large clasts of quartzite, milky quartz, and grey chert, and mud clasts are common in some beds.

The formation is predominantly thickly bedded, with both low and high-angled cross-bedding. Despite quartz overgrowths, and the presence of clay matrix and calcite in many beds, the formation is an important aquifer.

The Hutton Sandstone conformably overlies the less sandy more labile and tighter Evergreen Formation. To the east it becomes steadily more feldspathic and labile and grades imperceptibly into the upper part of the Marburg Sandstone of the Moreton Basin above the Kumbarilla Ridge.

The Hutton Sandstone was derived from varied, but generally quartz-rich, terrains to the northeast, southeast, and southwest. Houston (1972) has shown that the sediment varies considerably in composition: near Roma the sandstones contain around 20 percent lithic fragments, with some potash feldspar and varying amounts of plagioclase; east of Taroom they contain about 50 percent lithic fragments and some plagioclase. The increased lithic content (largely volcanics) and the predominance of plagioclase over potash feldspar suggest derivation from the Camboon Andesite in the east. The formation was deposited by meandering streams on a broad plain. The isopach map (Fig. 21) indicates that the drainage was mainly to the north or east.

The thickness of the Hutton Sandstone varies considerably, but the great variations in the thickness of the Hutton Sandstone/Walloon Coal Measures (Fig. 21) can be attributed mainly to the Walloon Coal Measures. In most of the basin the Hutton Sandstone is between 120 and 180 m thick; along the relatively active eastern margin it is more variable, ranging for example from 75 m in UKA Moonie No. 1 to 240 m in UKA Undulla No. 1 60 km to the north.

Plant stems, logs, and small indeterminate pelecypods have been found in the Hutton Sandstone (Mollan *et al.*, 1972). Palynological dating (de Jersey & Paten, 1964) suggests that most of the formation is Early Jurassic, but that it probably extends into the Middle Jurassic. Evans (1966) has shown that it contains spores of his divisions J3 and J4 of Early Jurassic age.

Injune Creek Group

The name Injune Creek Group was used by Exon (1966) to replace the informal name Injune Creek Beds of Jensen (1921), and covers a number of Middle and Upper Jurassic non-marine formations. The group consists predominantly of mudstone, siltstone, and labile sandstone, with some calcareous beds and coal. The group generally crops out poorly in clayey plains that support a calciphile vegetation.

In the Surat Basin the Group typically comprises (in ascending order) the Eurombah Formation, the Walloon Coal Measures, the Springbok Sandstone, and the Westbourne Formation, and is up to 1000 m thick. In the Eromanga Basin it consists of the Birkhead Formation, the Adori Sandstone, and the Westbourne Formation, and is seldom more than 300 m thick. In the southern part of the Surat Basin the Springbok Sandstone and Westbourne Formation are replaced by the quartzose Pilliga Sandstone, and the Eurombah Formation is absent; although the Walloon Coal Measures persist into this area the name Injune Creek Group is no longer applicable.

On the accompanying geological map and cross-sections the various formations within the group are not always differentiated, although they can generally be identified on well logs, and in some areas in outcrop.

Eurombah Formation

Exon (1971) used the name Eurombah Beds for the sequence which crops out at and near the Eurombah Dome north of Roma, between the Hutton Sandstone and Birkhead Formation. After the sequence had been drilled by the Queensland Department of Mines the name was amended to Eurombah Formation by Swarbrick *et al.* (1973). The type section is in corehole DRD No. 22, near Eurombah homestead on the southwest flank of the Eurombah Dome.

In the type section the upper 50 m consists of poorly sorted greenish grey very fine to very coarse-grained labile sandstone and minor conglomerate. The lower 40 m consists of interbedded fine-grained greenish grey labile sandstone and light grey, greenish grey, or brown mudstone and siltstone; minor pebble bands are present.

On the geological map the Eurombah Formation has been included in the undivided Injune Creek Group, but it is known to crop out in the north as far west as Injune and as far east as Wandoan. Subsurface it can be recognized around the northern margin of the basin from the Nebine Ridge to the eastern side of the Mimosa Syncline.

In outcrop it consists of thickly bedded cross-bedded fine to coarse-grained clayey labile sandstone and polymictic conglomerate, and thinly bedded to laminated siltstone and mudstone. In the subsurface (Houston, 1972) the sandstones are very kaolinitic and lithic, with siderite a common constituent, and some calcite and chlorite cement. Porosity is low. The lithic grains consist predominantly of acid to intermediate volcanics.

The Eurombah Formation rests conformably between the Hutton Sandstone and the Walloon Coal Measures, but its lateral relation to these units is not clear. Coarse sandstone, pebbly sandstone, and conglomerate are much more common than in the enclosing formations. The sandstones are more labile than those of the Hutton Sandstone and less labile than those of the Walloon Coal Measures. Swarbrick *et al.* (1973) state that on wireline logs 'the base can be taken at the top of the highest resistivity peak of Hutton Sandstone type, below which the log does not return to the Walloon Coal Measures baseline for a considerable depth.'

The Eurombah Formation was deposited by meandering streams on a broad plain. In comparison with the Hutton Sandstone, the streams were less vigorous and there was less reworking of the sediment.

The formation is 100 m thick near Injune, but thins to the west, south, and east. It contains plants of probable Jurassic age, and Burger (1968) has found spores belonging to Evans' (1966) division J4 of Middle Jurassic age in AAO No. 1 (Roma).

Walloon Coal Measures

The Walloon Beds were named by Cameron (1907) in the Walloon-Rosewood area of the Moreton Basin. Reid (1921) renamed them Walloon Coal Measures and Whitehouse (1954) designated a type area near Walloon township. Gould (1968) stated 'the name is now applied to the coal measures conformably resting on the . . . Marburg Formation in the Clarence-Moreton Basin.' In the type area, where coal measures crop out poorly, the sequence is about 200 m thick. Samples obtained by drilling show that the coal measures consist of light grey mudstone, siltstone, fine-grained clayey lithic sandstone, and thin seams of coal. The sandstone has a montmorillonitic matrix and disintegrates rapidly on exposure.

The Walloon Coal Measures crop out extensively in the Moreton Basin. In the Surat Basin they are widespread in the subsurface, and crop out poorly across the northern part of the basin and near the northern tip of the Texas High.

Most of the outcrops consist of calcareous sandstone, which occurs mainly as concretions. The sandstone is fine to medium-grained, brown or grey, and labile. Beds of siltstone, mudstone, coal, and cone-in-cone limestone also crop out, but only where there has been rapid recent erosion. Mud-pebble conglomerate occurs at several horizons.

Extensive stratigraphic drilling (e.g. Gray, 1972; Swarbrick, 1973) has provided much information on the lithology in the northern part of the basin. Swarbrick (1973) has shown that a number of sub-units can be traced considerable distances, although facies changes are common. Lithic sandstone is predominant, but carbonaceous siltstone and mudstone are common. Coal is rare in the lower part of the sequence, abundant in the middle, and fairly common in the upper part. The petrological work of Houston (1972) has shown that the sandstones consist mainly of rock fragments and a clay matrix. They contain up to 40 percent quartz and feldspar, and some muscovite, biotite, and chlorite may be present. The rock fragments consist predominantly of intermediate volcanics, but shale and quartzite are also common (Exon *et al.*, 1967).

Although some of the sandstone beds are fairly thick, the coal measures consist mainly of laminated and thinly bedded sequences. The logs of petroleum exploration wells indicate that the lithology is fairly consistent throughout the basin.

The coal measures conformably overlie the Eurombah Formation in the northern part of the basin, the Hutton Sandstone in the south, and the Marburg Formation in and near the Cecil Plains Syncline; the contacts are transitional. The coal measures are finer-grained and more labile than the underlying units. In the west near the Nebine Ridge, the coal measures grade into the more sandy and less coaly Birkhead Formation of the Eromanga Basin. The sand/shale ratio map of Power & Devine (1970, fig. 10) suggests a meridional transition between Injune and Mitchell, where the sequence thins rapidly to the west. In the southwest and southeast the coal measures overlap the Hutton Sandstone, and rest directly on basement rises.

Most of the sequence was laid down in coal swamps, although the lower part consists mainly of stream deposits, especially overbank deposits. The abundance of montmorillonite and intermediate volcanic debris suggests contemporaneous volcanism farther east. The isopach map of the Hutton Sandstone/Walloon Coal Measures interval (Fig. 21), which is dominated by the Walloon Coal Measures, shows that rapid subsidence took place in the north and east, where the coal measures are more than 400 m thick. As in Hutton Sandstone time, the drainage was presumably either to the north or the east.

The coal measures contain a rich and varied flora which has been reviewed recently by Gould (1974a). He reports 'at least 33 species distributed among the Bryophyta, Arthrophyta, Pterophyta, and gymnosperms. The Coniferophyta are dominant; Ginkgophyta are conspicuously absent.' He also states that 'the Walloon megaflora contains many forms which occur in the Jurassic and Lower Cretaceous', and further that the occurrence of *Osmundacaulis gibbiana* 'appears to be good evidence in support of a Middle Jurassic age.' De Jersey & Paten (1964), who have examined the microflora, have assigned a Middle Jurassic age to the coal measures in the type area.

Birkhead Formation

The Birkhead Formation (Exon, 1966) is named after Birkhead Creek, 40 km north of Tambo in the Eromanga Basin, and its type section is in the Amoseas Westbourne No. 1 well. In the Eromanga Basin outcrops consist mainly of fine-grained sandstone and siltstone, but in the subsurface mudstone is common.

The formation crops out along the eastern margin of the Eromanga Basin, and extends across the Nebine Ridge into the Surat Basin. Subsurface, it is widespread in the Eromanga Basin, and is recognizable in the westernmost part of the Surat Basin.

In the Surat Basin the formation consists predominantly of grey, carbonaceous, and in part calcareous, mudstone and siltstone, but fine-grained labile sandstone with abundant intermediate volcanic fragments is common. Coal is widespread, but relatively unimportant.

The Birkhead Formation rests conformably on the Hutton Sandstone over most of the Surat Basin, and is laterally continuous with the Walloon Coal Measures. The name Birkhead Formation was preferred until lateral continuity with the Walloon Coal Measures was proved during the regional mapping program by the BMR and Geological Survey of Queensland (e.g. Exon, 1971), and the old name Walloon Coal Measures can now be applied to the thick coal-measure sequence that stretches across the Moreton and Surat Basins almost to the Nebine Ridge. The sand/shale ratio and isopach maps presented by Power & Devine (1970, fig. 10), and our work suggest that the two units may be separated by a boundary running north-south through Mitchell, to the west of which sand predominates. Furthermore, in the west the sequence is generally less than 120 m thick, compared with over 200 m in most of the Surat Basin. As only a small area of Birkhead Formation is present in the basin, it has been included in the Walloon Coal Measures in the maps and figures.

The Birkhead Formation is probably mainly lacustrine, and is generally less than 150 m thick. Most of the abundant plant debris has not been identified, but palynological evidence points to a Middle Jurassic age (divisions J4 and J5 of Evans, 1966).

Springbok Sandstone

The Springbok Sandstone was named and defined as the Springbok Sandstone Lens by Exon (1966), after the Parish of Springbok

Fig. 35. Large-scale grouped cross-bedding in fine-grained sublabile sandstone of the Springbok Sandstone. East bank of the Maranoa River, 5 km west-northwest of the Amoseas Donnybrook No. 1 well.

in the Roma Sheet area. When its full extent was realized it was renamed the Springbok Sandstone Member (Exon *et al.,* 1967), and later the Springbok Sandstone (Power & Devine, 1968). In the type section in BMR Mitchell No. 3 it consists of 12 m of feldspathic sublabile to lithic sandstone.

The formation crops out around the northern and eastern sides of the Surat Basin, but has not been mapped separately in most of the area because of the scarcity of good outcrop. It is widely recognizable in the subsurface.

Throughout the basin the sequence consists mainly of sandstone, with some interbedded siltstone and mudstone and a few thin seams of coal. In outcrop north and west of Roma (Exon *et al.,* 1967) the sandstone is generally calcareous and labile, and ranges from feldspathic to lithic. It is generally fine-grained, but coarser poorly sorted beds also occur. Bedding ranges from medium to very thick, and scour and planar cross-beds (Fig. 35) are common. The calcite cement has been dissolved and redeposited as large ovoid concretions in certain beds during the recent weathering cycle.

Subsurface in the north (Exon *et al.,* 1967; Gray, 1972; Swarbrick, 1973; Houston, 1972) the formation consists mainly of lithic sandstone containing subordinate quartz, abundant feldspar, and considerable clay matrix. A calcite cement is common in some beds. The minor constituents include biotite, muscovite, magnetite, zircon, rutile, and tourmaline, and a little garnet in some beds. The rock fragments consist mainly of green, purple, and black intermediate volcanics. Swarbrick (1973) has reported that the sequence in GSQ

Roma Nos. 6 and 7 is characterized by porous, permeable and friable sandstone, especially towards the base. Mudstone is an important constituent, and coal, mud-pebble conglomerate, and bentonite are significant minor constituents.

In the Cecil Plains area in the east (Exon, Mond *et al.*, 1972) the subsurface sequence consists of a monotonous succession of clayey fine to medium-grained lithic sandstones interbedded with carbonaceous and micaceous siltstone and mudstone. The sandstone contains up to 5 percent red garnet.

The Springbok Sandstone rests conformably on the much finer-grained Walloon Coal Measures, although there may be some scouring at the base (Swarbrick, 1973). The undefined 'Proud Sandstone' in the Roma area (Traves, 1962) appears to be the permeable lower part of the Springbok Sandstone. In outcrop the formation pinches out on the Nebine Ridge, but in the subsurface it intertongues across the ridge with the Adori Sandstone of the Eromanga Basin. The Adori Sandstone is white, sublabile, and non-calcareous, whereas the Springbok Sandstone is green or grey, lithic, and commonly calcareous. In the south the Springbok Sandstone interfingers with the lower part of the coarse quartzose and highly porous Pilliga Sandstone (Fig. 22).

The Springbok Sandstone was deposited mainly by streams. The prevalence of overbank and swamp deposits in the upper part of the sequence indicates that the streams become less vigorous with time. During Springbok Sandstone time the basin was taking up its present configuration, and sediment transport was largely centripetal. The thickening of the sequence to the east (e.g. Fig. 22) suggests that there was an outlet to the east through the Moreton Basin. The lithic sands derived from the north and east, which contain much bentonite (Springbok Sandstone), indicate contemporaneous volcanism, whereas the sands from the south were quartzose (Pilliga Sandstone). The Springbok and Pilliga Sandstones intertongue in a zone to the north of St George and Goondiwindi (Fig. 22).

The thickness of the formation generally ranges from 100 to 200 m, with the thickest deposits where the Springbok Sandstone/Westbourne Formation interval is thickest (Fig. 22). Correlations suggest that in places, where there is an increase in the thickness of the Springbok Sandstone, there is a corresponding decrease in thickness of the Westbourne facies, and vice versa.

The plant remains have not been identified, and no palynological results have yet been published. On stratigraphic grounds the formation is of late Middle Jurassic and possibly early Late Jurassic age.

Adori Sandstone

The Adori Sandstone (Exon, 1966) is the Eromanga Basin equivalent of the Springbok Sandstone, and is included in it in the subsurface maps. In the type section northeast of Tambo it consists of 48 m of white clayey fine to medium-grained cross-bedded sublabile to labile sandstone; similar rock types interfinger with the Springbok Sandstone across the Nebine Ridge. The Adori Sandstone is a stream deposit with a different (northerly) source area to the Springbok Sandstone.

Westbourne Formation

The Westbourne Formation (Exon, 1966) is named after the Amoseas Westbourne No. 1 well 40 km south of Tambo in the Eromanga Basin. The type section in the well consists of 113 m of interbedded mudstone, siltstone, and very fine-grained quartzose sandstone.

It crops out around the northern part of the Surat Basin, but has been mapped only as far east as Gunnewin. In the subsurface it is recognizable throughout much of the basin, although the high-density gamma-ray log, which is a characteristic feature of the formation in the Eromanga Basin, obtains only in the northwest.

The outcrops in the Mitchell Sheet area in the northwest include two rock assemblages in roughly equal proportions. The first consists of grey carbonaceous micaceous well-bedded siltstone and mudstone, and the second of buff friable cross-bedded quartz-rich siltstone and very fine-grained sandstone. The rock assemblages alternate with each other in an apparently random manner.

The weathered sandstones cropping out are quartz-rich, but in the subsurface they are usually lithic or lithic sublabile and clayey. The clasts consist mainly of quartz, shale, quartzite, and feldspar; some biotite and muscovite are also present. About 15 percent of chlorite and glauconie* pellets were recorded in a core from BMR Mitchell No. 5. In places the heavy minerals, iron oxides, tourmaline, zircon, and rutile are concentrated in thin seams. Calcareous concreations are common, and at one locality barite nodules up to 5 cm in diameter are present. The numerous small-scale planar and scour cross-beds in the thinly to medium-bedded sandstones have very variable azimuth directions.

In the subsurface in the northeast (Swarbrick, 1973; Swarbrick *et al.*, 1973) the formation is about 100 m thick; the sequence can be subdivided into a lower part consisting of alternating mudstone and lithic sandstone with minor siltstone and coal (Norwood Mudstone Member), and an upper part composed of thinly bedded to laminated siltstone and impermeable quartzose to sublabile sandstone (see Fig. 37). The Norwood Mudstone contains some bentonitic beds. Similar rock types are present throughout the basin, but their proportions and distribution vary.

The Westbourne Formation rests conformably on the Springbok Sandstone, and in much of the southern and eastern parts of the basin it is difficult to separate these two formations. They probably represent different facies of the same fluvial cycle—the Springbok Sandstone being laid down by vigorous streams and the Westbourne Formation by sluggish streams. In the south (Fig. 22) both formations intertongue with, and grade into, the Pilliga Sandstone.

In the Surat Basin the formation consists mainly of stream deposits laid down by meandering streams in channels and backswamps. The presence of glauconie, heavy mineral concentrations, barite nodules, and acritarchs in some beds suggests shallow-marine incursions, presumably in low-lying areas. The fine-grained quartzose sandstones of the northwest, which are characterized by highly variable low-angled cross-bedding, could be beach deposits.

The isopach map of the Springbok Sandstone/Westbourne Formation interval (Fig. 22) suggests that drainage was to the northeast and east, where the thickest sediments accumulated. The thickness of the Westbourne Formation ranges from less than 100 m in the west to over 250 m in the east.

No marine macrofossils have been found in the Westbourne Formation, and none of the poorly preserved plant remains have been identified. Evans (appendix 2 *in* Exon *et al.*, 1967) and A. M. Williams (pers. comm.) have recorded Late Jurassic spores in the samples from stratigraphic holes. The stratigraphic evidence also indicates a Late Jurassic age.

Pilliga Sandstone

Kenny (1928) named and briefly described the Pilliga Series as 'coarse sandstone and grit with some conglomerate, highly ferruginous in most places.' The type area is around Pilliga township, near Coonabarabran, after which the formation is named. Dulhunty (1939) used the names Pilliga Beds and Pilliga Sandstone and described the sequence as 'coarse porous sandstone.' In his discussion of the Mesozoic stratigraphy of the Narrabri-Couradda district Dulhunty (1968) used the presently accepted name of Pilliga Sandstone (see, for example, Hind & Helby, 1969).

The Pilliga Sandstone and its equivalents crop out for 400 km along the southeastern margin of the Great Artesian Basin. They extend north-northeast from Dubbo in New South Wales to the Queensland border and beyond as far as Inglewood. The formation is the main artesian aquifer in northwestern New South Wales.

* 'Glauconie' is defined by Millot (1970, p. 205) as 'A variable mixture of minerals in which illite, montmorillonite, chlorite, or various mixed layers can be identified. The total aspect remains that of green clay minerals, but it is not known whether one part or another yet merits the name "glauconite".' All the minerals called 'glauconite' in the Surat Basin in the past, are better named 'glauconie'; the few that have been analysed are not glauconite.

In New South Wales the formation consists mainly of fine to coarse-grained massive sandstone, with some grit, pebbly sandstone, and conglomerate, and minor shale and siltstone. In outcrop it is commonly ferruginous; in places it is cliff-forming, but elsewhere, as for example in the Pilliga Scrub country, it forms extensive sandy plains.

The outcrops extending northwards from around Yetman to Inglewood consist predominantly of pale yellow to white porous quartzose to sublabile sandstone. The sandstone is generally medium-grained, with subangular to angular grains, and in places contains small quartz pebbles and grains of garnet and feldspar. Some white fine to medium-grained silty and clayey sandstone, together with thinly bedded siltstone and mudstone containing plant debris, are present higher in the sequence. Thin beds of conglomerate and breccia occur throughout the formation.

In the subsurface near the Queensland-N.S.W. border (e.g. in the AOG-Harbourside Werrina No. 1 well) the sandstone is quartzose, but contains subordinate lithic grains; it is light grey, fine to very coarse-grained, and occasionally pebbly. It contains angular to rounded grains, and is clean, friable, and porous. The logs of petroleum exploration wells (Pls 4, 5) and wireline-logged water-bores show that rare interbeds of shale and siltstone are present. Nearer outcrop, in the continuously cored DM Rawdon No. 1 bore, 70 km south of Goondiwindi, the sequence is 100 m thick, and consists mainly of porous quartzose sandstone, but contains a considerable proportion of clayey sandstone, labile sandstone, and siltstone (Bourke, 1974a). The formation is an excellent aquifer, and flows of 25 litres per second are not uncommon.

The Pilliga Sandstone rests unconformably on a great variety of older rocks around the margin of the basin and on local basement rises within the basin, including the Carboniferous Texas Beds and the Permian granite outcrops near Yetman. Farther into the basin it rests with apparent conformity on the Walloon Coal Measures and its southerly equivalent, the Purlawaugh Formation. In the past (e.g. Gould, 1968) it has been equated with the quartz-rich Gubberamunda Sandstone in the northern part of the Surat Basin, but the present subsurface studies show (e.g. Pls 4, 5) that its true correlates are the labile Springbok Sandstone and the Westbourne Formation, although the Pilliga and Gubberamunda Sandstone aquifers are in vertical contact between Goondiwindi and St George. The general position of the zone of intertonguing of the Pilliga Sandstone with the Springbok Sandstone and Westbourne Formation is indicated in Figure 22. The Injune Creek Group is not recognized to the south of this zone.

The Pilliga Sandstone was laid down by streams draining to the north, northwest, and west from the Central Western and New England Fold Belts (Fig. 1). The coarse grainsize and the general lack of overbank deposits suggest that braided stream systems were predominant in most of the depositional area; the fine material was presumably incorporated in the Springbok Sandstone and Westbourne Formation.

The formation is generally about 200 m thick; it thickens to the north from about 120 m in the type area to as much as 300 m west of Moree, but thins towards the Queensland border. In general it is thicker in the centre of the Coonamble Lobe than along its eastern margin, but it is apparent that its original extent to the east and south was greater than its present extent. The isopach map (Fig. 22) shows that the formation is about 230 m thick near Talwood and in the Dirranbandi Syncline, and that it thins to less than 100 m over the small anticlines near St George.

The fossil plants in the formation have not been identified and no palynological ages have been published. The formation overlies the Middle Jurassic Walloon Coal Measures and Purlawaugh Beds, and is laterally equivalent to the Upper Jurassic Springbok Sandstone and Westbourne Formation. Thus it is of Late Jurassic age, but possibly extends slightly into the Middle Jurassic.

Gubberamunda Sandstone

The Gubberamunda Sandstone was named and mapped by Reeves (1947). Day

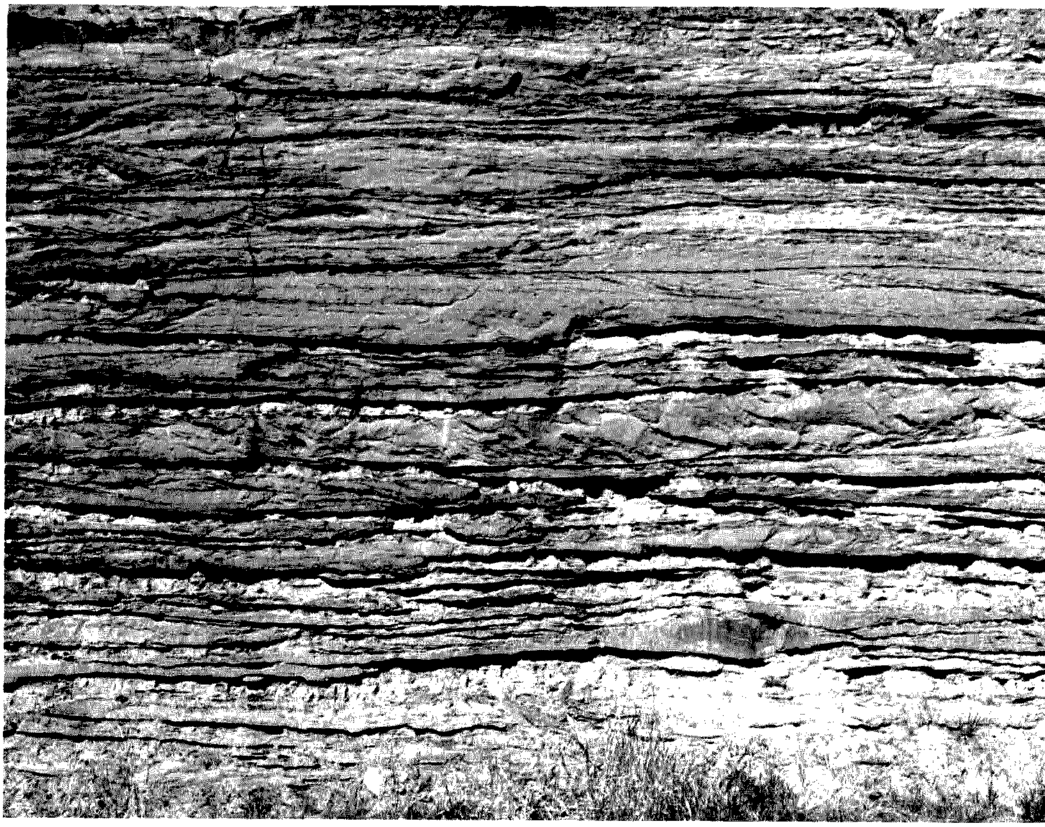

Fig. 36. Interbedded sandstone and siltstone of the Gubberamunda Sandstone; the beds probably represent periodic chute-bar deposition in a cut-off meander. Looking east in roadcut 1 km northwest of BMR Roma No. 7, on the Roma-Injune road, 37 km north of Roma. The height of the outcrop is 4 m.

(1964) nominated the type area near Bungil Creek north of Roma, where the formation consists of medium to coarse-grained poorly cemented sandstone.

The formation has been mapped across the northern part of the basin, and in the east it is recognizable in places within the Kumbarilla Beds. It is widespread in the subsurface, but gives way to the Hooray Sandstone in the west.

The outcrops in the Roma area consist of quartzose and sublabile sandstone and subordinate conglomerate, siltstone, mudstone, and claystone (Exon *et al.*, 1967). The sandstone beds are generally thick to massive, with common planar and scour cross-bedding, and solitary cross-bedding in places (Fig. 36). The sandstone outcrops have generally been intensely leached and ferruginized, and the clay matrix removed. The sandstone is composed mainly of quartz, feldspar, and fragments of siltstone, shale, and quartzite, with a little muscovite, biotite, iron oxide, and garnet. Abundant plant impressions, clay clasts, and mud-balls are present in some beds.

The formation is generally coarser-grained in the east than in the west, and contains extensive polymictic conglomerates, composed mainly of basaltic pebbles and cobbles, southwest of Wandoan.

Stratigraphic drilling near Roma (Gray, 1972) has shown that in places the sequence contains roughly equal proportions of sandstone and thinly bedded laminated siltstone and mudstone. The cores contain minor

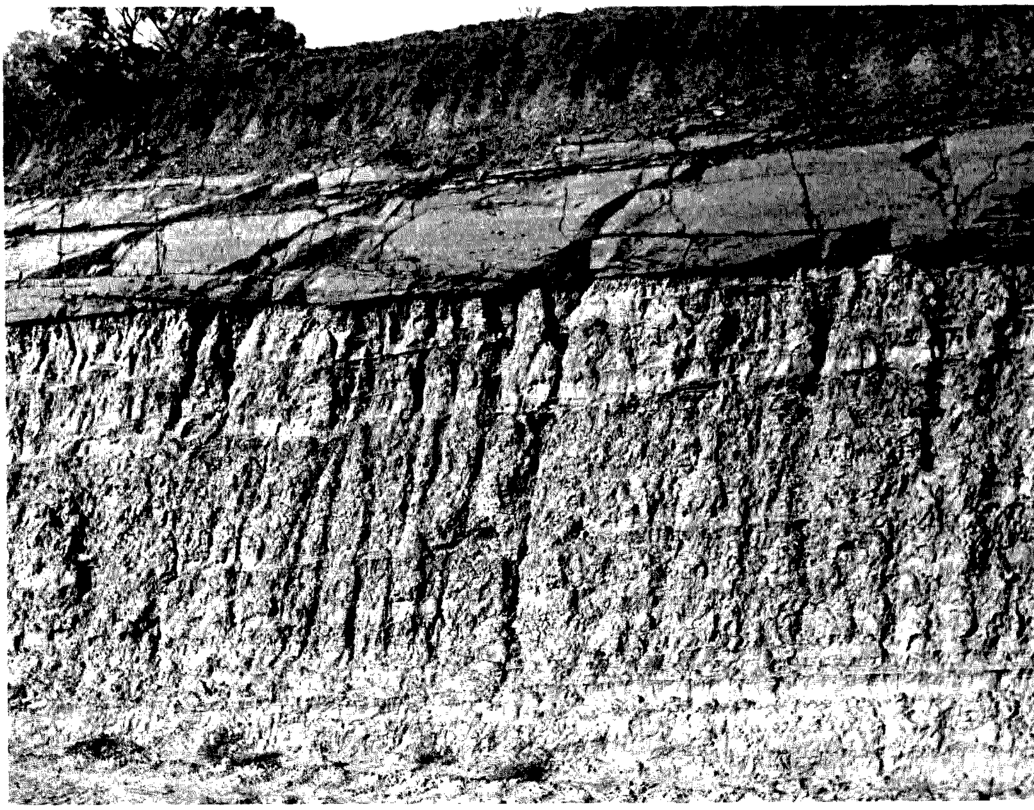

Fig. 37. Well bedded siltstone and fine sandstone of the Westbourne Formation unconformably overlain by basal sandstone of the Gubberamunda Sandstone. Looking east in roadcut 2 km northeast of ARO No. 2 well on the Roma-Injune road, 33 km north of Roma. The height of the outcrop is 6 m.

nodular pyrite, and the sandstone generally has a high porosity. Houston (1972) has shown by petrographic examination that the sandstone contains about 50 percent quartz, with abundant pore space, and that feldspar is predominant over lithic (mainly volcanic) grains. The sandstones are more labile than they appear in outcrop. Exon & Vine (1970) examined cores from the UKA Cabawin No. 1 well and reported that the common 'clayey quartz sandstones' of the subsurface are weathered labile sandstones, which originally consisted mainly of quartz and volcanic rock fragments. Enough porous beds are present to make the formation a major aquifer, which yields bicarbonate water.

The Gubberamunda Sandstone is regionally conformable on the Westbourne Formation but is locally disconformable and overlaps it around the margins of the basin. In the basalt-cored anticline near Gubberamunda homestead north of Roma the presence of a local unconformity (Fig. 37) suggests that there was some movement in the Jurassic. In the southern part of the basin it persists as a thin sequence, and is recognizable in those bores in which it overlies the silty upper sequence of the Pilliga Sandstone. In the west, on the eastern flank of the Nebine Ridge and the St George/Bollon Slope, it grades laterally into the lower part of the Hooray Sandstone. This is more a change of name than a change of facies, as the Mooga and Gubberamunda Sandstone are indistinguishable once the Orallo Formation pinches out (see Fig. 23).

The Gubberamunda Sandstone was deposited by braided and meandering stream systems draining the surrounding highlands. The isopach map (Fig. 23) suggests that

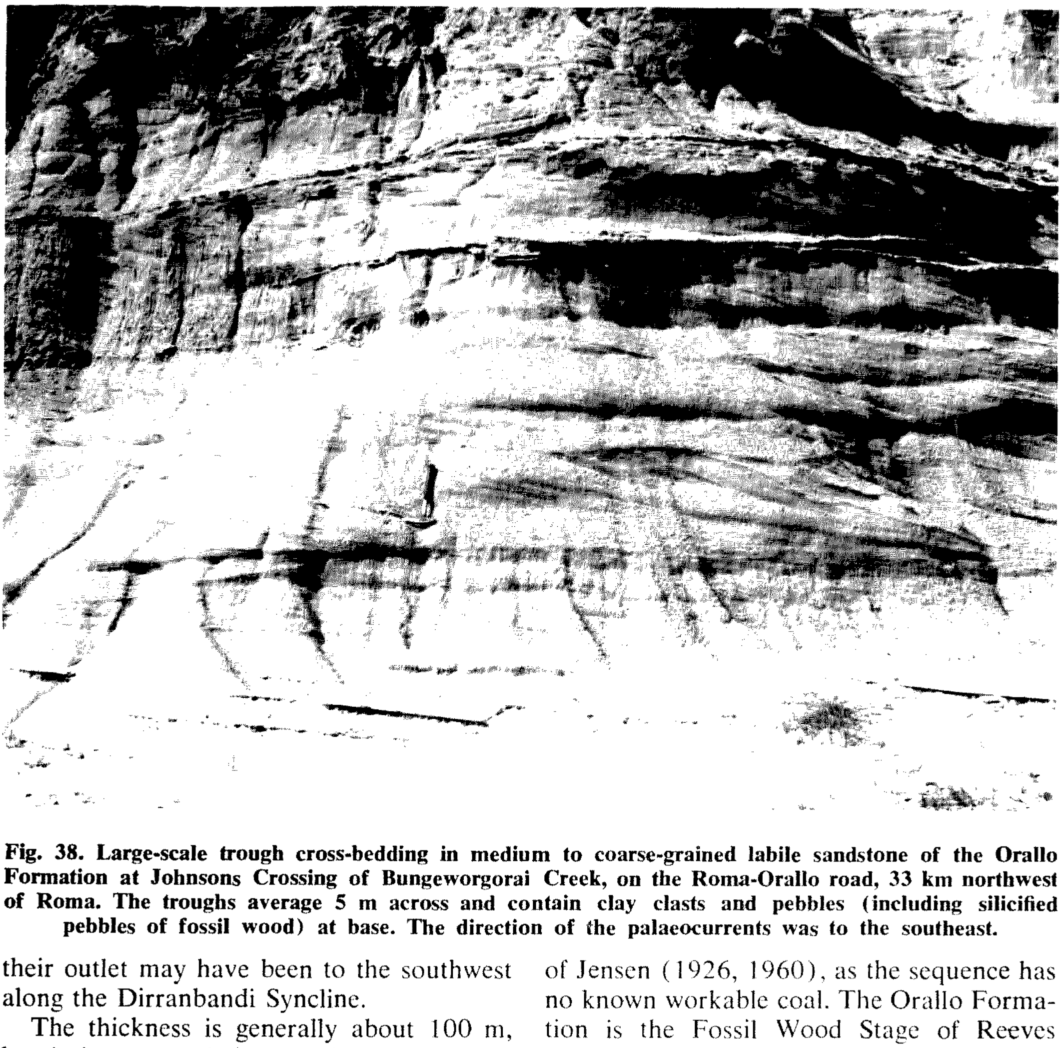

Fig. 38. Large-scale trough cross-bedding in medium to coarse-grained labile sandstone of the Orallo Formation at Johnsons Crossing of Bungeworgorai Creek, on the Roma-Orallo road, 33 km northwest of Roma. The troughs average 5 m across and contain clay clasts and pebbles (including silicified pebbles of fossil wood) at base. The direction of the palaeocurrents was to the southeast.

their outlet may have been to the southwest along the Dirranbandi Syncline.

The thickness is generally about 100 m, but is less around the margin of the basin, and as much as 200 m in the centre of the basin northeast of St George. Thus the changes in thickness are generally similar to those in the entire Gubberamunda Sandstone/Mooga Sandstone interval shown in Figure 23.

None of the plant remains in the formation have been identified, but spores of Evans' (1966) division J6, of Late Jurassic age, were reported from the Surat Sheet area by Thomas & Reiser (1968). On stratigraphic grounds the Gubberamunda Sandstone is of Late Jurassic age.

Orallo Formation

Day (1964) used the name Orallo Formation in place of the Orallo Coal Measures of Jensen (1926, 1960), as the sequence has no known workable coal. The Orallo Formation is the Fossil Wood Stage of Reeves (1947) and the Fossil Wood Beds of Whitehouse (1954). Day (1964) designated the type area near Bungeworgorai Creek in the vicinity of Orallo township.

The Orallo Formation has been mapped across the northern part of the basin, and is recognizable in places within the Kumbarilla Beds in the east (Exon & Vine, 1970). It is generally unresistant and crops out poorly. It is widespread in the subsurface, but to the west gives way to Hooray Sandstone (see Fig. 23).

In outcrop (Exon *et al.*, 1967) the sequence consists of thin-bedded siltstone and mudstone and thickly bedded cross-stratified friable fine to coarse-grained calcareous lithic sandstone, with minor conglom-

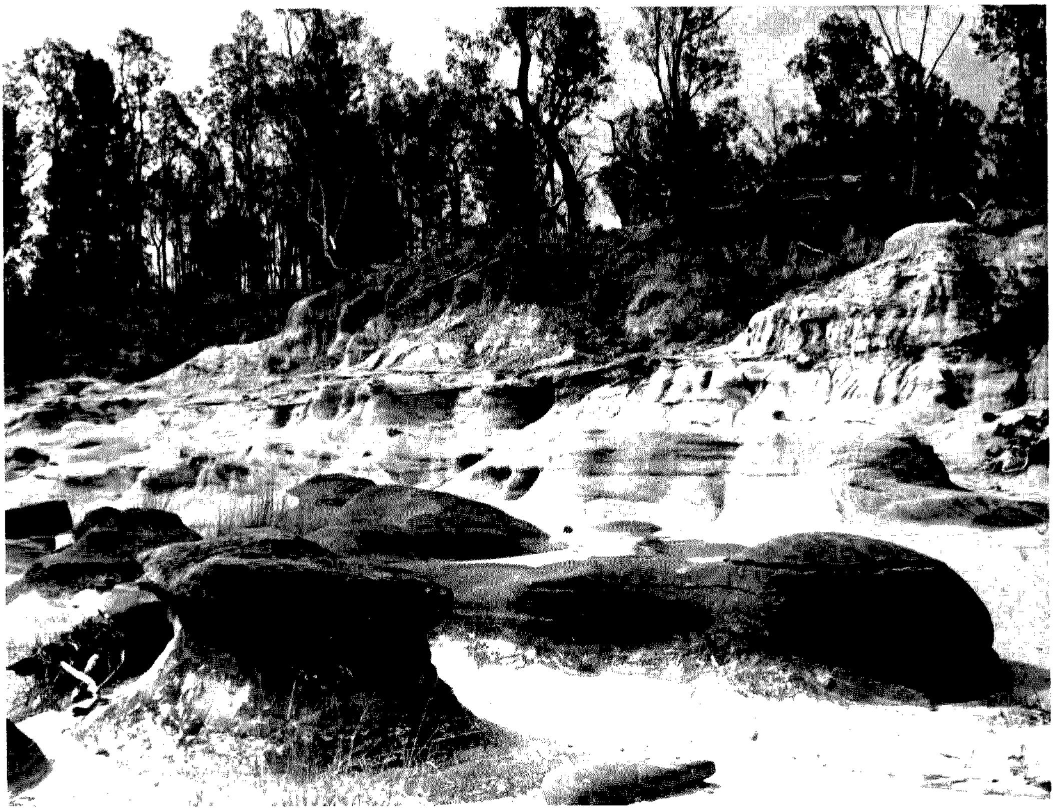

Fig. 39. Calcareous concentrations in labile sandstone of the Orallo Formation at Johnsons Crossing. Most of the concretions lie along the junctions between cross-bedding troughs. The average thickness of the concretions is 50 cm.

erate, bentonite, and coal; fossil wood rubble is widespread. The formation becomes finer-grained upward. The cross-bedding in the coarser units is dominantly large-scale and occurs in troughs (Fig. 38).

The original composition varied considerably. The rock is leached to varying degrees, and carbonate is concentrated in large elongate concretions (Fig. 39) that were commonly formed along the joints in the cross-bedding troughs. Day (1964), who examined outcrop material, and Houston (1972), who examined material from stratigraphic holes, have shown that lithic sandstone predominates in unweathered samples. Houston has shown that in borehole DRD No. 26 near Roma, the sandstones are consistently lithic; they contain about 40 percent lithic grains, 20 percent quartz, 20 percent feldspar, and considerable clay matrix and pore space. The lithic grains are predominantly andesitic and trachytic, but grains of metamorphic rock are common; the feldspar grains consist mainly of plagioclase. Muscovite, biotite, iron oxide, and calcite or siderite cement are common minor constituents.

Similar lithic sandstones containing less than 40 percent quartz predominate throughout the basin. Red garnet is common in the east.

Polymictic conglomerates are widespread, especially low in the sequence, and are particularly abundant in the east (Exon *et al.*, 1968). The clasts commonly consist of quartz, quartzite, acid porphyry, indurated sediments, trachyte, andesite, basalt, granite, and fossil wood.

Bentonitic clays, and bentonite with good rheological properties have been described

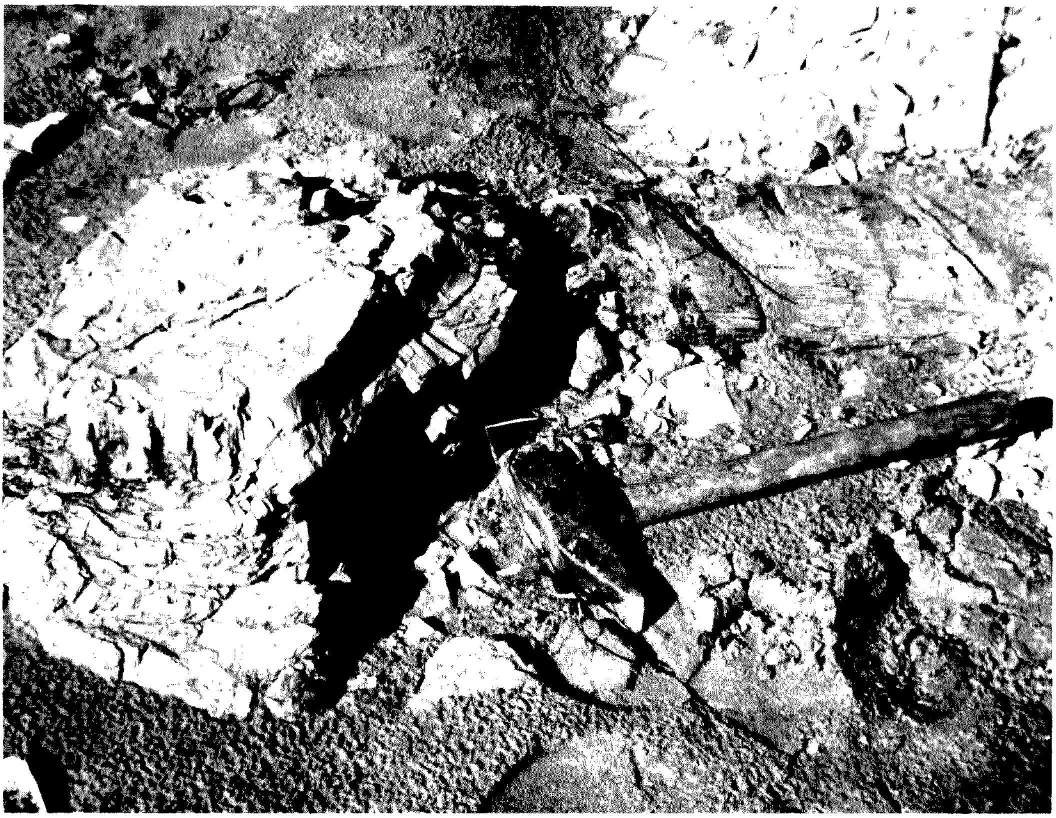

Fig. 40. Fossil tree stump in clayey siltstone and fine sandstone of the Orallo Formation. Note lateral root running to the right. Well preserved fronds at this locality represent a Taeniopteroid, a conifer, and a fern. In unnamed tributary of Nine Mile Creek immediately north of junction and 11 km north-west of Miles.

from outcrops and shallow holes between Orallo and Miles (Duff & Milligan, 1967; Exon & Duff, 1968; Gray, 1972). Beds are up to 2 m thick and have formed by the weathering of fine-grained tuff composed of andesitic glass shards.

The Orallo Formation rests conformably on the Gubberamunda Sandstone over most of the basin, and on the Pilliga Sandstone in the south. The contact is gradational in the central part of the basin. In the west the formation thins towards the Nebine Ridge and up the St George/Bollon Slope, and eventually pinches out (Pls 2, 3). Where the Orallo Formation is absent, the Gubberamunda and Mooga Sandstones can no longer be distinguished separately and the combined unit is mapped as the Hooray Sandstone.

The Orallo Formation was deposited by streams that generally flowed toward the centre of the Surat Basin. On the Kumbarilla Ridge the direction of flow was to the east into the Moreton Basin (Fig. 23), but the general trends of the isopachs suggest that the main outlet of the basin was to the south, along the Dirranbandi Syncline. Alternatively, the widespread distribution of carbonate and thin coal seams suggests that the area may have been an internal drainage basin. Coarser sand and gravel were deposited in stream channels, and fine sand, silt, and mud in overbank deposits. The source material was largely volcanic, and the bentonite beds indicate contemporaneous explosive volcanism. In some areas, where the sequence was weathered before burial, the rock fragments were altered to clay. The

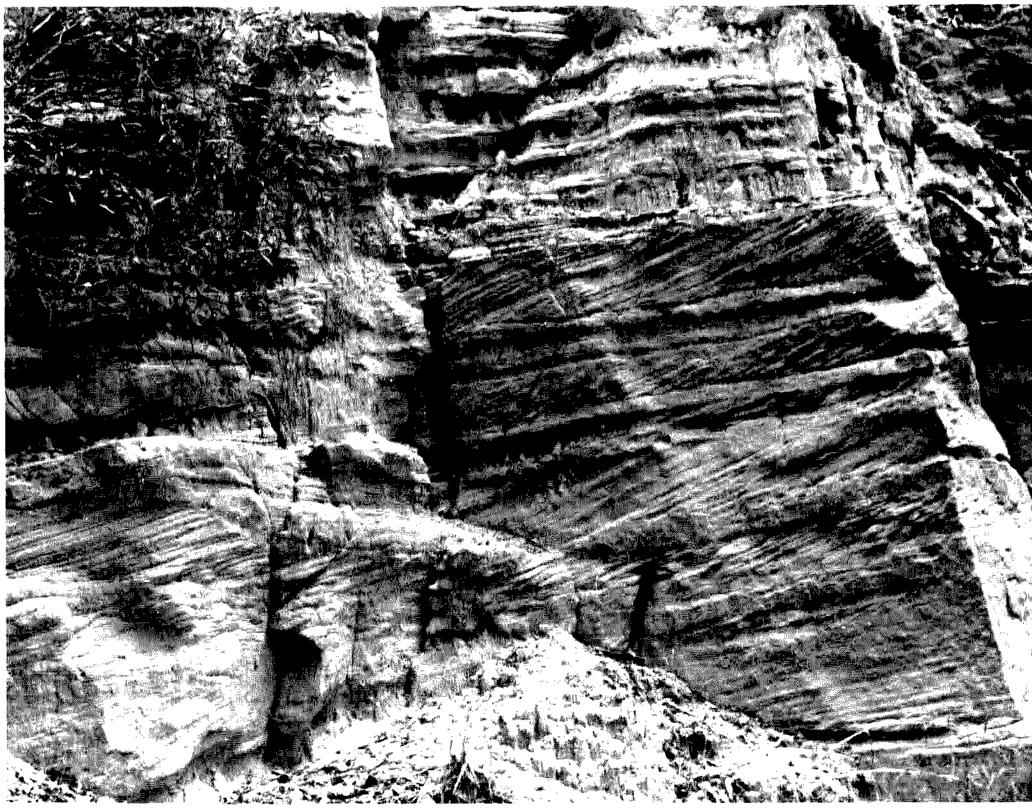

Fig. 41. Planar cross-bedding in fine to medium-grained sandstone in the basal part of the Mooga Sandstone overlain by well bedded fine sandstone and siltstone. In bend of Bungeworgorai Creek, 4 km east of the ARO No. 10 well, immediately north of the Roma-Orallo road, 29 km northwest of Roma.

presence of tree trunks in living position near Miles (Fig. 40) shows that after the soils were formed they were rapidly covered by sediment.

The variations in thickness are similar to those of the Gubberamunda Sandstone/ Mooga Sandstone interval. The formation is about 150 m thick in the north, and up to 250 m thick in the central and southern parts of the basin, but thins to zero to the west.

Both fossil wood and leaves are abundant; 8 species are listed by Day (1964) and discussed by Gould (1974a), and 15 species are listed by White (1967b). The flora suggests a Jurassic or Early Cretaceous age. Spores of Evans' (1966) division J6 of Late Jurassic age are present and, although the formation possibly ranges into the Early Cretaceous, its age is generally accepted as Late Jurassic.

Mooga Sandstone

The Mooga Sandstone was named and mapped by Reeves (1947). Day (1964) included it as a member of his Bythesdale Formation, and nominated a type area. The Mooga Sandstone was re-established as a formation by Exon & Vine (1970), who also slightly modified the type area north of Roma. In the type area, where the formation is 30 m thick, it consists mainly of quartzose to sublabile sandstone.

The formation has been mapped across the northern part of the basin, and is present within the Kumbarilla Beds in the east. It is widespread in the subsurface, but gives way in the west to the Hooray Sandstone.

In the general outcrop area the lithology is variable, but three major subunits are commonly identifiable (Exon *et al.,* 1967). The lower subunit is generally less than 5 m thick and consists of sublabile to quartzose sandstone, which is commonly conglomeratic. The beds are generally massive, and high-angled cross-bedding is common (Fig. 41). The middle subunit is of similar thickness and consists essentially of massive dark grey mudstone, while the upper is generally the thickest, and consists of thinly bedded fine to medium-grained sublabile sandstone with some lenses of pebbles and thin shaly siltstone. In places the upper subunit also contains labile sandstone and calcareous concretions.

In stratigraphic hole DRD No. 27 near the type area (Gray, 1972) thinly interbedded fine-grained sublabile sandstone and siltstone predominate above the basal sandstone sequence. The sandstone is commonly calcareous. Houston (1972) examined the unweathered sandstones from this hole, and has shown that they range from lithic sublabile to lithic. The lithic fragments consist mainly of volcanic rocks and the feldspar is predominantly plagioclase. The apparent porosity ranges up to 20 percent and there is very little clay matrix and calcite.

Similar sandstones predominate in the subsurface throughout the area, but siltstone and mudstone are also common, and in the central part of the basin they form nearly half the sequence.

The Mooga Sandstone is generally regionally conformable on the Orallo Formation, although local disconformities occur. In the west, on the flank of the Nebine Ridge and the St George/Goondiwindi Slope, it overlaps the Orallo Formation and rests directly on the Gubberamunda Sandstone. In the Eromanga Basin the Mooga and Gubberamunda Sandstones cannot be distinguished separately and the combined sequence is mapped as the Hooray Sandstone. The Mooga Sandstone consists of a number of quartz-rich sand bodies and intervening finer sediments, and it is the sand bodies which distinguish the formation from the underlying Orallo Formation or overlying Bungil Formation (see well correlation diagrams). As the sand occurs as discontinuous lenses, the upper and lower boundaries of the formation tend to move up and down the stratigraphic column. The Mooga Sandstone can generally be distinguished from the Orallo and Bungil Formations by the comparative abundance of porous aquifers containing bicarbonate water.

The Mooga Sandstone was deposited by streams draining the surrounding higher areas; the streams flowed perhaps to the southwest along the depression occupied by the Dirranbandi Syncline. The sands were more strongly reworked than those of the underlying Orallo Formation, and hence are better sorted and less labile. Around the margins of the basin both braided (especially initially) and meandering stream systems developed, but farther into the basin, where gradients were lower, abundant overbank deposits were laid down by meandering streams.

In the north, east, and south the Mooga Sandstone is seldom over 100 m thick, but in the central area it thickens to as much as 200 m. The variations in thickness are generally similar to those of the Gubberamunda and Mooga Sandstones (Fig. 23).

The formation commonly contains plant remains; Day (1964) identified ten species in the Roma area, most of which are long-ranging Jurassic to Early Cretaceous forms. Marine macrofossils have not been found, but Day (1964) found *Unio* sp. at one locality. The spores (e.g. Burger, 1972) belong to Evans' (1966) division K1a of Neocomian age. The Mooga Sandstone is thus, and on stratigraphic grounds, of earliest Cretaceous age.

Hooray Sandstone

The Hooray Sandstone was named by Hill & Denmead (1960), and a formal definition and type section were presented by Exon (1966). The type section in Hooray Creek, 10 km east-northeast of Tambo in the Eromanga Basin, consists of 75 m of very fine-grained to pebbly white sublabile sandstone and conglomerate.

The formation is widespread in the subsurface in the Eromanga Basin and crops out around the northeastern margin of the basin (Exon, Galloway *et al.*, 1972). It crops out in the northwestern part of the Surat Basin (Mollan *et al.*, 1972), and occurs in the subsurface west of a meridional line extending through Mitchell and Dirranbandi (Fig. 23).

The sequence cropping out in the north-western part of the Surat Basin (Mollan *et al.*, 1972) is about 120 m thick. It consists mainly of sandstone, which ranges from porous and quartzose to clayey and lithic; the main rock type is a white clayey coarse-grained sublabile sandstone, containing scattered pebbles. The sandstone is generally medium to thick-bedded, with abundant high-angled cross-bedding; some worm tubes are present. The sandstones are commonly porous and consist of about 50 percent quartz, 15 percent fine-grained sediments, and 10 percent feldspar, set in a clay matrix. Some iron oxide, mica, zircon, and tourmaline may be present. Thick-bedded cross-stratified conglomerate is widespread. It generally contains pebbles of quartz, acid volcanics, chert, sediments and, less commonly, fossil wood, set in a white sandstone matrix.

In the south near the Maranoa Anticline (Exon *et al.*, 1967) the formation is finer-grained. Beds of white clayey siltstone and claystone are common, especially in the upper part of the sequence. The upper sequence, which is about 50 m thick, consists essentially of thinly to thickly bedded, but rarely cross-bedded, very fine to fine-grained clayey sandstone, and laminated to thinly bedded white clayey siltstone. The siltstone commonly contains plant remains and micaceous partings. Below the upper sequence is a poorly exposed siltstone sequence, perhaps 30 m thick, consisting of thinly bedded siltstone, fine-grained clayey sandstone, and white claystone. The lower part of the formation consists mainly of fine-grained sandstone.

Subsurface the Hooray Sandstone is thicker than in outcrop, and contains excellent aquifers that yield bicarbonate water. In the Amoseas Scalby No. 1 well (Hamilton, 1966) the sequence consists chiefly of white to grey quartzose sandstone, of variable grainsize, with a white clay matrix. Interbeds of grey silty to sandy carbonaceous mudstone and grey argillaceous carbonaceous siltstone are common, and there are also few thin seams of coal.

The Hooray Sandstone generally overlies the much finer-grained Westbourne Formation with regional conformity, but local disconformities are not uncommon. In the south it overlaps the Westbourne Formation and rests directly on basement rocks. It is generally laterally equivalent to the Gubberamunda Sandstone, Orallo Formation, and Mooga Sandstone; the outcropping finer-grained upper part is equivalent to much of the Bungil Formation in the Roma area. The relation is complex and rather variable (see Pls 2, 3). Where the Orallo Formation pinches out the Gubberamunda and Mooga Sandstones cannot be differentiated, and together they make up most of the Hooray Sandstone. The outcropping upper finer-grained part of the Hooray Sandstone is approximately equivalent to the paralic Cadna-owie Formation which is widespread subsurface in the Eromanga Basin and extends for some distance subsurface into the Surat Basin (see Exon & Senior, 1976).

The Hooray Sandstone was deposited by streams which, on the evidence of isopach and limited palaeocurrent data, flowed to the east and southeast. Sedimentation began with the deposition of coarse high-angled, cross-bedded sandstone, with little or no fines, probably by braided streams, but in the north meandering streams predominated later and fine-grained overbank deposits are common. The detritus was probably derived from both the south and north. In the south the Cunnamulla Shelf was eroded in early Hooray Sandstone time; after it was covered the sediment was derived solely from the Central Western Fold Belt farther south. The high content of recycled Late Permian and Triassic fossils in places (e.g. Evans, appendix 2 *in* Exon *et al.*, 1967) indicates that some of the sediment was derived from the older Mesozoic and Palaeozoic sandstones in the north. The presence of some glauconie and acritarchs in the outcropping upper part of the Hooray Sandstone suggests marine incursions, the effects of which are more apparent in the Cadna-owie Formation.

Farther east into the basin larger quantities of fines accumulated, and the largely

TABLE 20. MARINE CRETACEOUS STRATIGRAPHY

	Name (map symbol)	*Maximum Thickness* (m)	*Lithology*	*Fossils*	*Environment of Deposition*	*Relations*	*Major References*
Middle to Upper(?) Albian	Griman Creek Formation (Klg)	480	Lithic sandstone thinly interbedded with siltstone, mudstone; some intraformational conglomerate and coquinitic sandstone. Sandstone commonly calcareous and glauconie-bearing	Marine and freshwater molluscs, plants, spores and pollen of K2a division, some dinoflagellates	Marine regression: shallow marine, including beach deposition at first; terrestrial (stream) deposition later	Conformably overlies Surat Sltst. Older in axis of Mimosa Syncline than elsewhere, so Mimosa Syncline Klg is equivalent to Klg, Kls, and possibly part of Klc on S part of Roma Shelf	Jenkins (1959, 1960), Reiser (1970), Burger (1972)
Lower to Middle Albian	Surat Siltstone (Kls)	150	Lower part: thinly interbedded siltstone and mudstone with some thick mudstone beds; upper part: thinly interbedded siltstone and fine sandstone with some thick sandstone beds. Sandstone commonly calcareous and glauconie-bearing	Marine mulluscs, benthonic foraminifera, spores and pollen of Kld-K2a divisions, some dinoflagellates of *Muderongia tetracantha/Odontochitina operculata* Zone, rare ostracods	Shallow marine: finer deposits laid down below wave base; coarser deposits above wave base	Conformably overlies Coreena Mbr. Kls of Mimosa Syncline is equivalent to Kls and upper part of Klc on S part of Roma Shelf	Reiser (1970), Burger (1972), Haig (1973)
	Coreena Member (Wallumbilla Fm) (Klc)	210	Siltstone, mudstone, very fine to fine labile and sublabile sandstone, minor intraformational conglomerate and coquinite. Sandstone and siltstone commonly calcareous and glauconie-bearing	Marine molluscs, spores and pollen of Kld-K2a divisions, some benthonic foraminifera and dinoflagellates, rare ostracods	Marine regression: shallow marine including beaches, at first; coastal plain deposition later	Conformably overlies Doncaster Mbr. Klc of Mimosa Syncline is equivalent only to lower Klc on S part of Roma Shelf	Vine et al. (1967), Day (1969), Burger (1972)
Upper Aptian	Doncaster Member (Wallumbilla Fm) (Kld)	270	Mudstone, carbonaceous in part, siltstone, fine to very fine labile to quartzose sandstone. Calcareous concretions and glauconie at some levels	Marine molluscs, including belemnites, rare ammonites, and brachiopods, algal colonies, sponges, crinoids, benthonic foraminifera, spore and pollen of Klb-c division, dinoflagellates of *Dingodinium cerviculum* Zone, rare ostracods and fish teeth, wood	Shallow marine: above and below wave base. Good connexion with open sea at times	Conformably overlies Bungil Fm	Vine & Day (1965), Day (1969), Burger (1972), Haig (1973)

TABLE 20. MARINE CRETACEOUS STRATIGRAPHY—*(cont.)*

	Name (map symbol)	Maximum Thickness (m)	Lithology	Fossils	Environment of Deposition	Relations	Major References
Neocomian to Lower Aptian	Bungil Formation (Kly)	270	Labile to quartzose sandstone, glauconie-bearing and calcareous in part, siltstone, mudstone, carbonaceous in part, bioturbidites	Marine and fresh-water molluscs, including belemnites and brachiopods, arenaceous foraminifera, dinoflagellates, spores and pollen of Kla and Klb-c divisions, plants	Coastal plain, deltaic, shoreline, shallow restricted marine	Conformably overlies Mooga Sst. Divisible in Roma-Mitchell area into four members	Exon & Vine (1970), Burger (1972, 1974)
Lower Aptian	Minmi Member (Bungil Fm)	70	Fine to medium quartzose to sublabile sandstone, glauconie-bearing and calcareous in part, some siltstone, mudstone, bioturbidites, and mud pebble conglomerate	Marine molluscs, including belemnites, freshwater molluscs, and brachiopods, arenaceous foraminifera, rare dinoflagellates but abundant other microplankton at some levels, spores and pollen of Kla and Klb-c divisions, wood	Very shallow marine and shoreline	Conformable within Bungil Fm; overlies Nullawurt Sst Mbr	Day (1964; Appendix 1), Burger (1974)
Neocomian	Nullawurt Sandstone Member (Bungil Fm)	25	Well bedded very fine to fine quartzose to sublabile sandstone grading into siltstone, mudstone, minor labile sandstone and coarse quartzose sandstone. Glauconie towards top in Merivale Syncline; equivalents in Mimosa Syncline are glauconie-bearing	Marine (in Merivale Syncline only) and freshwater pelecypods and gastropods, abundant microplankton at some levels, worm burrows, marine? plant roots, spores and pollen of Kla division, plant debris	Shoreline and near-shore nonmarine	Conformable within Bungil Fm; overlies Kingull Mbr near Roma, Claravale Sst Mbr in Merivale Syncline	Day (1964, 1969), Burger (1974)
	Claravale Sandstone Member (Bungil Fm)	15	Cross-bedded fine to coarse clayey quartzose sandstone, minor siltstone and mudstone	Wood and leaf remains, worm casts	Stream deposition on coastal plain	Conformable within Bungil Fm; confined to Merivale Syncline where it overlies Klk equivalents within Southlands Fm	Mollan et al. (1972)
	Kingull Member (Bungil Fm)	45	Very fine to medium well bedded clayey labile to quartzose sandstone, calcareous and carbonaceous in part, mudstone	Abundant microplankton at some levels, spore and pollen of Kla division, plants, *Unio*	Stream deposition on coastal plain; brackish lagoonal, estuarine, and deltaic environments	Conformable within Bungil Fm; conformably overlies Mooga Sst in Roma area, included within Southlands Fm in Merivale Syncline	Day (1964), Burger (1974)

fine-grained Orallo Formation can be separated, enabling subdivision of the equivalents of the Hooray Sandstone into the typical Surat Basin formations.

The thickness of the Hooray Sandstone is as shown in Figure 23. The thickness on the Nebine Ridge is less than 150 m, but the formation thickens into the basin to as much as 400 m in the Dirranbandi Syncline.

No plants have been identified, and no marine macrofossils have been found. Evans (appendix 2 *in* Exon *et al.,* 1967) has found spores of Late Jurassic and Jurassic/Cretaceous age in the formation. On stratigraphic grounds its age is Late Jurassic to Early Cretaceous—possibly as young as early Aptian.

Kumbarilla Beds

The Kumbarilla Beds were named and defined by Exon & Vine (1970). The type area is around Kumbarilla township, west of Dalby, where the outcrops consist of sandstone, siltstone, and mudstone, with some conglomerate.

The beds crop out extensively in a meridional belt, extending from Miles to Yelarbon in the eastern part of the basin. They are equivalent to the sequence from the Springbok Sandstone to the Bungil Formation, and these formations can still be recognized in the subsurface beneath and west of the Kumbarilla Beds.

White (1969) identified eight plant species from one locality, and three different species from another locality in the upper part of the Kumbarilla Beds.

Some of the equivalent formations are recognizable in some of the outcrop areas, but the deep weathering and extensive soil cover made it impracticable to map the various formations separately.

Thus the Kumbarilla Beds are best regarded as restricted to outcrop. They are shown on the surface geological map, but not on the various isopach maps, where the constituent formations have been identified.

Dominantly Marine Lower Cretaceous Sequence (Table 20)

Bungil Formation

The Bungil Formation was named and defined by Exon & Vine (1970) and corresponds to the Transition Beds of Whitehouse (1954). The type area is along Bungil Creek north of Roma. It includes the Kingull, Nullawurt Sandstone, and Minmi Members of Day (1964), and the Claravale Sandstone Member of Mollan *et al.* (1972).

In outcrop the Bungil Formation has been mapped across the northern part of the basin and in the northeast; it has been included in the Kumbarilla Beds in the southeast. Subsurface it is widespread, but gives way in the west to the Cadna-owie Formation of the Eromanga Basin (see Exon & Senior, 1976).

The sequence consists mainly of fine-grained lithic sandstone, siltstone, and mudstone, with subordinate sublabile and quartzose sandstones that grade into coarse-grained sandstone, especially in the type area. Calcareous or glauconie-bearing beds and concretions are common in the upper part. The siltstone and mudstone are commonly carbonaceous and contain plant remains. Bedding ranges from laminated in the finer rock types to thickly cross-bedded in the coarser rocks. The formation yields poor supplies of fairly saline water in places.

Stratigraphic drilling (Gray, 1972; Exon, 1972a) has shown that basin-wide it consists of lithic sandstone, siltstone, and mudstone in about equal proportions; sublabile and quartzose sandstones are present only around the northern and eastern margins of the basin. The lithic sandstones from drill cores (Houston, 1972; Exon, 1972a) seldom contain over 40 percent quartz, and around Surat 20 percent; other major constituents are feldspar, mainly potash feldspar (10-20%), volcanic rock fragments (up to 70%), chlorite, glauconie pellets, calcite, and clay. The clay matrix and the glauconie have been shown by X-ray diffraction to consist mainly of montmorillonite. Glauconie is concentrated in the upper half of the formation.

In outcrop individual members can generally be recognized, but widespread subsurface correlations, although possible, are of dubious validity. The members in the Roma area have been discussed in detail by Day (1964) and Exon *et al.* (1967), and only the main features are discussed here.

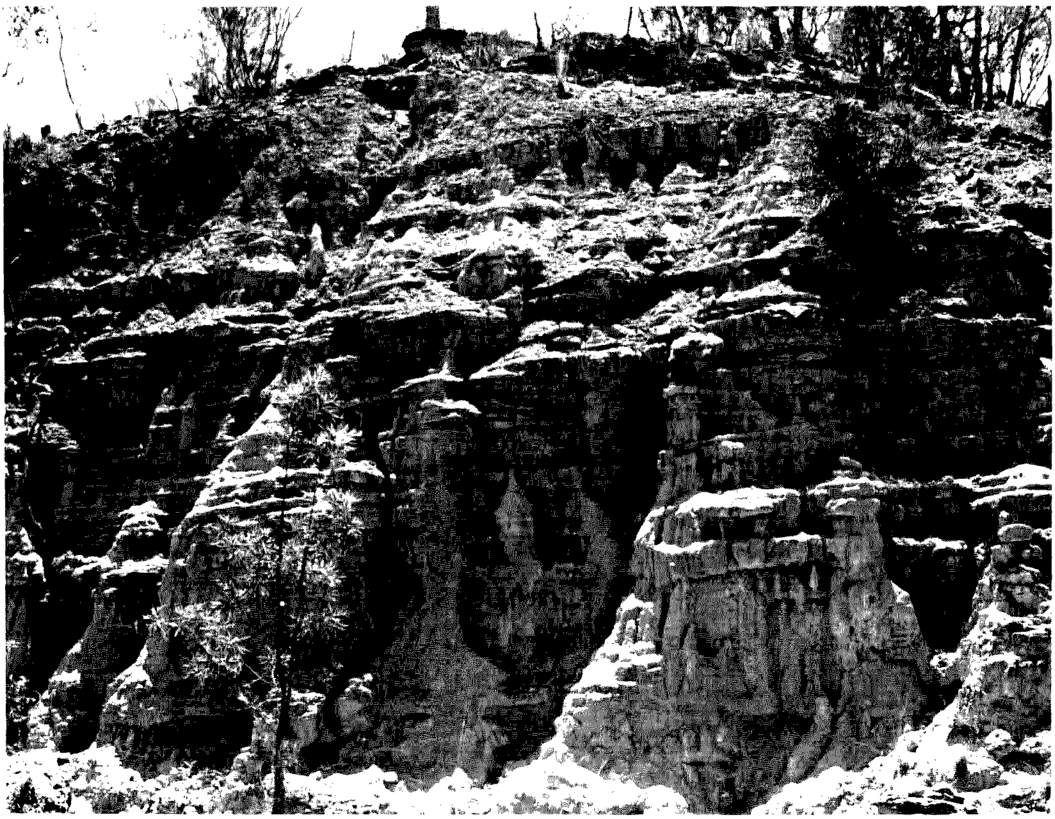

Fig. 42. Well bedded trough cross-bedded calcareous labile sandstone (lower 7 m) and siltstone (upper 3 m) of the Kingull Member overlain by 1 m of Nullawurt Sandstone. Immediately north of turn-off to Nareeten from the Roma-Orallo road, 20 km northwest of Roma.

The *Kingull Member,* which crops out poorly, consists of 30 to 50 m of carbonaceous mudstone and muddy siltstone and sandstone. The sandstone ranges from quartzose to labile and from fine to gritty, and is clayey or calcareous, or both. Where not calcareous it is very friable, probably owing to leaching. It is characterized by the abundance of angular quartz grains, cross-bedding (Fig. 42), scour channels, lenses with heavy-mineral accumulations, and concentrations of calcium carbonate. In places it is very well bedded (Figs 43, 44). Well preserved plant material is common in the finer sediments. The member has been mapped in a belt extending from south of Gunnewin to north of Yuleba.

The *Claravale Sandstone Member* is confined to the Mimosa Syncline, where it overlies the equivalent of the Kingull Member in the Southlands Formation (Mollan *et al.,* 1972). It consists of 10 to 30 m of quartzose sandstone with a little siltstone and mudstone. The sandstone ranges from white to brown and is porous in outcrop. In places it contains quartz pebbles and bands of clay clasts. The rock is typically poorly bedded, and the thickness of the beds ranges from medium to very thick; small-scale cross-bedding is common. The sandstone consists mainly of quartz, a clay matrix, a considerable proportion of rock fragments and feldspar, and minor mica, iron oxide, tourmaline, rutile, and zircon. Wood impressions are common in the sandstone, and leaf fragments in the finer beds.

The *Nullawurt Sandstone Member* is 20 to 30 m thick, and generally overlies the

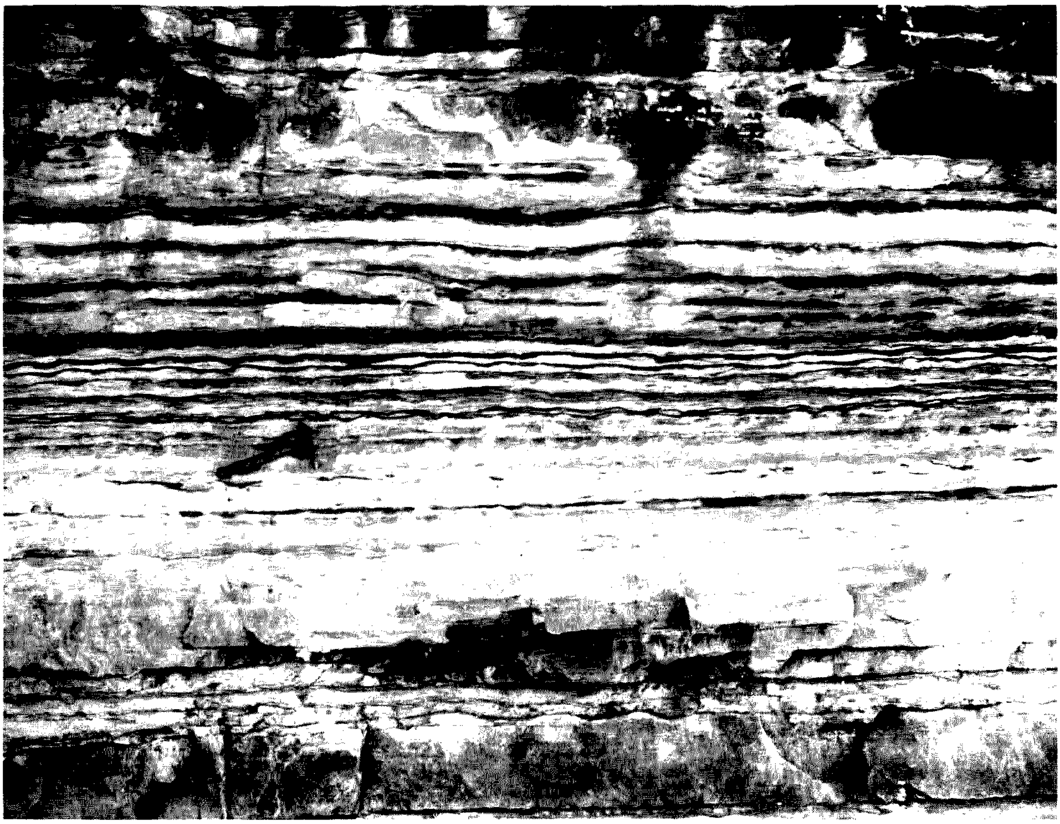

Fig. 43. Well-bedded fine-grained sandstone in equivalent of the Kingull Member within the Southlands Formation. Cliff section north of 'Mountain View' track, 2 km east of where it joins the Mitchell-Tooloombilla road, 47 km northeast of Mitchell.

Kingull Member, although in the Merivale Syncline it rests on the Claravale Sandstone Member. The Nullawurt Sandstone Member consists mainly of white to buff, very well sorted, very fine to fine-grained quartzose to sublabile sandstone, siltstone, and carbonaceous mudstone, but both labile and coarse labile sandstone occur. Bedding is generally thin to medium, and very regular with low-angled cross-bedding and ripple marks quite common. The sandstones consist mainly of quartz and fragments of quartzite and fine-grained sedimentary rocks, with some clay matrix and a little feldspar, mica, and iron oxide, and rare tourmaline, rutile, and zircon. Plant roots occur at some localities and vertical worm burrows and tracks and trails occur at others. Infilled desiccation cracks have also been observed (Fig. 45).

In the Merivale Syncline, where the lithology is similar, the sequence consists of well bedded fine-grained clayey quartzose sandstone and siltstone, showing low-angled cross-bedding and ripple marks, but marine pelecypods and glauconie are abundant in some beds in the upper part.

The Nullawurt Sandstone Member has been mapped westwards to the Maranoa River, and eastwards to north of Wallumbilla.

The *Minmi Member* consists of 20 to 70 m of lithic to quartzose sandstone with subordinate siltstone and mudstone. It rests on the Nullawurt Sandstone Member. The sandstone is in places calcareous and resistant, or leached and friable. It commonly contains glauconie, clayey rock fragments, fossil wood, and plagioclase, and a little mica and

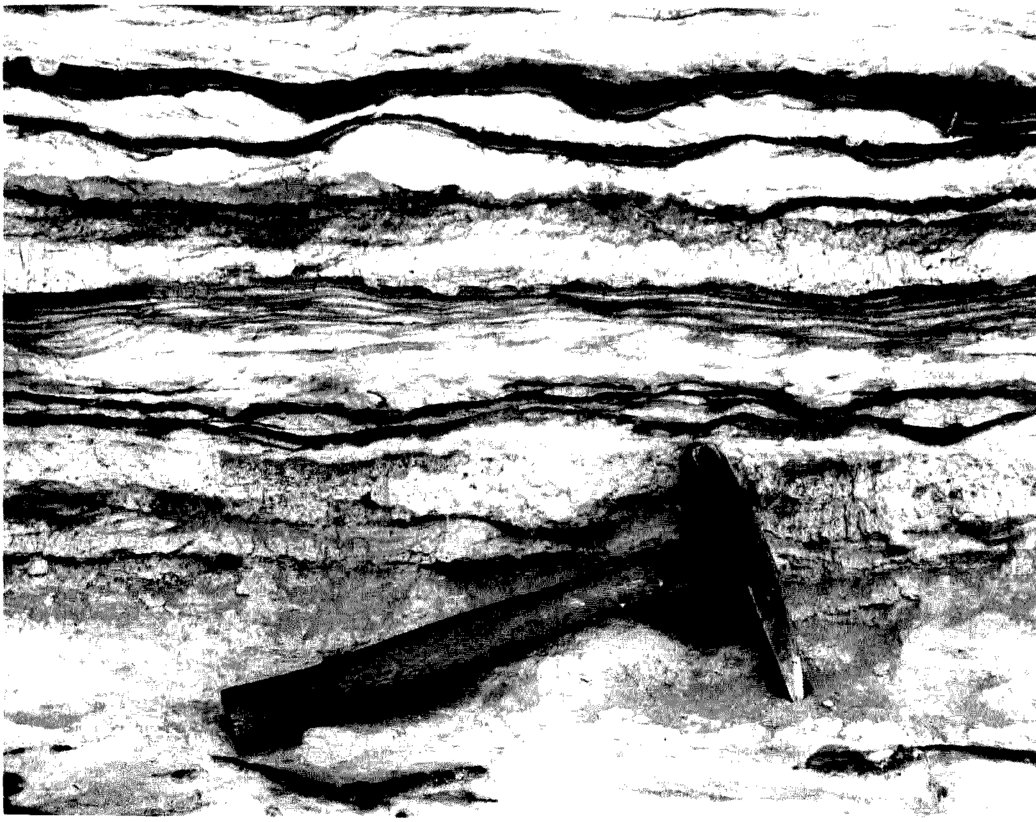

Fig. 44. Ripple marks, cross-lamination, and carbonaceous partings in fine-grained labile sandstone of the equivalent of the Kingull Member. Same locality as Figure 43.

iron oxide in some beds. Sporadic pebble bands contain subangular pebbles of quartz, quartzite, cherty sediments, and acid and intermediate volcanics. Mud-pebble conglomerates are characteristic in the Roma area. The sandstone is thickly and poorly bedded, and strongly cross-stratified (both low and high-angled); interference and current ripple marks and worm burrows may be present. The siltstone and mudstone are laminated to thin-bedded, commonly carbonaceous and micaceous, and in places rich in glauconie. Stratigraphic drilling (Exon, 1972a) has shown that extreme bioturbation with intimate intermixing of siltstone and sandstone is a characteristic feature at some horizons in places. Burrowing pelecypods are common, and undoubtedly caused much of the bioturbation.

The Minmi Member has been mapped westwards to the Maranoa River and eastwards to north of Yuleba.

The Bungil Formation rests conformably on the Mooga Sandstone and Southlands Formation. In the western part of the basin it grades laterally into the upper part of the Hooray Sandstone and the lower part of the Doncaster Member in outcrop, and the Cadna-owie Formation in the subsurface. In the southeast the Bungil Formation is equivalent to much of the Mooga Sandstone in the centre of the basin (Pls 3, 5).

The formation consists of paralic sediments with an increasing proportion of marine beds upwards. They are mainly calcareous and lithic, but current and wave action resulted in the deposition of quartzose sand in places. The calcareous and poorly

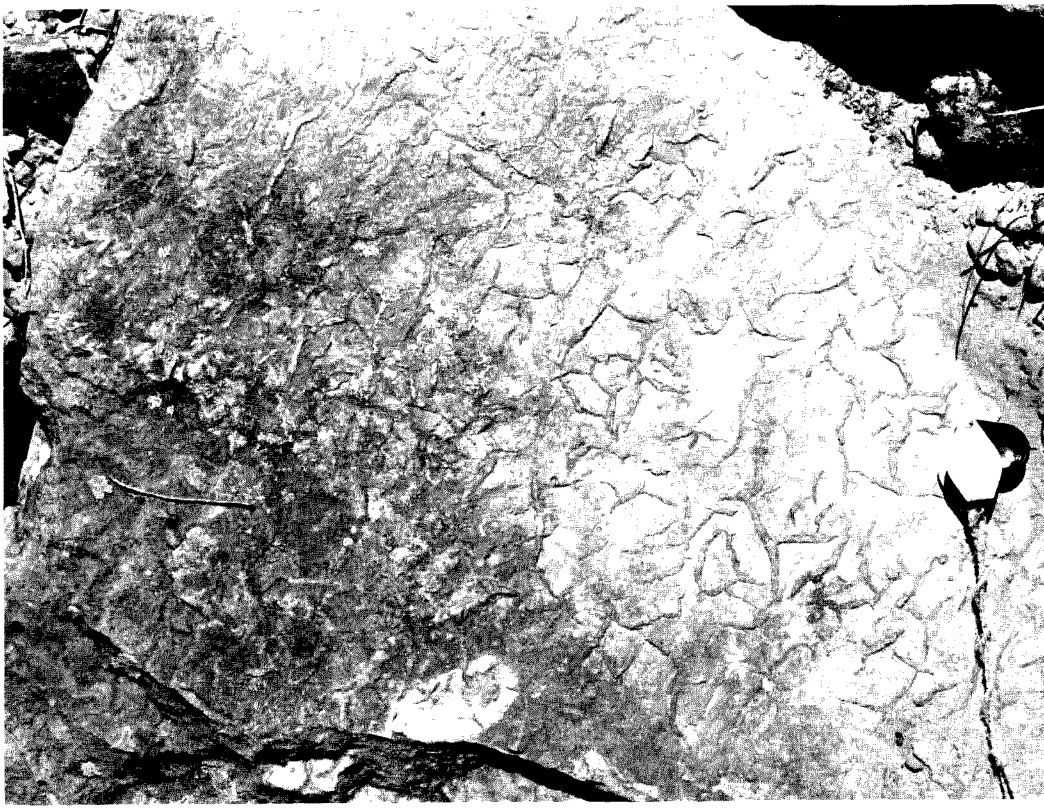

Fig. 45. Infilled desiccation cracks on underside of slab of very fine-grained basal Nullawurt Sandstone. The sandstone is quartzose, well sorted and medium-bedded. Ripple marks, vertical worm tubes and animal tracks are associated features. Locality as for Figure 42.

sorted sediments of the Kingull Member were laid down by sluggish streams in and near swamps, but the abundance of brackish-water microplankton in GSQ Roma No. 3 (Burger, 1974) suggests close proximity to the sea. The Claravale Sandstone was deposited by fairly fast-flowing streams that carried the fines farther south and east. Most of the well sorted fine-grained sandstones in the Nullawurt Sandstone Member, with their great continuity and low-angled cross-bedding, are probably beach sands, although they contain marine macrofossils only in the Merivale Syncline, where marine deposition probably began. However, although all the quartzose sands were apparently sorted on and near beaches, some of them came to rest in lagoons, bays, and estuaries. Some of the sands were vegetated and probably formed sheets of sand on land. The intervening calcareous and labile sandstones and finer-grained sediments were probably lagoonal, and the vertical alternation of lithosomes suggests a fluctuating sea level. The macrofauna in the Merivale Syncline consists of both marine and freshwater species, but in the Roma area only freshwater species are known (Day, 1969; Appendix 1). However, even in the Roma area Burger (1974) has found a large proportion of brackish microplankton in the Nullawurt Sandstone Member in BMR Roma No. 1 and DRD No. 27.

The Minmi Member contains abundant marine macrofossils and has long been regarded as shallow marine (see e.g. Day, 1964). The quartzose sandstones with glauconie probably represent beach sands or bars, and the bioturbated glauconie-rich sands, silts, and muds could have been formed on mud flats, or in deeper water. Much of the member contains no macrofossils. Terpstra (1967) has identified a number of arenaceous foraminifera in BMR Mitchell No. 11. Burger (1974) has shown that the proportion of brackish microplankton varies greatly, and that marine dinoflagellates are not very abundant, except in the upper part of the member. Thus most of the sequence consists of brackish lagoonal lithic sands and carbonaceous silts and muds, over which the sea advanced and retreated from time to time. The macrofauna has been transported and was probably 'derived from a number of littoral and near coastal shallow water communities' (Day, Appendix 1).

Even where the members have not been recognized, similar transgressions and regressions must have taken place, giving rise to a varied suite of paralic sediments. Day (1969) has noted the close similarity between the Surat and Maryborough Basin faunas in Bungil Formation time, and suggests that a seaway connected the two areas. Palaeotemperature data (Day, 1969) suggest a cool climate.

The thickness of the Bungil Formation ranges from less than 100 m in the north and west to as much as 300 m in the southeast; this trend is even more marked than in the thickness of the Bungil Formation/Doncaster Member interval as a whole (Fig. 25).

Most of the plant species are long-ranging, but some of them have been assigned to the Early Cretaceous (White, 1967a). The Nullawurt Sandstone Member contains at least four species of marine macrofossils and is probably of Neocomian age (Day, 1969). The Minmi Member contains 20 species of pelecypods (both burrowers and surface dwellers), several gastropods, and one belemnite, and is of early Aptian age (Day, 1969; Appendix 1). The member also contains about 10 species of arenaceous foraminifera (Crespin, 1960; Terpstra, 1967) of Early Cretaceous (probably Aptian) age.

The spores show that the lower part of the formation belongs to Evans' (1966) K1a division, and the upper part of the Minmi Member to his K1b-c division, both of which are of Early Cretaceous age (e.g. Burger, 1974). Burger (1973) has formalized the K1a division as the *Murospora florida* Zone, which in the Roma area contains three subzones corresponding approximately to the Mooga Sandstone, Kingull Member, and Nullawurt Sandstone Member plus the lower part of the Minmi Member (Burger, 1974).

The age of the formation is thus, on fossil evidence, Neocomian to early Aptian.

Doncaster Member
(Wallumbilla Formation)

The Doncaster Member of the Wilgunya Formation was named and defined by Vine & Day (1965), and was made a member of the Wallumbilla Formation by Vine *et al.* (1967). In the type area near Doncaster homestead, 48 km north-northeast of Richmond in the Eromanga Basin, it consists mainly of 'blue grey mudstone with subsidiary glauconitic mudstone and glauconitic siltstone; the occurrence of beds rich in glauconite is diagnostic of the unit' (Vine & Day, 1965). In the type area siltstone grades into very fine-grained sandstone.

The Doncaster Member crops out extensively across the northern part of the basin as far east as Miles. East and south of Miles outcrops are rare and generally deeply weathered. The member is everywhere identifiable in the subsurface in the Surat Basin.

The best outcrops are in the Roma area, where they were studied by Day (1964), who followed Whitehouse's (1954) nomenclature of 'Roma Formation'. Between Morven and Jackson the member was mapped and described by Exon *et al.* (1967). The following description of the outcrops is based mainly on the work of E. N. Milligan (Exon *et al.*, 1967).

The lithology is similar to that in the type area; the sequence consists mainly of mudstone with subordinate siltstone and sandstone. In outcrop in the Surat Basin the member is characterized by the interlamination of fine and coarse mudstone. Glauconie is rarely seen in outcrop, but beds rich in glauconie occur sporadically in the shallow stratigraphic holes.

The sequence also includes rare beds of black mudstone, fossiliferous and unfossiliferous dark grey spherical limestone concretions, thin lenticular coquinite bands, algal stromatolites, lenses of coarse-grained calcareous quartzose sandstone, cone-in-cone limestone, gypsum, fibrous calcite, and sideritic calcite. The limestone concretions and beds may be partly original and partly weathering products, and the gypsum was presumably formed as a result of the weathering of pyrite.

Information from wells shows that the member near outcrop is about 100 m thick. In outcrop it is difficult to establish a reliable composite because of poor exposures, low regional dip, and minor faulting. However, the following three units (from top to bottom) have been recognized:

Unit 3. Mudstone interbedded with *siltstone* beds up to 2 m thick. Thinly interbedded mudstone and siltstone/fine sandstone sequences are present in some areas (e.g. Clerk Creek at its junction with Bungeworgorai Creek). The concretions are oblate-ovoid or coalesced to form distinct beds; they are rarely fossiliferous. Fossils are few in number and type and include rare pelagic belemnites. Small lenses of mudstone pebbles (and rarely fossils), woody material, fibrous calcite, and cone-in-cone limestone are common.

Unit 2. A uniform succession of massive *mudstone*. Most of the concretions are dark grey, spherical, and poorly fossiliferous. The fossils consist mainly of *Cyrenopsis* sp. and burrowers (*Panopea* sp., etc.).

Unit 1. Mudstone with rare lenses of calcareous *quartzose sandstone*. Thin lenses of *siltstone* and *coquinite* are common, and algal colonies are present near the base of the sequence. The concretions are generally large and oblate, and incorporate lenses of siltstone and coquinite, and rarely fossil logs; some of the concretions are small and irregular. The rich fauna is characterized by sessile forms such as brachiopods, entire crinoids, sponges, and oysters, and by a pelagic element comprising belemnites and rare ammonites.

Unit 1 is roughly equivalent to the '*Purisiphonia* horizon' of Day (1964, p. 17). It has been traced in outcrop for 250 km from north of Mitchell to north of Drillham. Unit 2 is the probable equivalent of the 'abundant *Cyrenopsis* horizon' of Day (1964, p. 17; appendix 1 *in* Exon *et al.*, 1967).

Stratigraphic drilling (e.g. Exon *et al.*, 1967; Gray, 1972) and petroleum exploration wells have shown that the member consists mainly of mudstone, with abundant siltstone and relatively minor sandstone. The stratigraphic drilling suggests that there are two sequences of basinwide extent: an upper mudstone-siltstone sequence corresponding to unit 3 in outcrop, and a lower mudstone subdivision corresponding to unit 2.

The Doncaster Member conformably overlies the Bungil Formation in most of the basin. In outcrop west of the Maranoa Anticline it is not seen in contact with an underlying unit, but in BMR Mitchell No. 7 the Doncaster Member rests directly on yellow-brown weathered Hooray Sandstone. Farther south, in the subsurface, it overlies the Cadna-owie Formation. The outcropping Doncaster Member in the west contains some rock types typical of the Minmi Member, and it is possible that it grades gradually eastward into the Bungil Formation. The lower part of the Doncaster Member would then be an offshore facies of the Minmi Member. The member weathers to soft grey mudstone, then to a light grey clay, and finally to a 'black soil' that distinguishes it from the overlying Coreena Member and the underlying Minmi Member which weather to brown soils.

The environment of deposition around the margin of the basin is revealed by the outcrop sequence. The presence of winnowed deposits (coquinites, and coarse quartzose sandstone lenses) and scour-and-fill and cross-lamination structures indicates that there was periodic strong current or wave action during the deposition of unit 1. However, the supply of coarse sediment was less than when the Minmi Member was laid down, and the main sediment being deposited was mud. Strong currents brought a pelagic fauna into the area. The abundance of sessile forms indicates that a stable substrate existed nearby, perhaps as semi-consolidated sands in the Minmi Member, or as accumulations of bioclastic material too coarse for the currents to shift. Some of the calcareous concretions are encrusted by serpulid colonies, which suggests that they formed during deposition, thus providing local hard bottom. Locally, littoral conditions allowed algal colonies to form, but most of the sediments were probably deposited below normal wave base. Sand was carried in during exceptional storms.

Unit 2 was apparently laid down in a restricted deeper-water environment, where mud formed the substrate for a number of burrowing pelecypods.

The conditions prevailing during the final stage of deposition (unit 3) are transitional to those of the Coreena Member. Current action was stronger and brought in coarser sediment and a significant pelagic element. Some of the regularly interbedded sediments may well have been laid down in deltas with annual alternation of fine and coarse sediment.

For the basin as a whole it seems that a rapid transgression occurred and deeper-water muds (unit 2) were deposited directly on the brackish-water sediments of the Bungil Formation farther into the basin, whereas around the margin of the basin the transitional sediments of unit 1 were laid down first. The depression continued to fill rapidly (see Fig. 25) and when the sea level fell again, shallow-water sediments (unit 3) were deposited across the whole basin.

Day (1964, p. 17) remarked that 'The detailed distribution of the fossils is rather puzzling; they are frequently abundant in only one bed of an exposure, while adjacent lithologically identical beds are quite barren.' This could be explained by the formation of a periodic density barrier in the waters of a restricted epicontinental sea, between an upper layer of relatively fresh water and a lower layer of relatively salty water, similar to that found in the Baltic Sea (Exon, 1972b). Below such a barrier reducing conditions prevail, and the calcareous fauna is dissolved in the bottom muds soon after death; in the Baltic Sea only arenaceous foraminifera are preserved under these conditions. Periodic increases in the inflow of salt water, possibly as a result of storms, or of subsidence in the straits area, destroys the density barrier and the reducing conditions, and in these circumstances the calcareous organisms are preserved. Under such conditions there would be little difference in the bulk lithology of the fossiliferous and non-fossiliferous sediments.

That reducing conditions prevailed during the deposition of the Doncaster Member is confirmed by the abundance of carbonaceous material and glauconie. Crespin (1960) and Haig (1973) have shown that the ratio of species of arenaceous foraminifera to calcareous foraminifera varies considerably, and that arenaceous forms alone are present in some beds (see Fig. 46). This suggests that the calcareous forms were dissolved when reducing conditions prevailed.

The Doncaster Member is thickest in the middle of the basin, but the variation in thickness only ranges from 100 to 150 m. The thinness of the sequence in north and south suggests that there may have been seaways to the west and east. Day (1969) has suggested that the Surat Basin was connected to the open sea both to the west, via the Eromanga and Carpentaria Basins, and to the east, via the Maryborough Basin. The easterly connexion was possibly via the Mulgildie Rift or the Moreton Basin. As in Bungil Formation time the climate appears to have been cool (Day, 1969).

The Doncaster Member contains the Roma shelly fauna (see Vine *et al.*, 1967) that was first described by Whitehouse (1925), and which contains about 40 species (Day, 1969). It is dominated by pelecypods, but gastropods, belemnites, brachiopods, crinoids, and sponges are abundant at some horizons, and ammonites have also been found. The age of the fauna is late Aptian (Day, 1969).

Crespin (1960) and Terpstra (1969) recorded the presence of foraminifera in the member, and Haig (1973) has identified about 40 species belonging to three faunas, which he regards as Aptian.

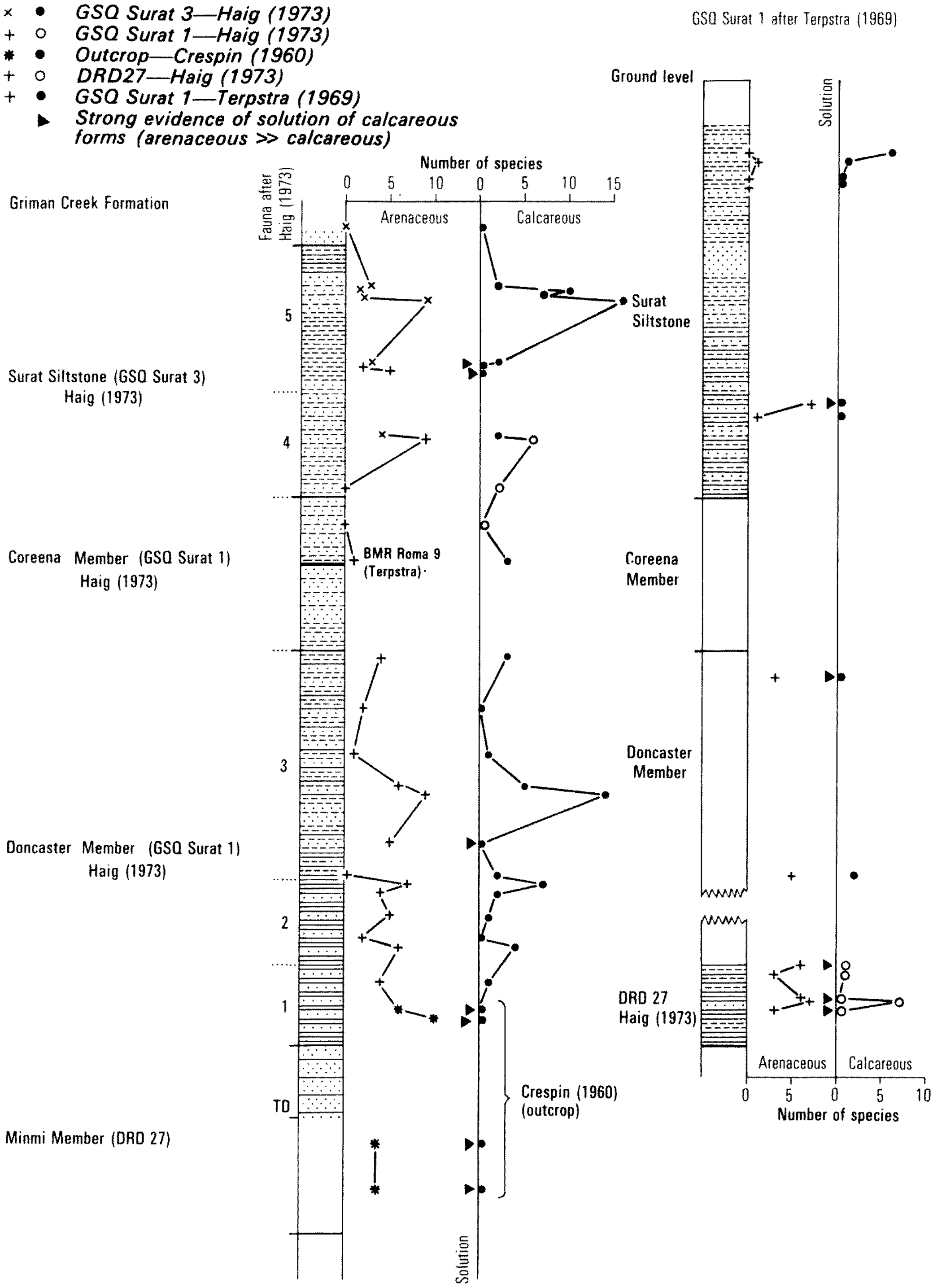

Fig. 46. Distribution of Cretaceous foraminifera.

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Burger (1968, 1974) has studied the palynology of the member, which belongs to Evans' (1966) spore division K1b-c of Aptian age. Acritarchs, and the dinoflagellates *Odontochitina operculata, Muderongia tetracantha,* and *Dingodinium cerviculum* are abundant at some horizons.

The late Aptian age of the member depends on the macrofossils, and in particular on the ammonites, which Day (1969, p. 158) says 'offer good evidence for intercontinental correlation' despite some difficulties.

Coreena Member (Wallumbilla Formation)

The Coreena Member was named and defined as a member of the Wallumbilla Formation by Vine *et al.* (1967). It is named after Coreena station, some 32 km northeast of Barcaldine in the Eromanga Basin. In the type area it consists of interbedded siltstone, which grades into labile and sublabile sandstone, and mudstone. Some beds contain glauconie. Coquinites and intraformational conglomerate are locally important.

It crops out virtually continuously from the type area to the Surat Basin, where the outcrops form a discontinuous zone across the northern part of the basin from south of Morven to Miles. Deep weathering is widespread, and the member commonly forms mesas. It is widespread in the subsurface in the Eromanga and Surat Basins.

In outcrop in the Surat Basin (Exon et *al.*, 1967) siltstone predominates over mudstone, and as in the type area, calcareous concretionary beds, glauconie, coquinites, intraformational conglomerates, and cross-lamination are common in places. Some of the intraformational conglomerates near the base of the member contain reworked Aptian fossils as well as Albian fossils.

The shallow stratigraphic holes in various parts of the sequence have shown that near Amby (BMR Mitchell No. 10; Exon *et al.*, 1967) it consists mainly of siltstone, south of Roma (BMR Roma No. 9; Exon, 1972a) of tough grey mudstone grading into siltstone, and near Surat (GSQ Surat No. 1; Gray, 1972) of siltstone, labile sandstone, intraformational conglomerate, and minor coal. Throughout the basin the petroleum exploration wells penetrated a silty sequence that commonly contains a little coal.

Examination of cores from the Surat area (Houston, 1972) has shown that the sandstones are lithic; they contain about 30 percent volcanic lithic grains, 15 percent feldspar, and 10 percent quartz, a clay matrix, cement, and pore space. Common cements are calcite and siderite; chlorite, mica, and glauconie are also present. The porosity (Gray, 1972) averages 29 percent.

The Coreena Member overlies the Doncaster Member with regional conformity, but the presence of reworked Doncaster fossils within the Coreena Member shows that the contact is erosional in places.

The Coreena Member was laid down during a regression, and the presence of intraformational conglomerate, coquinites, glauconie-rich siltstone, carbonaceous mudstone, and coal attests to local variability in time and space. The environment ranged from shallow open marine to coastal mud flats, lagoons, and swamps. Day (1969) has suggested that the area was open to the sea in the west, but that the eastern seaway had been closed; he also gave evidence for a cool temperate climate.

The member is generally about 100 m thick, but thins to less than 50 m in the west, and thickens to over 150 m in the east (Pls 3, 5).

An impoverished Albian macrofauna has been recorded in the Surat Basin. It consists of ten species of shelly macrofossils and includes the two belemnites *Peratobelus selheimi*? and *Dimitobelus diptychus* (Day, 1969; Appendix 1). *Peratobelus selheimi*? is believed to be an Aptian form, and was apparently derived from the Doncaster Member. Foraminifera are rare, although Terpstra (1969) identified three calcareous and one arenaceous species in BMR Roma No. 9. The ostracods found in one core in BMR Surat No. 1 suggest a middle Albian age by correlation with Germany (Jones, 1968).

The plant remains present have not been identified. Microplankton and dinoflagellates are relatively uncommon (D. Burger, pers. comm.), and rare ostracods have been reported (e.g. Terpstra, 1968). The spores generally fall within Evans' (1966) division K1d (e.g. Burger, 1972) which is of early Albian age, but the occasional presence of division K2a suggests that the member ranges into the Middle Albian.

Surat Siltstone

The Surat Siltstone, named after Surat township, and defined by Reiser (1970), is confined to the Surat Basin. The type section is continuous core in GSQ Surat No. 1 in the interval from 50 to 460 feet (15-140 m); it consists of interbedded siltstone and mudstone.

The formation crops out very poorly indeed, and has only been identified in scattered outcrops in the western part of the basin. North of Surat its position is marked by a broad band of Cainozoic alluvium along the Balonne River. In the east it probably crops out in a few places, but has not been identified. It is present in the subsurface throughout the central part of the basin and almost all our knowledge is based on well and water-bore data.

The sequence consists mainly of thinly interbedded siltstone and mudstone, with numerous sandstone lenses at some levels. In the type section the basal fifth consists mainly of mudstone, and the remainder predominantly of siltstone. The mudstone is generally carbonaceous and commonly pyritic; the siltstone is grey to black, and contains carbonaceous plant remains and mica; the sandstone is fine to very fine-grained, lithic, and commonly contains glauconie and rare red grains presumed to be garnet. Examination of cores from near Surat (Houston, 1972) has shown that the sandstone and siltstone contain 30 to 60 percent lithic grains, 10 to 20 percent quartz, 10 to 20 percent feldspar, and abundant glauconie, chlorite, and calcite. In the eastern part of the basin lithic sandstone is more important, and forms half the upper 50 m of the sequence in BMR Dalby No. 2; it is generally very fine to fine-grained, but medium-grained beds occur. Exon (1972a) recorded about 30 percent clay matrix and up to 50 percent carbonaceous debris in the sandstone in the east, where high-angled cross-bedding is fairly common.

The Surat Siltstone rests conformably on the thicker-bedded and somewhat coarser-grained Coreena Member. This boundary is well defined on the electrical logs of petroleum exploration wells, but is difficult to identify on the gamma-ray logs of water-bores. The member's relation to the Eromanga Basin sequence, with which it may not be in lateral continuity, is not clear. A natural lithological correlate is the upper Albian Allaru Mudstone, but palaeontological evidence suggests that the Surat Siltstone is older, and a correlate of the upper part of the Coreena Member and the Toolebuc Limestone in the Eromanga Basin.

The formation is predominantly shallow marine, although plant roots occur high in the sequence in BMR Dalby No. 2 (Exon, 1972a). The presence of abundant foraminifera (Haig, 1973) and small shelly fossils (e.g. Gray, 1972, p. 45) at some levels indicates full marine, or almost full marine, conditions; the scarcity of dinoflagellates and other microplankton (Burger, 1972; & pers. comm.) suggests a shallow-water environment. Glauconie is also assumed to indicate marine conditions. Thus the organisms and the fine-grained thinly bedded nature of the sediments suggest that the beds were laid down in a shallow sea, mainly on tidal flats and in protected bays. The carbonaceous mudstones may have been laid down in coastal swamps, and the cross-bedded sandstones in stream and tidal channels. Compared with the Coreena Member there is a higher proportion of marine beds.

The thickness of the member ranges from generally 100 to 130 m.

The plant remains and small shelly fossils have not yet been identified. Benthonic foraminifera are abundant in GSQ Surat Nos. 1 and 3 (Haig, 1973) with up to 16 calcareous and 9 arenaceous species in a single sample (see Fig. 46); the foraminifera suggest correlation with the lower to middle Albian Coreena Member in the Eromanga Basin. Spores of Evans' (1966) divisions K1d and K2a, of Albian age, are present in the Surat Basin (Burger, 1972), along with the dinoflagellates *Odontochiina operculata* and *Muderongia tetracantha* and other microplankton. Ostracods have been reported (Terpstra, 1968, 1969) but not specifically identified.

The fossil evidence clearly indicates that the member is of Albian age. The foraminifera and pollens suggest that, by correlation with the Eromanga Basin, where ages based on shelly macrofossils (Day, 1969) are fairly secure, the member is no younger than middle Albian. Thus, although the lithology suggests correlation with the upper Albian Allaru Mudstone, the palaeontological data indicates that an early to middle Albian age is more likely.

Griman Creek Formation

The Cretaceous sequence cropping out in the Surat Inlier* was named the Griman Creek Group, after Griman Creek, by Jenkins (1959); later he amended the name to Griman Creek Formation (Jenkins, 1960). Reiser (1970) fully defined the formation, and modified its usage slightly. Jenkins (1959) had separated the deeply weathered part of the Griman Creek Group as the Telgazli Formation, thinking it to be a different unit; Thomas & Reiser (1968) have shown that it is part of the Griman Creek Formation, so the area mapped by Jenkins as Telgazli Formation is now included in the Griman Creek Formation. Because the section along Griman Creek, which was nominated by Jenkins (1959) as the type section, is only the lower part of the sequence, Reiser (1970) redefined the type section as the interval from 25 to 1135 feet (8-346 m) in the continuously cored GSQ Surat No. 3 hole, where it consists predominantly of sandstone and siltstone.

The Griman Creek Formation is confined to the Surat Basin, where it crops out extensively in the Surat Inlier and in a belt between the Moonie and Weir Rivers as far east as Moonie. Farther west it crops out only sporadically. Most of the outcrops are in mesas capped by a deep weathering profile up to 45 m thick, with fresh rock confined to the lower slopes. In the central part of the basin it can be identified on the wireline logs of petroleum exploration wells and, with less certainty, on the gamma-ray logs of water-bores.

The formation crops out poorly, except near its base around Surat (Thomas & Reiser, 1968), where the sequence consists of fine-grained labile sandstone grading into siltstone and mudstone; macrofossils are fairly abundant, and in places form coquinites. Elsewhere the formation is covered by black soil, through which calcareous beds and concretions protrude, or forms part of the deeply weathered profile in which the original bedding and grainsize are recognizable, although the rock has been extensively altered. In fresh outcrops rounded glauconie pellets are common and mica is generally present; carbonaceous plant fragments also occur.

The best subsurface section is in GSQ Surat No. 3, which has been illustrated and described by Gray (1972). The most common sequence consists of thinly interbedded siltstone, fine-grained sandstone, and mudstone, but fine to medium-grained sandstone is common in places. Some beds of intraformational conglomerate and coal are present, particularly in the upper part of the formation.

Houston (1972) examined the cores from GSQ Surat No. 3, and has shown that the lower 60 m is different in composition to the upper 280 m. The rocks in the lower sequence contain about 50 percent lithic grains, 10 percent quartz, 15 percent feldspar, 5 percent chlorite and glauconie, and a total of 20 to 30 percent clay matrix, carbonate cement and pore space; the rocks in the upper sequence are composed of about 60 percent lithic grains, 5 percent quartz, 5 percent feldspar, 15 percent chlorite and glauconie, and about the same proportion of clay matrix, carbonate cement, and pore space. Gray (1972, p. 63) has suggested that the lower sequence is probably marine, and that the upper part is transitional (165-287 m) and freshwater (7-165 m).

* The area of Cretaceous outcrop bounded by Cainozoic sediments of the Condamine, Balonne, and Moonie Rivers.

The rock types cropping out outside the Surat Inlier are similar to those described above (e.g. Exon, Mond *et al.*, 1972).

The formation conformably overlies the much finer-grained Surat Siltstone, from which it can be distinguished in petroleum exploration wells by strong deflections on the electric logs caused by porous and permeable sandstones. Unfortunately, the boundary is very difficult to identify on the gamma-ray logs of water-bores. The formation contains aquifers which give small supplies of chloride water. The upper surface is generally erosional, and in places it is overlain by Cainozoic sediments.

In the Surat Inlier, and probably elsewhere, the Griman Creek Formation was deposited during the final regressive stage of the Cretaceous sea. The lower sequence, with its shelly coquinas composed mainly of brackish or freshwater forms, or both, worm burrows, and rare dinoflagellates, was probably laid down in shallow-marine, beach, and lagoonal environments. The type of sediment laid down also suggests these types of environment.

The upper sequence contains freshwater pelecypods, but no dinoflagellates, and is probably largely non-marine. The presence of coal and the abundance of intraformational conglomerate also indicate that the beds are non-marine. It is surprising that glauconie pellets, and the related non-pelletal chlorite blebs are more common in the upper sequence than in the lower. Glauconie is almost ubiquitous in the sandstones of the Rolling Downs Group and Bungil Formation, many of which contain marine fossils. The abundance of glauconie in the apparently non-marine upper part of the Griman Creek Formation suggests that the sequence is marine, but it seems more likely that the glauconie was derived from older marginal sequences rich in glauconie.

The maximum preserved thickness is 400 m in the Surat Inlier, but it is thinner towards the margins of the basin.

Fossil collections made by Laing & Allen (1955) included *Peratobelus* sp. (Roma fauna) and *Dimitobelus* sp. (Tambo fauna). Jenkins (1960) recorded *Peratobelus australis,* nine species of pelecypod, and one gastropod. Collections made by Thomas & Reiser (1968) were examined by R. W. Day, who has reported that most of them were undescribed forms. Only the belemnites (Day found only a single belemnite specimen: *Peratobelus* sp.) are definitely marine, and shells higher in the sequence in the Surat and Dalby Sheet areas are almost certainly freshwater forms, reminiscent of the faunas of the Winton Formation. The presence of *Dimitobelus* sp. indicates that the lower part of the formation is not older than Albian (e.g. Day, 1969). Foraminifera were not found by Haig (1973).

The plant macrofossils have not been identified, but spores of Evans' (1966) division K2a (e.g. Burger, 1976) of middle Albian age are present.

On stratigraphic and palaeontological evidence the formation is probably of middle Albian age, but it possibly ranges into the late Albian.

CAINOZOIC ROCKS
(Table 21)

Gabbro

The Tabor Gabbro in the northwest is probably of Tertiary age and is believed to be genetically related to the Oligocene and Miocene basalts in the north and east (Mollan *et al.*, 1972). It consists of a basin-shaped sill and three stocks of olivine microteschenite that intrude the Hutton Sandstone. The sill is elliptical, with a long axis of 8 km, and is about 45 m thick.

Two small bosses of gabbro have been recorded in the northeast (Mollan *et al.*, 1972, p. 76); they are probably of Mesozoic age, but could be Tertiary.

The gabbroic rocks recorded south of Roma in the AAO Brucedale No. 1 and nearby wells appear to transgress the surrounding Lower Jurassic sediments slightly and are probably part of a large sill. They are assumed to correlate with the Oligocene-Miocene basalts cropping out to the north.

In the Coonamble Lobe of the Surat Basin, south of the area studied, gabbro sills are present in a number of wells (e.g. Amoseas Bohena No. 1); they may also be of mid-Tertiary age.

TABLE 21. CAINOZOIC IGNEOUS ROCKS AND SEDIMENTS

	Name (map symbol)	*Lithology*	*Maximum thickness* (m)	*Fossils and Environment of Deposition*	*Relations*	*Main References*
Pleistocene and Holocene	(Qa)	Alluvium: unconsolidated gravel, sand, silt, clay, soil	100+	Abundant vertebrate fossils in SE include *Diprotodon* and other mammals, birds, reptiles, and fish. Present-day streams	Overlies or grades laterally into Qs. Unconformably overlies older units	Bartholomai (1972; Appendix 3); Senior (1970)
Mainly Pleistocene	(Q)	Alluvium as above on older river terraces and in valleys. Also general sand, gravel, and soil cover	100+	Pleistocene streams, also colluvial and aeolian	Disconformably overlies older Cainozoic units. Unconformably overlies pre-Cainozoic units	Senior (1970)
Cainozoic	(Czc)	Collapsed sheets of Tertiary basalt	100	Subaerial collapse due to erosion of soft underlying units	Unconformably overlies several U. Permian and Triassic units	Mollan et al. (1969)
	(Czs)	Weakly consolidated sandstone, conglomerate, siltstone, mudstone; residual soil	5	Colluvium, alluvium	Unconformably overlies Jurassic sediments	
Pliocene	Chinchilla Sand (Tc)	Weakly consolidated labile sand, grading into grit and conglomerate, and also to sandy clay. Minor thin lithified calcareous beds	30	Abundant vertebrate fossils: *Euryzygoma dunense* and other mammals, crocodiles, tortoises, goannas, fishes, and birds. Deposition by ancestral Condamine R.	Unconformably overlies Jurassic sediments	Woods (1960), Bartholomai & Woods (Appendix 2)
Oligocene-Miocene (18-24 m.y.)	(Tmb)	Olivine basalt, some tuff and agglomerate	120	Subaerial extrusion of basalt on uneven surface	Include Main Range Volcanics, Amby basalts, and basalts of NSW central volcanic province. Unconformable on Mesozoic units	Webb et al. (1967), McDougall & Wilkinson (1967)
Upper Oligocene (23-27 m.y.)	Springsure basalts (Tob)	Flood basalts, largely olivine basalt. Minor trachyte and pyroclastics	300+	Subaerial extrusion of lava on uneven surface	Unconformable on Mesozoic and Permian sediments	Mollan et al. (1969, pp. 53-4), Webb & McDougall (1967)
Tertiary (probably Oligocene-Miocene)	(Tb)	Olivine basalt and pyroclastics		Subaerial extrusion	Unconformable on older units	Hill & Denmead (1960, pp. 366-9)
Tertiary (probably Oligocene-Miocene)	(Tt)	Gabbro intrusions: sills, stocks, and plugs	50 for sills	Intrusions	Intruded into Jurassic rocks in outcrop (e.g. Tabor gabbro) and in subsurface. Intrusive equivalents of Tmb, Tob, and Tb	Mollan et al. (1972, pp. 76-8)
Tertiary (largely older Tertiary)	(T)	Alluvium: weakly to well consolidated sandstone, conglomerate, siltstone; silicified near Millmerran	30+	Deposition by streams ancestral to present ones	Largely older than basalt. Unconformable on Mesozoic and Palaeozoic rocks	

Basalt

Remnants of formerly extensive subhorizontal basalt flows are present in the northern part of the Surat Basin, and along the eastern margin. All are of Oligocene or Miocene age. Extrusion took place over a period of about 10 million years, and the volcanism was apparently related to a single long period of epeirogenic uplift. There is a general decrease in age of the basalts from the northwest to southeast.

Most of the northern basalts appear to have been extruded along the fault zones associated with the Merivale Syncline and the Springsure-Serocold Anticline.

The basalts associated with the Springsure-Serocold Anticline have been described by Mollan *et al.* (1969) and Mollan *et al.* (1972). Olivine basalt predominates, but fine-grained olivine-free basalt is common, and a few intermediate flows are present. Pyroclastic rocks are common around and north of Springsure. The volcanic sequence is up to 250 m thick, and whole rock K-Ar dating has shown that the lavas are of Oligocene age (Webb & McDougall, 1967).

The basalts in the Merivale Syncline (Exon *et al.,* 1970) are thinner and less widespread. Several flows are present with a total maximum preserved thickness of 80 m. They appear to have flowed down the synclinal depression from the north. The basalts range from massive to slightly vesicular, and both tholeiitic olivine basalt and olivine basalt are represented. Despite extensive erosion, which has involved inversion of relief, the basalt bodies still extend for 100 km down the synclinal axis. K-Ar dating of whole rock samples has shown that they are of late Oligocene to early Miocene age (Exon *et al.,* 1970). The basalts north of Roma are similar and of comparable age (Langford-Smith, Dury, & McDougall, 1966), but were extruded from local vents.

The basalts north of Taroom in the Mimosa Syncline (Mollan *et al.,* 1972) are vesicular, amygdaloidal, and massive, and are interbedded with subordinate sandstone. They are up to 45 m thick.

The westerly outrunners of the Main Range Volcanics (Stevens, 1965; Webb, Stevens, & McDougall, 1967) crop out along the eastern margin of the basin (Exon *et al.,* 1968; Exon, Mond *et al.,* 1972). They consist essentially of alkaline olivine basalt and most of them appear to have been erupted from fissures along the line of the present-day Main Range, and to have made their way down-slope into this area, although local vents also play a part (Exon *et al.,* 1968). Most of them have been extensively eroded and some have been covered by alluvium. The sequence consists mainly of massive and vesicular basalts with subordinate agglomerate and tuff, and minor white clayey tuff? and green clay. Most of the basalts are very fine-grained, but some contain acicular feldspar, and a few are rich in olivine phenocrysts up to 3 cm across. Columnar basalt is locally common (Fig. 47).

The maximum thickness cropping out probably exceeds 120 m, and flows of basalt over 30 m thick have been recorded in water-bores below the alluvium along the Condamine River near Dalby. K-Ar dating (Webb *et al.,* 1967) has shown that the Main Range Volcanics are of late Oligocene to early Miocene age.

Outliers of fine-grained basalt of the Central Volcanics Province of New South Wales are present in the southeast. They crop out in small and low rises, but considerably more basalt may be present under the Quaternary sediments. The volcanic province extends as far south as Armidale, and K-Ar dating has yielded lowermost Miocene ages (McDougall & Wilkinson, 1967).

Cainozoic Sediments

In Late Cretaceous time the southerly tilt of the basin increased and the Cretaceous rocks were partly eroded. No Upper Cretaceous sediments are preserved. By Early Tertiary time the land surface had stabilized, and periodic variations in rainfall resulted in a strongly fluctuating water-table that gave rise to a deeply weathered profile on the bevelled Cretaceous rocks. Renewed tectonic movement, which was probably related to the Oligocene-Miocene volcanism and epeirogenic movements in the north and east, led to subsidence of the central part of

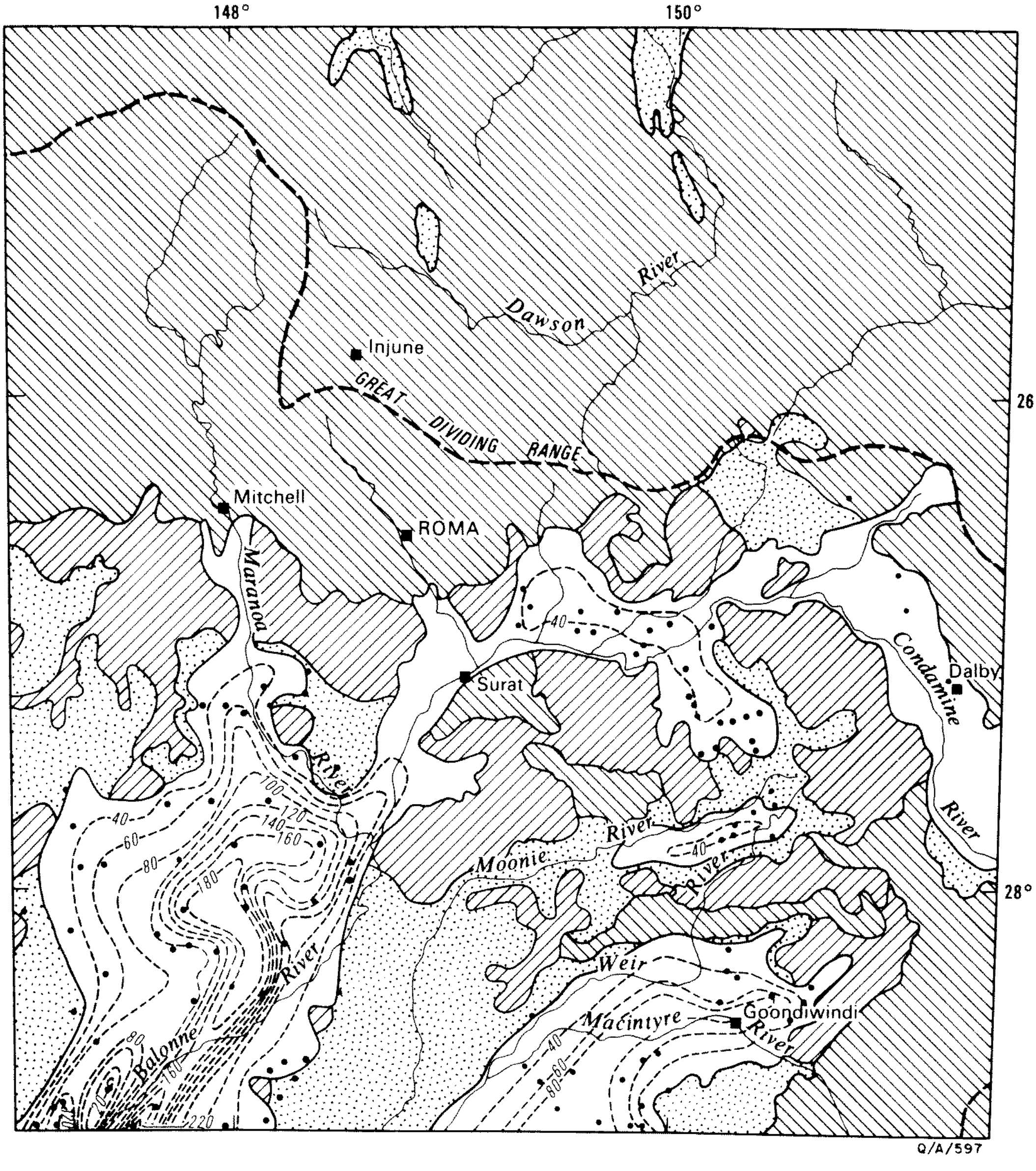
Fig. 47. Columnar basalt of Tertiary age in Malaoff Quarry, 6 km east of Jimbour.

the basin and to extensive stream sedimentation.

The thickest deposits (Fig. 48) were laid down by the Condamine-Balonne and Macintyre-Weir River systems. About one-quarter of the present Surat Basin in Queensland is covered by Cainozoic sediments over 20 m thick. In outcrop (see geological map) they can be broadly subdivided into: the Tertiary Chinchilla Sand (Tc), general Tertiary sediments (T), alluvium of old flood plains (Q), and alluvium of present-day flood plains (Qa). In the subsurface these subdivisions are only locally recognizable, and all Cainozoic sediments have been grouped together (as Cz) in Figure 48.

The five major depositional systems are: the Condamine system southeast of Chinchilla, the Condamine system between Cabawin and Surat, the Balonne system, the Macintyre-Weir system, and the Moonie system east of the Alton Oil Field. All are part of the drainage network flowing southwest into the Darling River. West of the Kumbarilla Ridge, the alluvia of the Balonne and Macintyre systems rest on downfolded deeply weathered Cretaceous rocks (Senior, 1970); this suggests that the Cainozoic basins have been formed by sagging of the older rocks. Abundant vertebrate faunas have been recovered east of the Kumbarilla Ridge, but none to the west; this may mean that lush vegetation was confined to the east, with intermittent streams and drier country in the west.

The Condamine System southeast of Chinchilla consists of Pliocene stream deposits of the Chinchilla Sand and its equivalents, Pleistocene stream and lake deposits, and Quaternary stream deposits (Lumsden, 1966). Up to 100 m of sediment was laid



Cainozoic sediments thicker than 20 m

Cainozoic sediments thinner than 20 m

Deeply weathered Mesozoic sediments

Fresh Mesozoic sediments

• Data points

--20-- Thickness of Cainozoic sequence (m)

(Balonne system contours modified after Senior, 1970)

Fig. 48. Distribution and thickness of Cainozoic sequence.

down in a depression cut in the relatively unresistant Walloon Coal Measures by various streams. The sequence forms a broad plain that falls to the northwest from about 380 m south of Millmerran to about 300 m near Chinchilla.

The Chinchilla Sand (Woods, 1956; Bartholomai & Woods, Appendix 2), which may be 95 m thick near Dalby (Lumsden, 1966), consists of variably consolidated sandstone, grit, conglomerate, silt, and clay. The Kumbarilla Ridge possibly prevented outlet to the west, and the general flow during deposition of this 'fan-type' alluvium (Lumsden, 1966) may have been to the east, or to the northeast via the Durong plain and the Boyne River (G. G. Beckmann, pers. comm.). In Pleistocene time the area acted as an internal drainage basin, at least periodically, and lake and stream muds, silts, and sands were laid down (Lumsden, 1966); these are still generally unconsolidated, although somewhat calcareous, and have a maximum thickness of up to 100 m in the southeast. The vertebrate fauna (Bartholomai, 1972; Appendix 3) is dominated by marsupials. Bartholomai (1973) on faunal evidence states that during both Pliocene and Pleistocene times the region 'comprised well watered open sclerophyll and open grassland areas ideally suited to grazing and browsing macropodids.' In late Pleistocene and Holocene times the elevation of the alluvium has certainly exceeded that of the Kumbarilla Ridge, and stream sands and silts (probably less than 20 m thick) have been laid down by the northwesterly-flowing Condamine River and its tributaries.

The Condamine System between Cabawin and Surat consists essentially of the deposits of the westerly-flowing Condamine River and of a tributary lobe north of Cabawin (Fig. 48). Up to 50 m of mud, silt, sand, and gravel was deposited by westerly-flowing streams in a valley cut in and through the deep-weathering profile. Along the Condamine River itself the restriction of the Quaternary alluvium to the present-day flood plain, which lies to the south of extensive alluvial Tertiary deposits, suggests that the river migrated laterally to the south into the basin.

The Balonne System (see Senior, 1970) consists of up to 220 m (Fig. 48) of a sequence of strongly cross-bedded unconsolidated quartz-rich sands, gravel, silt and 'ironstone', which was laid down by fast-flowing, though probably intermittent, streams. Because the Cainozoic sediments rest on deeply weathered Cretaceous sediments, which he believes to have been downwarped after they had been weathered on a nearly flat land surface, Senior (1970) considers that active tectonism occurred in the Cainozoic. However, the thickening of various Jurassic units into the depression (Figs 19-23) suggests that it is an ancient structure in which tectonic movements and compaction have played a part for over 170 million years, and the downwarping of the deeply weathered profile could be due mainly to compaction of the underlying sediments.

The Macintyre-Weir System is generally similar to the Balonne System (Senior, 1970) although the isopachs and structural maps show that it does not rest on a pre-Tertiary depression. The sediments consist of unconsolidated stream sands, clayey sands, and gravels, and are up to 95 m thick (Fig. 48). In Tertiary time, when gradients were steeper, the ancestral streams probably cut a broad deep valley into the downwarped deeply weathered profile; the valley was filled in as the gradient decreased.

The Moonie System contains up to 50 m of unconsolidated sandy sediment deposited by westerly-flowing streams (Fig. 48) that cut into and through the deep-weathering profile. Consolidated Tertiary outcrops flank the present stream along part of its course.

WEATHERING PHENOMENA

Weathering is widespread in the Surat Basin, where there has been remarkably little sedimentation since mid-Cretaceous time. The Tertiary land surface was deeply weathered and toughened, and the eroded remnants of this surface dominate the topography in the southern part of the basin where they obscure the older structural

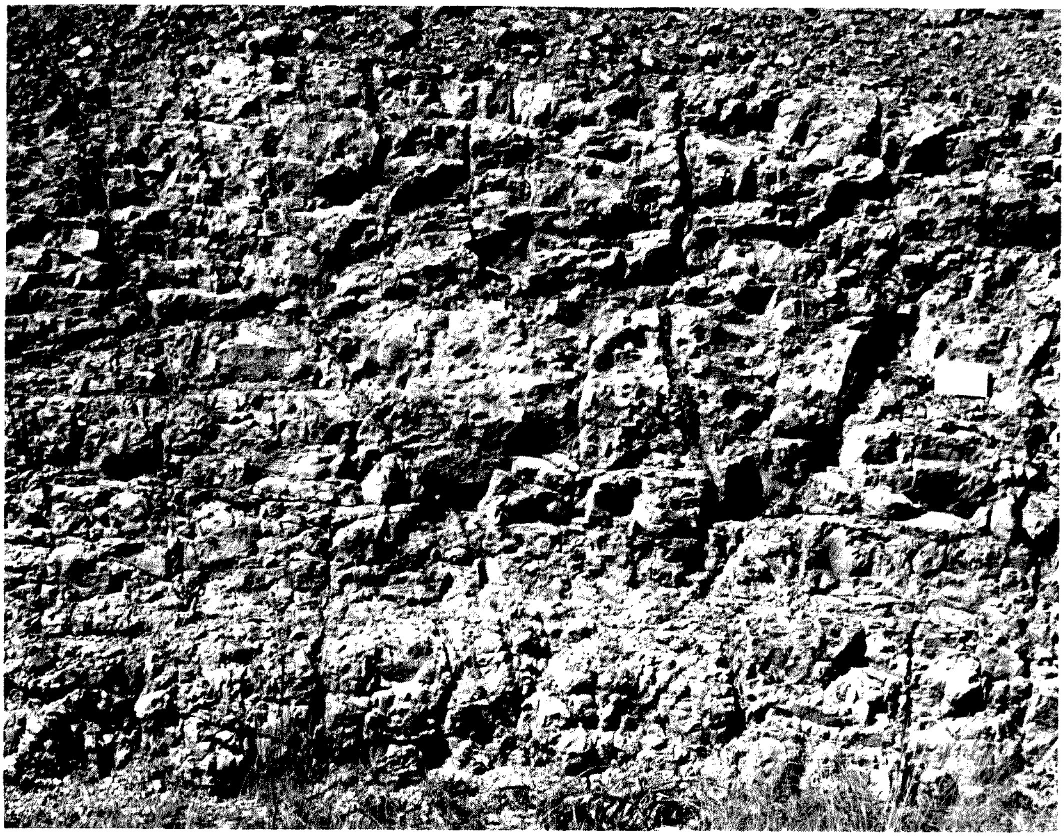


Fig. 49. Leached, mottled and weakly silicified mudstone, with blocky weathering, in deep-weathering profile developed on the Coreena Member. Cut beside Warrego Highway, 18 km west of Miles. The outcrop is 2 m high.

trends. Much of the area is blanketed by recent soils.

Tertiary Deep Weathering

Woolnough (1927) coined the term 'duricrust' for the indurated capping on a weathering profile, and stated that the duricrust was apparently of the same age throughout Australia. He thought that the duricrust formed 'during a period of highly perfect peneplanation, about Miocene in age, on a land surface almost devoid of topographic relief, and in a climate marked by the dominantly seasonal character of the rainfall.' He pointed out that the length of the 'seasons' was unimportant, and that there may have been annual wet seasons or occasional wet periods alternating with years of drought.

In the Surat Basin the weathered profiles occur as erosional remnants, and were formed essentially as Woolnough suggested, but in pre-Miocene time. Such profiles are common, but Exon *et al.* (1970) have pointed out that 'the crust of the profile is seldom preserved and hence the term "deep-weathering profile" is preferred to "duricrust profile" '.

Typical profiles have been described by Exon *et al.* (1970) and Thomas & Reiser (1968); they consist of 10 to 40 m of weathered Cretaceous lithic sandstone, siltstone, and mudstone. Both mottled and pallid zones exist, but cannot always be differentiated. In most places the upper part of the profile is tougher than the fresh rock. The morphology of the outcrops is quite variable; homogeneous fine-grained rocks tend to weather into blocks (Fig. 49), but in bedded rocks the bedding is accentuated.

The original grainsize, distribution of rock types, and bedding characteristics are identifiable despite the deep weathering. Within the profile calcite has been leached and feldspar has broken down to kaolin that forms an interstitial matrix. Iron oxides have been formed by the alteration of grains of other iron and ferromagnesian minerals. Resistant lithic and quartz grains are relatively unaffected.

During the long stable period that followed Cretaceous deposition in the Great Artesian Basin (i.e. from Late Cretaceous onward) erosion led eventually to pediplanation. The pediplaned surface was subjected to a long period of weathering under conditions characterized by variable rainfall. Constant fluctuations of the water-table resulted in leaching in the zone of fluctuation, and in the development of a weathering profile that was very deep and probably had a resistant ferruginous capping.

In Oligocene time epeirogenic movements began. They resulted in an increase in the basinward tilt and led to some erosion of the pediplaned surface before the Oligocene-Miocene basalts were poured out over large areas (Exon *et al.,* 1970); more erosion followed.

Headward erosion by northerly-flowing streams has stripped most of the deep-weathering profile and basalts from the strongly uplifted northern part of the area where the land surface has been lowered in places by 600 m since the Miocene.

In the south, where uplift was much less, headward erosion by southwesterly-flowing streams has been relatively less effective. As a result large areas of deeply weathered material form plateaux along the major divides, and mesas and buttes elsewhere. More than half the area of Cretaceous rocks exposed in the Surat Basin is deeply weathered. The relief attributable to the resistant deeply weathered surface is considerable, and in the Surat Inlier the surface lies 100 m above the surrounding streams, which are virtually at base level.

Thomas & Rieser (1968, p. 45) have discussed the occurrence of opal in the Surat Inlier, where it occurs in the deep-weathering profile of the Griman Creek Formation, particularly near its base. Silica-rich solutions, the silica coming from higher in the profile, apparently percolated downward until they came to a permeability barrier, where opal solidified from a gel (see also Ingram, 1968).

Silcrete

The term silcrete was coined by Lamplugh (1902) for 'sporadic masses in loose material of the "greyweather" type, indurated by a siliceous cement'. The term is now generally used in Australia (see Exon *et al.,* 1970; Senior & Senior, 1972) for extremely siliceous sediments that have been silicified during weathering. Silcrete is an extremely hard greyish rock composed of numerous grains of quartz, and in places chert, set in an amorphous siliceous matrix. It breaks through grains rather than around them.

Throughout the Surat Basin (as in the Roma-Amby area: Exon *et al.,* 1970) the formation of silcrete was not restricted to any one period. Silcrete cobbles are present in both silicified and unsilicified sandstones. In the Eromanga Basin (B. R. Senior, pers. comm.) silcrete is younger than the deep-weathering profile, and the same generally applies in the Surat Basin. At several localities, however, the silcrete appears to rest on the profile, and could possibly be related to it.

Silcrete has been formed in siliceous sandstones by reaction with silica-bearing groundwater. The silica in solution was probably derived mainly as a result of decomposition of clay minerals. Where the groundwater was trapped above the water-table by permeability barriers, such as clayey beds, either during normal percolation or when the water-table was falling, evaporation occurred and silica was precipitated.

Senior & Senior (1972) have described a classic example in the Tertiary Glendower Formation of Innamincka Dome, where as many as three silcrete horizons, each up to

2 m thick, have been formed in a sequence of siliceous sandstone about 30 m thick.

Solid silcrete horizons are rare in the Surat Basin, but the aprons of boulders and cobbles of silcrete ('grey billy') surrounding mesas indicate that it was formerly widespread, especially in the north. It was probably concentrated predominantly in the quartzose Tertiary sandstones, most of which have since been eroded away. Siliceous beds are forming in modern streams in the Surat Inlier (Thomas & Reiser, 1968), and elsewhere, but the main period of formation of silcrete was in the mid-Tertiary, when suitable host rocks (quartzose sandstones) were abundant.

Silcrete could have been formed in much of Australia, when suitable quartz-rich sandstones were exposed, and when climatic conditions were suitable. Favourable climatic conditions were variable rainfall, which resulted in substantial vertical movement of the water-table, and warm temperatures, which resulted in relatively rapid evaporation of the trapped water.

To sum up it may be said that similar climatic conditions prevailed during the formation of silcrete and deep-weathering profiles, and the main difference appears to have been the rock type. Thus in Early Tertiary time, when slow erosion of labile Cretaceous sediments was taking place throughout the Eromanga and Surat Basins, the development of soils with deep-weathering profiles was normal. In later Tertiary times, when quartzose sandstones were widespread, silcrete was commonly formed as a result of weathering.

Recent Weathering

During the Holocene erosion generally appears to have kept pace with weathering, and thick deep-weathering profiles have not developed.

The quartzose sandstones tend to disintegrate under the influence of weathering, but more notable changes have taken place in the mixed mudstone/siltstone/labile sandstone sequences. The mixed sequences have broken down to brown soils on the plains, although they are only slightly altered where the relief is greater. Carbonate, which is generally widespread in low concentrations in the subsurface, has been concentrated in the relatively rare porous beds during weathering, in places as concretions. In the final stage of weathering the carbonate has been replaced by iron oxide in some sequences, presumably by the oxidation of sideritic concretions and beds.

A feature of some low-lying areas of clay soils in the development of gilgais—depressions formed in heavy soils of the grey clay association, which alternate with mounds to form a more-or-less complete network; the depressions are roughly circular, up to 5 m in diameter, and some are more than a metre deep. They are particularly common in the Surat Sheet area where, for example, the soils overlying the Griman Creek Formation around Glenmorgan are extensively 'gilgaied' (Thomas & Reiser, 1968).

Thomas & Reiser (1968) found that the gilgais were invariably associated with montmorillonitic clays, and that they were commonly underlain by pure quartz sand of possible aeolian origin. They state that 'The most frequently advanced explanation of gilgais invokes the tremendous expansion and contraction of montmorillonite with alternate wetting and drying. The form of the gilgais . . . suggests relief of pressure through upward buckling in a fairly uniform body of expanding material.'

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APPENDIX 1

APTIAN AND ALBIAN MACROFOSSILS FROM THE MITCHELL AND ROMA 1:250 000 SHEET AREAS

by

R. W. Day

Geological Survey of Queensland

The following work was submitted to the Bureau of Mineral Resources as a series of preliminary reports in 1966 and 1967. Papers by Day (1969, 1974) embody the conclusions of these reports, which have received only minor editing for this publication.

Map references given below apply to the 20 000-yard transverse mercator grid shown on the 1:250 000 Sheets.

Aptian Macrofossils from the Northern Half of the Mitchell Sheet Area; 1965 Collections

Of 14 collections reported here, 3 (GAB 1942, 1950, and 2168) are from the Minmi Member, the remainder are from the Doncaster Member. The collections from the Doncaster Member are reported in approximate ascending stratigraphic order.

Minmi Member

LOCALITY:
GAB1942: Tributary of Pegleg Creek, east of the Mitchell/Forestvale Homestead road (grid ref. 618725)

Collectors:
D. J. Casey, R. W. Day, M. C. Galloway

Lithology:
Fine-grained glauconitic calcareous sandstone

Determinations:
Maccoyella barklyi (Moore)
Fissilunula clarkei (Moore)
Palaeomoera? sp.
'Nuculana' sp. ind.
?*'Nucula'* sp. ind.
Indet. trigonid
Indet. belemnite
fossil wood

Age:
Aptian

LOCALITY:
GAB1950: Burgagay Creek, about 0.8 km southeast of where the Amby/Walhallow Homestead road crosses (grid. ref. 645720)

Collector:
D. J. Casey

Lithology:
Fine-grained calcareous sandstone

Determinations:
Fissilunula clarkei (Moore)
Tatella maranoana (Etheridge Jnr)
Lingula cf. *subovalis* Davidson

Age:
Aptian

LOCALITY:
GAB2168: Eastern tributary of Amby Creek, about 4 km west-southwest of Echo Homestead (grid. ref. 652717)

Collector:
M. C. Galloway

Lithology:
Fine-grained glauconitic calcareous sandstone

Determinations:
Maccoyella barklyi (Moore)
fossil wood

Age:
Aptian

Doncaster Member

LOCALITY:
GAB2162: East bank of the Maranoa River, about 9.5 km north-northwest of Mitchell (grid ref. 611720)

Collector:
M. C. Galloway

Lithology:
Calcareous mudstone, silty limestone concretions, and glauconitic siltstone

Determinations:
Pseudavicula anomala (Moore)
Camptonectes socialis (Moore)
Cyrenopsis meeki (Etheridge Jnr)
Mesosacella randsi (Etheridge Jnr)
Leionucula quadrata (Etheridge Jnr)
Maranoana etheridgei Day
Laevidentalium sp.

Age:
Aptian

LOCALITY:
GAB2163: 22 m northeast of GAB2162

Collector:
M. C. Galloway

Lithology:
Calcareous mudstone and glauconitic siltstone

Determinations:
Tropaeum leptum (Etheridge Jnr)
Maccoyella barklyi (Moore)
Pseudavicula anomala? (Moore)
Camptonectes socialis (Moore)
Mesosacella randsi (Etheridge Jnr)
?*Cyrenopsis* sp. ind.
Euspira reflecta? (Moore)
Laevidentalium sp.
crinoid pinnules
fossil wood

Age:
Aptian (probably late Aptian)

LOCALITY:
GAB2166: Near roadside about 4 km east-northeast of Gap Plains Homestead (grid. ref. 636727)

Collector:
M. C. Galloway
Lithology:
Limestone concretions and glauconitic siltstone
Determinations:
Maccoyella barklyi (Moore)
Pseudavicula anomala (Moore)
Panopea maccoyi (Moore)
Onestia aff. *etheridgei* (Etheridge Jnr)
Pholadomya sp.
'Nuculana' sp. ind.
?Cucullaea sp.
Peratobelus sp. ind.
Purisiphonia clarkei Bowerbank
Lingula cf. *subovalis* Davidson
Isocrinus sp. ind.
Indet. rhynchonelloid brachiopod
worms burrows
Age:
Aptian

LOCALITY:
GAB2169: Small creek about 5 km south of Echo Homestead (grid ref. 656713)
Collector:
M. C. Galloway
Lithology:
Silty limestone concretions
Determinations:
Maccoyella barklyi (Moore)
Pseudavicula anomala (Moore)
Lingula cf. *subovalis* Davidson
Indet. belemnite
crinoid brachials
Age:
Aptian

LOCALITY:
GAB2167: Tributary of Five Mile Creek, about 5 km east-northeast of The Peaks Homestead (grid ref. 629717)
Collector:
M. C. Galloway
Lithology:
Silty limestone concretions
Determinations:
Tropaeum or *Australiceras* sp. ind.
Pseudavicula anomala (Moore)
Maccoyella corbiensis (Moore)
Cyrenopsis sp. ind.
Laevidentalium sp.
Lingula cf. *subovalis* Davidson
Indet. naticoid gastropod
worm burrows
Age:
Aptian

LOCALITY:
GAB2156: About 8 km east of Bangor Homestead (grid ref. 575734)
Collector:
M. C. Galloway
Lithology:
Silty limestone concretions
Determinations:
Maccoyella barklyi (Moore)
Pseudavicula anomala (Moore)
Panopea mooret Day
Indet. mytilid
Lingula cf. *subovalis* Davidson
calcareous tubes (annelid?)
Age:
Aptian

LOCALITY:
GAB2155: About 5 km north of Mount Lonsdale Homestead (grid ref. 574732)
Collector:
M. C. Galloway
Lithology:
Calcareous glauconitic mudstone and siltstone with mud pebbles
Determinations:
Maccoyella barklyi (Moore)
Pseudavicula anomala (Moore)
Cyrenopsis sp. ind.
ganoid? fish scale
Age:
Aptian

LOCALITY:
GAB1887: Back Creek, about 5 km south-southwest of Bangor Homestead (grid ref. 567729)
Collector:
N. Exon
Lithology:
Siltstone with mud pebbles
Determinations:
Maccoyella barklyi (Moore)
Camptonectes socialis (Moore)
Panopea moorei Day
calcareous tubes (annelid?)
Age:
Aptian

LOCALITY:
GAB2159: Near earth tank about 9 km northeast of Dulbydilla Homestead (grid ref. 555731)
Collector:
M. C. Galloway
Lithology:
Limestone concretions
Determinations:
Maccoyella sp. ind.
Leionucula sp. nov.
fossil wood
Age:
Aptian

LOCALITY:
GAB2098: South bank of the Maranoa River, where the river curves from the southeast to the east-northeast, about 4 km west of Mitchell (grid ref. 611711)
Collectors:
D. J. Casey, R. W. Day, M. C. Galloway
Lithology:
Calcareous concretions and silty mudstone
Determinations:
Tropaeum or *Australiceras* sp. ind.
Purisiphonia clarkei Bowerbank
Maccoyella barklyi (Moore)
Maccoyella corbiensis (Moore)
Pseudavicula anomala (Moore)
'Mytilus' rugocostatus (Moore)
Tancretella plana (Moore)
Panopea maccoyi (Moore)

Tatella maranoana (Etheridge Jnr)
Inoperna ensiformis (Etheridge Jnr)
Cyrenopsis meeki (Etheridge Jnr)
Onestia aff. *etheridgei* (Etheridge Jnr)
?'*Nucula* sp. ind.
Euspira reflecta (Moore)
Laevidentalium sp.
crinoid pinnules
fossil wood

Age:
Aptian

LOCALITY:
GAB2152: Earth tank about 5 km east-north-east of Brunel Downs Homestead (grid ref. 516739)

Collector:
M. C. Galloway

Lithology:
Limestone concretions

Determinations:
Pseudavicula anomala (Moore)
Panopea moorei Day
Lima randsi (Etheridge Jnr)
Cyrenopsis meeki (Etheridge Jnr)
'*Gari*' *elliptica* Whitehouse
Eyrena linguloides (Hudleston)
Mesosacella randsi (Etheridge Jnr)
Actaeon hochstetteri? (Moore)
Laevidentalium sp.
Lingula cf. *subovalis* Davidson
crinoid brachials

Age:
Aptian

REMARKS

Fossils from the three localities in the Minmi Member (GAB1942, 1950, and 2168) are similar to those recently reported from sandstones at the base of the Doncaster Member in the Tambo area. Similarities with faunas of the overlying Doncaster Member in the Mitchell area, and the Minmi Member and Doncaster Member of the Roma area, are also apparent. The pelecypods *Maccoyella barklyi, Fissilunula clarkei,* and *Tatella maranoana* are common to all units. More species were listed by Day (1964a, table 3) from the Minmi Member of the Roma area, than are reported here. However, the Roma area has been more intensely collected.

Palaeomoera? sp. and the single indeterminate trigonid reported from GAB1942 have not been observed in collections from the Minmi Member of the Roma area. *Palaeomoera?* sp. is represented at GAB 1942 by numerous specimens with closed valves. The form has a deep pallial sinus, but it is proportionately higher than the holotoype of *Gari elliptica* Whitehouse figured by Etheridge Jnr (1901, pl. 2, fig. 8) (1902, pl. 2, fig. 25) from the Lake Eyre basin of South Australia.

The occurrence of a large specimen identified as *Tropaeum leptum* at GAB2163, close to the base of the Wallumbilla Formation, indicates a probable late Aptian age for this horizon. The specimen is 450 mm in diameter and lacks the initial whorls and a short portion behind the last septum. The ornament is non-tuberculate and the ribbing is relatively uniform throughout. Although the specimen has been compressed to a certain extent, the whorl section is elevated like that of the type figured by Etheridge Jnr (1909, pl. 30, figs 1-3) from Lind River Homestead (Carpentaria Basin). The present specimen is larger and much more complete than the type.

Tropaeum or *Australiceras* sp. ind. from GAB2098 and 2167 are septate fragments with quadrate whorl sections like those of *T. australe* and *T. arcticum*.

Ammonites are comparatively rare in the Surat Basin. *Tropaeum australe* (Moore, 1870, pl. 15, fig. 3) from the 'Upper Maranoa', and *T. arcticum* (Stolley) from 'Roma' (figured by Etheridge Jnr, 1909, pl. 32, fig. 2; pl. 34, fig. 1, as *Crioceras jackii*) have been described from this area. According to Casey (1960, p. 41) the latter is very like the English species *T. subarcticum,* a characteristic ammonite of the upper Aptian *nutfieldensis* Zone.

The fauna in all collections from the Wallumbilla Formation in the Mitchell area corresponds closely with that of the *Purisiphonia* horizon reported from the Roma area by Day (1964a, p. 17). The species in common include *Purisiphonia clarkei, Maccoyella barklyi, M. corbiensis, Pseudavicula anomala, Fissilunula clarkei, Tatella maranoana,* '*Gari*' *elliptica, Tancretella plana, Camptonectes socialis, Inoperna enisformis, Eyrena linguloides, Onestia* aff. *etheridgei, Cyrenopsis meeki, Maranoana etheridgei,* and *Mesosaccella randsi.*

The brachiopod *Lingula* cf. *subovalis* occurs quite frequently in these collections, and is from GAB1950, 2152, 2156, 2166, 2167, and 2169. Curiously in the Roma area, it was noted at only one locality (RD78).

Pholadomya sp. is represented by a small specimen with closed valves. Radial ribbing is very prominent on the anterior parts of the shell.

The Maryborough species *Lima randsi* Etheridge Jnr (1892, pl. 21, fig. 13) has not been previously reported from the Surat or Eromanga Basins. Five left valves from GAB2152 closely approach the shape and ribbing of the holotype.

A Marine Fauna of Possible Neocomian Age from the Nullawurt Sandstone Member in the Mitchell Sheet Area: 1966 Collections

LOCALITY:
SB210: 5 km west-southwest of Claravale Homestead (grid ref. 626746)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Tancredia sp.
cf. *'Corbicellopsis' nanutarraensis* Cox
Unionid pelecypods
cf. *Purpurina ? yanreyensis* Cox
fossil wood
Age:
Probably Neocomian

LOCALITY:
SB211: 5 km west-southwest of Claravale Homestead (grid ref. 626747)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Tancredia sp.
cf. *'Corbicellopsis' nanutarraensis* Cox
Unionid pelecypods
Indet. naticoid gastropod
Age:
Probably Neocomian

LOCALITY:
SB221: About 8 km south of Katanga Homestead (grid ref. 639740)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Meleagrinella sp.
Tancredia sp.
cf. *'Corbicellopsis' nanutarraensis* Cox
Maranoana? sp.
?*Tancretella* sp.
Leionucula aff. *quadrata* (Etheridge Snr)
?belemnite moulds
?gastropod trails
Age:
Probably Neocomian

LOCALITY:
SB230: About 5 km southwest of Katanga Homestead (grid ref. 635740)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Meleagrinella sp.
Tancredia sp.
cf. *'Corbicellopsis' nanutarraensis* Cox
Maranoana? sp.
Modiolus sp.
Leionucula aff. *quadrata* (Etheridge Snr)
worm burrows
plant fragments
Age:
Probably Neocomian

LOCALITY:
SB233: Near Eastern Creek, about 2.5 km north of SB232 (grid ref. 619738)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Meleagrinella sp.
Age:
Probably Neocomian

LOCALITY:
SB239: About 4 km north of Walhallow Homestead (grid ref. 651742)
Lithology:
Fine-grained quartzose sandstone
Determinations:
Meleagrinella sp.
plant fragments
Age:
Probably Neocomian

Remarks

The six collections made by N. F. Exon from the Nullawurt Sandstone Member in the Mitchell Sheet area provide the first record of marine macrofossils in this unit. In the Roma-Wallumbilla area to the east, where the unit was first defined, Day (1964a, p. 12) reported only freshwater pelecypods, coprolites?, worm tracks and burrows, and plant fossils. In that area, the lowest stratigraphic horizon yielding a marine macrofauna was the Minmi Member, which immedately overlies the Nullawurt Sandstone Member. As there are at present no records of post-Permian marine macrofossils in the Surat Basin, other than those from the Minmi Member and from the Wallumbilla Formation, the fossils reported herein probably represent the oldest Mesozoic marine macrofauna found in the Surat Basin to date.

Occurrences of a marine fauna as well as a freshwater one in the Nullawurt Sandstone Member suggest that the member was deposited in near-shore environments. The marine influence apparently did not extend as far east as the Roma-Wallumbilla area, where at present only freshwater fossils are known.

Unfortunately, the collections contain no ammonites and it is not possible to determine the age of the Nullawurt fauna with confidence. However, from the evidence considered below it is suggested that the fauna is of Neocomian age.

Neocomian affinities are displayed by the species from SB221, 230, 233, and 239, which is designated *Meleagrinella* sp. This form is represented by numerous internal and external moulds of left valves and a few right valves. In ornament and outline they show a close resemblance to *Pseudomonotis* sp. figured by Whitehouse (1946, pl. 1, figs 7-8) from the Neocomian (Valanginian?) Stanwell Coal Measures. The species figured by Brunnschweiler (1960, p. 20, text-fig. 15a-d, pl. 1, figs 20, 22, 25) from the early Neocomian Jowlaenga Formation of the Dampier Peninsula, Western Australia, as *Meleagrinella* cf. *superstes* is also similar. In addition, the single specimen described from the Minmi Member by Day (1967b) as *Meleagrinella* sp. is comparable with the present form. However, all other *Meleagrinella* specimens known from the Minmi Member were referred by Day (1967b) to a new species which closely resembles *Pseudomonotis superstes* Spitz (1914, pl. 18, figs 6-7) from the Lower Cretaceous Guiemal Sandstone of the Himalayas.

Tancredia sp. from SB210, 211, 221, and 230 is more transversely elongated than the new species of *Tancredia* described from the Minmi Member by Day (1967b). To date no comparable species has been observed.

A few large specimens from SB221 are doubtfully referred to the genus *Tancretella* Ludbrook (1966), the type species of which is the Aptian *Myacites planus* Moore (1870, p. 254, pl. 12, fig. 10). In shape and musculature they are not unlike large forms identified by Woods (1963) from the Laura Basin at the 'crossing of Normanby River, 1.5 miles northeast of Lakefield homestead' as *'Macrocallista'* sp. nov. At that locality *'Macrocallista'* sp. nov. was associated with the presumably Neocomian (Hauterivian?) ammonite *Hatchericeras lakefieldense* Woods (1962).

Specimens from SB221 and 230 designated aff. *Maranoana?* sp. are possibly congeneric with the Aptian species figured by Etheridge Jnr (1892, pl. 28, figs 2-5) and referred by Day (1967b, p. 12) to a new genus and species, *Maranoana etheridgei*. The Nullawurt specimen may have some affinity with the *?Tatella* sp. nov. recorded by Woods (1963) from the same locality as *'Macrocallista'* sp. nov.

In shape and to a certain extent in dentition, several specimens from SB210, 211, and 230 resemble an anteriorly incomplete specimen described by Cox (1961, p. 24, pl. 2, figs 10a-b) from the Nanutarra Formation of Western Australia as *'Corbicellopsis' nanutarraensis*. Species of the Aptian-Albian genus *Tatella* are somewhat similar in outline, but have less prominent umbones, are not as inflated, and lack lateral teeth. Cox (1961) assigned the Nanutarra fauna a general Early Cretaceous age, although S. K. Skwarko (pers. comm.) regards the age of the fauna as Neocomian.

A further possible link with the Nanutarra fauna is provided by two gastropods from SB210. In coiling and ornament these are quite like *Purpurina ? yanreyensis* Cox (1961, p. 33, pl. 7, figs 6a-b).

Modiolus sp. is represented by a single carinate nondescript internal and external mould of a left valve from SB230.

A few internal moulds of left valves from SB221 and 230 have taxodont dentition and internal ligament pits. They are designated *Leionucula* aff. *quadrata* as they resemble in shape the Aptian and Abian species described by Etheridge Snr (1872, p. 341, pl. 19, fig. 5; pl. 20, fig. 3) from Maryborough.

Collections SB210 and 211 contain numerous medium-sized strongly inflated internal and external moulds of pelecypods with closed valves. The shape, ornament of coarse concentric ribs, and the eroded condition of the umbones recall features well displayed by freshwater unionid pelecypods. They may have some relationship to 'Unionid gen. & sp. nov.' reported from the Roma-Wallumbilla area by Day (1964a, p. 15, table 4).

Various collections also contain plant fragments, worm burrows, gastropod? trails, and belemnite? moulds.

In view of the small number of species represented in the Nullawurt fauna, and the absence of ammonite species therein, it is difficult to determine the age of the fauna precisely. The difficulty is compounded by the lack of well-documented faunas of Late Jurassic to Early Cretaceous age in Australia. Probably the best evidence as to age is provided by *Meleagrinella* sp., which appears to be conspecific with an unnamed species of *Meleagrinella* in the Neocomian fauna from Stanwell. This form is quite distinct from the Late Jurassic species of *Meleagrinella,* which are markedly multicostate and have emarginate posterior ears. Occurrences of ?*Tancretella* sp. and *Maranoana* ? sp. may indicate links with the Neocomian fauna of the Laura Basin, but this line of evidence is rather tenuous. If the specimens from the Nullawurt Sandstone Member compared with *'Corbicellopsis' nanutarraensis* and *Purpurina ? yanreyensis* are conspecific with those Western Australian species, there is the possibility of correlation with the Nanutarra Formation. However, the age of the Nanutarra Formation is uncertain. *Leionucula* aff. *quadrata* suggests affinities with younger fauna, but the Nullawurt representatives are not conspecific with this Aptian-Albian species.

Except for similarities in *Meleagrinella* species, the fauna described by Day (1967b) from the overlying Minmi Member is quite distinct. The single specimen of *Meleagrinella* sp. found in the Minmi Member might be regarded as a remanié fossil. The other, more commonly occurring *Meleagrinella* species in the Minmi Member is specifically different. More than half the species in the Minmi fauna also occur in the overlying Doncaster Member, where they are associated with ammonites of probable late Aptian age. The remainder of the fauna comprises new species. Only *Meleagrinella woodsi* has apparent Neocomian affinities. For this reason Day (1967b) preferred an early Aptian age for the Minmi fauna. Negative evidence, from the absence of Roma (Aptian) species, and the stratigraphic occurrence below the Minmi fauna, suggests that the Nullawurt fauna is somewhat older.

Considering the evidence available at present, a Neocomian age seems the most likely possibility, although the Nullawurt fauna cannot be regarded as securely dated. A well-dated marine horizon in the Nullawurt Sandstone Member would be of value in placing the Jurassic-Cretaceous boundary in this part of the Surat Basin.

Aptian Marine Fossils from the Minmi Member in the Mitchell and Roma Sheet Areas: 1966 Collections

Mitchell Sheet Area (Collector N. F. Exon)

LOCALITY:
SB200: Near road about 2.5 km southwest of Eastern Creek Homestead (grid ref. 626739)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
fossil wood fragments

Age:
Aptian

LOCALITY:
SB203: About 5 km northwest of Nade Homestead (grid ref. 643735)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tancretella plana (Moore)
Tatella maranoana (Etheridge Jnr)
Inoperna ensiformis (Etheridge Jnr)

Age:
Aptian

LOCALITY:
SB207: About 5 km northeast of Eastern Creek Homestead (grid ref. 631743)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tancretella plana (Moore)
Tatella maranoana (Etheridge Jnr)

Age:
Aptian

LOCALITY:
SB209: About 3 km north of Heather Downs Homestead (grid ref. 638735)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tatella maranoana (Etheridge Jnr)
Euspira reflecta (Moore)

Age:
Aptian

LOCALITY:
SB226: About 0.5 km northwest of Kilmorey Homestead (grid ref. 635758)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tancretella plana (Moore)
Meleagrinella woodsi Day
Maccoyella subangularis Etheridge Jnr
fish scale
worm tubes

Age:
Aptian

LOCALITY:
SB227: About 1 km west of Kilmorey Homestead (grid ref. 633758)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tancretella plana (Moore)
Cyrenopsis balli Day
Inoperna ensiformis (Etheridge Jnr)
Meleagrinella woodsi Day
Indet. trigoniid
Euspira reflecta (Moore)
fossil wood
fish scale

Age:
Aptian

LOCALITY:
SB228: About 3 km southeast of Kilmorey Homestead (grid ref. 633756)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Tancretella plana (Moore)
Cyrenopsis balli Day
Meleagrinella woodsi Day
Maccoyella subangularis Etheridge Jnr
'Nuculana' minmiensis Day
Euspira reflecta (Moore)

Age:
Aptian

LOCALITY:
SB231: On a tributary of Eastern Creek, about 5 km southwest of Eastern Creek Homestead (grid ref. 623735)

Lithology:
Medium-grained glauconitic sandstone

Determinations:
Fissilunula clarkei (Moore)
Tancretella plana (Moore)
Tancredia (Corburella) trigoniformis Day
Meleagrinella woodsi Day

Age:
Aptian

LOCALITY:
SB232: About 7 km east of Homeleigh Homestead (grid ref. 618736)

Lithology:
Medium to coarse-grained glauconitic sandstone

Determinations:
Tancretella plana (Moore)
Cyrenopsis balli Day
Euspira reflecta (Moore)

Age:
Aptian

LOCALITY:
SB264: Burgagay Creek, about 1 km southeast of where the Amby/Walhallow Homestead road crosses (grid ref. 645720) (near locality GAB1950)

Lithology:
Fine and medium-grained glauconitic sandstone

Determinations:
Tancretella plana (Moore)
Tatella maranoana (Etheridge Jnr)
Inoperna ensiformis (Etheridge Jnr)
Eyrena linguloides (Hudleston)
Eyrena tatei (Etheridge Jnr)
Panopea maccoyi (Moore)
fish scales
fossil wood

Age:
Aptian

ROMA SHEET AREA (Collector E. N. Milligan)

LOCALITY:
SB107: Sawpit Creek, about 9 km north-northwest of Bindango Homestead (grid ref. 678710)

Lithology:
Fine-grained calcareous glauconitic sandstone

Determinations:
Tancretella plana (Moore)
Tatella maranoana (Etheridge Jnr)
Maccoyella barklyi (Moore)
Panopea maccoyi (Moore)

Age:
Aptian

LOCALITY:
SB118: Bungeworgorai Creek, about 2.5 km south of Eumina Siding (grid ref. 147706)

Lithology:
Coquina band in fine-grained calcareous glauconitic sandstone

Determinations:
Peratobelus australis (Phillips)
Tatella maranoana (Etheridge Jnr)
Maranoana etheridgei Day
Maccoyella barklyi (Moore)
calcareous annelid tubes

Age:
Aptian

LOCALITY:
SB122: About 9 km south-southwest of Lucky Downs Homestead (grid ref. 248728)

Lithology:
Leached fine and medium-grained sandstone

Determinations:
Tatella maranoana (Etheridge Jnr)
Maranoana etheridgei Day
Onestia aff. *etheridgei?* (Etheridge Jnr)
Meleagrinella woodsi Day
fossil wood

Age:
Aptian

LOCALITY:
SB124: About 19 km northeast of Bendemere Homestead (grid ref. 238723)

Lithology:
Leached fine-grained sandstone

Determinations:
Meleagrinella woodsi Day
Cyrenopsis balli Day

Age:
Aptian

LOCALITY:
SB127: About 8 km east of Muggleton Homestead (grid ref. 216719)

Lithology:
Leached fine-grained sandstone

Determinations:
Palaeomoera? sp.
Meleagrinella woodsi Day
Panopea maccoyi (Moore)
Goniasterid starfish
plant fragments

Age:
Aptian

LOCALITY:
SB128: About 13.5 km north-northwest of Jackson (grid ref. 243705)

Lithology:
Leached fine-grained sandstone

Determinations:
Tatella maranoana (Etheridge Jnr)
Maranoana etheridgei Day
Meleagrinella woodsi Day

Age:
Aptian

REMARKS

The fauna represented in these collections from the Minmi Member in the Mitchell and Roma Sheet areas is virtually identical with that described by Day (1967b) from the Minmi Member in the Roma-Wallumbilla area.

Most of the species also occur in the overlying Doncaster Member of the Wallumbilla Formation. They include the belemnite *Peratobelus australis,* the gastropod *Euspira reflecta,* and the pelecypods *Tatella maranoana, Maranoana etheridgei, Palaeomoera* ? sp., *Tancretella plana, Fissilunula clarkei, Inoperna ensiformis, Eyrena linguloides, Eyrena tatei, Maccoyella barklyi, Maccoyella subangularis,* and *Panopea maccoyi. Onestia* aff. *etheridgei* is known from the Doncaster Member, but it is not certain whether the Minmi Member specimens from SB122 are conspecific. *Thracia primula* has not been observed in collections from the predominantly mudstone Doncaster Member, but the species occurs in the sandy Coreena Member which overlies the Doncaster Member. The remaining identifiable species, *'Nuculana' minmiensis, Tancredia (Corburella) trigoniformis, Cyrenopsis balli,* and *Meleagrinella woodsi* are at present known only from the Minmi Member. *Meleagrinella woodsi* has Neocomian affinities, but in view of the preponderance of associated Aptian (Roma) species, an early Aptian age is preferred for the Minmi Member.

Meleagrinella woodsi is closely related to *Pseudomonotis superstes* Spitz (1914, pl. 18, figs 6-7) from the Guiemal Sandstone of India. The species has not been observed in collections from marine sandstones that conformably underlie mudstones of the Doncaster Member in the Tambo area in the Eromanga Basin. This may be due to collection failure. Alternatively its absence may suggest that the basal marine Cretaceous sandstones in the Eromanga Basin are slightly younger than the sandstones of the Minmi Member in the Mitchell and Roma areas.

'Nuculana' minmiensis has more anterior umbones than *'Nuculana elongata'* (Etheridge Snr, 1872, pl. 20, fig. 5) and *Mesosaccella randsi* (Etheridge Jnr, 1892, pl. 26, fig. 10) from the Aptian Maryborough Formation.

Cyrenopsis balli is more elongate than other described species of that genus.

Specimens of *Fissilunula clarkei, Tancretella plana, Tatella maranoana,* and *Inoperna ensiformis* found in medium-grained sandstones, do not appear to differ from specimens of those species collected from finer-grained rocks.

A single left valve from SB127 has the same shape as specimens identified from SB129 in the overlying Doncaster Member as *Palaeomoera*? sp.

Several rather large internal and external moulds from SB122 have equilateral shape and concentric ornament. In these respects they resemble the Aptian Maryborough species *Onestia etheridgei* (Etheridge Jnr, 1892, pl. 27, fig. 1). However, the hinge is not visible and the identification can only be tentative.

Collection SB128 contains an asteroid starfish which is probably referrable to the family Goniasteridae. The arms are short and the inter-radials of the oral surface bear ridges resembling the rod-shaped ossicles of the Indian Jurassic genus *Indiaster* Rao. The matrix is too coarse for ready determination of the nature of the plates. Fragments of starfish arms were reported from the Minmi Member by Day (1964a).

APTIAN MACROFOSSILS FROM THE DONCASTER MEMBER IN THE MITCHELL AND ROMA SHEET AREAS: 1966 COLLECTIONS

MITCHELL SHEET AREA (Collector E. N. Milligan)

LOCALITY:
SB104: Near the Maranoa River about 2.5 km northeast of Mulgavale Homestead (grid ref. 622695)

Lithology:
Fine-grained calcareous sandstone with mud pebbles

Determinations:
Panopea sp.ind.
plant fragments

Age:
Probably Aptian

LOCALITY:
SB105: Maranoa River, about 1.5 km downstream from Mitchell (grid ref. 617708)

Lithology:
Fine-grained glauconitic silty sandstone

Determinations:
Maccoyella reflecta (Moore)
Maccoyella corbiensis (Moore)
Cyrenopsis meeki (Etheridge Jnr)
Peratobelus oxys (Tenison-Woods)
?*Dimitobelus* sp. ind.

Age:
Aptian

LOCALITY:
SB106: Sawpit Creek, about 9 km east-southeast of Mount Bindango (grid ref. 670710)

Lithology:
Concretionary limestone

Determinations:
Maccoyella barklyi? (Moore)
Camptonectes socialis? (Moore)
Tancretella plana (Moore)
Lima gordoni Moore
Inoperna ensiformis (Etheridge Jnr)
Euspira reflecta (Moore)
Peratobelus sp. ind.
Purisiphonia clarkei Bowerbank
Isocrinus sp. ind.
algal structures
worm burrows

Age:
Aptian

LOCALITY:
SB129: Maranoa River, about 9.5 km north-northwest of Mitchell (grid ref. 611720) (locality is close to GAB2162-2163)

Lithology
Concretionary limestone with some coquina bands

Determinations:
Peratobelus australis (Phillips)
Maccoyella barklyi (Moore)
Maccoyella subangularis Etheridge Jnr
Camptonectes socialis (Moore)
Camptonectes aequilineatus (Moore)
Pseudavicula anomala? (Moore)
Inoceramus cf. *neocomiensis* d'Orbigny
'Nuculana elongata' (Etheridge Snr)
Leionucula cooperi (Moore)
Leionucula quadrata (Etheridge Snr)
Inoperna ensiformis (Etheridge Jnr)
Cyrenopsis meeki (Etheridge Jnr)
'Ostrea' sp.
Panopea moorei Day
Thracia wilsoni Moore
Palaeomoera? sp.
Laevidentalium sp.
Euspira reflecta (Moore)
Isocrinus sp. ind.

Age:
Aptian

LOCALITY:
SB130: Maranoa River, about 1.5 km downstream from SB129 (grid ref. 609720) and about 1 km east-northeast of Brooklyn Homestead

Lithology:
Fine-grained silty sandstone

Determinations:
Leionucula cooperi (Moore)
Thracia wilsoni? Moore
crinoid fragments
plant fragments

Age:
Aptian

ROMA SHEET AREA (Collector E. N. Milligan)

LOCALITY:
SB110: Near Muckaby Creek, about 6.5 km north-northeast of Bindango Siding (grid ref. 734703)

Lithology:
Coquina band in calcareous mudstone

Determinations:
Maccoyella barklyi (Moore)
Inoperna ensiformis Etheridge Jnr)
Fissilunula clarkei? (Moore)
Laevidentalium sp.
Indet. naticoid gastropod
crinoid fragments

Age:
Aptian

LOCALITY:
SB112: Wallumbilla Creek, about 7 km southeast of Wallumbilla (grid ref. 205689)

Lithology:
Fine-grained friable sandstone

Determinations:
Eyrena linguloides (Hudleston)

Cyrenopsis meeki (Etheridge Jnr)
'Nuculana' sp. ind.
Camptonectes sp. ind.
Laevidentalium sp.
Euspira reflecta (Moore)
plant fragments

Age:
Aptian

LOCALITY:
SB114: Wallumbilla Creek, near SB112

Lithology:
Fine grained friable sandstone

Determinations:
Peratobelus oxys (Tenison-Woods)
Inoceramus cf. *neocomiensis* d'Orbigny

Age:
Aptian

LOCALITY:
SB115: Wallumbilla Creek, about 6.5 km south-southeast of Wallumbilla (grid ref. 205688)

Lithology:
Concretionary limestone

Determinations:
Maccoyella sp. ind.

Age:
Probably Aptian

LOCALITY:
SB116: West of Wallumbilla Creek, about 6.5 km south-southeast of Wallumbilla (grid ref. 205690)

Lithology:
Limestone concretions

Determinations:
Maccoyella reflecta (Moore)
Maccoyella umbonalis (Moore)
Fissilunula clarkei (Moore)
Eyrena linguloides (Hudleston)
Onestia aff. *etheridgei* (Etheridge Jnr)
'Gari' elliptica? Whitehouse
Thracia wilsoni Moore
Panopea maccoyi (Moore)

Age:
Aptian

LOCALITY:
SB117: Wallumbilla Creek, about 7 km south-southeast of Wallumbilla (grid ref. 206690)

Lithology:
Limestone concretions

Determinations:
Peratobelus australis (Phillips)
Pseudavicula anomala (Moore)
Camptonectes socialis (Moore)
'Mytilus' rugocostatus Moore
Tatella maranoana (Etheridge Jnr)
Onestia aff. *etheridgei* (Etheridge Jnr)
Thracia wilsoni Moore
Euspira reflecta (Moore)

Age:
Aptian

LOCALITY:
SB119: Roma-Orallo road, about 10 km from Roma (grid ref. 155703)

Lithology:
Limestone concretions

Determinations:
Pinna sp. ind.
Laevidentalium sp.

Age:
Probably Aptian

LOCALITY:
SB120: Wallumbilla Creek, 7 km east of Bundilla Homestead (grid ref. 205684)

Lithology:
Silty sandstone

Determinations:
Panopea maccoyi (Moore)

Age:
Aptian

LOCALITY:
SB121: Near where the road from Wallumbilla to the Condamine Highway crosses Pickanjinnie Creek (grid ref. 200677)

Lithology:
Silty sandstone

Determinations:
Maccoyella reflecta (Moore)

Age:
Aptian

LOCALITY:
SB123: About 5.5 km west-northwest of Pickanjinnie (grid ref. 189770)

Lithology:
Silty calcareous concretions

Determinations:
Tropaeum undatum? Whitehouse
Maccoyella corbiensis (Moore)
Onestia aff. *etheridgei* (Etheridge Jnr)
Euspira reflecta (Moore)
Indet. belemnites
'Rhynchonella' rustica (Moore)
Isocrinus australis (Moore)
Purisiphonia clarkei Bowerbank
calcareous annelid tubes

Age:
Probably late Aptian
Isocrinus australis (Moore)
SB125: About 9 km northwest of Drillham (grid ref. 284699)

Lithology:
Coquinite band in calcareous silty limestone

Determinations:
Maccoyella barklyi (Moore)
Maccoyella corbiensis (Moore)
Camptonectes socialis (Moore)
Inoceramus cf. *neocomiensis* d'Orbigny
Leionucula sp. ind.
Indet. trigoniids
Indet. mytilid
Laevidentalium sp.
Euspira reflecta (Moore)
Purisiphonia clarkei Bowerbank
Isocrinus sp. ind.
Lingula cf. *subovalis* Davidson
Indet. belemnites
calcareous annelid tubes
worm burrows

Age:
Aptian

LOCALITY:
SB126: Dulacca Creek, about 2.5 km south of Dulacca (grid ref. 265688)

Lithology:
Fine-grained silty sandstone
Determinations:
'Lucina' sp.
Lingula cf. *subovalis* Davidson
Indet. shell fragments
Age:
Aptian

REMARKS

The vast majority of the species identified in the present collections from the Mitchell and Roma Sheet areas were previously reported from those areas by Day (1964a, (1966a). The fauna is a typical Roma (Aptian) fauna, with one possible Tambo element. This is a single very small belemnite guard from SB105, which may be a representative of the Tambo genus *Dimitobelus*. However, the specimen is not well preserved and cannot be referred with confidence to that genus.

Collections SB106, SB110, SB119, SB123, SB125, SB129, and SB130 probably belong to the *Purisiphonia* horizon as their fauna corresponds closely to that reported by Day (1964a) from this horizon in the Roma area. The remaining collections are from stratigraphically higher horizons. Some of these may correspond to 'the horizon with abundant *Cyrenopsis*', although *Cyrenopsis* is not abundant in the collections.

The new collections have shown that a few species range higher than was evident in collections from the limited area mapped by Day (1964a). Numerous specimens from SB117 indicate that the pelecypod *Pseudavicula anomala* (Moore) ranges above the *Purisiphonia* horizon. *Pseudavicula anomala* was reported from very near the top of the Aptian sequence in the Hughenden area (Day, 1964b) and from similar levels in the Tambo and Augathella areas (Day, 1966b). Likewise, the occurrence of the belemnite *Peratobelus australis* (Phillips) at SB116 indicates the range of this species overlaps that of *P. oxys*. Several guards found near the top of the Aptian sequence in the Tambo area were tentatively identified with *P. australis* by Day (1966b). *Tatella maranoana* (Etheridge Jnr) also occurs above the *Purisiphonia* horizon, as forms listed by Day (1964a) as *Tatella? aptiana* Whitehouse are now regarded as conspecific with *T. maranoana*.

Maccoyella reflecta (Moore) appears to be the most characteristic fossil of strata above the *Purisiphonia* horizon. The related *M. barklyi*, which has shorter ears, seems to be confined to the lower part of the Aptian sequence. This closely parallels the situation reported by Day (1964b) in the Hughenden area where, however, the ranges of the two species overlap slightly.

The only ammonite observed in these collections occurred at SB123, and is doubtfully identified as *Tropaeum undatum* Whitehouse. It is represented by a large body chamber fragment with a quadrate whorl section, and external impressions of smaller whorls.

An unusual feature of these collections is the occurrence of *Inoceramus* at SB114, SB125, and SB129. Aptian records of *Inoceramus* are quite rare. The species is an erect one with ornament not unlike that of the species compared with *I. anglicus* Woods and *I. neocomiensis* d'Orbigny by Brunnschweiller (1960). Albian species are quite distinct.

Pinna sp. ind. represented at SB119 by a single incomplete specimen with closed valves is the first *Pinna* the writer has observed in collections from the Surat Basin. The genus has previously been reported from the Australian Lower Cretaceous by Hudleston (1890, pl. 9, fig. 16—*Pinna australis* from Primrose Springs in South Australia) and by Etheridge Jnr (1892, pl. 20, figs 16-17 — *Pinna* sp. ind. from Walsh River, Carpentaria Basin).

The single specimen designated *'Ostrea'* sp. is the first Aptian oyster noted by the writer. Oysters have been reported previously from the Mackunda Formation in the Manuka and Muttaburra areas.

'Nuculana elongata', which is represented by several well-preserved left and right valves from SB129, is conspecific with *'Leda elongata'* Etheridge Snr (1872, pl. 20, fig. 5) from the Maryborough Formation.

Two specimens from SB129 are doubtfully referred to the tellinid genus *Palaeomoera Stocliczka*. The species were reported from GAB1942 in the Minmi Member of the Mitchell area and from GAB1134 in the Doncaster Member of the Hughenden area as *Tatella* aff. *maranoana* (Etheridge Jnr). In outline the species resembles *'Gari' elliptica,* but the umbones are centrally placed and the species is proportionately higher than *'G' elliptica. Tellina* sp. figured by Etheridge Snr (1872, pl. 20, fig. 7) from Maryborough may be related.

Collection SB125 contains several specimens of the crinoid *Isocrinus australis* (Moore) and the sponge *Purisiphonia clarkei* Bowerbank in positions of growth. Associated with these are the brachiopods *'Rhynchonella' rustica* Moore (1870, p. 245, pl. 10, figs 7-9) and *'Argyope' wallumbillaensis* Moore (1870, p. 243, pl. 10, figs 3-5). Brachiopods are not common in the Aptian sequence and are even rarer in the Albian.

Albian Fossils from the Coreena Member in the Surat Basin: 1966 Collections

The seven collections reported below provide the first record of Albian macrofossils in the Surat Basin. Two of the collections are from the Roma Sheet area, the remainder from the Mitchell Sheet area.

Mitchell Sheet Area (Collector E. N. Milligan)

LOCALITY:
SB100: Near tributary of Emu Creek, about 5 km east of Mount Abundance (grid ref. 668684)

Lithology:
'Belemnite conglomerate' in cross-laminated glauconitic siltstone

Determinations:
Dimitobelus diptychus (McCoy)
Peratobelus sp. nov.
Indet. pelecypod

Age:
Early Albian

LOCALITY:
SB101: Near tributary of Emu Creek, about 3 km east of Mount Abundance (grid ref. 667685)

Lithology:
Coquina bands in calcareous siltstone

Determinations:
Aucellina hughendenensis (Etheridge Snr)
Barcoona trigonalis (Moore)
Maccoyella corbiensis (Moore)
Mesosaccella randsi (Etheridge Jnr)
'Yoldia' freytagi Ludbrook
Euspira reflecta (Moore)
Indet. belemnite

Age:
Probably early Albian

LOCALITY:
SB102: East of where road crosses Back Creek, about 6.5 km north of Amby (grid ref. 638708)

Lithology:
Siltstone

Determinations:
Dimitobelus diptychus (McCoy)

Age:
Albian

LOCALITY:
SB103: Northern end of the Maranoa Range, near the head of Stewart Creek, about 5 km east of Spreydon Homestead (grid ref. 644679)

Lithology:
Fine grained silty sandstone

Determinations:
Barcoona trigonalis (Moore)
Cyrenopsis meeki? (Etheridge Jnr)
Tancretella secunda Ludbrook

Age:
Albian

LOCALITY:
SB109: Near the headwaters of Paddy Creek, about 3 km south of One Tree Hill (grid ref. 671671)

Lithology:
Calcareous siltstone

Determinations:
Dimitobelus diptychus (McCoy)
Barcoona trigonalis (Moore)
Camptonectes sp.

Age:
Albian

Roma Sheet Area (Collector E. N. Milligan)

LOCALITY:
SB108: Middle Creek, where Mount Abundance road crosses (grid ref. 140688)

Lithology:
Calcareous siltstone

Determinations:
?*Tatella aptiana* Whitehouse

Age:
Probably Albian

LOCALITY:
SB111: Blyth Creek, near where the Carnarvon Highway crosses (grid ref. 173678)

Lithology:
Calcareous siltstone

Determinations:
Tatella aptiana Whitehouse
Indet. pelecypods
worm burrow
plant fragments

Age:
Probably early Albian

REMARKS

An Albian age for these collections is indicated by the presence of the belemnite *Dimitobelus diptychus* at SB100, SB102, and SB109, and the pelecypod *Aucellina hughendenensis* at SB101.

The fauna and its mode of preservation are remarkably similar to those reported by Day (1966b) from the lower part of the Coreena Member in the Augathella and Tambo areas. Collection SB100 is a 'belemnite conglomerate' composed of large numbers of *Dimitobelus diptychus* together with several guards of a new species of the typically Aptian genus *Peratobelus*.

Identical 'belemnite conglomerates' with a mixture of Aptian and Albian species were reported by Day (1966b, 1967a) from GAB1933 in the Tambo area, and from GAB2039, GAB2057, and GAB2059 in the Augathella area. Coquinas of the small pelecypod *Barcoona trigonalis* occur at SB101 and SB109. In the Coreena Member these are strikingly developed, although the species is known to occur in the Doncaster Member of the Tambo area, and in the Mackunda Formation of the Manuka area. Only *Aucellina hughendenensis* is not known from the Coreena Member in the Augathella and Tambo areas, but this species is common in outcrops of the Coreena Member near Barcaldine and Aramac.

The correspondence of faunas is closely paralleled by lithological and stratigraphical similarities. The silty sediments with the fauna reported herein are very like those of the Coreena Member. Further, they occupy a similar stratigraphic position immediately above the Aptian Doncaster Member. Clearly, these silty sediments cropping out south of Mitchell and Roma are to be correlated with the Coreena Member of the Augathella and Tambo areas.

Dimitobelus diptychus is abundantly represented at SB100 by fairly large clavate forms, together with smaller spindle-shaped guards, which in reports on Coreena Member fossils from the Tambo and Augathella areas were compared with *Dimitobelus liversidgei*. The latter may be young individuals of *D. diptychus*. Several specimens clearly exhibit the double lateral lines and dorsolateral and ventrolateral grooves which typify the genus. At SB102 and SB109, *D. diptychus* is represented by fewer specimens which are less well preserved. Reasons for considering *D. diptychus* an early Albian species were elaborated in the reports on the Coreena Member fossils from the Tambo area (Day, 1966b, 1967a).

There are several guards designated *Peratobelus* sp. nov. in the 'belemnite conglomerate' at SB100, but this species is not nearly as abundant as *D. diptychus*.

The guards are large and cylindrical and show the two simple ventrolateral grooves characteristic of *Peratobelus*. The alveolus is very deep and is capable of accommodating a large phragmocone. Large phragmocones were described from the 'Palmer River' (Carpentaria Basin) by Tenison-Woods (1883, p. 150, pl. 7, fig. 1) as *Belemnites selheimi*. However, the writer has observed large phragmocones associated with quite small guards in Geological Survey of Queensland collections from the 'Walsh River'. Thus the present guards represent a different species. As remarked in earlier reports *Peratobelus* is a typically Aptian genus and some of its occurrences with the Albian *Dimitobelus* may be remanié ones.

Aucellina hughendenensis is represented at SB101 by a few left and right valves. The left valves have the narrow umbones, posterior obliquity, and radial ornament characteristic of the early to late Albian species.

At SB101 there is a single well-preserved left valve identified with the Aptian species *Maccoyella corbiensis*. This species was reported from GAB1933 in the Coreena Member of the Tambo area, where it was regarded as a derived species (Day, 1967b). This explanation may be invoked again here, although like *Peratobelus* sp. nov., the species may range into the early Albian.

The single left valve of *Camptonectes* sp. from SB109 has strong radial ornament. The form is conspecific with similarly designated pectinids from the Coreena Member, Allaru Mudstone, and Mackunda Formation.

An internal mould of a left valve of *Tatella* from SB111 has the shape of the probable Albian species *Tatella aptiana*

Whitehouse (1925) from the 'Lake Eyre Basin'. The specimen from SB108 is less complete.

Left valves of posteriorly truncate nuculanids are referred to two species, *Mesosacella randsi* and *'Yoldia' freytagi*. These forms have been reported from the Coreena Member, Allaru Mudstone, and Mackunda Formation.

The sole gastropod in these collections is the naticid *Euspira reflecta*, which is represented at SB101 by several small specimens. In the Eromanga Basin this species ranges through the entire Aptian-Albian sequence.

In addition collection SB111 contains numerous plant fragments and worm burrows.

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APPENDIX 2

NOTES ON THE VERTEBRATE FAUNA OF THE CHINCHILLA SAND*

by
A. Bartholomai (Queensland Museum) and J. T. Woods (Geological Survey of Queensland)

The name Chinchilla Sand was proposed by Woods (1960) for a predominantly sandy sequence of fluviatile sediments exposed mainly in the valley of the Condamine River for a distance of 65 km between Nangram Lagoon in the west and Warra in the east. Previously Woods (1956) had used the name Chinchilla Formation for representatives of this sequence near Chinchilla.

The Chinchilla Conglomerate of Etheridge (1892) is a part of the formation, and thin beds of well lithified calcareous sandstone grading into grit and conglomerate are prominent in outcrop, including the type section along the north bank of the Condamine River near the Chinchilla Rifle Range. The main sediment is weakly consolidated grey to yellowish and light brown sand, which grades into grit and sandy clay. The presence of quartzitic material, including silcrete and ferruginous sandstone, in the coarser clastics suggests that they were derived from the Orallo Formation and its lateritized profiles. In places low down in the streams the Chinchilla Sand can be seen to rest on eroded mottled surfaces of these Mesozoic rocks.

In the west the Chinchilla Sand appears as outliers, but to the east it crops out in inliers before disappearing below the dark alluvial clays of Quaternary age. Other Quaternary alluvia show a valley-in-valley relation with the Chnchilla Sand in the vicinity of the type section, and it appears that there is a small angular unconformity between the Chinchilla Sand and the Quaternary alluvia, and that the regional dip of the formation is less than, or the reverse of, the present stream gradient.

The northern boundary of the sequence is difficult to map because of the lack of exposures and the similarity of the pedocalcic clay soils developed both on the Injune Creek Beds and many parts of the Chinchilla Sand. The homogeneous orange-red sands so conspicuous in the town of Chinchilla are not part of the Chinchilla Sand, and apparently represent a younger terrace deposit along Charleys Creek.

The measured thickness in the type area is 20 m, while at least 32 m is present in Browns Bore at Brigalow (on the evidence of samples preserved by the Geological Survey of Queensland).

Vertebrate fossils and, in particular, reptilian remains, are common in the Chinchilla Sand. They include teeth and dermal scutes of the large crocodile *Pallimnarchus pollens,* carapace fragments of the freshwater tortoises *Chelodina insculpta, Chelymys arata, C. uberima, C. antiqua, Pelocomastes ampla,* and *Trionyx australiensis,* and teeth and vertebrae of the large goanna *Varanus dirus.* Fish remains include buccal plates of the lungfish *Epiceratodus forsteri,* while the large bird fauna includes fragmentary remains of *Anas elapsa, Biziura exhumata, Chosornis praeteritus, Dendrocygna valdipinnis, Fulica prior, Gallinula strenuipes, Nyroca reclusa, N. robusta, Plotus parvus, Porphyrio? reperta, Xenorhynchus nanus, Necraster alacer, Dromaius gracilis, D. patricius,* and *Platalea subtenuis.*

The predominant marsupial is the diprotodontid *Euryzygoma dunense,* which is sufficiently abundant to be useful as a guide fossil for the sequence. Other diprotodontids include *Euowenia grata* and *Palorchestes parvus.* Dasyurids are represented by *Sarcophilus prior* and *Thylacinus rostralis,* while the phalangerids include *Pseudochirus? notabilis* and the 'marsupial lion' *Thylacoleo crassidentatus.* Macropodids are moderately abundant, the most common being *Sthenurus antiquus, S. notabilis, Troposodon minor, Macropus pan, Protemnodon anak,* and *'Halmaturus' indra.*

* This Appendix was written for BMR Record 1968/53 in 1968 and has not been fully up-dated.

A tentative Pliocene age was assigned to the Chinchilla Sand by Woods (1960), mainly on the faunal evidence. In 1920 Sahni assigned a Tertiary age to three specimens of fossil wood from the Condamine River, near Fairymeadow, southwest of Chinchilla: they were the conifers *Mesembrioxylon fluviale* and *M. fusiforme* and an indeterminable dicotyledon.

Recently, evidence of superposition of the Pleistocene alluvia, characterized by the *Diprotodon optatus* fauna, on the Chinchilla Sand in its subsurface extent has become available at Dalby. A tooth of *Euryzygoma dunense* was recovered from sand at a depth of 26.5 to 27.4 m in the Dalby Town Bore, adjacent to the existing Production Bore No. 2, por. 16, Par. St Ruth.

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APPENDIX 3

NOTES ON THE FOSSILIFEROUS PLEISTOCENE FLUVIATILE DEPOSITS OF THE EASTERN DARLING DOWNS

by

A. BARTHOLOMAI*

(Queensland Museum)

Widespread fluviatile deposits containing abundant remains of Pleistocene vertebrates occur in the eastern Darling Downs. The deposits lie to the east of Warra and are exposed mainly in the banks of the Condamine River and its tributaries. The presence of vertebrate remains has been known since the first settlement in the 1840s.

Leichhardt (1847), Stutchbury (1853, 1854), Bennett (1872), and Gregory (1879) made notes on the geology of the deposits. A full discussion, together with described sections for King Creek and the Condamine River, is presented in Woods (1960). Most of the fossil vertebrates recovered have come from poorly consolidated black and dark red-brown calcareous clay soils, but some come from coarse ferruginous quartzose sands in the Dalby-Macalister area. The Pleistocene sediments were formed as a result of dissection of the widespread weathered sediments of the pre-Miocene surface, and the basalts of the Great Divide. The Main Range, the Bunya Mountains, and attendant spurs and mesas represent the remnants of this major source. The sands appear to have been derived from Mesozoic rocks.

Recent black surface soil, which does not appear to be much more than a metre deep, is widespread, and outcrops of the underlying Pleistocene sediments are restricted to sporadic exposures in creeks and wells. The deposits generally stand at a higher topographic level than the recent drainage system, but it is difficult to establish the detailed stratigraphy because of the lenticularity of the beds, the rapid lateral variations in lithology, and the discontinuity of outcrops.

Water-bores and wells have provided some information on the distribution of the Pleistocene sediments away from the river sections. Bennett (1872) recorded a fossil kangaroo at a depth of 42 m at Jimbour Plains, and Pleistocene species have been recorded from nearby surface exposures along Jimbour Creek. These facts give an indication of the possible minimum thickness of Upper Cainozoic sediments in that area. Woods (1960) estimated that the thickness of alluvium in the Dalby section of the Condamine River ranges up to 49 m, although the sequence may include some Pliocene sediments.

The Pleistocene fluviatile deposits have been referred to as 'Older Alluvial or Fossil Drift' by Gregory (1879), and Etheridge (Jack & Etheridge, 1892) applied the term 'Fluviatile Deposits' to them. In the same publication, Jack listed 'High-Level River and Lake Drifts' and 'Bone Drifts' in his post-Pliocene deposits. The name *'Diprotodon Beds'* was proposed by Bryan (1928) for these fossiliferous alluvia. Macintosh (1967) informally introduced several stratigraphic names for soil units in the Dalyrymple/King Creek area to the southwest, but recent CSIRO Soils Division cores retrieved from that area suggest a more complex stratigraphic relation than envisaged in that paper.

Bartholomai & Woods (Appendix 2) have shown that the Pleistocene alluvia are superimposed on the Pliocene? Chinchilla Sand at Dalby at a depth of 26.5 to 27.4 m.

Among the fossil vertebrates recorded in the Pleistocene fluviatile deposits, marsupials predominate, but birds, reptiles, and fish are also present. The monotreme *Ornithorhynchus agilis* is rare. The large marsupial *Diprotodon optatus* dominates the fauna, but other diprotodontids, including *D. minor, Nototherium inerme, Zygomaturus trilobus,* and *Palorchestes azael,* are also widely dis-

* This Appendix was written for BMR Record 1972/53 in 1969, and has not been fully up-dated.

tributed. Dasyurids are represented by *Thylacinus cynocephalus, Sarcophilus laniarius,* and *Dasyurus* sp., and phalangerids include the 'marsupial lion' *Thylacoleo carnifex.* Smaller marsupials, including peramelids, are poorly represented. The Macropodidae is numerically the best represented family, with grazing forms more frequently encountered than browsing types. *Propleopus oscillans* is recorded, but is rare. *Macropus titan* is particularly abundant, and other kangaroos such as *M. ferragus* and *M. altus* are also present. Extinct protemnodonts constitute a large proportion of the fossil sample and include *Protemnodon anak, P. brehus,* and *P. raechus. Troposodon minor* is also moderately well represented, but potoroines, including *Aepyprymnus,* are less common. Wallabies such as *'Halmaturus' siva, 'H.' thor,* and *'H.' indra* are occasionally encountered, as are the more specialized macropodids *Sthenurus andersoni, S. oreas, S. pales, S. tindalei, Procoptodon goliah, P. rapha,* and *P. pusio.* Vombatids present include *Phascolonus gigas, Phascolomys augustidens, P. magnus, P. medius, P. mitchelli,* and *Lasiorhinus latifrons.*

Among the reptilian fossils are the large horned tortoise *Meiolania oweni* and the gigantic goanna *Megalania prisca.* Crocodilian and tortoise remains are rare.

A large bird fauna includes *Tophaetus brachialis, Pelecanus proavus, Lobivanellus* sp., *Progura gallinacea, Gallinula peralata, G. strenuipes, Lithophaps ulnaris, Metapteryx bifrons, Platalea subtenuis, Dromaius patricius, Palaeopelargus nobilis, Nacraster alacer,* and *Tribonyx effluxus.* The supposed Queensland Moa, *Dinornis queenslandiae,* has been shown by Scarlett (1969) to have been derived from a New Zealand Maori midden site.

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APPENDIX 4

CLAY MINERALS IN THE MID-JURASSIC TO LOWER CRETACEOUS SEQUENCE

by

N. F. Exon

In mid-1972 18 core samples from BMR stratigraphic holes in the Surat Basin were submitted to the Australian Mineral Development Laboratories (AMDEL) for semi-quantitative clay analysis. Standard AMDEL methods were used and a report on the methods and results was prepared by Brown (1972). R. R. Vine in a BMR file note had pointed out in 1969 that within the Eromanga Basin 'individual members and formations have consistent distinguishing features in their clay mineralogy, even though absolute differences are small'. The presently reported work was designed to see what trends might emerge from clay mineral analysis within the Surat Basin. The location of the holes is shown in the accompanying map (Fig. A) and their stratigraphy is discussed by Exon *et al.* (1967) and Exon (1972). The positions of the samples in each hole are given in Table A.

The sequences involved, from oldest to youngest, are the fluvial Springbok Sandstone, the lacustrine Westbourne Formation, the fluvial Gubberamunda Sandstone, the lacustrine Orallo Formation (all Jurassic), and the fluvial Mooga Sandstone and the paralic Coreena Member (both Early Cretaceous). The Gubberamunda and Mooga Sandstones are important aquifers.

The results are summarized in Table A and Figures B and C and the main results can be outlined as follows:

(a) The assemblages are dominated by montmorillonite or kaolinite, the proportions of which show a reciprocal relation (Fig. B).

(b) The proportions of chlorite and illite are directly related to the proportion of kaolinite (Fig. B).

(c) Montmorillonite is predominant in most of the samples. Only in the two porous aquifer sequences (the lower part of the Mooga Sandstone, and the Gubberamunda Sandstone) is kaolinite predominant (Fig. B).

(d) The clay mineral assemblages do not show any obvious relation to the grain-size of the sediment (Fig. B).

(e) Quartz and feldspar trends run parallel (Fig. C).

(f) Siderite is common in the Coreena Member, Westbourne Formation, and in the Mooga and Springbok Sandstones (Fig. C).

(g) Glauconite was nowhere identified, although round green grains of glauconie were very abundant in sample 12.

Discussion

The clay mineralogy distinguishes the two aquifer sequences (the Gubberamunda and Mooga Sandstones) from the remaining sequences. These are the sequences in whose deposition streams played the greatest part. The predominance of kaolinite in these two sequences compared with montmorillonite in the other sequences could be due to any one, or a combination, of three reasons:

(a) The source material was different.

(b) The source material (montmorillonitic) was similar, but the different weathering regime in the fluvial sands altered the clay minerals to kaolinite.

(c) The source material and the surface weathering regime were similar, but groundwater moving through the coarser fluvial aquifer sands gradually altered the montmorillonitic matrix to kaolinite, illite, and chlorite.

There is little evidence to indicate which of these possibilities is the more likely. There are no indications of major tectonic changes until post-Mooga Sandstone time, so it is unlikely that there was a change in source material in the older sequences owing to tectonic activity. Climatic changes giving rise to changes of source material cannot be discounted, but there is no relevant evidence.

TABLE A. GENERAL DETAILS OF SAMPLES SUBMITTED TO AMDEL FOR SEMI-QUANTITATIVE CLAY MINERAL ANALYSES

Sample No.	*BMR Borehole*	*Depth (ft)*	*Unit*	*Unit Thickness (ft)*	*Approximate Position in Unit (depth below top) (ft)*	*Lithology*	*Clay Fraction (%)*	*Colour of Clay Fraction*	*Illite: Kaolinite Ratio*
72580012	Roma 9	197′ 0″	Coreena	300	290	Sandstone	13	Greenish-grey	1:3
72580013	Roma 9	204′ 2″	Member	300	300	Mudstone	40	Dark brown	1:1
72580016	Mitchell 11	347′ 3″		100	45	Siltstone	43	Dark brown	1:5
72580001	Roma 1	378′ 3″	Mooga	100	20	Sandstone	28	Greyish-brown	1:10
72580002	Roma 1	392′ 8″	Sandstone	100	30	Sandstone	12	Grey	1:5
72580003	Roma 1	413′ 2″		100	55	Sandstone	11	Light grey	1:10
72580004	Roma 2	36′ 8″		400	40	Mudstone	56	Brown	1:1
72580005	Roma 2	42′ 10″	Orallo	400	45	Sandstone	13	Grey	1:2
72580006	Roma 2	61′ 2″		400	65	Siltstone	22	Greyish-brown	1:2
72580007	Roma 2	69′ 8″	Formation	400	70	Sandstone	12	Grey	1:1
72580014	Chinchilla 2A	148′ 7″		400	200?	Sandstone	33	Fawn	—
72580008	Roma 7	51′ 3″	Gubberamunda	100	70	Sandstone	13	Grey	1:4
72580009	Roma 7	52′ 5″	Sandstone	100	70	Siltstone	30	Grey	1:3
72580010	Roma 7	104′ 11″	Westbourne	250	25	Siltstone	36	Dark brown	1:5
72580011	Roma 7	158′ 0″	Formation	250	80	Sandstone	18	Grey	1:5
72580017	Dalby 1	162′ 9″	Springbok	500	200	Sandstone	11	Grey	1:5
72580018	Dalby 1	243′ 0″		500	280	Sandstone	13	Grey	1:5
72580015	Mitchell 3	127′ 3″	Sandstone	33	25	Sandstone	28	Brown	—

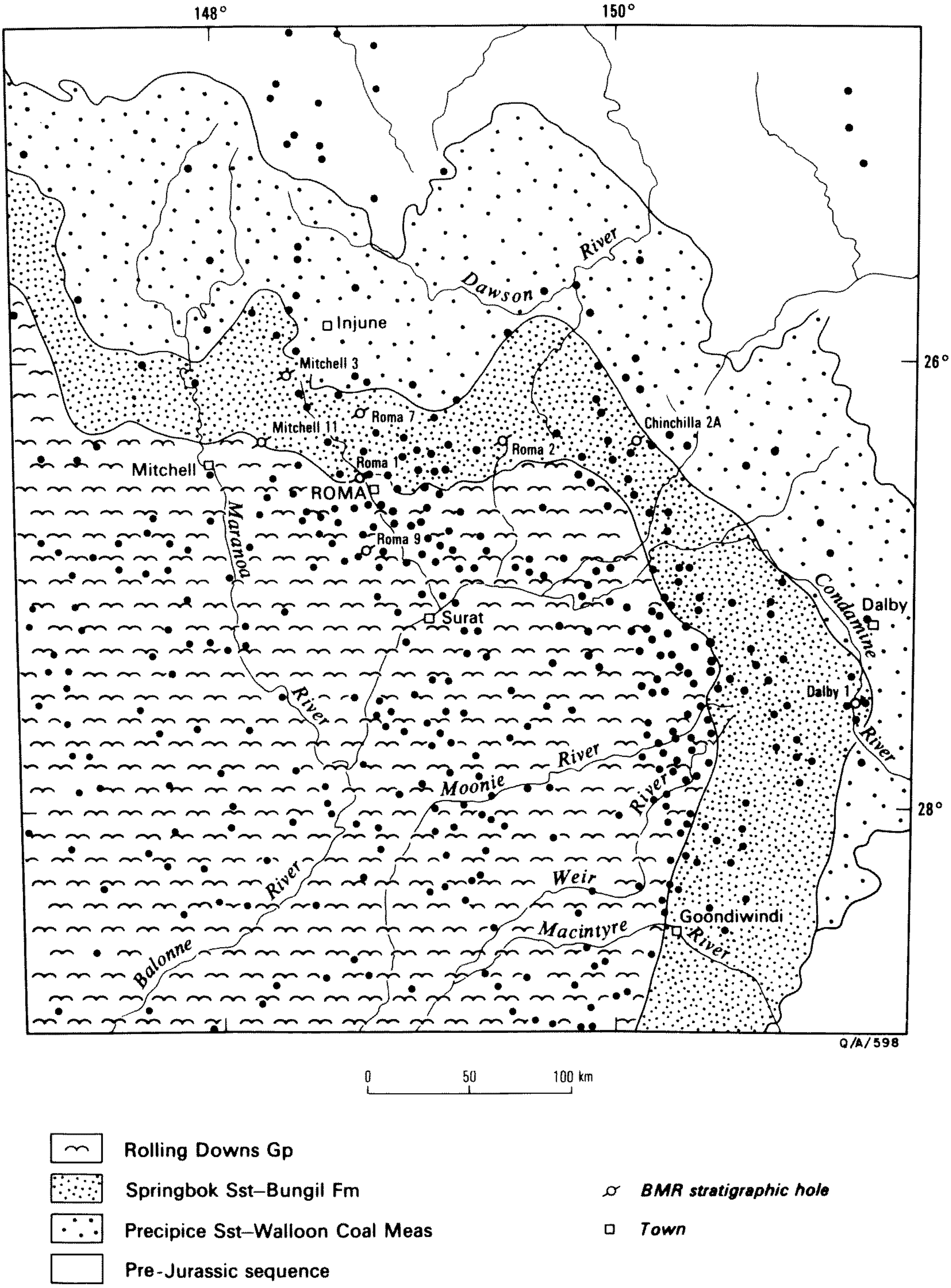
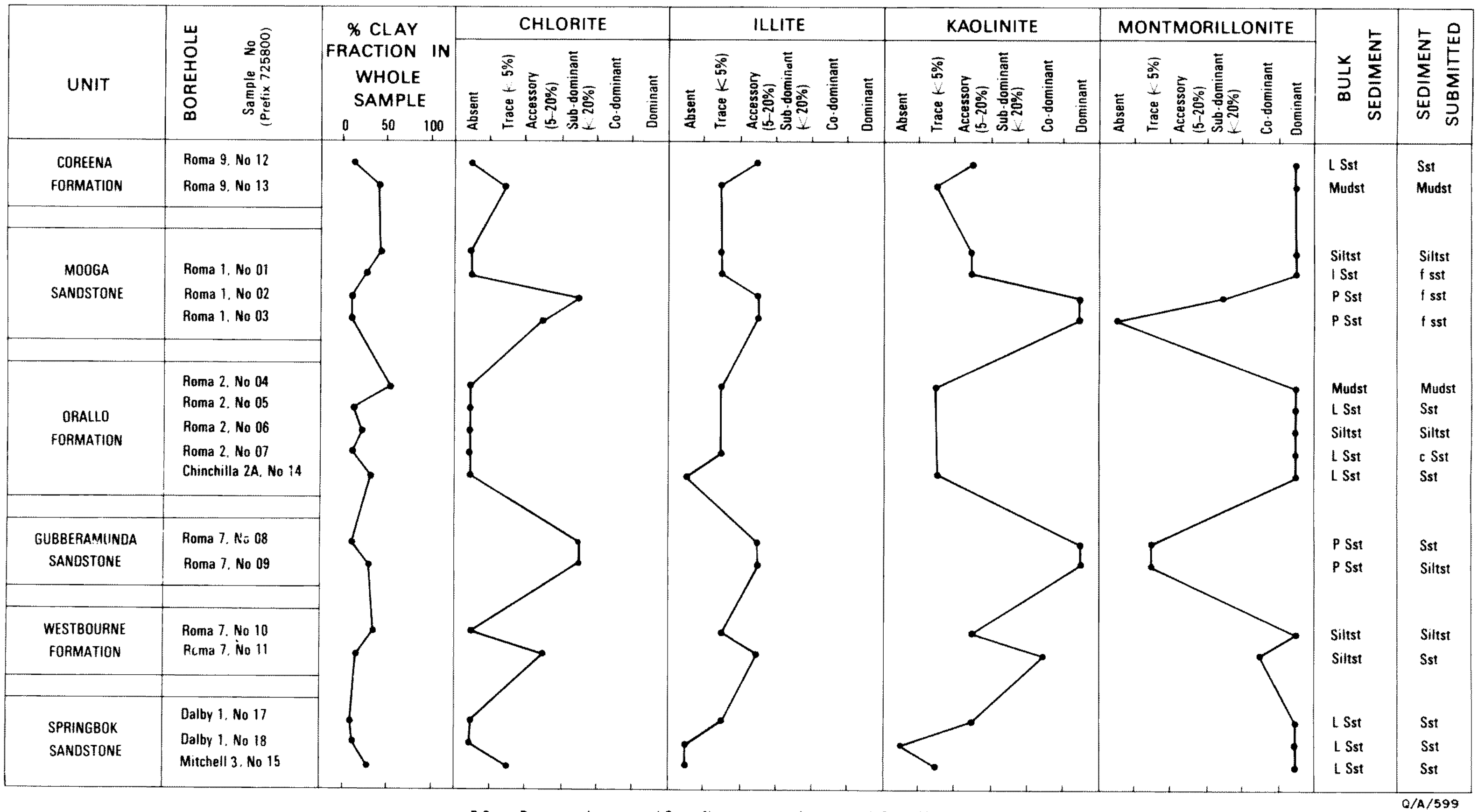


Fig. A. Location of BMR stratigraphic holes.



P Sst= Porous sandstone I Sst= Non-porous sandstone L Sst= Lithic sandstone

Sst= Sandstone Sltst= Siltstone Mudst= Mudstone f= fine c= coarse

Fig. B. Relative abundance of clay minerals. (Based on BMR stratigraphic holes).

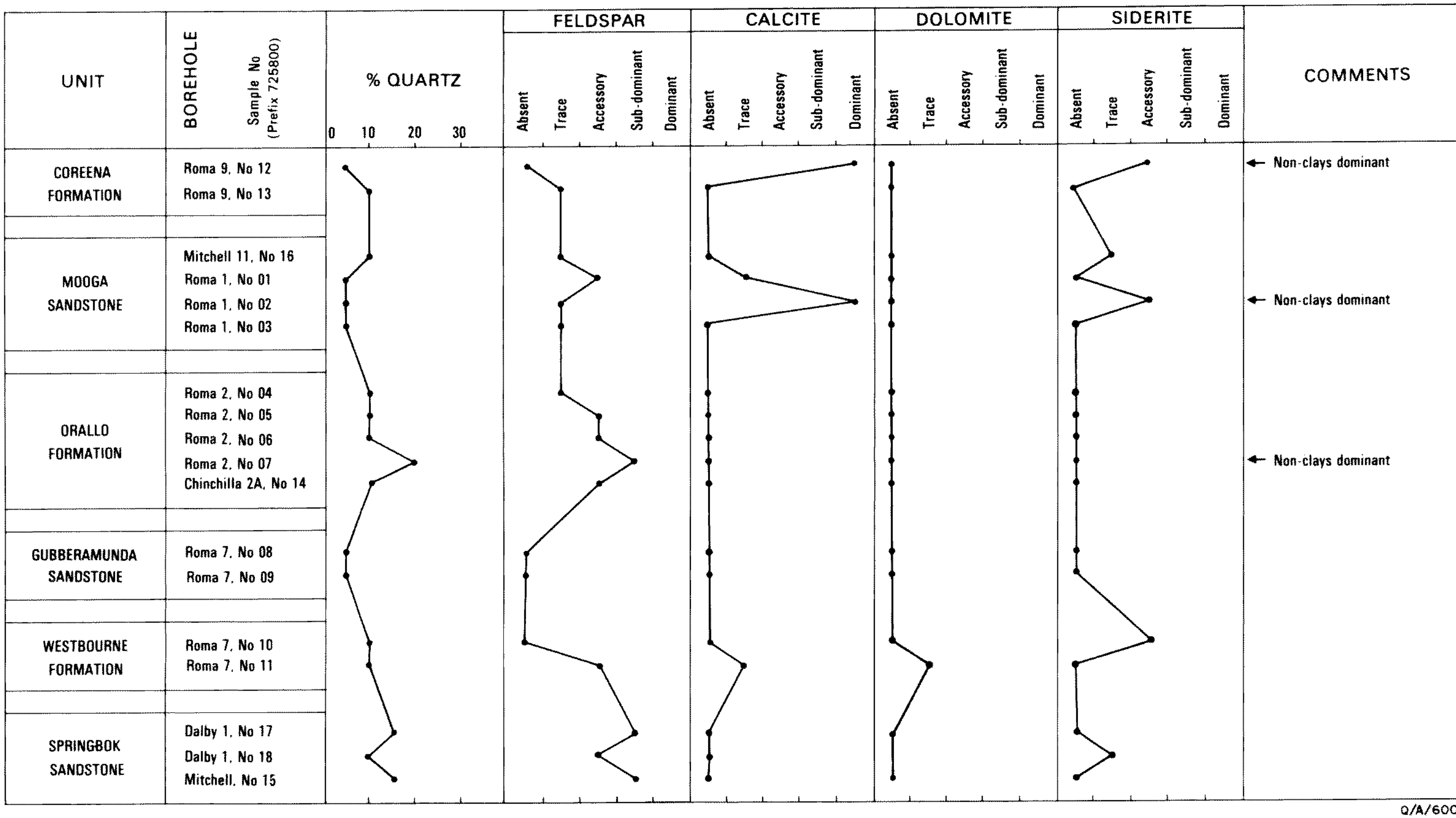


Fig. C. Proportions of non-clay minerals in clay fraction.

There is evidence of volcanic activity (tuffaceous bentonites) in the Orallo and Westbourne Formations, and it could be argued that the montmorillonitic sequences were derived from contemporaneous volcanic ash, whereas the kaolinitic sequences were derived from basement rocks such as granites, volcanics, and metasediments.

However, the simplest explanation is that there was little change in the source material, at least until Coreena Member time, and that the differences are due to alteration during and after deposition. The original clays would then have been largely montmorillonite, which Papadakis (1969) states can be produced from almost any source rocks by leaching at a low temperature, or by slow leaching in a cold or dry climate, or both.

Stream deposits laid down on alluvial plains would be subject to repeated reworking and weathering, and with a general regime different to that in the hinterland, montmorillonite could alter to kaolinite. The lacustrine and paralic sediments would be less reworked and more quickly buried, leaving the montmorillonite unchanged.

Alteration of the stream sediments by groundwater after they were buried would be possible if there was sufficient pore space to allow water to penetrate through sandstones with a montmorillonitic matrix, despite any swelling of the montmorillonite. This could certainly occur in the common coarser sediments, which may have contained little matrix originally. Water flowing through coarser beds could gradually have altered the clays of adjacent finer-grained sediments to kaolinite, allowing even greater penetration of the water into previously monmorillonitic beds.

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APPENDIX 5

WIRELINE-LOGGING OF WATER-BORES IN THE SURAT BASIN, 1960 to 1974

by

N.F. EXON and JEAN MORRISSEY

CONTENTS

PLATES

SUMMARY

Between 1960 and 1974, 264 water-bores and 20 petroleum exploration wells converted to water-bores were logged in the Surat Basin, predominantly in Queensland. Most logging was done by or for the Bureau of Mineral Resources to provide both stratigraphic and hydrological information. Both flowing and non-flowing bores were logged; the basic scale used was 1" = 100 feet (1:1200), and logs at a scale of 5" = 100 feet (1:240) were also commonly run.

Gamma-ray logs are available for all the bores listed, and neutron, temperature, differential temperature, flowmeter, and casing collar locator logs are available for many. Typical logs are presented.

The bores are indexed by their Registered Numbers, as given by the Queensland Irrigation and Water Supply Commission and the NSW Water Conservation and Irrigation Commission. Their localities are plotted on a base map at a scale of 1:1 000 000. A complete list in numerical order of all bores logged, related to the 1:250 000 Sheet area in which they fall, is provided. For each Sheet area the bores are listed in numerical order, with converted petroleum wells separately listed in alphabetical order, and the following statistics are tabulated where available: name, elevation, depth drilled, depth logged, logs available, salinity, the unit the bore spudded in, the deepest aquifer presently tapped, the water level for non-flowing bores, and the flow rate for flowing bores. The aquifer statistics are consolidated for each Sheet area, and for the basin as a whole.

Water samples from many bores were chemically analysed by the Government Chemical Laboratory in Brisbane, and the analysis sheets are held at the Bureau of Mineral Resources. Water quality for six major aquifers is summarized graphically by plotting total dissolved solids against the HCO_3^-/Cl^- ratio for the western and eastern parts of the basin. This preliminary work has shown the potential of chemical analysis to distinguish between aquifers.

The logging has enabled reliable stratigraphic and aquifer correlations to be made throughout the basin, in conjunction with information from petroleum exploration wells. A gamma-ray correlation line is presented to illustrate the stratigraphic use of the data, and the correlations have been extensively used in a stratigraphic review of the basin.

The chemical data, in combination with estimates of flow rates, have revealed the characteristics of the major aquifers of the eastern and western sides of the basin. Flow rates are higher and water quality is generally better in the west than in the east, although the Pilliga Sandstone in the southeast yields excellent water and is probably the most productive aquifer. The depth to the shallowest major aquifer never exceeds 900 m.

INTRODUCTION

Between 1960 and 1974, 264 water-bores and 20 converted petroleum exploration wells in the Surat Basin (Fig. 1) were wireline-logged for the Bureau of Mineral Resources (BMR) in co-operation with the Queensland Irrigation and Water Supply Commission and the Geological Survey of Queensland (GSQ). BMR officers carried out the early work, which proved the value of the method, but later programs were carried out by private companies under contract to BMR. The aim of the project was to:

a) Provide stratigraphic information of benefit to BMR-GSQ geological field parties and oil company geologists;

b) Provide hydrological information of benefit to hydrologists and engineers dealing with large-scale and small-scale problems within the Great Artesian Basin.

Pioneering work was carried out by BMR in 1960 and 1962, using gamma-ray and temperature tools. The 1960 program, during which 11 bores and 2 petroleum wells were gamma-ray logged in the Surat Basin, was reported by Jesson, Radeski, & Jewell (1963). The 1962 program, when a further 16 water-bores were gamma-ray logged in the Surat Basin, was reported by Jesson & Radeski (1964). This work showed that correlation of gamma-ray logs of water-bores was fairly reliable when the bores were spaced less than 25 km apart. However the 'temperature logs were of little practical value because the bores were not in a static state while being logged' (Jesson & Radeski, op. cit.).

In late 1964, Schlumberger gamma-ray logged a number of water-bores in the northwestern Surat Basin and eastern Eromanga Basin for American Overseas Petroleum Pty Ltd, and the results suggested that the conventional correlation of the Hooray Sandstone/Upper Intermediate Series/Adori Sandstone of the Tambo area with the Mooga Sandstone/Orallo Formation/Gubberamunda Sandstone of the Roma area was probably incorrect. The correlation was later confirmed by field work and palynological studies. Transparencies of the Schlumberger logs were given to BMR, and copies can be obtained from the address given below.

In 1967/68 a new program of logging began in the Eromanga and Surat Basins with Down Under Well Services working under contract to BMR. Initially the standard logs run were gamma-ray and casing collar locator, and electric and flowmeter-caliper logs in suitable bores. During the contract a temperature-differential temperature log was added, and proved to be a most useful tool for aquifer studies. In the Surat Basin few logs were run in this year, the bulk of the work being done in the Eromanga Basin.

1968/69 the program continued using the same contractor, working mainly in the Homeboin, Dirranbandi, and St George 1:250 000 Sheet areas in the southwestern Surat Basin. In 1970/71 logging was extended into the Goondiwindi, Dalby, Chinchilla, Surat, Roma, and Mitchell Sheet areas. In 1969/70 and 1971/72 there was no logging in the Surat Basin.

In 1972/73 Down Under Well Services logged 45 bores in the Dalby and Goondiwindi Sheet areas in the southeastern Surat Basin. They used a neutron log in addition to those used in the earlier work. In 1973/74 Down Under Well Services completed coverage of the Queensland portion of the Surat Basin by logging 54 bores in the Taroom, Mundubbera, Chinchilla, and Roma Sheet areas in the northeastern part of the basin. Prints of the various logs are available from:

The Copy Service,
Government Printer (Production),
P.O. Box 84,
CANBERRA. A.C.T. 2600.

THE LOGS

Typical gamma-ray, neutron, temperature, differential temperature, and casing collar locator logs are shown in Plates 3 & 4, and a gamma-ray correlation of water-bores between Roma and Moonie is shown in Plate 5. The basic scale is 1" = 100' but for many bores logs at a scale of 5" = 100' are also available. The quality of the wireline logs is generally excellent. Where drillers' logs of the bores exist these have been added to the gamma-ray log by the Queensland Irrigation and Water Supply Commission.

The gamma-ray tool measures the natural radiation of the strata penetrated, and the apparatus produces a log showing the intensity of radiation in API units at all depths. Clay minerals have relatively high radiation whereas quartz and feldspar grains have low radiation. Thus quartzose sandstones give low values, whereas lithic sandstone, siltstone, and shale give high values. The gamma-ray log is the best stratigraphic tool available for holes which are cased, and most bores logged are cased for most of their depths.

Electric logs are only valuable where there is no casing, and hence few electric logs have been run. The electric logs consist of a self-potential curve recorded in millivolts, and resistivity curves recorded in ohms m^2/m.

The neutron log is produced by a high-energy neutron source which bombards the rocks penetrated, and a detector which captures and records those neutrons which have been sufficiently slowed (moderated) by collision with other particles. The most efficient moderator is hydrogen, which in the sequences penetrated is common only in water. Thus neutron logs measure moisture content above the water-table and total porosity below the water-table. Hence they are of both hydrological and stratigraphic use. Higher values in API units indicate higher moisture content or greater porosity.

Flowmeter-caliper logs measure the revolutions per second of a propeller and the diameter of the hole, from which the flow per second in the bore can be calculated. With the tools employed until recently, the technique was effective only in rapidly flowing bores as the rotor in the current meter was unreliable at low rates. An improved tool now allows low flow rates to be measured. The logs indicate the position of the major aquifers in uncased bores and allow their flows to be calculated. In cased bores they indicate the position of perforations in the casing, and increase or decrease of flow rates by gain or loss of water through the perforations.

The temperature-differential temperature logs are valuable for aquifer studies and have been run in most bore-holes. A sensor measures the temperature (^{o}C) as it is lowered into the borehole. This temperature is marked directly onto the temperature log. It is also stored on the memory of the instrument and compared with the temperature 15 cm deeper; the resultant temperature differential is recorded continuously, giving the differential temperature log, which is more sensitive than the normal temperature log.

When water enters the hole at any level it is normally cooler than water rising up the borehole from below that level. In a few bores noted in the Eromanga Basin, hot water has made its way into a higher aquifer, probably along a fault, and anomalously high values are than recorded from the aquifer. The differential temperature log records the entry of water through perforations in the casing (or directly from the sediment in uncased bores) from the various aquifers, and for larger flows the actual change of the water temperature is recorded on the temperature log.

The casing collar locator is run in conjunction with the other logs. It provides a depth reference in the hole, enables the other logs to be correctly interpreted, and gives direct information about the state, and presence or absence of the casing. We use the simplest type, which consists of a permanent magnet wrapped in a coil of wire. Changes in the magnetic flux cause a small current to flow in the wire, and the current is recorded. At the casing collars there is much more steel than elsewhere in the casing, and the increase in magnetic flux is marked by peaks on the log. Where the casing has parted, or in the commonly uncased part of the hole in the lowest aquifer, no events are recorded. This information is important in that the presence or absence of casing affects the gamma-ray and neutron logs. Furthermore if a large part of the hole is uncased, electric logs can usefully be run. For the property owner the casing collar locator log shows the state of the casing, and whether repairs are needed.

STRATIGRAPHY

The Jurassic and Cretaceous Surat Basin (Fig. 1) forms most of the eastern part of the hydrological Great Artesian Basin, and its sediments are similar to those of the Eromanga Basin to the west, with which it intertongues across the Nebine Ridge and its broad southerly extension the Cunnamulla Shelf. It is bounded to the south by the Central West Folded Belt, to the east by the New England Fold Belt, the Moreton Basin, and the Auburn Arch, and to the north it has been eroded.

The basin is a simple depression with up to 1200 m of marine and paralic Lower Cretaceous sediments which are generally aquicludes, and up to 1700 m of freshwater Jurassic and lowermost Cretaceous sediments which contain several excellent aquifers. The structure is illustrated by contours on the top of the Walloon Coal Measures (Pl. 2), which horizon lies about halfway up the aquifer sequence and covers most of the basin. The Surat Basin sequence lies on rocks ranging in age from Devonian to Middle Triassic, and in composition from granite, schist, and gneiss to undeformed sediments. The stratigraphy of the Surat Basin sequence is summarized in Table 1; nomenclature used is based on that of Exon (1971).

THE TABLES

Tables 6 to 17 detail information for bores from each 1:250 000 Sheet area; each bore is located in Plate 1. The various headings in the tables are discussed below. Consolidated statistics for all bores and for bores by Sheet areas are presented in Tables 2 and 3.

1) Reg. No. The Registered Number is the number issued for each bore, by the Queensland Irrigation and Water Supply Commission in most cases. In cases where a subheading 'NSW Bores' appears, the numbers are those issued by the New South Wales Water Conservation and Irrigation Commission. Considerable data on the bores are available from these organizations e.g. strata penetrated, water supplies at various levels, details of bore casings.

2) Name. Names are applied to the bores by their owners, and recorded by the two water supply commissions.

3) Elevation. The elevation above mean sea level of the ground surface at the bore, measured in feet and converted by us to metres, is recorded where it is available. In some cases this comes from original water-bore records, in others from the contractors who carried out the logging.

4) Depth drilled. The depth drilled in feet as measured by the driller was recorded by the two commissions, and we have converted this to metres.

5) Depth logged. This depth was recorded, in feet, by the wireline-logging contractor for each log run. Under this heading we have noted the number of metres logged with the gamma-ray tool, unless by some mischance this log was not run, in which case the number of metres from the differential temperature log is recorded. In many bores the depth logged is considerably less than the depth drilled; this generally means that there is an obstruction in the hole. Commonly the holes were cased for only the upper part of their depth, and have caved in below the casing. In some bores the depth logged is greater than the recorded depth drilled; this generally means that the hole has been deepened since it was originally drilled, and commission records have not been updated.

6) Logs available. The logs available vary from hole to hole. The symbols used in this column are:

G = gamma ray log
N = neutron log
Dt = Temperature-differential temperature log
T = temperature log alone
E = electric log (below casing only)
F = flowmeter-caliper log

In almost all holes a casing collar locator log was also run.

7) Salinity. For some bores the salinity of the water has been measured electrically both in the field and in the laboratory, and conventional chemical analyses have also been carried out, mostly by the Government Chemical Laboratory in Brisbane.

The 'analysed T.D.S.' column records the total dissolved solids in parts per million (ppm). In many cases this has been calculated by us, simply by adding together the values for all the ions analysed in the laboratory.

The 'conductivity', measured electrically in μS/cm, of some samples has been recorded in the field, and of others in the laboratory. Field recordings are denoted by 'F', and laboratory recording by 'L'. As field readings are a better record of the water as it emerges from the bore, they have been preferred where two figures are available for one bore.

The 'field salinity' was measured by the contractor with an instrument which converted the electrical data directly into its equivalent value in terms of sodium chloride (NaCl) salinity in parts per million. This value does not imply that the NaCl content of the water is that recorded, because other salts are always present and are commonly dominant. It merely implies that an NaCl solution of this concentration would give the measured electrical response. Thus the 'field salinity' bears a direct relation to the conductivity (which can be determined graphically - Fig. 2). The temperature is of great importance to these calculations, and values are normally expressed at 25°C.

The HCO_3^-/Cl^- column records the ratio between the bicarbonate and chloride ions in the water (in terms of chemical equivalents). These are the dominant ions, and hence this ratio is important. Values less than one mean that chloride is dominant, whereas values greater than one mean that bicarbonate is dominant. In the artesian aquifers $NaHCO_3$ is dominant, whereas in the relatively unproductive subartesian aquifers within the Rolling Downs Group and the Injune Creek Group NaCl is dominant.

Total dissolved solids has been plotted against the HCO_3^-/Cl^- ratio for individual bores in Figure 3, yielding useful information about the various aquifers. From the chemical analyses held at BMR much more could be learnt about water quality, but such a study is outside the scope of the present report.

8) Spudded in. The unit in which the bore 'spudded' (i.e. the unit first penetrated) is recorded in this column. For bores in which substantial amounts of Tertiary (T), Cainozoic (Cz), or Quaternary (Q) sediments overlie the Mesozoic sediments, both groups are recorded. Post-Mesozoic sediments are as much as 200 m thick in places, and commonly yield subartesian water. The symbols are explained in Table 1.

9) Deepest aquifer presently tapped. This column records the deepest important aquifer which today yields water in each bore (symbols explained in Table 1). In many bores this is the most important aquifer.

Many bores have caved in below the casing, or have been deliberately plugged below a certain depth, so that deeper aquifers which were originally penetrated no longer affect the bore. In general we have assumed that water is not being derived from aquifers below the depth which was logged, on the grounds that if the relatively small logging tool could not penetrate any deeper, the hole was blocked.

10) Water-level. The water-level has been recorded in metres below the ground surface, where available. In bores where water is flowing out at the surface the term 'flow' has been used. In cases where water has to be pumped, but the water-level has not been recorded, the term 'pump' has been used.

Where the water is flowing out at the surface, estimated flow rates (m^3/day) have been included (1000 gallons per day = 4.546 m^3/day). In most bores these estimates were made by the log operator or property owner at the time the bore was logged, but sometimes they are the original estimates of the driller. In bores where original and recent estimates are available, flow rates appear to have declined considerably with time. Although these estimates are not particularly accurate, it is apparent from plotting them (Fig. 4) that taken in bulk they are informative.

THE AQUIFERS

The generalizations in the following section are based on the assumption that the deepest aquifer presently tapped in each bore provides the great bulk of the water in the bore. This is true in many but not all bores.

Some features of the water chemistry of the main aquifers in the Surat Basin are plotted in Figure 3, and estimated flow rates are plotted in Figure 4. These data are summarized in Table 4. Aquifers west of 149° have been separated from those east of 149° to demonstrate the changes across the basin. The interrelations of the aquifers are shown in Figure 5, and the distribution of the major aquifers and the depth to the Hooray and Mooga Sandstones, which generally contain the shallowest supplies, are shown in Figure 6.

The water chemistry has been summarized by plotting total dissolved solids (ppm) against the HCO_3^-/Cl^- ratio. The analyses provided by the Government Chemical Laboratory in Brisbane have shown that the dominant cation is sodium (Na^+), and that the dominant anions are chloride (Cl^-) and bicarbonate (HCO_3^-). In most aquifers HCO_3^- predominates over Cl^-, and the ratio can be informative. The Cl^- ion is dominant only in some of the aquifers of the Injune Creek Group, and in all the aquifers in the Rolling Downs Group. Thus low HCO_3^-/Cl^- ratios suggest that the bulk of the water is coming from an aquifer or aquifers in these units. Furthermore general salinity is highest in these units, and any inflow from them into bores drawing mainly from other aquifers could be expected to increase the salinity.

Figure 3 suggests that it may be difficult to separate the various major aquifers on the basis of water chemistry. In the west the salinity in terms of total dissolved solids ranges from 500 to 1650 ppm, and the HCO_3^-/Cl^- ratio from almost 0 to 6.5. Of the major aquifers the Gubberamunda Sandstone appears to contain water of the least salinity. The salinity values where the Hooray Sandstone is assumed to be the major aquifer show the greatest variability, probably because abundant highly saline water from the Rolling Downs Group is making its way into some bores.

In the east the major aquifers tend to deliver water of greater salinity, and the HCO_3^-/Cl^- ratio is highly variable (total dissolved solids 700 ppm - 2200 ppm; HCO_3^-/Cl^- ratio 0.6 - 17.6). The water is generally richer in bicarbonate in the east (average HCO_3^-/Cl^- ratio about 4) than in the west (about 2). The least saline water comes from the oldest aquifer and the most saline from the youngest (Pilliga Sandstone av. 900 ppm, Gubberamunda Sandstone 1200 ppm, Mooga Sandstone 1700 ppm).

The plot of estimated flow rates (Fig. 4) shows that supplies vary from aquifer to aquifer, and from west to east. The most prolific aquifers are the Hooray Sandstone in the west, and the Pilliga Sandstone in the southeast, with maximum supplies about 5000 m^3/day, and average supplies about 2500 m^3/day. The percentage of flowing bores in these two aquifers (Table 2) is also higher than average. The Gubberamunda and Mooga Sandstones are also excellent aquifers with high flow rates in the west (Gubberamunda maximum 4000 m^3/day, average 2500; Mooga maximum 3000, average 1500), but much lower flow rates in the east where there are many bores with low flow rates and many subartesian bores. In general these aquifers are deeper where they are tapped in the west than in the east, and the potentiometric surface is higher, so the greater flow rates may depend solely on hydraulics. The older Hutton and Precipice Sandstones are seldom tapped in the deeper part of the basin, despite the high flow rates suggested by data from petroleum exploration wells. The Adori Sandstone yields abundant good-quality water, but is confined to the far west of the basin.

To summarize for the eastern side of the basin, the Mooga Sandstone provides poor to satisfactory supplies of moderately good water at reasonable depths. Similar supplies of better water can be obtained from the Gubberamunda Sandstone, which is normally 100 to 200 m deeper. The best supplies and best water come from the Pilliga Sandstone, which is only slightly deeper than the Gubberamunda Sandstone but is confined to the area south of Goondiwindi and Inglewood.

On the western side of the basin water quality is generally good, and excellent supplies are available from the shallowest major aquifers, the Hooray and Mooga Sandstones. Similar supplies are also available from the deeper Gubberamunda Sandstone.

The generally higher salinity and bicarbonate content of the eastern waters are probably related to higher carbonate concentrations in the intake areas and the aquifer sandstones themselves. The eastern aquifers derive their water from areas in the northeast and southeast where carbonate-rich soils are common; in contrast, the western aquifers derive their water from areas in the north where carbonate-poor soils predominate. Furthermore, the sandstones of the eastern aquifers are generally less mature and contain more unstable minerals, including carbonates, than do those of the western aquifers.

In many places in the deeper parts of the basin, costs prevent property owners drilling as deep as the major aquifers, and they make use of comparatively small saline supplies of subartesian water from the Rolling Downs Group or Bungil Formation. The depth to which they would have to drill to reach the Mooga Sandstone is as much as 800 m north of Talwood (Fig. 6).

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TABLE 1. SURAT BASIN : GENERALIZED STRATIGRAPHY

Age		Unit	Maximum thickness (m)	Environment and lithology	Gamma-ray log character	Water	Relations
Early Cretaceous	Rolling Downs Group	Griman Creek Formation Klg	480	Paralic and freshwater: sandstone, siltstone, mudstone	Generally low values: variable*	Minor aquifers: saline	
		Surat Siltstone Kls	150	Marine: siltstone, mudstone, sandstone	Fairly high values: consistent	Aquiclude	
		Coreena Member (Wallumbilla Formation) Klc	210	Paralic and freshwater: siltstone, mudstone, sandstone	Moderate values: variable	Minor aquifers: saline	
		Doncaster Member (Wallumbilla Formation) Kld	270	Marine: mudstone; some siltstone	High values: consistent	Aquiclude	
		Bungil Formation Kly	270	Freshwater and paralic: mudstone, siltstone, sandstone	Moderate values: variable	Some aquifers	Eastern equivalent of Kle
		Cadna-owie Formation Kle	100	Paralic: siltstone, sandstone	Moderate values: variable	Some aquifers	Western equivalent of Kly
Jurassic to earliest Cretaceous		Hooray Sandstone JKh	400	Freshwater: sandstone; some siltstone	Generally low values	Major aquifers	
		Mooga Sandstone Klm	300	Freshwater: sandstone; some siltstone, mudstone	Variable values: some very low	Major aquifers	
		Orallo Formation Juo	270	Freshwater: labile sandstone, siltstone, mudstone, coal	Variable values: some very high	Minor aquifers	
		Gubberamunda Sandstone Jug	300	Freshwater: sandstone; some siltstone, conglomerate	Low values: fairly consistent	Major aquifers	
		Pilliga Sandstone Jp	300	Freshwater: sandstone, conglomerate	Low values: consistent	Major aquifers	Southeastern equivalent of Juw & Js

Age		Unit	Maximum thickness (m)	Environment and lithology	Gamma-ray log character	Water	Relations
Jurassic to earliest Cretaceous	Injune Creek Group	Westbourne Formation Juw	200	Freshwater and possibly paralic: siltstone, mudstone, sandstone	High values: consistent	Aquiclude	
		Springbok Sandstone Js	250	Freshwater: labile sandstone, siltstone, mudstone	Generally low values	Minor aquifers	Eastern equivalent of Ja
		Adori Sandstone Ja	100	Freshwater: quartzose sandstone, siltstone	Low values	Major aquifers	Western equivalent of Js
		Walloon Coal Measures Jw	650	Coal measures: labile sandstone, siltstone, mudstone, coal	Generally high values: variable	Aquiclude	
		Eurombah Formation Jme	100	Freshwater; sandstone; some conglomerate, siltstone, mudstone	Very variable values	Minor aquifers	
		Hutton Sandstone Jlh	250	Freshwater: sandstone; some siltstone, mudstone	Generally low values: variable	Major aquifers	
		Evergreen Formation Jle	260	Freshwater and paralic: siltstone, mudstone, sandstone	Generally high values: variable	Some aquifers	
		Precipice Sandstone Jlp	150	Freshwater: quartzose sandstone; some siltstone mudstone	Generally low values	Major aquifers	

* 'Variable' or 'consistent' refers to vertical variation in any one log.

TABLE 2. AQUIFER STATISTICS FOR ALL BORES (INCLUDING PETROLEUM EXPLORATION WELLS) LOGGED

Deepest aquifer presently tapped	Number of bores	Status		% Flowing bores
		Flowing bores	Pumped bores	
Hooray Sandstone (JKh)	35	29	6	83
Mooga Sandstone (Klm)	73	60	13	82
Gubberamunda Sandstone (Jug)	62	32	30	52
Pilliga Sandstone (Jp)	19	18	1	95
Hutton Sandstone (Jlh)	47	10	37	22
Precipice Sandstone (Jlp)	17	5	12	28
Other	31	7	24	23
TOTAL	284	161	123	56

TABLE 3. AQUIFER STATISTICS FOR BORES LOGGED, BY SHEET AREA

1:250 000 Sheet area	Deepest aquifer presently tapped							Status	
	Hooray (Jkh)	Mooga (Klm)	Gubber-amunda (Jug)	Pilliga (Jp)	Hutton (Jlh)	Precipice (Jlp)	Other	Flow	Pump
Eddystone	1								1
							2		2
Taroom					22			4	18
						5		2	3
Mundubbera					1				1
						7		3	4
Mitchell	6							2	4
		1							1
					13			2	11
							2	1	1
Roma		17						14	3
			6					1	5
					3			2	1
							6		6
Chinchilla		3						2	1
			2						2
					4				4
						5			1
							5		5
Homeboin	16							15	1
		1							1
			3					3	
					3			1	2
							8	4	4
Surat		7						5	2
			6					3	3
					1			1	
							1		1

TABLE 3 (contd)

1:250 000 Sheet area	Deepest aquifer presently tapped							Status	
	Hooray (Jkh)	Mooga (Klm)	Gubber-amunda (Jug)	Pilliga (Jp)	Hutton (Jlh)	Precipice (Jlp)	Other	Flow	Pump
Dalby		26						22	4
			15					2	13
							3		3
Dirranbandi	12							12	
		4						4	
			2					2	
							1	1	
St George		6						6	
			5					5	
				16				15	1
Goondiwindi		8						7	1
			23					16	7
				3				3	
							3	1	2

TABLE 4. WATER PROPERTIES OF VARIOUS AQUIFERS

Aquifer	Maximum supply (m^3/day)		Total dissolved solids (ppm)		HCO_3^-/Cl^- ratio	
	west	east	west	east	west	east
Griman Creek Formation Klg	Low	Low	High	High	Chloride dominant	
Coreena Member Klc	Low	Low	High	High	Chloride dominant	
Bungil Formation Kly and Cadna-owie Formation Kle	Low	Low	Moderate	Moderate	Bicarbonate dominant	
Hooray Sandstone J-Kh	5350	Absent	600-1600	Absent	0.54	Absent
Mooga Sandstone Klm	3150	1350	600-1600	1350-2200	1.4-5.0	0.8-8.2
Gubberamunda Sandstone Jug	4100	2300	650-900	850-2100	1.4-3.6	0.6-11.0
Adori Sandstone Ja	2650	Absent	-	Absent	-	Absent
Pilliga Sandstone Jp	-	5000	Absent	750-1000	Absent	2.7-4.4
Hutton Sandstone Jlh	500	-	-	-	-	-
Precipice Sandstone Jlp	-	500	-	-	-	-

High = 200 ppm

Moderate = 1500-2000 ppm

Absent = aquifer absent

- means no information available

west = west of 149°

east = east of 149°

TABLE 5. BORE NUMBERS RELATED TO 1:250 000 SHEET AREAS

10	Surat	3477	Homeboin	11950	Goondiwindi
24	Homeboin	3819	Dirranbandi	11954	Homeboin
37	Homeboin	3820	Dirranbandi	11995	Goondiwindi
39	Homeboin	3850	Roma	12088	Goondiwindi
40	Homeboin	3851	Roma	12106	Mitchell
55	Dirranbandi	3852	Roma	12136	Chinchilla
59	St George	3979	Mitchell	12158	Goondiwindi
62	Dirranbandi	4028	St George	12188	Chinchilla
64	Dirranbandi	4042	Dirranbandi	12190	Dalby
73	St George	4043	St George	12236	Taroom
89	Homeboin	4044	St George	12278	Dalby
97	Homeboin	4045	St George	12421	Roma
106	St George	4051	Surat	12447	Dalby
127	Surat	4052	Surat	12565	Dalby
132	St George	4053	Surat	12569	Dalby
133	St George	4185	Eddystone	12631	Goondiwindi
134	St George	4257	Roma	12633	Dalby
147	Dirranbandi	4399	St George	12639	Goondiwindi
149	Homeboin	4401	St George	12700	Roma
150	Homeboin	4585	Mitchell	12702	Goondiwindi
167	Dirranbandi	4587	Homeboin	12714	Goondiwindi
168	Homeboin	4687	Mitchell	12741	Mitchell
285	Mitchell	4918	Dirranbandi	12814	Taroom
303	Roma			12883	Homeboin
387	Mitchell	4920	Dirranbandi	13030	Dalby
388	Mitchell	4921	Dirranbandi	13038	Roma
397	St George	4999	Homeboin	13139	Dalby
1482	Homeboin	8551	Goondiwindi	13140	Dalby
1483	Homeboin	8654	Homeboin	13155	Roma
1485	Homeboin	10284	Goondiwindi	13180	Mundubbera
1599	Mitchell	10479	Roma	13248	Roma
1600	Mitchell	10809	Chinchilla	13300	Goondiwindi
1601	Mitchell	10841	Roma	13471	Chinchilla
1603	Mitchell	10984	Mitchell	13455	Dalby
1604	Mitchell	11051	Homeboin	13518	Chinchilla
1605	Mitchell	11287	Mitchell	13586	Dirranbandi
1609	Mitchell	11306	Mundubbera	13682	Dalby
1610	Mitchell	11354	Eddystone	13710	Dalby
1773	Eddystone	11410	Surat	13744	Goondiwindi
2339	Roma	11421	Dalby	13757	Chinchilla
2340	Roma	11434	Taroom	13809	Dalby
2414	Dirranbandi	11492	Chinchilla	13820	St George
2621	Mitchell	11495	Surat	13878	Chinchilla
2622	Mitchell	11501	Taroom	13882	Mundubbera
2623	Mitchell	11523	Dalby	13936	Mitchell
2686	Dirranbandi	11555	Dalby	13951	Mitchell
2762	Homeboin	11560	Roma	13999	Goondiwindi
2770	Homeboin	11645	Goondiwindi	14027	Roma
2822	Goondiwindi	11701	Chinchilla	14141	Dalby
2883	Homeboin	11739	Taroom	14190	Taroom
2884	Homeboin	11740	Surat	14204	Taroom
2973	St George	11743	Goondiwindi	14307	Roma
2975	Homeboin	11754	Mitchell	14388	Taroom
2976	Homeboin	11758	Taroom	14506	Chinchilla
3475	Homeboin	11857	Homeboin	14598	Mundubbera
3476	Homeboin	11866	Homeboin	14609	Taroom

TABLE 5. (Contd.)

14680	Taroom
14712	St George
14742	Dalby
14810	Roma
14857	Chinchilla
14861	Taroom
14906	Surat
14930	Roma
15036	Surat
15101	Surat
15124	Dalby
15171	Taroom
15183	Homeboin
15180	Goondiwindi
15302	Roma
15465	Goondiwindi
15473	Dirranbandi
15487	Mundubbera
15508	Chinchilla
15523	Homeboin
15525	Taroom
15590	Mundubbera
15624	Goondiwindi
15663	Goondiwindi
15670	Chinchilla
15696	Roma
15728	Taroom
15976	Goondiwindi
16000	Taroom
16029	Surat
16039	Goondiwindi
16065	Mundubbera
16140	Goondiwindi
16174	Roma
16204	Roma
16225	Taroom
16234	Dalby
16235	Roma
16264	Roma
16275	Goondiwindi
16281	Goondiwindi
16354	Goondiwindi
16400	Chinchilla
16445	Dalby
16476	Dirranbandi
16503	Goondiwindi
16524	Goondiwindi
16500	Dalby
16589	Taroom
16607	Taroom
16631	Roma
16654	Surat
16684	Roma
16686	Mundubbera
16735	Dirranbandi
16783	Dirranbandi
16788	Dirranbandi
16837	Dirranbandi
16984	Dalby
17070	Taroom
17191	Roma
17236	Roma
17385	Dalby
17435	Dalby
17511	Dalby
17689	Dalby
17877	Goondiwindi
117987	Dalby
18083	Dalby
22140	Goondiwindi
30054	Taroom
30316	Dalby
30346	Dalby
30535	Taroom
30788	Taroom
31127	Goondiwindi
31293	Goondiwindi
31371	Chinchilla
31489	Chinchilla
31860	Dalby
32735	Taroom
33283	Taroom
34768	Goondiwindi
34814	Goondiwindi
35251	Dalby
35458	Taroom
36075	Goondiwindi
New Bore	Taroom

NSW Bores

4024	St George
4032	St George
4099	St George
4121	St George
4132	St George
4163	St George
4185	St George
4578	Goondiwindi
4611	St George
4685	St George

Converted petroleum exploration wells

U.K.A. Alton West No. 1	Surat
U.K.A. Bennett No. 2	Dalby
M.O.C. No. 1 (Boyanda)	
U.K.A. Burunga South No. 1	Chinchilla
U.K.A. Cobbareena No. 1	Dalby
U.K.A. Currajong No. 1	Dalby
U.K.A. Crowder No. 1	Dalby
U.K.A. Crowder East No. 1	Dalby
U.K.A. Davidson No. 11	Dalby
U.K.A. Dockerill No. 1	Dalby
U.K.A. Dogwood No. 1	Chinchilla
U.K.A. Kentucky No. 1	St George
A.A.O. Latemore East No. 1	Roma
U.K.A. Mt Driven No. 1	St George
A.R.O. No. 19 (Wallumbilla)	Roma
U.K.A. Moonie North No. 1	Dalby
U.K.A. Paloma No. 1	Surat
U.K.A. Retreat No. 1	Dalby
U.K.A. Tey No. 1	Dalby
U.K.A. Tingan No. 1	Goondwindi
U.K.A. Widgewa No. 1	Dalby

TABLE 6. WIRELINE-LOGGED WATER-BORES IN THE EDDYSTONE 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm Na Cl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3 /day)
1773	Wallace's	508	244	233	G	-	-	-	-	Kld	Jkh	Pump
4185	Woolshed No. 2*	539	274	208	G	-	-	-	-	Jmb	Jlh	Pump
11354	Karil*	561	245	239	G	-	-	-	-	Jmb	Jlh	Pump

* Schlumberger logs run for American Overseas Petroleum

x See text for explanation

TABLE 7. WIRELINE-LOGGED WATER-BORES IN THE TAROOM 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
11434	Roche Dale	-	305	234	G.N. Dt.	-	-	4,500	-	Jw	Jlh	9
11501	Bangildoon	-	466	431	G.N. Dt.	-	-	-	-	Jw	Jlh	14
11739	Langdale	-	611	593	G.N.	-	-	-	-	Jw	Jlh	46
11758	Belle Eau	-	329	327	G.N. Dt.	-	-	-	-	Jlh	Jlp	34
12236	Broadmere No. 4	-	293	266	G.N. Dt.	-	-	350	-	Jw	Jlh	9
12814	Moss Vale	-	365	513	G.N. Dt.	-	-	-	-	Jw	Jlh	7
14190	Alkoomie No. 2	-	312	309	G.N.	-	-	-	-	Jw	Jlh	52
14204	Wainui No. 2	-	373	362	G.N. Dt.	-	-	1,100	-	Jw	Jlh	30
14388	Bimbadeen	-	371	356	G.N.Dt.	-	-	500	-	Jw	Jlh	43
14609	Rushian No. 2	-	350	168	G.N. Dt.	-	-	-	-	Jlh	Jlh	49
14680	Acacia Plateau	-	285	28	GN. Dt.	-	-	-	-	Jw	Jlh	40
14861	G	-	-	261	G.	-	-	-	-	Js?	Jlh	Pump
15171	G	-	238	257	G.	-	-	-	-	Jw	Jlh	Flow
15525	Robinson Creek	-	319	275	G.N. Dt.	-	-	-	-	Jlh	Jlh	80
15728	Mayfield No. 3	-	338	235	G.N. Dt.	-	-	1,700	-	Jw	Jlh	30
16000	Bridge Creek No. 3		274	549+	G.N. Dt.	-	-	-	-	Jw	Jlh	44
16225	Cudgee	-	767	744	G.N. Dt.	-	-	-	-	Jw	Jlp	39
16589	Carra	-	498	473	G.N. Dt.	-	-	900	-	Jw	Jlh	/Flow
16607	Kinnoul G	-	596	596	G.	-	-	-	-	Jw	Jlh	Pump
17070	Moorland No. 4	-	323	322	G. Dt.	-	-	-	-	Jlh	Jlp	Flow (90)
30054	Yurnga 1	-	299	239	G.N. Dt.E.	-	-	-	-	Jlh	Jlh	52
30535	Illuka	-	579	493	G.N. Dt.	-	-	-	-	Jw	Jlh	62
30788	Verbena Park	-	305	304	G.N. Dt.	-	-	300	-	Jlh	Jlh	Flow
32735	Taroom Town G	-	685	685						Jw	Jlp	Pump
33282		-	305	297	G.N. Dt.	-	-	800	-	Jw	Jlh	Flow (13)
35458		-	463	459	G.N. Dt.	-	-	-	-	Jw	Jlh	17
New Bore	New Bore	-	-	1052	G.N. Dt.	-	-	100	-	Jw	Jlp	Flow (455)

G = Logged by GSQ; logs available from Brisbane

x = See text for explanation

TABLE 8. WIRELINE-LOGGED WATER-BORES IN THE MUNDUBERRA 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
11306	Bentley Park	-	335	351	G.N. Dt.	-	-	150	-	Jlh	Jlp	Flow (33)
13180	Pontypool No. 2	-	395	392	G.N. Dt.	-	-	-	-	Jlh	Jlp	31
13882	Cluehead No. 2	235	372	227	G.N. Dt.	-	-	-	-	Jle	Jlp	Flow (small)
14598	Knockbine No. 3	-	425	346	G.N. Dt.	-	-	-	-	Jlh	Jlp	78
15487	Daldownie		599	593	G.N. Dt.	-	-	-	-	Jw	Jlp	31
15590	Beaumont		274	271	G.N. Dt.	-	-	100	-	Jlh	Jlp	Flow (32)
16065	Bungabun	258	390	291	G.N. Dt.E.					Jlh	Jlh	7
16686	Knockbine No. 5		320	385	G.N. Dt.	-	-	-	-	Jlh	Jlp	60

x See text for explanation

TABLE 9. WIRELINE-LOGGED WATER-BORES IN THE MITCHELL 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/ day)
285	Muckadilla	358	1147	109	G.	-	-	-		Klc	Klm?	3
387	Mitchell Town Bore*	336	916	905	G.	-	-	-		Kld	Jhl	Pump
388	Morven Town Bore*	429	807	810	G.	-	-	-		Kld	Jlh	Pump
1599	Parnassus*	394	1044	1020	G.	-	-	-		Klc	Jlh	Pump
1600	Woolshed*	363	922	919	G.	-	-	-		Klc	Jlh	Flow, ceased
1601	Bonus Downs*	363	923	922	G.	-	-	-		Klc	Jlh	Flow, ceased
1603	Oolandilla Creek*	372	874	869	G.	-	-	-		Klc	Jlh	Flow, ceased
1604	Annie Vale	356	977	179	G.					Klc	Jkh	Pump
1609	Cytherea No. 1*	355	897	881	G.	-	-	-		Klc	Jlh	Flow, ceased
1610	Cytherea No. 2	367	1039	937	G.T.	-	-	-		Klc	Jlh	Pump
2622	Washpool Creek	351	835	833	G. Dt.	569	720L	340	2.11	Klc	Js	Flow (45)
2623	Washpool Creek	383	966	550	G. Dt.	573	720L	350	2.09	Kld	Js?	21
3979	Crochdantigh	354	891	890	G. Dt.	-	-	-		Klc	Jlh	4
4585	Leinster*	358	889	888	G.	-	-	-	-	Klc	Jlh	Flow, ceased
4687	Woolshed No. 2	342	549	389	G.	-	-	-	-	Kld	Jkh	Pump
10984	Horse Creek*	347	216	171	G.	-	-	-		Juw	Jlh	Pump
11287	Durella	-	306	298	G.	1658	2800L	-	.009	T/Kld	Jkh	Pump
11754	Dunkfeld	-	359	357	G. Dt.	-	-	750		Cz/Klc	Jkh	Flow (90)
12106	Leinster West	-	427	408	G.	-	-	-	-	Klc	Jkh	Pump ?
13936	Bullagai	-	335	328	G. Dt.	1259	1675L	850	1.19	Klc	Jkh	Flow (small)
13951	Mitchell No. 2	-	890	887	G.T.	-	-	-	-	Kld	Jlh	Flow
2621	Eurella Creek*	351	1151	1101	G.	-	-	-		Klc	Jlh	Flow (small)

* Schlumberger logs run for American Overseas Petroleum

x See text for explanation

TABLE 10. WIRELINE-LOGGED WATER-BORES IN THE ROMA 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
303	Roma Railway	316	1129	393	G	-	-	-		Kld	Jug?	Pump
2339	Coinda	327	666	638	G. Dt.	-	-	-		Kld	Js?	37
2340	Delmally No. 2	347	823	173	G. Dt.	-	-	-		Klc	Kly?	Pump
3850	Mt Abundance No. 1	-	497	729	G. Dt.	-	-	-		Klc	Jug	58
3851	Mt Abundance No. 116A	365	1181	494	G. Dt.	-	-	-		Kld	Jug?	29
3852	Lochiel	297	284	94	Dt.	-	-	-		Kld	Kly	5
4257	Roma Downs	320	496	361	G.N. Dt.	-	-	-		Kld	Klm	21
10479	Wandoan Test No. 2	243	655	334	G.T.	-	-	-		Juw	Jlh	Flow
10841	Combarngo	267	500	492	G.T.	-	-	-		T/Kls	Klm	Flow
11560	Roundhole	295	611	604	G.	-	-	-		Js	Jlh	Pump
12421	Taunton	294	342	329	G.T.	-	-	-		Klc	Klm	Flow
12700	Wallabella No. 4	282	366+	318	G.N. Dt.	-	-	-		Klc	Klm	Flow (9.1)
13038	Oakland No. 3	-	497	486	G. Dt.	-	-	-		Js	Jlh	36
13155	Wandolin No. 2	280	348	329	G.T.	-	-	-		Klc	Klm	Flow
13248	Rippon Lea	285	570	523	G.T.	-	-	-		T/Klc	Klm	Flow
13816	Coolabong	308	358	357	G.N. Dt.	-	-	-		Klc	Klm	Flow
14027	Dalkeith No. 2	-	482	466	G. Dt.	-	-	-		Kld	Jug	30
14307	Moraby	-	520	518	G. Dt.	1561	1790L	950	3.69	T/Klc	Klm	Flow (90)
14810	Forest Grove No. 2	290	568	426	G.N. Dt.	-	-	-		Klc	Klm	Flow (680)
14930	Dundonnell No. 4	281	640	329	G.N. Dt.	-	-	-		Klc	Klm	11
15302	Deep Water	-	405	400	G. Dt.	-	-	-		T/Klc	Kly?	18
15696	Jackbore No. 2	-	621	264	G. Dt.	1350	1650L	900	1.90	Klc	Klm?	Flow (small)
16174	Salisbury Creek	-	564	562	G. Dt.	1756	1870L	950	6.70	Q/Klc	Klm	Flow (small)
16204	Pine Hills	-	477	474	G. Dt.	1954	2670L	1400	0.92	T/Klc	Klm	Flow (90)
16235	Camelot	-	518	497	G. Dt.	-	-	870	-	T/Klc	Klm	Flow (90)
16264	Moira Runda	-	612	603	G. Dt.	1535	1740L	850	3.34	Cz/Klc	Klm	Flow (90)
16631	Iona	294	366	360	G.N. Dt.	-	-	-		Kld	Klm	Flow (1365)

TABLE 10 (contd)

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity Conduct-ivity (S/cm) L,F	Salinity Field salinity (ppm NaCl)	Salinity HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
16684	Bardloming No. 2	290	326	226	G.N. Dt.	-	-	-		Klc	Kly	4
17191	Maffra No. 1	275	591	567	G.N. Dt.	-	-	-		Klc	Jug	Flow
17236	Maffra No. 2	281	587	534	G.N. Dt.	-	-	-		Klc	Jug	1
Petroleum Wells												
405	A.R.O. No. 19	318	1511	559	G.	-	-	-		Kly	Js?	Pump
14431	A.A.O. Latemore East	312	457	341	G.N. Dt.	-	-	-		Kld	Klm	18

x See text for explanation

TABLE 11. WIRELINE-LOGGED WATER-BORES AND CONVERTED PETROLEUM WELLS IN THE CHINCHILLA 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
10809	Staines Por 71	-	369	718	G. Dt.	-	-	-	-	JKk	Jlp	16
11492	Butter Factory No. 1	-	325	200	G. Dt.	-	-	-	-	Jw	Js	18
11701	Coolamunda	-	218	198	G.	-	-	-	-	Kly	Juo	Pump
12136	Binbian Plains	301	313	290	G.N. Dt.	-	-	-	-	Klc	Klm	40
12188	Redbank	288	381	376	G.N. Dt.	-	-	-	-	T	Klm	Flow (10)
13471	Hell Hole	315	333	308	G.N. Dt.	-	-	-	-	Jlh	Jlh	61
13518	Glenolive	301	407	370	G.N. Dt.	-	-	-	-	Klm	Jug	9
13757	Wieambilla	303	317	279	G.N. Dt.	-	-	-	-	Jug?	Js	15
13878	Brigalow	315	397	385	G.N. Dt.	-	-	-	-	T/Jw	Jlm	12
14506	Bawnduggie	319	376	344	G.N. Dt.	-	-	-	-	Jle	Jle	102
14857	Dundee No. 2	303	439	401	G.N. Dt.	-	-	-	-	T/Klc	Klm	Flow (14)
15508	Glen Laurel No. 5	-	544	539	G. Dt.	-	-	-	-	Jug	Jlh	34
15670	Ride & Sons Bore	324	374	338	G.N. Dt.	-	-	-	-	Klm	Jug	42
16400	Golden Valley	329	457	465	G.N. Dt.	-	-	-	-	Cz/Js	Jlh	35
31371	Tongy Park	-	920	918	G. Dt. E.	-	-	790	-	Js	Jlp	Pump
34227	Weringa		357	405	G.N. Dt.	-	-	-	-	Jw	Jlp	76
Petroleum Wells												
8406	M.O.C. No. 1 (Boyanda)	326	1439	730	G. Dt.	-	-	-		Juo	Jlh	0
22541	U.K.A. Burunga South No. 1	318	2598	761	G.N. Dt.	-	-	-	-	Jw	Jlp	54
22395	U.K.A. Dogwood No. 1	297	1261	1247	G. Dt.	-	-	-	-	Juo	Jlp	36

x See text for explanation

TABLE 12. WIRELINE-LOGGED WATER-BORES IN THE HOMEBOIN 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conductivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)	
24	Chippeway	210	931	930	G. Dt. F.	686	770 F	400	1.96	Cz/Klg	Jug	Flow	(Large)
37	Cypress	222	946	921	G. Dt. F.	834	880 F	470	2.04	Cz/Klg	Jug	Flow	(2270)
39	Powrunna	246	1077	1066	G. Dt. F.	795	825 F	500	1.37	Cz/Klg	Jkh	Flow	(1135)
40	Neabull	244	1068	1066	G. Dt. F.	708	720 F	430	2.09	Cz/Klg	Ja	Flow	(1590)
62	Hopeland Trust	335	1370	1364	G. Dt. F.	689	870 L	340	3.05	Cz/Klg	Jlh	Flow	(455)
89	Maroungle	230	954	955	G. Dt. F.	889	1210 F	580	1.44	Cz/Klg	Jug	Flow	(2270)
97	Mona Trust	213	847	605	G.	-	-	-	-	Cz/Klg	Jkh	Flow	
149	Weirbolla	227	1016	1011	G. Dt. F.	604	660 F	350	1.20	Cz/Klg	Ja	Flow	(2545)
150	Wild Horse	197	777	777	G. Dt. F.	733	737F	370	2.16	Q/Klg	Jkh	Flow	(3635)
168	Yunnerman	237	680	610	G.T.	-	-	-	-	Klg?	Jkh	Pump	
1482	Binda No. 1	211	490	213	G. Dt.	904	1020 F	500	2.94	Cz/Kls	Jkh	Flow	(227)
1483	Binda No. 2	210	595	559	G.T.	-	-	-	-	Cz/Kls	Jkh	Flow	
1485	Bindebango No. 2	224	563	552	G. Dt. F.	-	-	400			Jkh	Flow	(1590)
2762	Foyle View	320	951	236	G.	-	-	-	-	Cz/Klg	Klm		21
2770	Maranda Downs	290	989	971	G. Dt.	-				Cz/Kls	Ja		26
2883	Grassmere No. 1	247	536	507	G. Dt. F.	595	631 F	350	1.70	Cz/Klg	Jkh	Flow	(2270)
2884	Grassmere No. 2	231	549	573	G. Dt. F.	-	-	360	-	Cz/Kls	Jkh	Flow	(1820)
2975	Homeboin No. 2	260	708	695	G.	-	990 F	-	-	Klg?	Ja	Pump	
2976	Homeboin No. 3	-	991	943	G. Dt.	1753	2850 L	1250	0.22	Klg?	Ja		21
3475	Abbieglassie No. 1	-	792	164	G. Dt.	-	-	-	-	Klc	Jkh?	Pump	
3476	Abbieglassie	-	920	239	G. Dt.	-	-	-	-	Klc	Ja?	Pump	
3477	Albany Downs	335	939	290	G. Dt.	-	-	-	-	Klc	Ja?	Flow	
4587	Tongy No. 1	309	853	403	G. Dt.	-	-	-	-	Klc	Ja?		30
4999		-	856	853	G. Dt.	-	-	-	-	Cz/Klc	Jlh		10
8654	Coolaman	-	305	290	G. Dt.	1063	1320 F	550	0.97	Cz/Klc	Jkh	Flow	
11051	Toomoo No. 4	-	321	319	G. Dt.	1126	1540 F	750	0.07	Cz/Klc	Jkh	Flow	(45)
11857	Begonia No. 2	244	608	617	G. Dt.	1284	600 F	700	1.39	Cz/Klg	Klm	Flow	(small)
11866	Gunnawarra	290	303	299	G.T.	-	-	-	-	Cz/Klc	Jkh	Flow	
11954	Tullochard	279	408	402	G.T.	-	-	-	-	Cz/Klc	Jkh	Flow	
12883	Lullworth	194	346	727	G. Dt. F.	733	885 L	800	2.29	Cz/Klg	Jkh	Flow	(4000)
15183	Tongy 4	259	369	305	G.	-	2640 F	-	-	Cz/Klc	Jkh	Flow	
15523	Chesterfield No. 2	242	1437	1157	G. Dt. F.	-	-	-	-	Cz/Klg	Jlh	Abandoned	

x See text for explanation

TABLE 13. WIRELINE-LOGGED WATER-BORES AND CONVERTED PETROLEUM WELLS IN THE SURAT 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt,T, F, E^x	Analysed T.D.S. (ppm)	Salinity: Conductivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
10	Borah	334	1476	1465	G. Dt. F	1080	1150 L	-	6.53	Klc	Jlh	Flow (365)
127	Thomby	229	1213	1212	G. Dt. F.	-	-	600	-	Klg	Jug	Flow (2270)
4051	Noorindoo No. 1	-	1058	825	G. Dt.	-	-	-	-	Klg	Klm?	37
4052	Noorindoo No. 2	267	946	780	G. Dt.	-	-	-	-	Klg	Klm	3
4053	Noorindoo No. 3	272	1049	1047	G. Dt.	-	-	-	-	Klg	Jug	5
11410	Canmaroo	-	777	664	G. Dt.	2202	2340 L	550	3.86	Klg	Klm	Flow (36)
11495	Kilburnie	-	440	418	G. Dt.	-	-	-	-	T/Kls	Kly	3
11740	Woodlands	277	599	566	G. Dt. Cal	1881	2000 L	1050	4.81	T/Kls	Klm	Flow (small)
14906	Corack	-	861	854	G. Dt.	2081	2150 L	-	5.78	Klg	Jug?	Flow (small)
15036	Meandarra Town	282	1123	1121	G. Dt.	-	-	550	-	Klg	Jug	15
15101	Pongi	-	725	717	G. Dt.	1766	2000 L	-	7.35	Klg	Klm	Flow (45)
16029	Stirling Park	-	610	588	G. Dt. F.	1979	2050 L	550	5.29	Klg	Klm	Flow (365)
16654	Innisvale		732	726	G. Dt.	-	-	500	-	Klg	Klm	Flow (small)
	Petroleum Wells											
	U.K.A. Alton West No. 1	213	2097	1255	G. Dt.			500		Klg	Jug	Flow (590)
	U.K.A. Paloma No. 1	305	2334	1229	G. Dt.			-		Klg	Jug	19

x See text for explanation

TABLE 14. WIRELINE-LOGGED WATER-BORES AND CONVERTED PETROLEUM WELLS IN THE DALBY 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conductivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
11421	Lomond Downs	-	325	322	G.N. Dt.	1691	1840 L	1050	6.38	Kld	Klm	Flow (small)
11523	Bathampton		518	507	G.N. Dt.	2004	2820 L	1700	1.13	Cz/Kls	Kly	31
11555	Wahroonga No. 1	-	342	330	G. Dt.	-	-	-	-	Cz/Klc	Kly	29
12190	Thuruna No. 2	-	368	369	G.N. Dt.	1585	1720 L	-	4.62	Cz/Kld	Klm	6
12278	Wahroonga No. 2	-	427	407	G.N. Dt.	2366	3680 L	2700	0.37	Cz/Klc	Klm	26
12447	Warroon	-	610	565	G. Dt.	-	-	870		Cz/Klc	Klm	Flow (910)
12565	Cabawin		393	370	G.N. Dt.	1877	1990 L	1250	5.14	Cz/Klc	Klm	Flow (?)
12569	Greenfield	273	602	598	G.N. Dt.	2006	2160 L	1100	8.17	Cz/Klc	Klm	Flow (small)
12633	Warroon No. 2	-	549	540	G.N. Dt.	1912	2070 L	1250	5.72	Cz/Klc	Klm	Flow (small)
13030	Strathalbyn	290	644	630	G.T.	-	-	-	-	Cz/Klc	Klm	Flow
13139	Bramston	-	339	373	G.N. Dt.	-	-	-	-	Cz/Kld	Kls	Flow (small)
13140	Bellevue Park	290	458	439	G.T.	-	-	-	-	Cz/Klc	Klm	Pump
13455	Barramornie No. 3	282	541	533	G.T.	-	-	-	-	Cz/Kls	Klm	Flow
13682	Barramornie	-	567	534	G.N. Dt.	1780	2140 L	1100	3.76	Cz/Kls	Klm	Flow (36)
13710	The Oaks	-	535	527	G.N. Dt.	1980	2160 L	1100	8.05	Cz/Klc	Klm	Flow (9)
13809	Belara	-	524	496	G.N. Dt.	2042	2100 L	1000	6.46	Cz/Klc	Klm	Flow (90)
14141	Tara Town No. 2	312	611	555	G.N. Dt.	-	-	-	-	Kld	Jug	43
14742	Inverness	-	456	438	G.N. Dt.	-	-	750	-	Cz/Klc	Klm	Pump
15124	Moonie Weir	-	334	308	G.N. Dt.	.	.	.	.	Cz/Klc	Kly	2
16234	Warrowa	-	762	760	G. Dt.	1812	2010 L	800	10.99	Cz/Klc	Jug?	Flow (45)
16445	Coradon	-	408	726	G.N. Dt.	-	-	-	-	Cz/Kls	Jug	41
16550	Pippinford		674	635	G. Dt.	2019	2160 L	1050	5.83	Cz/Kls	Klm	Flow (70)
16984	Talinga	-	607	584	G.N. Dt.	-	-	-	-	Cz/Kld	Jug	28
17385	Ringwood Park	-	544	476	G. Dt.	2032	1925 L	920	7.37	Cz/Klc	Klm	Flow (small)
17435	Currajong No. 3	-	869	825	G. Dt.	1746	1820 L	900	17.61	Cz/Kls	Klm	Flow (23)
17511	Willara	-	466	462	G. Dt.	1977	2090 L	1100	7.38	Cz/Klc	Klm	Flow (23)
17689	Burnbrae		655	643	G.N. Dt.	1850	2725 L	1700	0.62	Cz/Kld	Jug	3
17986	The Deep	-	743	728	G.N. Dt.	1423	1520 L	950	4.28	Cz/Klc	Jug	35
18083	Gilgi	-	375	329	G. Dt.	5366	9500 L	6000	0.04	Cz/Kld	Klm	17
30316		-	643	624	G.N. Dt.	1321	1650 L	900	3.19	Cz/Klc	Klm	Flow small

TABLE 14 (contd)

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conductivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)	
30346	Duffields Bore	-	506	471	G.N. Dt.	1519	1570 L	1200	5.71	Cz/Klc	Klm	Flow	(4.5)
31860	Tullaville	-	504	476	G.N. Dt.	1764	2300 L	1400	1.46	Cz/Klc	Klm	Flow	(11)
35251	Biddybrook No. 2	-	645	629	G. Dt.	1438	1640 L	750	4.14	Cz/Klc	Klm	Flow	(23)
Petroleum Wells													
	U.K.A. Bennett No. 2	287	1728	628	G. Dt.					Cz/Kld	Jug		19
	U.K.A. Cobbareena No. 1	333	1576	422	G. Dt.					Kly	Jug		41
	U.K.A. Crowder No. 1	261	1787	771	G. Dt.					Klc	Jug		5
	U.K.A. Crowder East No. 1	262	1690	764	G. Dt.					Kld	Jug		8
	U.K.A. Currajong No. 1	257	1872	855	G.					Klc	Jug		4
	U.K.A. Davidson No. 1	284	2293	471	G. Dt.			1200		Cz/Klc	Klm	Flow	(9)
	U.K.A. Dockerill No. 1	254	1832	497	G. Dt.			850		Cz/Klc	Klm	Flow	(45)
	U.K.A. Moonie North No. 1	270	1833	742	G. Dt.					Cz/Klc	Jug		13
	U.K.A. Retreat No. 1	278	1900	665	G. Dt.					Cz/Klc	Jug		20
	U.K.A. Tey No. 1	289	1638	508	G. Dt.			900		Cz/Kld	Jug	Flow	(4.5)
	U.K.A. Widgewa No. 1	255	1885	834	G. Dt.					Klc	Jug		9

x See text for explanation

TABLE 15. WIRELINE-LOGGED WATER-BORES IN THE DIRRANBANDI 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
55	Eugen	217	1046	1012	G. Dt. F.	761	770 F	600	2.06	Cz/Klg	Jug	Flow (3410)
64	Ingie	-	1013	1013	G.F. Dt.	921	935 F	500	3.87	Cz/Klg	Jkh	Flow (5000)
147	Whyenbah	203	955	944	G. Dt. F.	652	660 F	380	2.36	Cz/Klg	Klm	Flow (2730)
167	Yanco North	172	732	728	G. Dt. F.	710	715 F	400	2.09	Cz/Klg	Jkh	Flow (5230)
2414	Yamburgan	222	946	921	G. Dt. F.	946	803 F	470	3.58	Cz/Klg	Jug	Flow (2270)
2686	Queens Birthday	172	641	629	G. Dt. F.E.	653	605 F	1000	2.19	Cz/Klg	Jkh	Flow (5365)
3819	Dunbar	179	755	673	G. Dt. F.	1445	1430 F	720	5.39	Cz/Klg	Jkh	Flow (135)
3820	Whitably	191	853	651	G. Dt. F.	729	715 F	410	2.50	Cz/Klg	Jkh	Flow (1820)
4042	Narine	165	944	944	G. Dt.	1603	1650 F	820	4.94	Cz/Klg	Klm	Flow (590)
4918	Wyenbah No. 1	190	869	866	G. Dt. F.	943	880 F	600	2.69	Cz/Klg	Klm	Flow (1820)
4920	Bullindigie	184	932	913	G. Dt. F.	1167	1210 F	600	4.90	Cz/Klg	Jkh	Flow
4921	Cawildi	176	914	908	G. Dt. F.	1241	990 F	640	5.12	Cz/Klg	Jkh	Flow (730)
13586	Glendon	-	413	399	G. Dt.	9878	16,500 F	8200	0.025	Cz/Klg	Klc	Small trickle (2230)
15473	Book Book No. 2	-	880	881	G. Dt. F.	916	803 F	480	3.34	Cz/Klg	Jkh	Flow
16476	Yartoo	-	752	751	G. Dt. F.	807	990 F	780	2.84	Cz/Klg	Jkh	Flow (2760)
16735	Ballandool No. 2	-	1036	492	G. Dt. F.	-	660 F	480	-	Cz/Klg	Jkh	Flow (1500)
16783	Calooma	-	1315	1006	G. Dt. F.	-	770 F	750	-	T/Klg	Jkh	Flow (1820)
16788	Koomalah	-	1097	823	G. Dt. F.	-	1430 F	400	-	Klg	Klm	Flow (910)
16837	Oban		914	880	G. Dt. F.	784	825 F	400	3.03	Cz/Klg	Jkh	Flow (2455)

x See text for explanation

TABLE 16. WIRELINE-LOGGED WATER-BORES AND CONVERTED PETROLEUM WELLS IN THE ST GEORGE 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E^x	Analysed T.D.S. (ppm)	Salinity			Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
							Conduct-ivity (S/cm) L,F	Field salinity (ppm NaCl)	HCO_3^- / Cl^- (emp)			
59	Geralda	245	1208	1204	G. Dt.	-	-	-	-	Q/Klg	Jp	13
73	Kaywanna Trust	232	1323	1320	G. Dt. F.	-	1100 F	500	-	Klg	Jp	Flow (1635)
106	Myall Plains	192	1083	876	G. Dt. F.	-	1045 F	700	-	Cz/Klg	Klm?	Flow (3180)
132	Weengallon No. 1	199	1117	1116	G. Dt. F.	-	1210 F	490	-	Q/Klg	Jp	Flow (4045)
133	Weengallon No. 2	222	1146	1146	G. Dt. F.	-	920 F	640	-	Q/Klg	Jp	Flow (1545)
134	Weengallon No. 3	229	1218	1218	G. Dt. F.	-	902 F	550	-	Klg	Jp	Flow (590)
397	St George	200	823	746	G. Dt. F.	-	7040 F	390	-	Cz/Klg	Klm	Flow (1365)
2973	Hollymount	238	914	898	G. Dt. F.	-	1100 F	500	-	Klg	Klm	Flow (455)
4028	Newingar	198	1100	1098	G. Dt. F.	-	-	600	-	Q/Klg	Jp	Flow (2730)
4043	Noondoo	174	1093	1049	G. Dt. F.	-	1056 F	500	-	Cz/Klg	Jug	Flow (1635)
4044	Maxlands	178	1087	1077	G. Dt. F.	-	1869 F	600	-	Q/Klg	Jp	Flow (2455)
4045	Bullwarrie	171	1101	1101	G. F.	-	1045 F	640	-	Q/Klg	Jug	Flow (2910)
4399	Boombah	197	922	665	G.	-	880 F	-	-	Cz/Klg	Klm	Flow
4401	Thuraggie	196	910	903	G. Dt. F.	-	1320 F	600	-	Cz/Klg	Klm	Flow (910)
13820	Noondoo Trust	-	1178	1178	G. Dt. F.	-	770 F	550	-	Cz/Klg	Jug	Flow (4090)
14712	Buckinbah No. 2	-	932	925	G. Dt. F.	-	990 F	600	-	Cz/Klg	Klm	Flow (1635)
NSW Bores												
4024	Boomi	177	1221	998	G. Dt. F.	795	825 F	450	3.48	Cz/Klg	Jp	Flow (3090
4032	Boronga No. 1	198	1322	1157	G. Dt. F.	778	792 F	400	2.76	Cz/Klg	Jp	Flow (2730)
4099	Careunga No. 1	201	1223	1098	G. Dt. F.	848	836 F	450	3.92	Cz/Klg	Jp	Flow (910)
4121	Coubal	174	1216	1213	G. Dt. F.	746	770 F	410	4.23	Cz/Klg	Jp	Flow (3090)
4132	Dolgelly	194	1245	1232	G. Dt. F.	823	814 F	430	3.90	Cz/Klg	Jp	Flow (1365)
4163	Careunga No. 2	195	1223	1016	G. Dt. F.	808	792 F	450	3.94	Cz/Klg	Jp	Flow (4090)
4185	Euraba	191	1220	1222	G. Dt. F.	1012	902 F	530	3.63	Cz/Klg	Jp	Flow (2385)
4611	Welbondongah	182	1138	987	G. Dt. F.	757	792 F	400	4.26	Cz/Klg	Jp	Flow (2865)
4685	Boronga No. 2	-	1393	1295	G. Dt. F.	819	825 F	420	2.87	Cz/Klg	Jp	Flow (3180)
Petroleum Wells												
	U.K.A. Kentucky No. 1	237	2146	1105	G. Dt.	-	-	900	-	Klg	Jug	Flow (90)
	U.K.A. Mt Driven No. 1	205	1743	1159	G. Dt. F.	-	-	500	-	Q/Klg	Jug	Flow (2275)

x See text for explanation

TABLE 17. WIRELINE-LOGGED WATER-BORES AND CONVERTED PETROLEUM WELLS IN THE GOONDIWINDI 1:250 000 SHEET AREA

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conductivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
2822	North Callandoon	209	960	943	G. Dt. F.	947	1175 L	600	2.69	Cz/Klc	Jug	Flow (2270)
8551	Billa-Billa	-	299	300	G.N. Dt.	-		1200		Kly	Klm	Flow (36)
10284	Yagaburne No. 3	-	301	250	G.N. Dt.	1206	1700 L	1100	0.88	Cz/Kly	Jug	Flow (14)
11645	Euloma	-	357	285	G. Dt.	1469	1675 L	840	3.27	Cz/Kly	Klm	Flow (23)
11950	Wyaga No. 2	-	366	216	G.N.	1264	1950 L	1100	0.59	Juo	Jug	11
11743	Monte Cristo	232	341	302	G.T.	-	-	-		Kly	Klm	Flow -
11995	Aronui	257	341	265	G.N. Dt.	-	-	-		Juo	Jug	8
12088	Farleigh No. 5		309	176	G.N. Dt.	-	-	-		Kly	Klm	13
12158	Iona No. 2		305	278	G.N. Dt.	1409	1650 L	1200	2.59	Cz/Juo	Jug	Flow (9)
12631	Gillina No. 2		307	297	G.N. Dt. E.	-	-	750		Cz/Juo	Jug	Flow (9)
12639	Bentwood	-	616	596	G.	1472	1675 L	800	3.28	Cz/Klm	Klm	Flow
12702	Wyaga No. 3	-	340	-	Dt.	-	-	-		Cz	Jug	13
12714	Wyaga No. 4	288	373	252	G.	-	-			Cz/Juo	Jug	Pump
13300	Springfield	-	320	315	G.N. Dt.	851	1190 L	850	2.20	Cz/Klm	Jug	Flow (small)
13744	Murra Cul Cul No. 2	-	354	293	G.N. Dt.	1495	1680 L	950	8.34	Kld	Klm	Flow (23)
13999	Wondalli	-	376	377	G.N. Dt.	1085	1325 L	650	3.99	Cz/Juo	Jug	Flow (90)
15180	Githawin No. 1		306	206	G.N. Dt.	1063	1450 L	750	1.55	Cz/Klm	Klm	Flow (2.7)
15465		-	338	262	G.N. Dt.	-	-	-	-	Klg	Klc	91
15624	Kildonnan No. 11		366	374	G.N. Dt.	947	1240 L	600	2.87	Klm	Jug	Flow (68)
15663	Melness	-	334	326	G.N. Dt.	1092	1330 L	700	4.82	Cz/Juo	Jug	Flow (68)
15976	Zilzie No. 2	-	373	372	G.N. Dt.	1044	1260 L	850	2.90	Cz/Klm	Jug	Flow (90)
16039	Lapunyah	-	1006	975	G. Dt.	.	.	1300	-	Klg	Klm	Flow (1135)
16140	O.K. No. 2		648	643	G. Dt.	1686	1740 L	1030	9.44	Kld	Jug	Flow (45)
16275	Kulai		338	329	G. Dt.	1703	2030 L	1000	2.17	Cz/Kly	Juo	Flow (45)
16281	Zilzie No. 3	-	369	369	G.N. Dt.	1129	1240 L	900	3.27	Cz/Juo	Jug	Flow (435)
16354	Undabri	-	682	651	G. Dt.	1767	2070 L	1000	2.66	Cz/Juo	Jp	Flow (45)
16503	Torridon No. 2	-	305	302	G.N. Dt.	1122	1220 L	850	4.04	Cz/Klm	Jug	Flow (45)

TABLE 17 (contd)

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available G,N,Dt, T, F, E[x]	Analysed T.D.S. (ppm)	Salinity: Conduct-ivity (S/cm) L,F	Salinity: Field salinity (ppm NaCl)	Salinity: HCO_3^- / Cl^- (emp)	Spudded in	Deepest aquifer presently tapped	Water-level m (flows in m^3/day)
17877	Merinda No. 2	299	367	177	G.N. Dt.					Juo	Jug	Flow (4.7)
22140	Arrowfield	-	482	408	G.N. Dt.	1246	1600 L	850	1.54	Kly	Juo	27
31127	Nindalyup	-	273	197	G.N. Dt.					Juo	Jug	6
31293		-	-	181	G.N. Dt.	-	-	-	-	Cz/Juo	Jug	14
34768		-	310	312	G.N. Dt.	1139	1300 L	700	5.71	Cz/Klm	Jug	Flow (340)
34814		-	418	412	G.N. Dt.	1034	1300 L	700	5.38	Cz/Juo	Jug	Flow (68)
36075			352	210	G.N. Dt.	-	-	-	-	Juo	Jug	13
4578	Tulloona No. 2 (N.S.W. Bore)	208	1117	671	G. Dt. F.	834	1025 L	450	3.94	Cz/Klg	Jp	Flow (5000)

<u>Petroleum Well</u>

Reg. No.	Name	Elevation (m)	Depth drilled (m)	Depth logged (m)	Logs available	Analysed T.D.S. (ppm)	Conductivity	Field salinity	HCO_3^- / Cl^-	Spudded in	Deepest aquifer presently tapped	Water-level
22181	U.K.A. Tingan No. 1	208	1816	1004	G. Dt. F.			1000		Cz/Klg	Jp	Flow (2045)

x See text for explanation

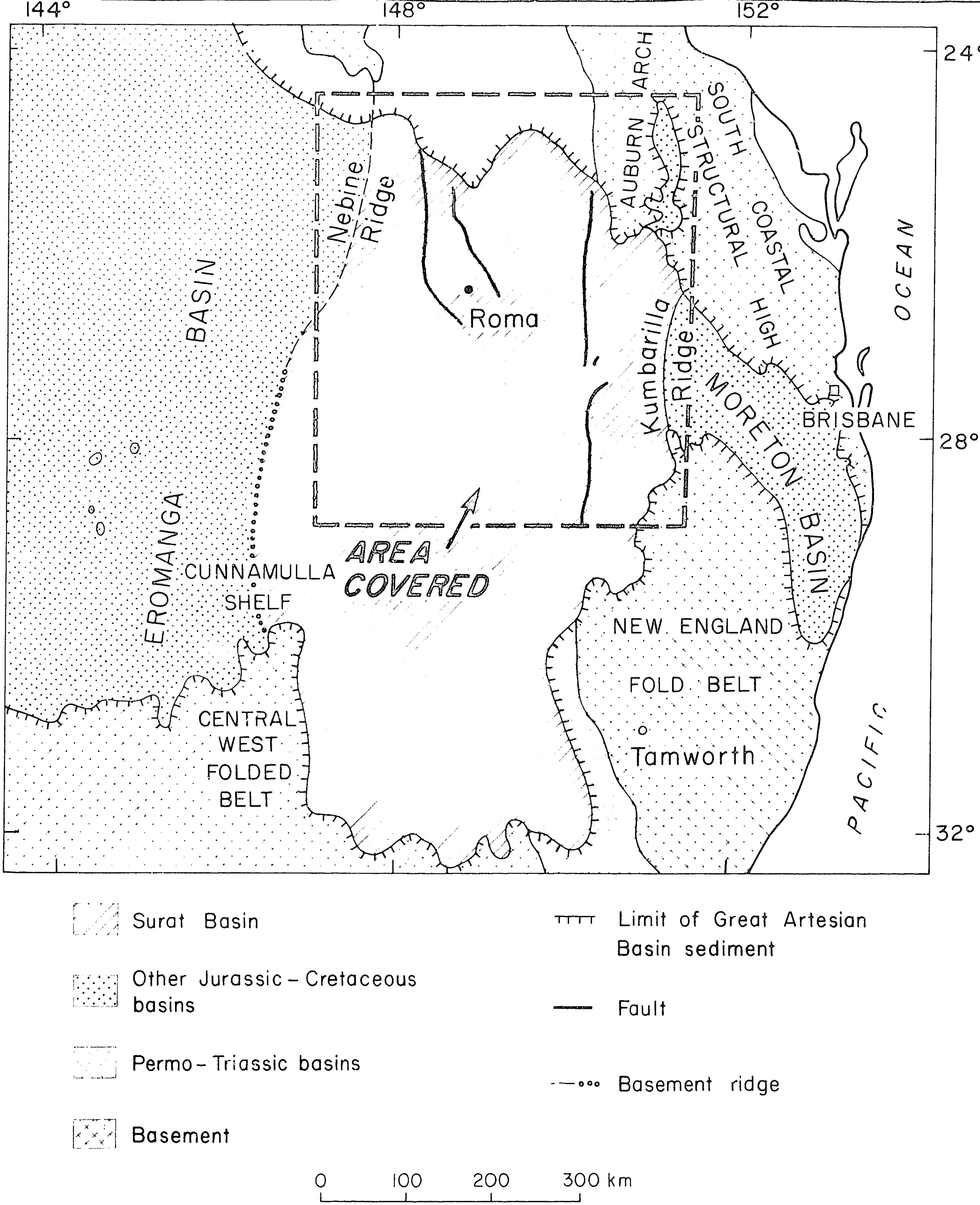


Fig. 1. Regional geological setting.

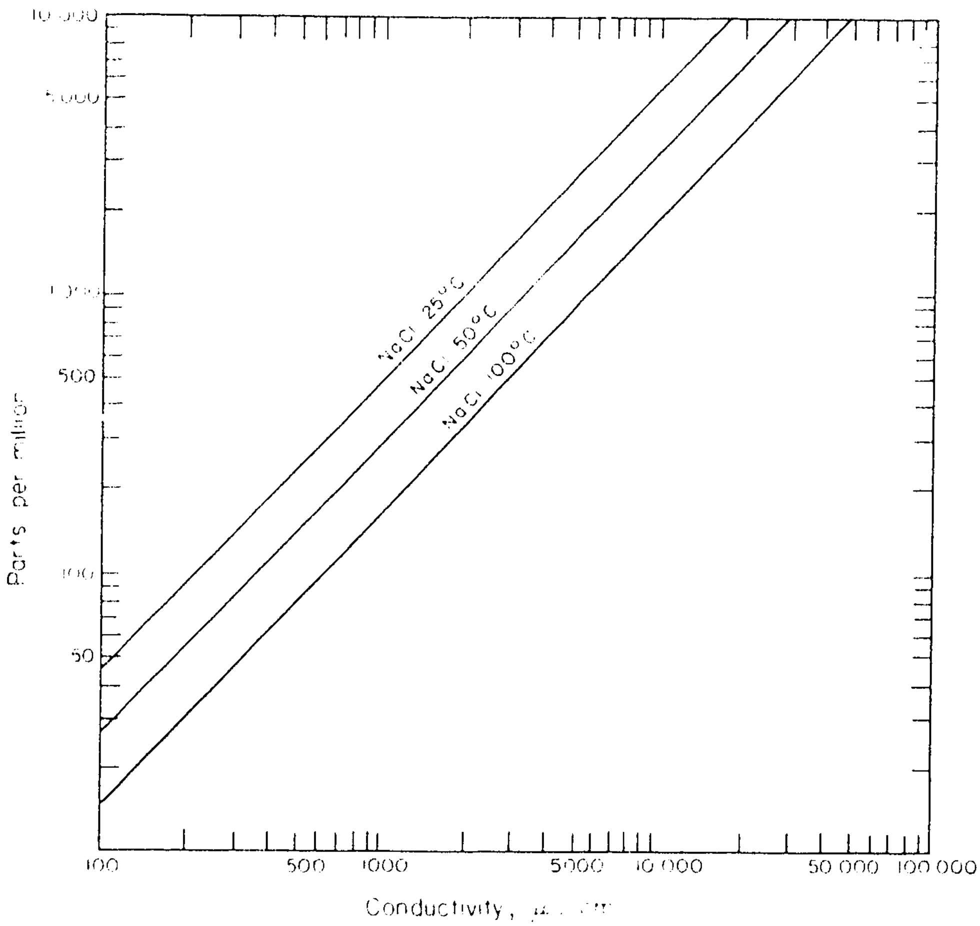
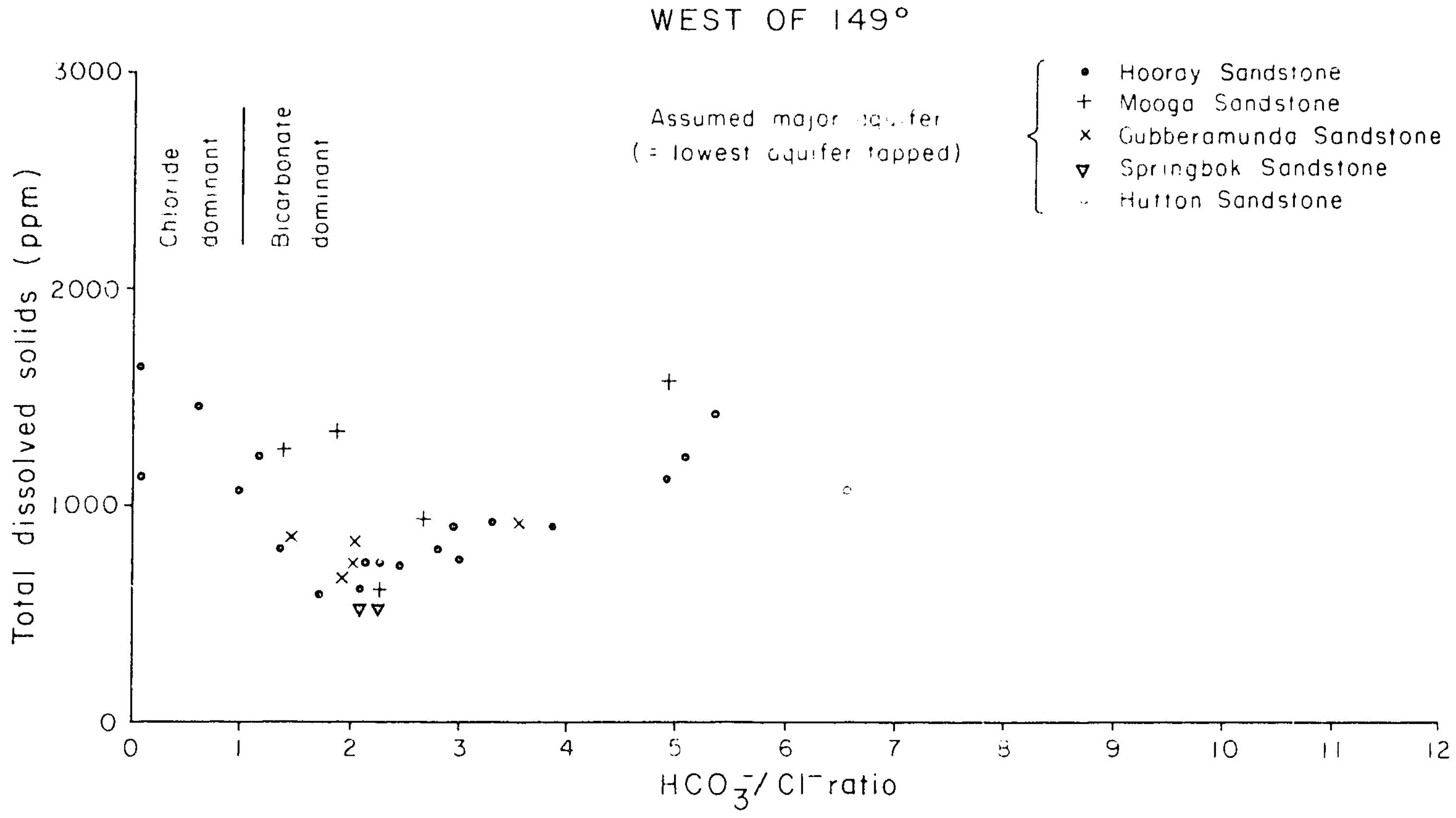


Fig 2 Conductivity of aqueous solutions of NaCl at various temperatures (adapted from fig 3.10 in Davis & de Wiest, 1966)



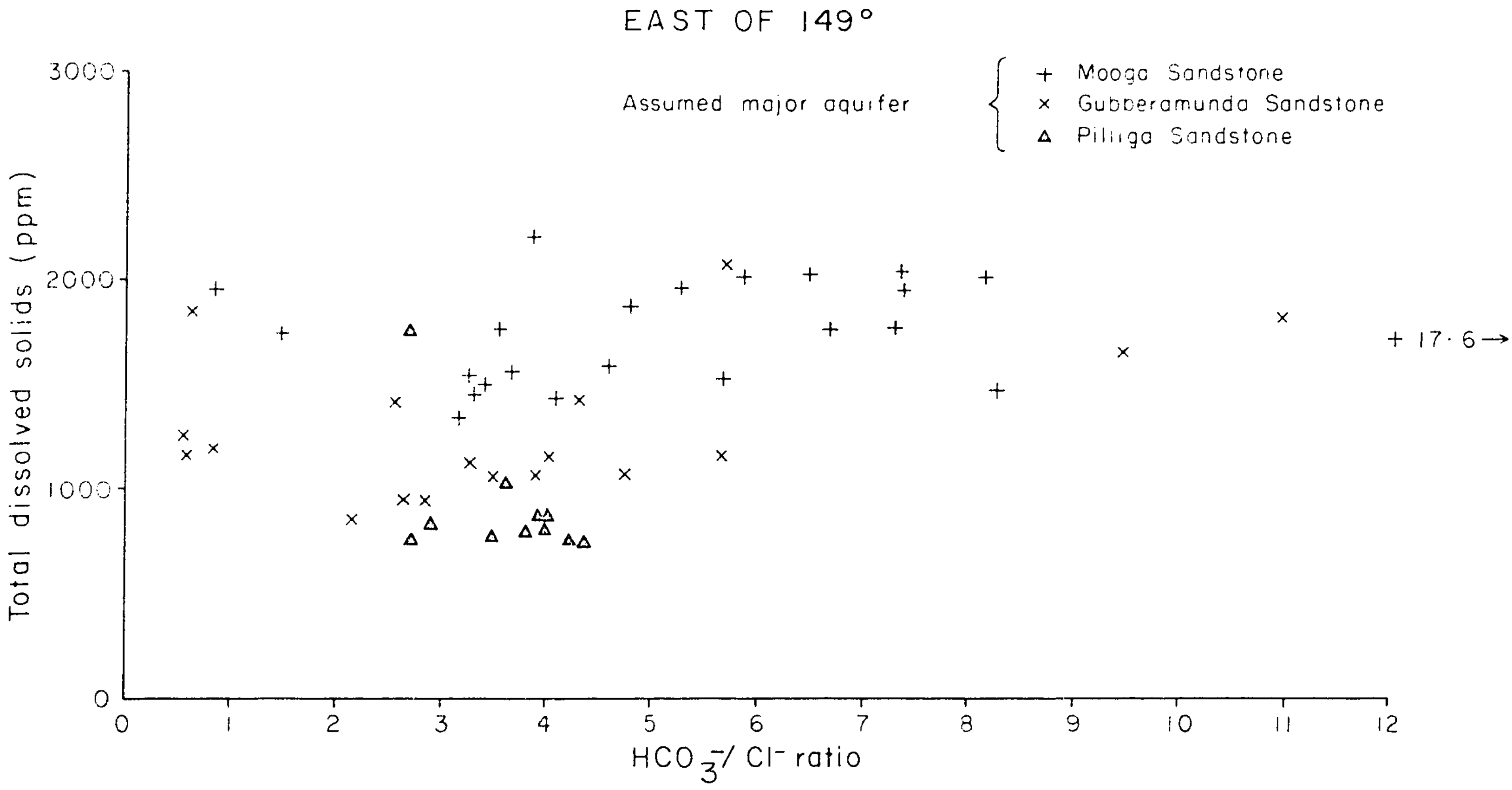


Fig. 3. Graphical presentation of water chemistry

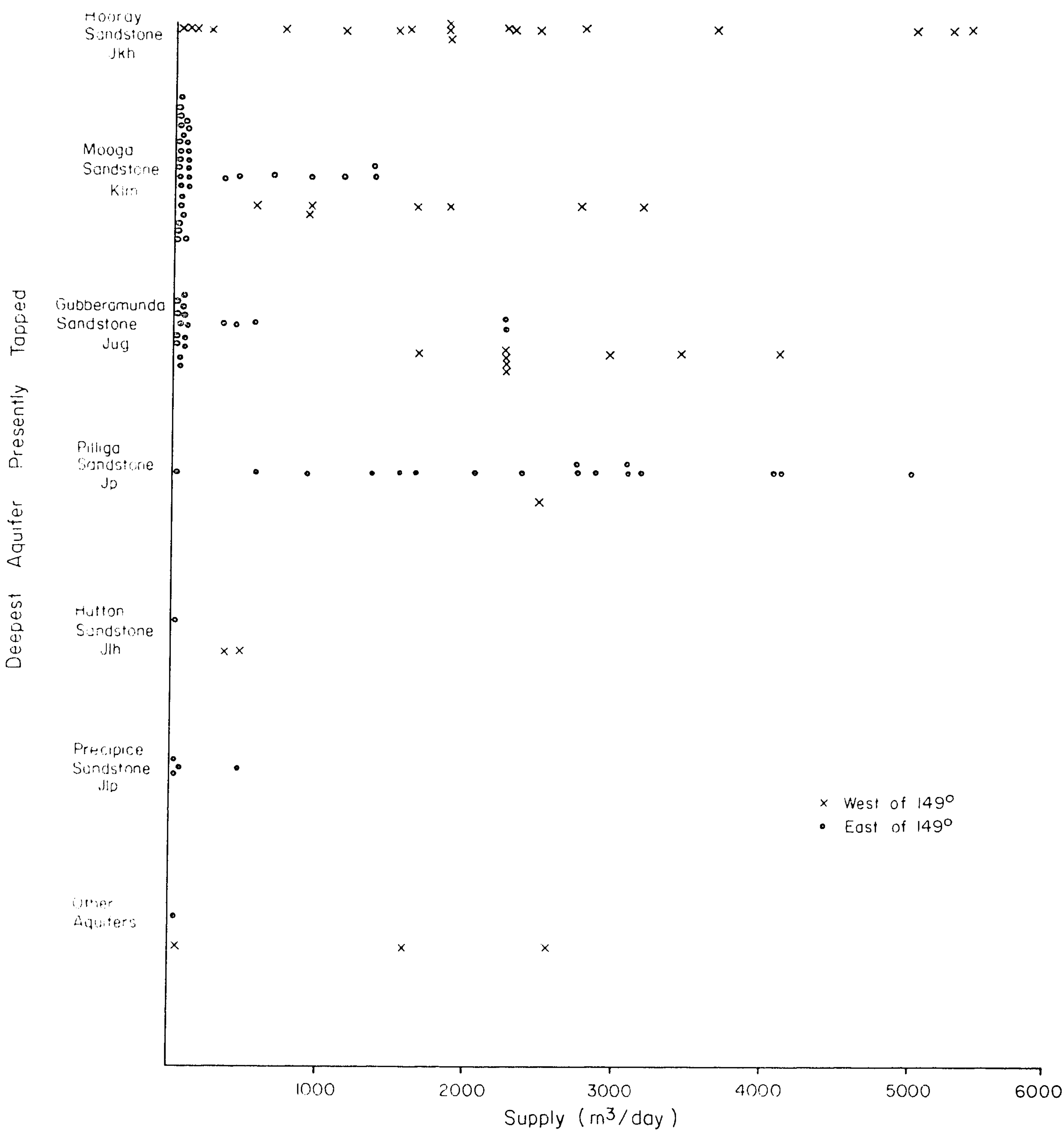


Fig. 4. Estimated flow rates of flowing bores drawing from various aquifers.

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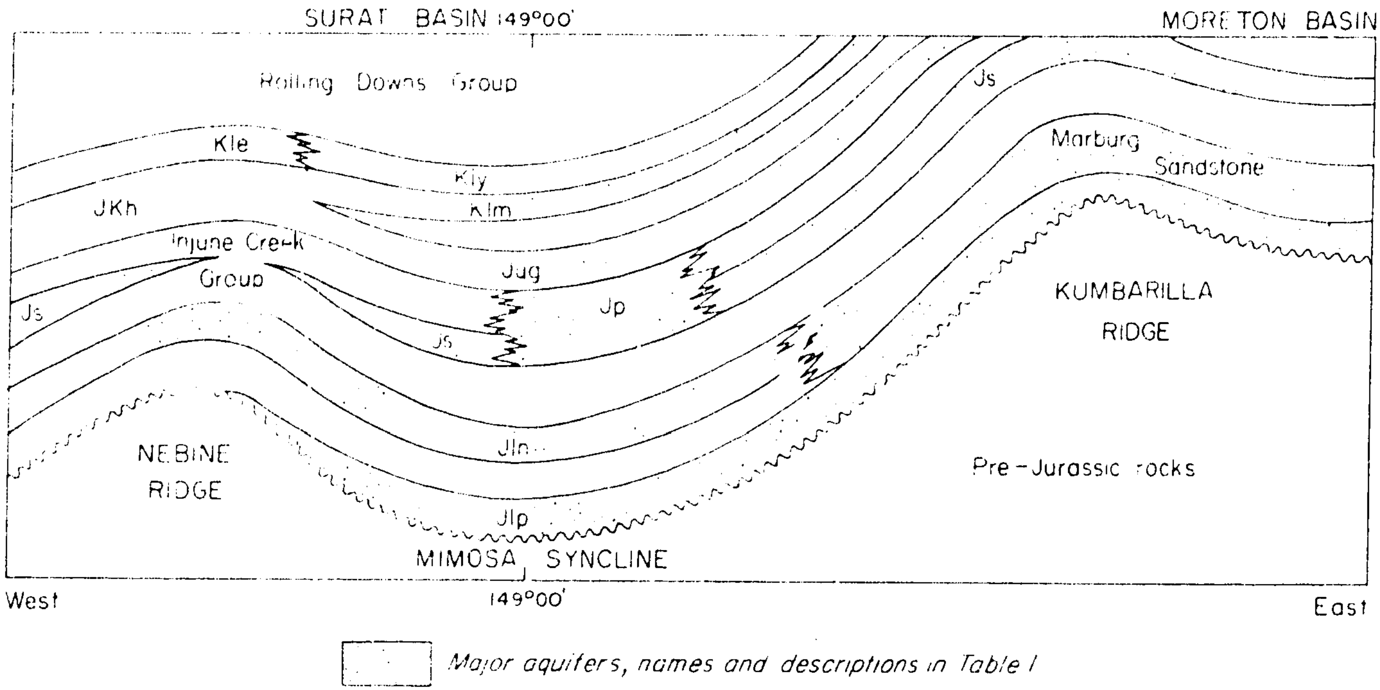
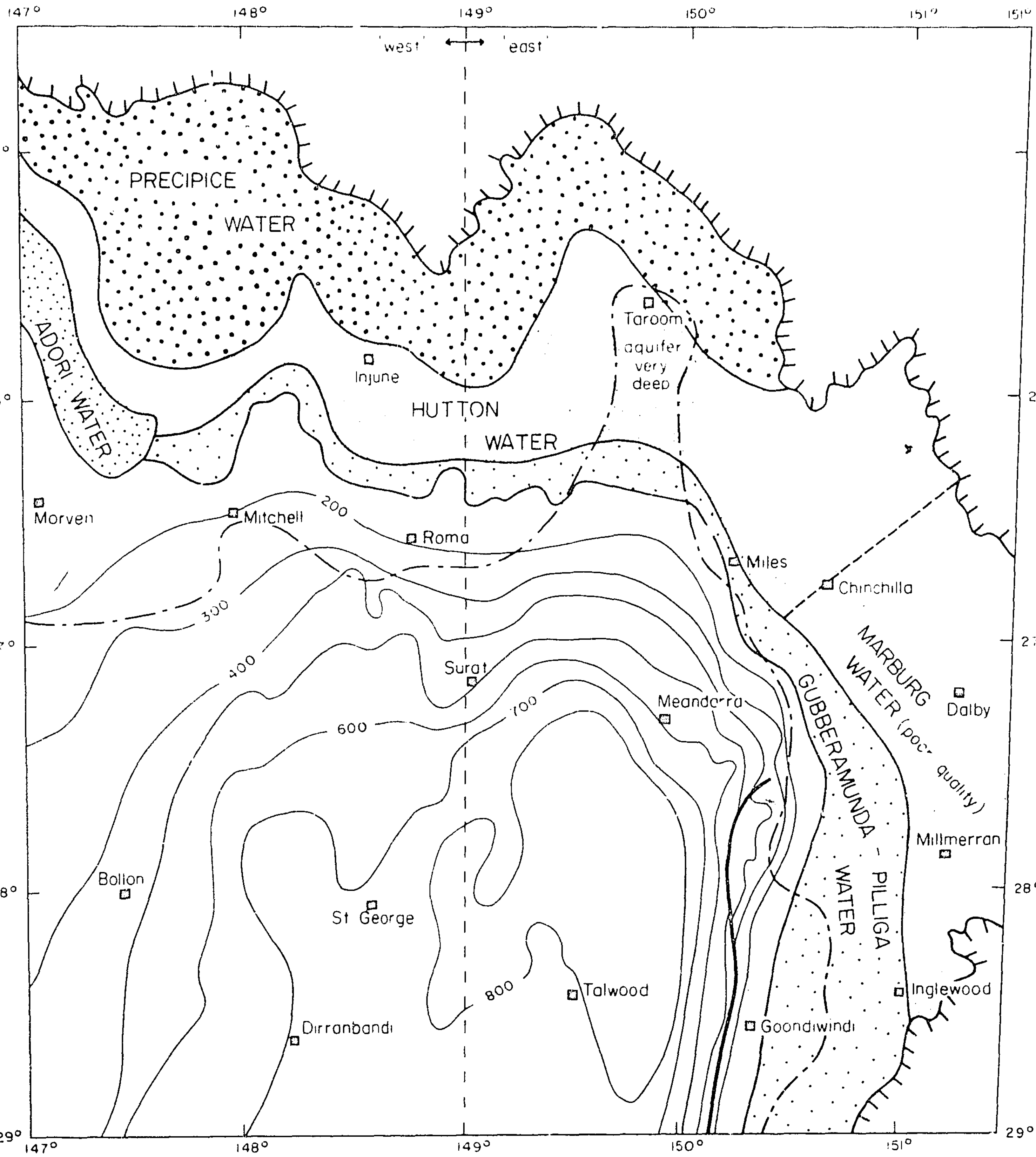


Fig 5 Schematic cross-section across the Surat Basin to show major aquifers.



Areas in which named aquifers are shallowest major sources of water.

Hooray - Mooga Sandstones	—200— Depth below ground of Hooray - Mooga aquifer (metres)
Gubberamunda - Pilliga Sandstones	Edge of Surat Basin
Adori Sandstone	Flowing bores are generally basinward of this line
Hutton Sandstone	Fault
Marburg Sandstone	
Precipice Sandstone	

Fig 6. Distribution of aquifers.

Plate I

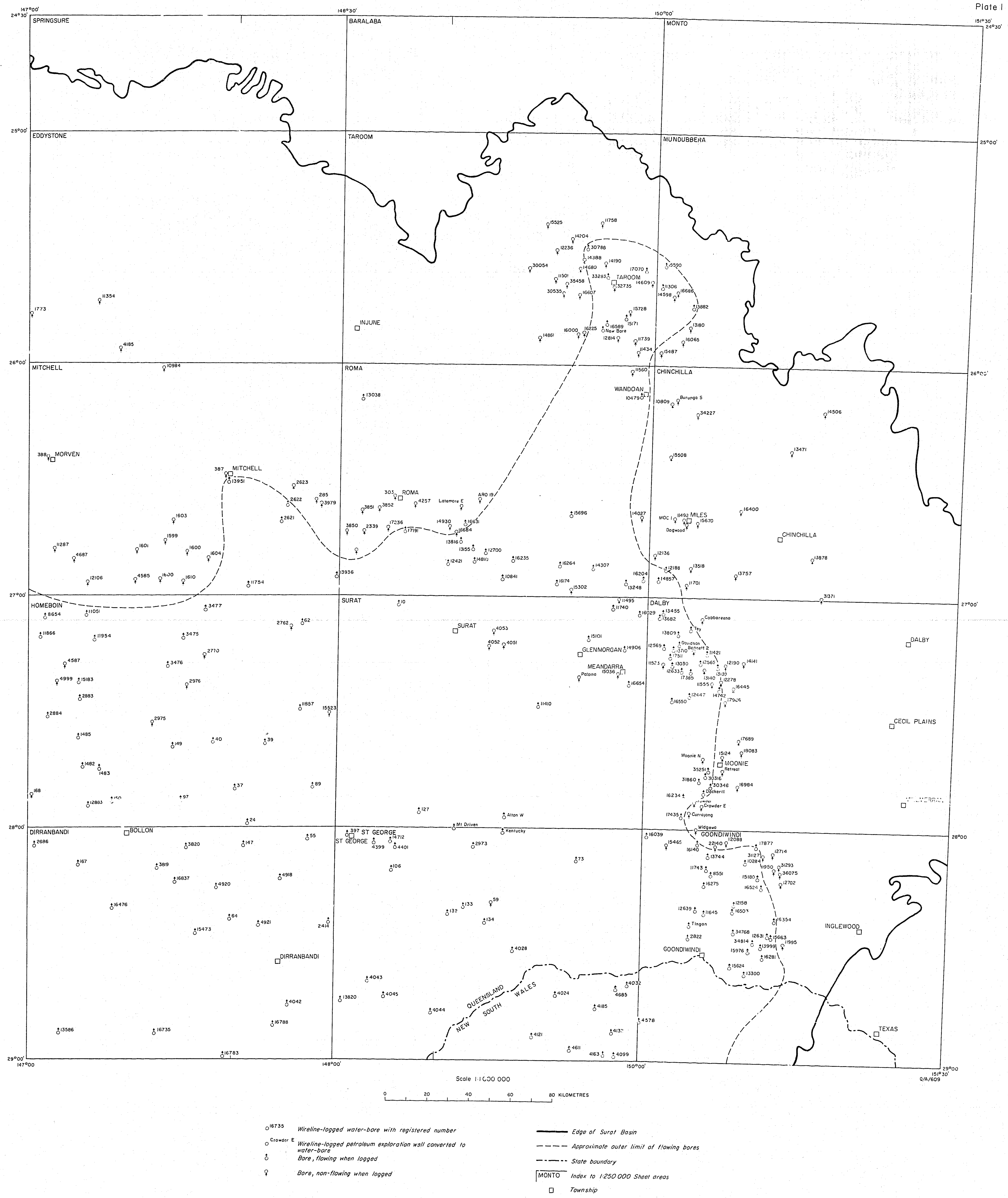
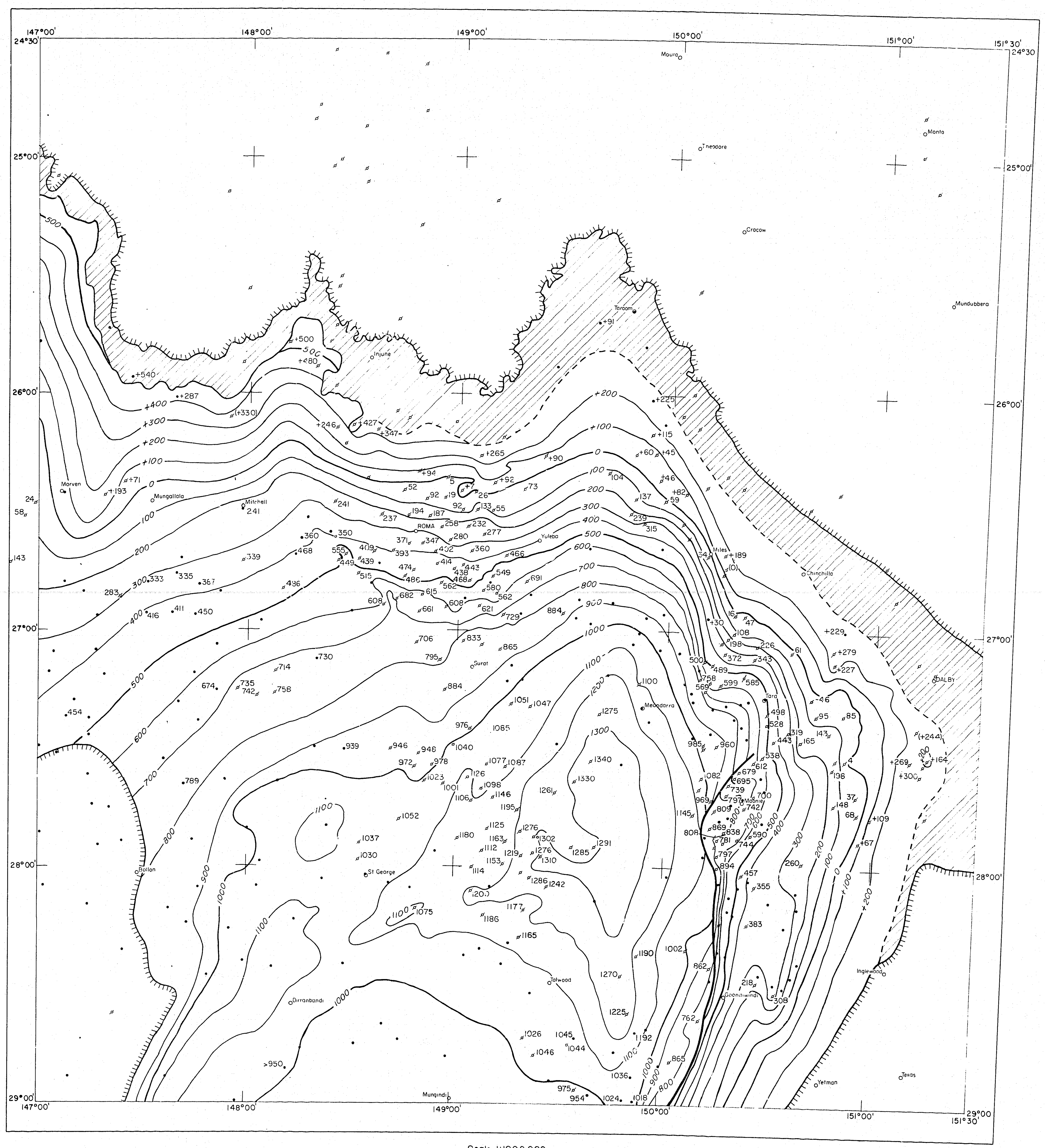


Plate I Wireline-logged water-bores in Northern Surat Basin

SURAT BASIN



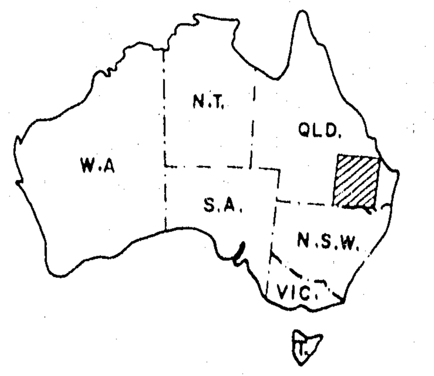
Scale 1:1000 000

Q/A 506

20 10 0 20 40 60 80 100 KILOMETRES

10 0 20 40 60 MILES

Contour interval 100 m



Limit of Walloon Coal Measures (=Birkhead Formation)

Outcrop top of Walloon Coal Measures

Fault

Outcrop of Walloon Coal Measures

Petroleum exploration well

Wireline logged water bore

Plate 2 Structure contours, top of Walloon Coal Measures

PLATE 3

DOWN UNDER WELL SERVICES PTY. LTD.

GAMMA RAY NEUTRON LOG

GAMMA RAY NEUTRON LOG
R.N. 11739
Name LANGDALE

BUREAU OF MINERAL RESOURCES
WATER BORE LOGGING PROGRAMME
GREAT ARTESIAN BASIN QUEENSLAND

R.N. 11739 Name LANGDALE

LOCATION: LAT. 25°53'27" LONG. 148°53'58"

OTHER SERVICES

PERMANENT DATUM	GL	ELEV	
MEASURED FROM	0	FT ABOVE PERM DATUM	
MEASURED FROM	GL		
ELEV	KB	DF	GL

DATE	8 Nov. 73
RUN No	GR-N
TYPE LOG	GR-N
DEPTH DRILLER	2006
DEPTH LOGGER	1947
BOTTOM LOGGED INTERVAL	1946
TOP LOGGED INTERVAL	20
TYPE FLUID IN HOLE	WATER
SALINITY PPM NaCL	-
DENSITY	-
LEVEL	150
MAX. REC TEMP. DEG F	106
OPERATING RIG TIME	-
RECORDED BY	A. RADESKI
WITNESSED BY	

BORE-HOLE RECORD				CASING RECORD			
RUN NO	BIT	FROM	TO	SIZE	WGT	FROM	TO
						0	1946

Q/A/610

FOLD HERE

THIS HEADIND AND LOG CONFORMS TO API RP 33

EQUIPMENT DATA

GAMMA RAY		
RUN No.	1	
TOOL MODEL No	CG 27x40	
DIAMETER	1 11/16"	
DETECTOR MODEL No	-	
TYPE	G-M	
LENGTH	18"	
DISTANCE TO N.SOURCE	9'	
GENERAL		
HOIST TRUCK No	-	
INSTRUMENT TRUCK No	1	
TOOL SERIAL No.	27	

NEUTRON		
RUN No	1	
LOG TYPE	N	
TOOL MODEL No	CG 27x40	
DIAMETER	1 11/16"	
DETECTOR MODEL No	-	
TYPE	PROP.	
LENGTH	6"	
SOURCE MODEL No	-	
SERIAL No	1278	
SPACING	17"	
TYPE	AmBe	
STRENGTH	3 Cu	

LOGGING DATA

GENERAL				GAMMA RAY				NEUTRON			
RUN No	DEPTHS FROM	DEPTHS TO	SPEED FT/MIN	T.C SEC	SENS SETTINGS	ZERO DIV L OR R	AP G.R. UNITS PER LOG DIV	T.C SEC	SENS SETTINGS	ZERO DIV L OR R	API N. UNITS PER LOG DIV.
1	1946	20	30	5	510	0	10		99	0	100

REFERENCE LITERATURE

REMARKS WATER SAMPLE NOT AVAILABLE

GAMMA RAY API UNITS	DEPTH	STRATIGRAPHY	NEUTRON API UNITS
0 — 100; 1 MIN MARKS; CASING COLLAR LOCATOR	Scale 1" = 100'		0 — 1000 — 2000; 2000 — 3000 — 4000

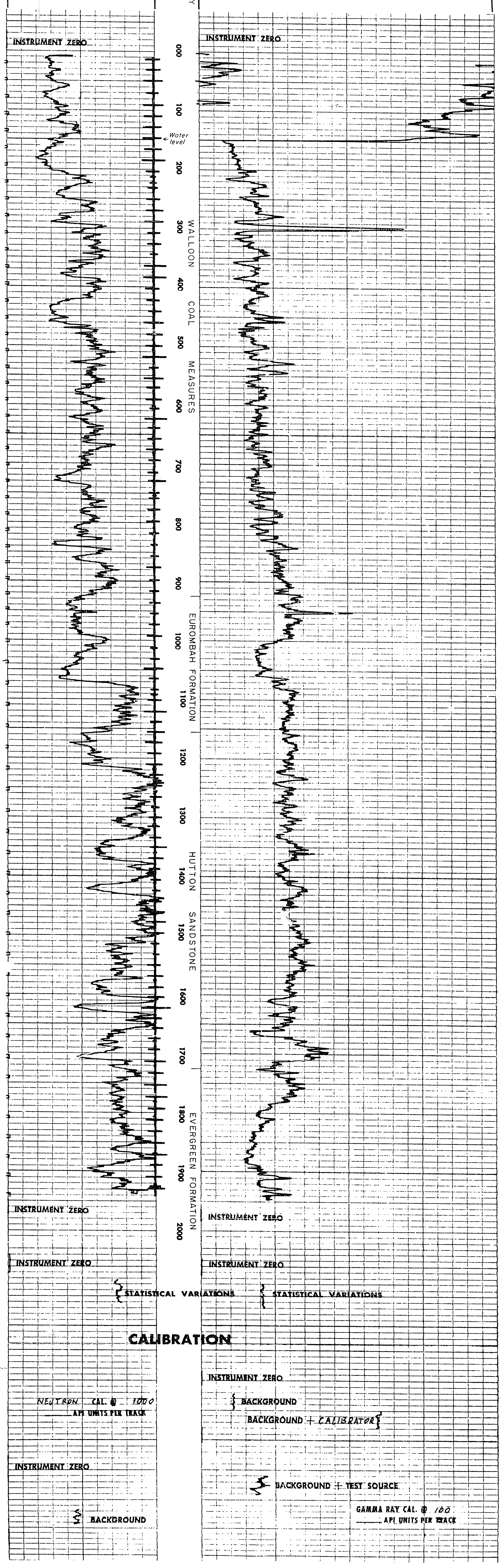


PLATE 4

DOWN UNDER WELL SERVICES PTY. LTD.

Differential Temperature Log

R.N. 11739
NAME LANGDALE

BUREAU OF MINERAL RESOURCES
WATER BORE LOGGING PROGRAMME
GREAT ARTESIAN BASIN QUEENSLAND

R.N. 11739 NAME LANGDALE

LOCATION. APPROX
LAT 25 ° 53 ' 27" MILES N
LONG 149 ° 53 ' 58" MILES E

OTHER SERVICES G.R ✓

PERMANENT DATUM. GL ELEV
LOG MEASURED FROM 0 FT. ABOVE PERM. DATUM
DRILLING MEASURED FROM GL

ELEV: KB
DF
GL

DATE	8 Nov 73		
RUN NO.	1		
DEPTH DRILLER	2006		
DEPTH LOGGER	1947		
BTM. LOG INTER.	1947		
TOP LOG INTER.	230		
TYPE LOG	dT & T		
TYPE FLUID IN HOLE	Water		
SALINITY, PPM NaCl	-		
DENSITY	1		
LEVEL	150		
MAX. REC. TEMP. °F	106		
OPERATING RIG TIME	-		
RECORDED BY	A. RADESKI		
WITNESSED BY			

BORE-HOLE RECORD				CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT	FROM	TO
						0	1946+

0/A/611

TEST DATA			
RUN No.	1	2	3
DEPTH FROM	230		
TO	1947		
LOGGING SPEED ft min.	30		
TIME: START			
FINISH			
TEMP. LOG: °F/INCH	4		
MAX TEMP	106		
DIFF. LOG: SENS.	100		
SPACING	6'		

EQUIPMENT DATA

TOOL: DIAM. 1 11/16"
No. CDT 23 TC 101
PANEL: No. DT 3A-42
TRUCK: No. 1
OTHER DATA

BORE DATA

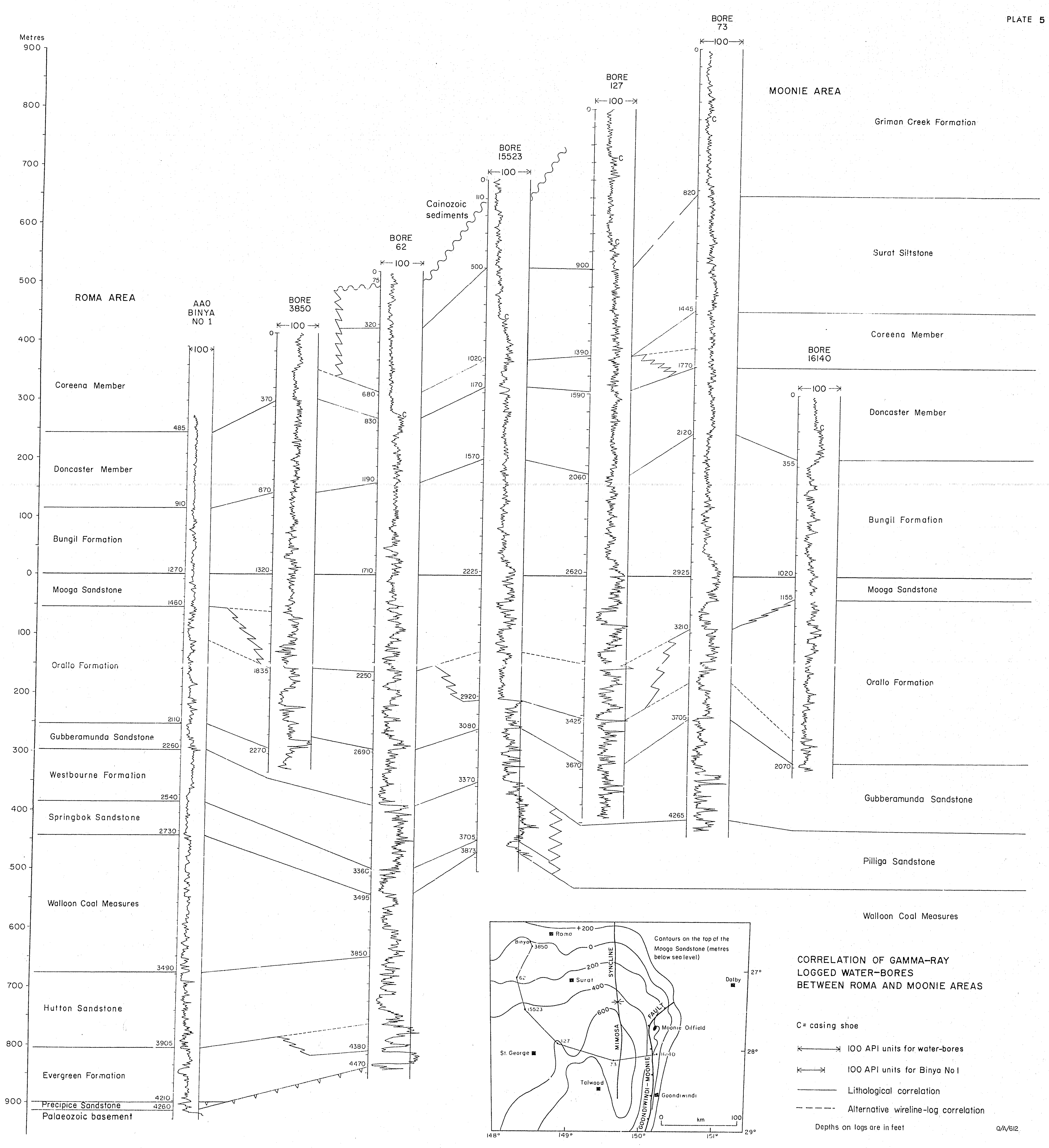
PUMPING
S.W.L. 150'
PUMP AT 220'

REMARKS: Recorded DOWN
WATER SAMPLE NOT AVAILABLE
RECORDING STARTED BELOW PUMP CASING

TEMPERATURE

C.C.L. DEPTH ← DECREASE INCREASE → 1 MIN. MARKS

PLATE 5



CORRELATION OF GAMMA-RAY LOGGED WATER-BORES BETWEEN ROMA AND MOONIE AREAS

PLATE A

GEOLOGY OF THE

NORTHERN PART OF THE SURAT BASIN

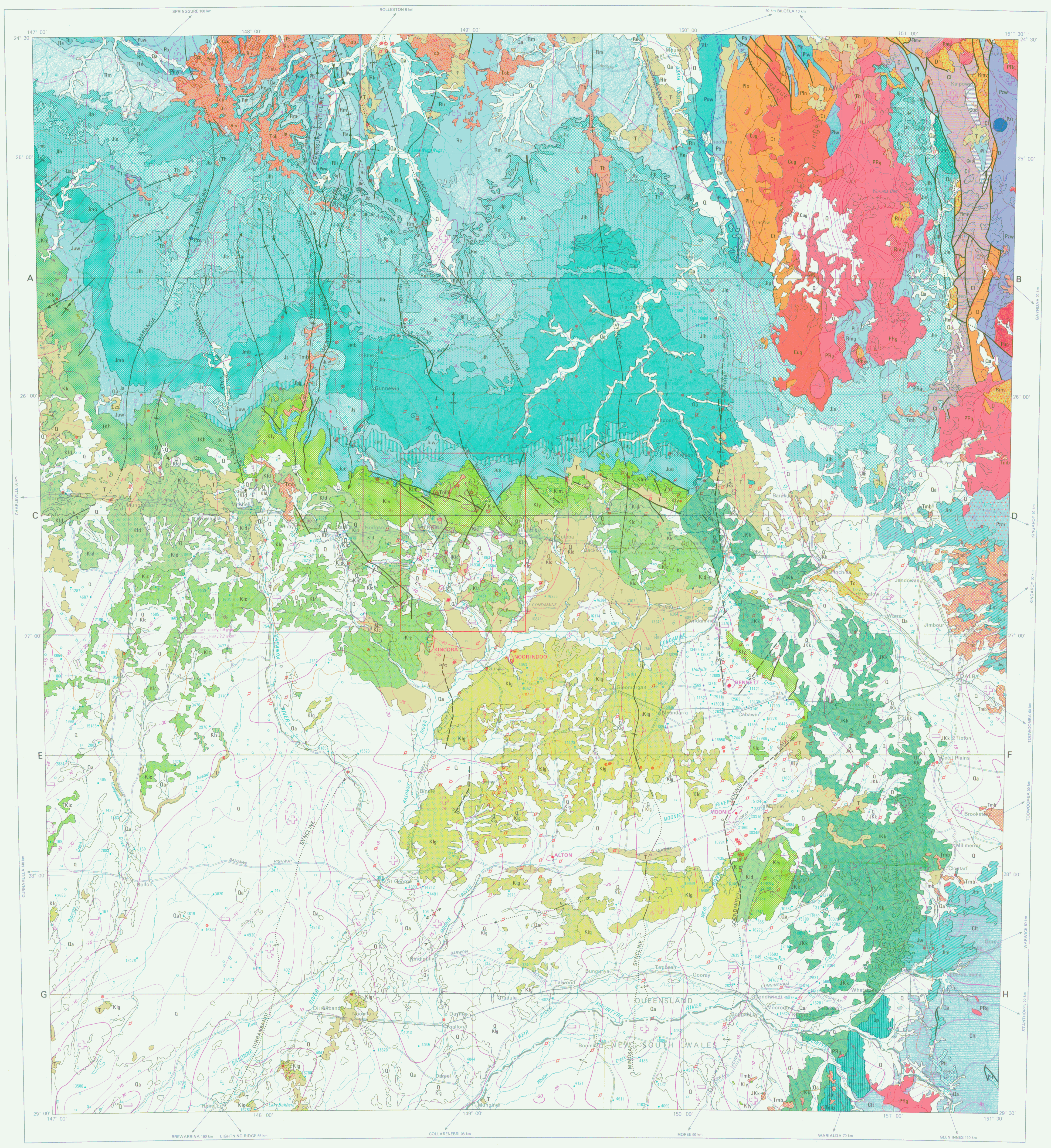
QUEENSLAND

1976

Scale 1 : 1 000 000

20 10 0 20 40 60 80 100 KILOMETRES

Lambert Conformal Conic Projection, standard parallels 25° 15′ and 28° 15′

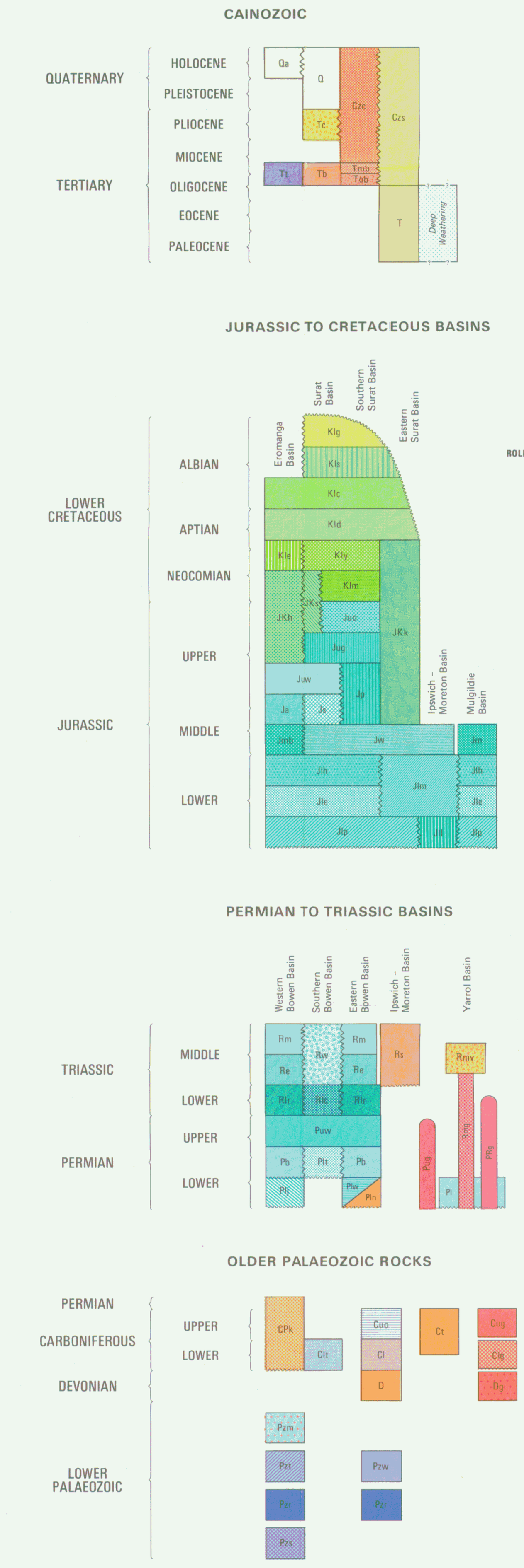


Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Resources. Issued under the authority of the Minister for National Resources.
Geology generalized from 1:250 000 Geological Series.
Base map compiled by BMR from 1:250 000 Planimetric Series of the Division of National Mapping, Department of National Resources and the Royal Australian Survey Corps.

Bibliographic reference: N. F. Exon 1975. The Geology of the Surat Basin in Queensland. Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin 166

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

Geology by officers of the Bureau of Mineral Resources, Geology and Geophysics, and the Geological Survey of Queensland
Compiled 1973-74 by N. F. Exon, J. G. A. Den Hertog, J. N. Mason
Gravimetry 1964 and 1968 by Geophysical Branch, B M R
Cartography by Geological Branch, B M R
Drawn by Mercury-Walch Pty Ltd, Hobart, Australia
Printed by Leigh-Mardon Pty. Ltd, Melbourne



Qa *Alluvium of present-day flood plains; vertebrate fossils in east*
Q *Alluvium of older flood plains; sand, gravel, soil*
Czc *Collapsed sheets of Tertiary basalt*
Czs *Poorly consolidated sandstone, conglomerate, siltstone, mudstone; residual soil*
Tc **CHINCHILLA SAND:** *Labile sandstone, conglomerate, siltstone, mudstone; vertebrate fossils*
Tmb *Basalt flows, minor pyroclastics*
Tob *Basalt flows, minor trachyte and pyroclastics*
Tb *Basalt flows, minor pyroclastics*
Tt *Gabbro intrusions including Tabor Gabbro*
T *Quartzose sandstone, conglomerate, siltstone*
Rock, mainly sediments, deeply weathered (kaolinized, ferruginized and silicified) during the Tertiary

Klg **GRIMAN CREEK FORMATION:** *Lithic sandstone, siltstone, minor mudstone; commonly glauconitic and calcareous. Shelly fossils*
Kls **SURAT SILTSTONE:** *Carbonaceous siltstone, mudstone, minor sandstone; commonly glauconitic and calcareous. Shelly fossils*
Klc **COREENA MEMBER:** *Siltstone, mudstone, sandstone; commonly glauconitic and calcareous. Shelly fossils*
Kld **DONCASTER MEMBER:** *Carbonaceous mudstone, siltstone, minor sandstone; some glauconitic and calcareous. Shelly fossils*

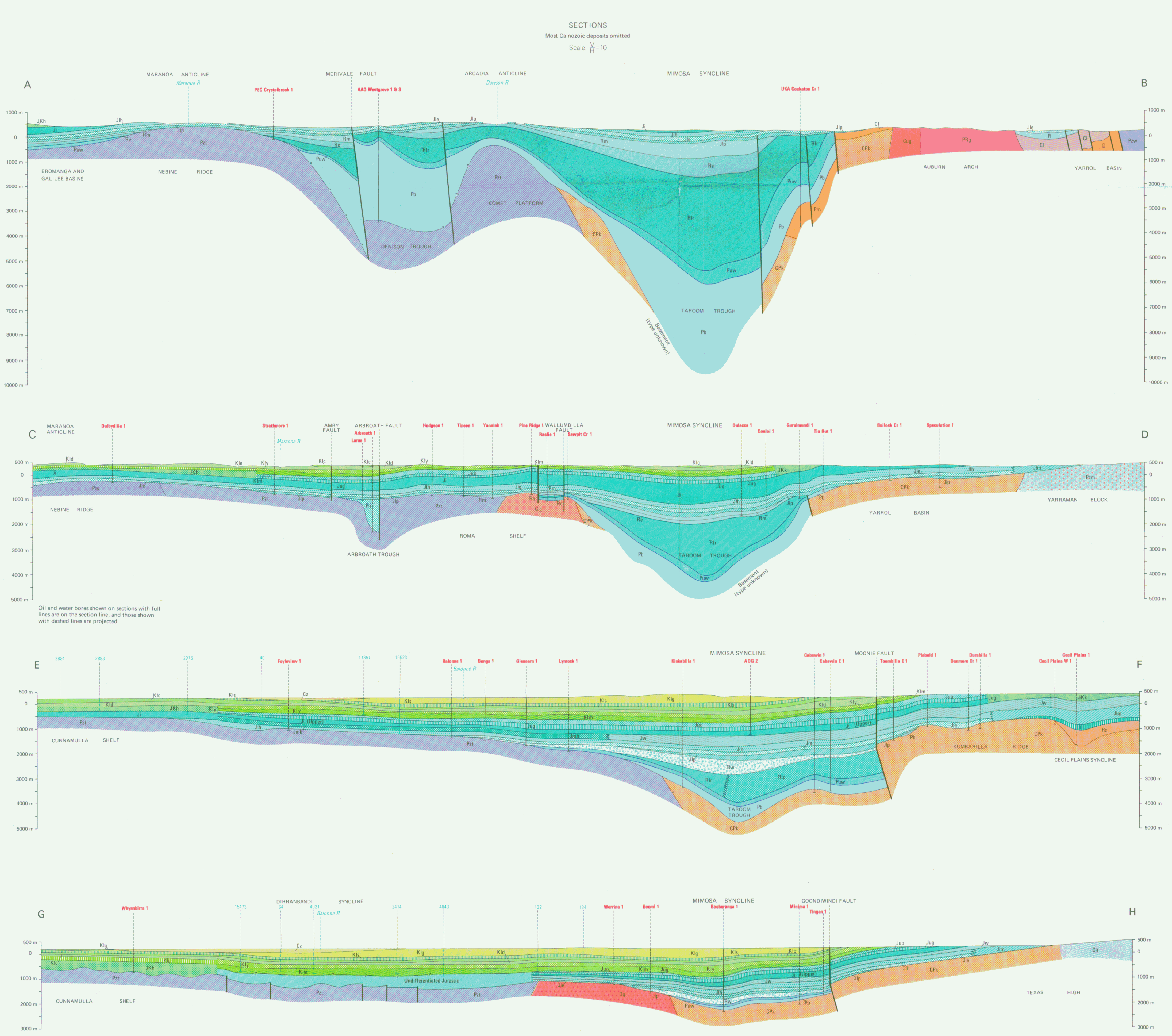
Kle **CADNA-OWIE FORMATION:** *Sandstone, siltstone; some calcareous. Shelly fossils. Section only*
Kly **BUNGIL FORMATION:** *Sandstone, siltstone, mudstone; some calcareous. Shelly fossils*
Klm **MOOGA SANDSTONE:** *Quartzose to lithic sandstone, some siltstone and mudstone*
Juo **ORALLO FORMATION:** *Lithic sublabile to very lithic sandstone, siltstone, mudstone, claystone; commonly calcareous*
Jug **GUBBERAMUNDA SANDSTONE:** *Quartzose to lithic sandstone, some siltstone*
JKs **SOUTHLANDS FORMATION:** *Quartzose to lithic sandstone, siltstone, mudstone*
JKh **HOORAY SANDSTONE:** *Quartzose to lithic sandstone, minor pebbly; some conglomerate, siltstone, mudstone*
JKk **KUMBARILLA BEDS:** *Sandstone, siltstone, mudstone*

Juw **WESTBOURNE FORMATION:** *Siltstone, mudstone, fine sublabile sandstone*
Ja **ADORI SANDSTONE:** *Quartzose to lithic sandstone*
Js **SPRINGBOK SANDSTONE:** *Lithic sublabile to very lithic sandstone, silstone, mudstone; commonly calcareous*
Jmb **BIRKHEAD FORMATION:** *Carbonaceous mudstone, siltstone, lithic to very lithic sandstone, coal*
Jw **WALLOON COAL MEASURES:** *Carbonaceous mudstone, coal, siltstone, lithic to very lithic sandstone*

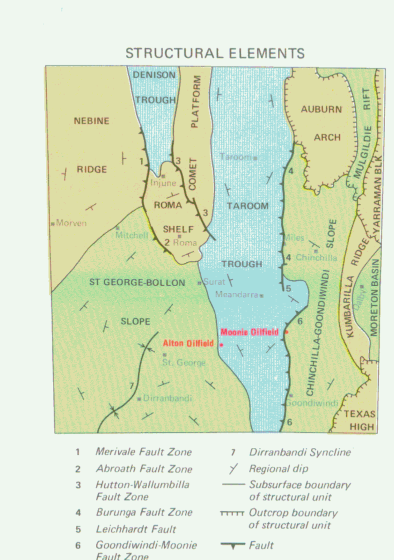
Jp **PILLIGA SANDSTONE:** *Quartzose sandstone and conglomerate*
Jm **MULGILDIE COAL MEASURES:** *Mudstone, siltstone, sandstone; some calcareous. Coal*
Jlh **HUTTON SANDSTONE:** *Quartzose sandstone, minor siltstone, mudstone*
Jle **EVERGREEN FORMATION:** *Siltstone, mudstone, quartzose to lithic sandstone; minor ironstone, some oolitic*
Jlm **MARBURG SANDSTONE:** *Sublabile to labile sandstone, siltstone; some calcareous*
Jlp **PRECIPICE SANDSTONE:** *Quartzose sandstone; some siltstone in upper part*
Jll **HELIDON SANDSTONE:** *Feldspathic sublabile sandstone, shale. Section only*

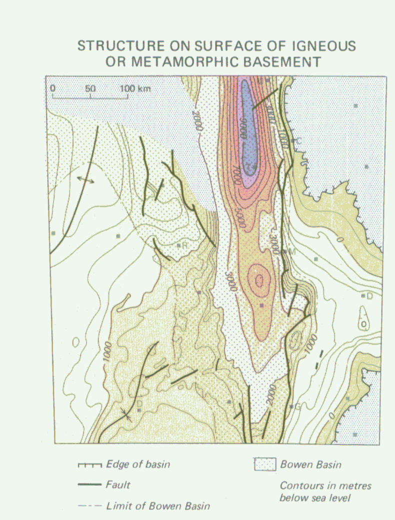
Rm **MOOLAYEMBER FORMATION:** *Sublabile to labile sandstone, siltstone, mudstone; some calcareous*
Re **CLEMATIS GROUP:** *Quartzose to sublabile sandstone; minor siltstone, mudstone*
Rlr **REWAN GROUP:** *Varicoloured shale, siltstone, sandstone, conglomerate; some tuffaceous*
Rw **WANDOAN FORMATION:** *Sandstone, conglomerate, siltstone, shale. Section only*
Rlc **CABAWIN FORMATION:** *Lithic sandstone, conglomerate. Section only*
Rs *Andesitic volcanics, conglomerate, shale, siltstone, sandstone. Section only*
Rmv *Acid to basic volcanics; minor sediments*
Puw **BLACKWATER GROUP:** *Shale, siltstone, labile sandstone, coal; some tuff in south*
Pb **BACK CREEK GROUP:** *Shale, siltstone, sandstone, conglomerate; some tuff in south. Shelly fossils*
Plt *Mudstone, pebbly mudstone, conglomerate, lithic sandstone; minor limestone. Shelly fossils. Texas area*
Plj **REIDS DOME BEDS:** *Shale, siltstone, sandstone; lesser conglomerate and coal. Section only*
Plw **RANNES BEDS:** *Mudstone, limestone, phyllite, slate, sandstone and chert with lenses of volcanics*
Pln **CAMBOON ANDESITE:** *Andesite, dacite, basalt, rhyolite, agglomerate*
Pl *Conglomerate, lithic sandstone, intermediate and acid volcanics, siltstone*
Rmg *Granite, granodiorite*
Pug *Granite, granodiorite*
PRg *Granite, granodiorite*

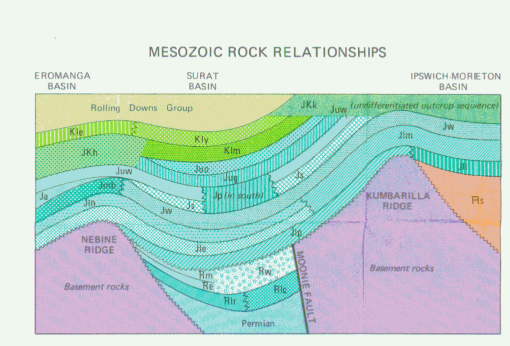
Ct **TORSDALE BEDS:** *Acid and intermediate volcanics, lithic sandstone, conglomerate, siltstone*
CPk **KUTTUNG FORMATION:** *Tuff, andesite, dacite, siltstone, sandstone, conglomerate, shale. Section only*
Cuo **BOILING CREEK GROUP:** *Lithic sandstone, siltstone, mudstone, conglomerate, limestone*
Clt **TEXAS BEDS:** *Lithic sandstone, mudstone, shale; minor chert, jasper, limestone, andesite. Shelly fossils*
Cl *Mudstone, siltstone, lithic sandstone, limestone, acid and intermediate volcanics*
D *Intermediate and basic volcanics, lithic sandstone, siltstone, conglomerate*
Cug *Granodiorite, adamellite, (Part of Auburn Complex)*
Clg **ROMA GRANITES:** *Adamellite, granite. Section only*
Dg *Granite. Section only*
Pzm *Schist, gneiss, foliated granodiorite; acid to basic dykes. Yarraman Block*
Pzt **TIMBURY HILLS FORMATION:** *Sandstone, siltstone, shale and metamorphosed equivalents. Section only*
Pzs *Gneiss, schist. Section only*
Pzr *Gabbro and ultrabasic plutonic rocks. Maranoa Anticline; Monto area*
Pzw **WANDILLA FORMATION:** *Siltstone, sandstone, chert*

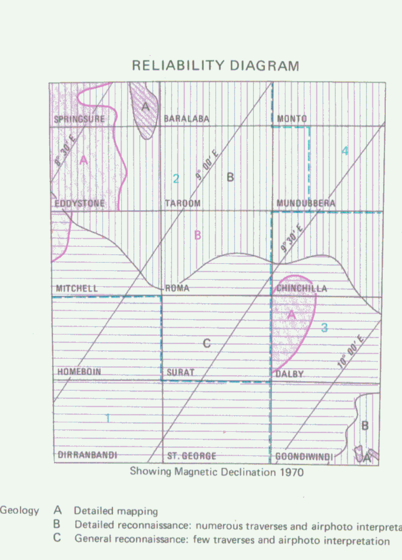


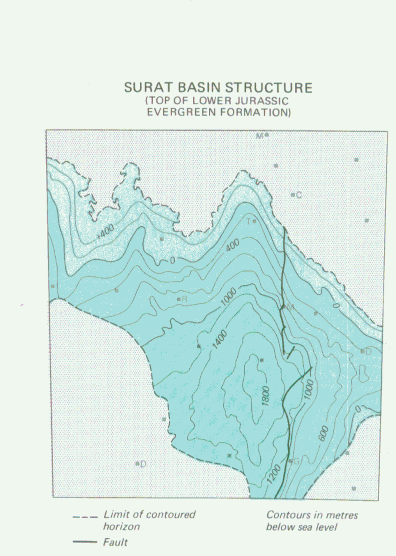
Geological boundary
Important regional unconformity – base of Surat Basin sequence
Anticline, showing plunge





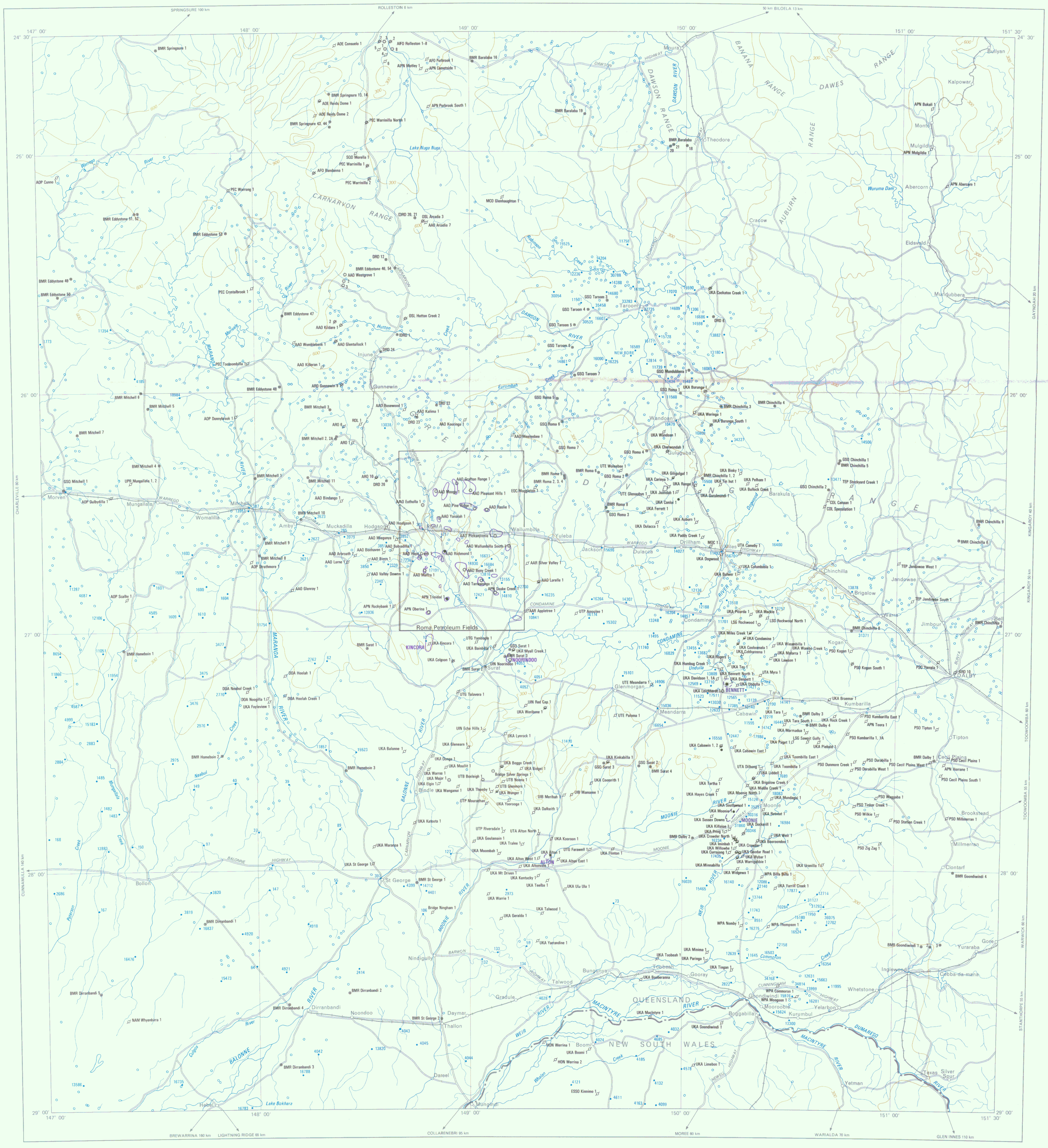






NORTHERN PART OF THE SURAT BASIN

1 : 1 000 000



PETROLEUM EXPLORATION WELLS AND WIRELINE LOGGED WATER BORES IN THE NORTHERN PART OF THE SURAT BASIN

Scale 1 : 1 000 000

20 10 0 20 40 60 80 100 KILOMETRES

Lambert Conformal Conic Projection

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of Minerals and Energy. Issued under the authority of the Minister for Minerals and Energy. Base map compiled by BMR from 1 : 250,000 Planimetric Series of the Division of National Mapping, Department of Minerals and Energy and the Royal Australian Survey Corps

Printed by: Mercury—Walch Pty Ltd., Hobart, Australia

Oil field

Gas field

Limit of group of wells with same name

Abandoned dry well

Oil well

Abandoned well with show of oil

Gas well

Abandoned gas well

Abandoned well with show of gas

Oil and gas well

Abandoned well with show of oil and gas

Gas condensate well

Stratigraphic drill hole

Water bore

24 Water bore, gamma-ray logged; with IWS registered number in Queensland, WCIC registered number in NSW

300 Topographic contour in metres

Highway

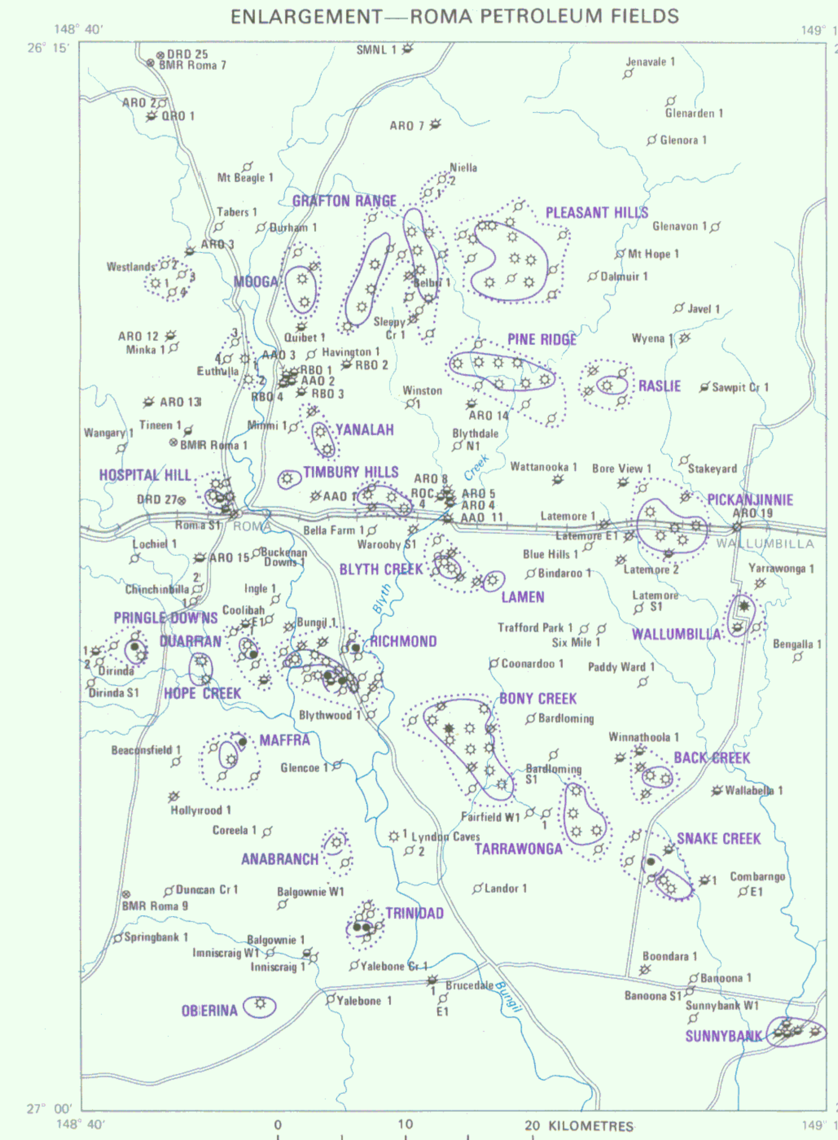
Road

Railway

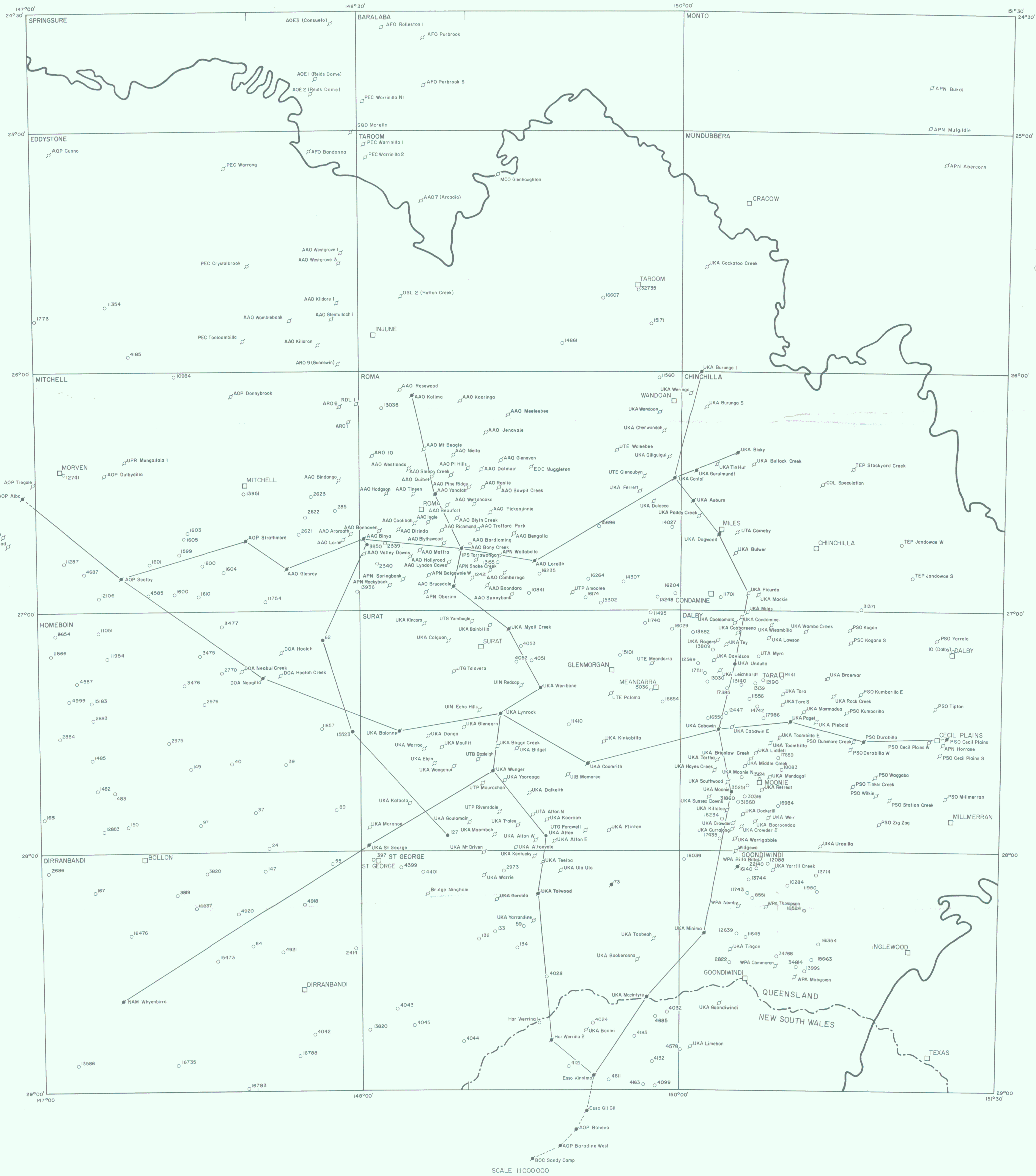
Town

State boundary

ENLARGEMENT—ROMA PETROLEUM FIELDS



PETROLEUM EXPLORATION WELLS AND WIRELINE LOGGED WATER BORES USED AS DATA POINTS



UKA Tey — *Petroleum exploration well*

UKA Binky — *Petroleum exploration well used for correlation diagrams*

1483 — *Wireline logged water bore with registered number*

15523 — *Wireline logged water bore with registered number used for correlation diagrams*

Line of correlation diagrams

Edge of Surat Basin

State boundary

ST GEORGE — *Index to 1:250 000 sheet areas*

PLATE 2

ELECTRIC LOG CORRELATION
OF PETROLEUM EXPLORATION
WELLS FROM WEST TO EAST
(MORVEN TO MILES)

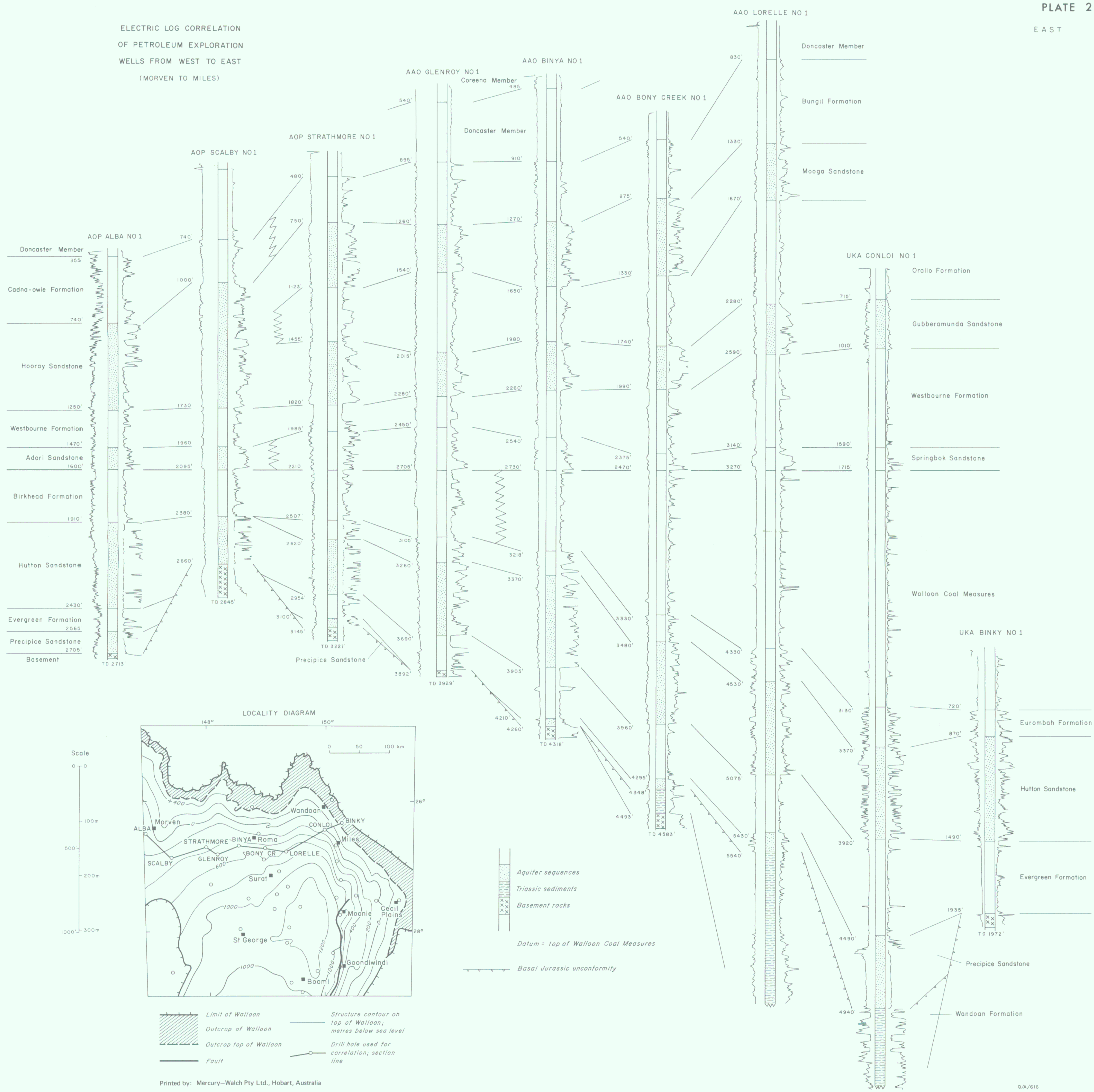


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PLATE 3

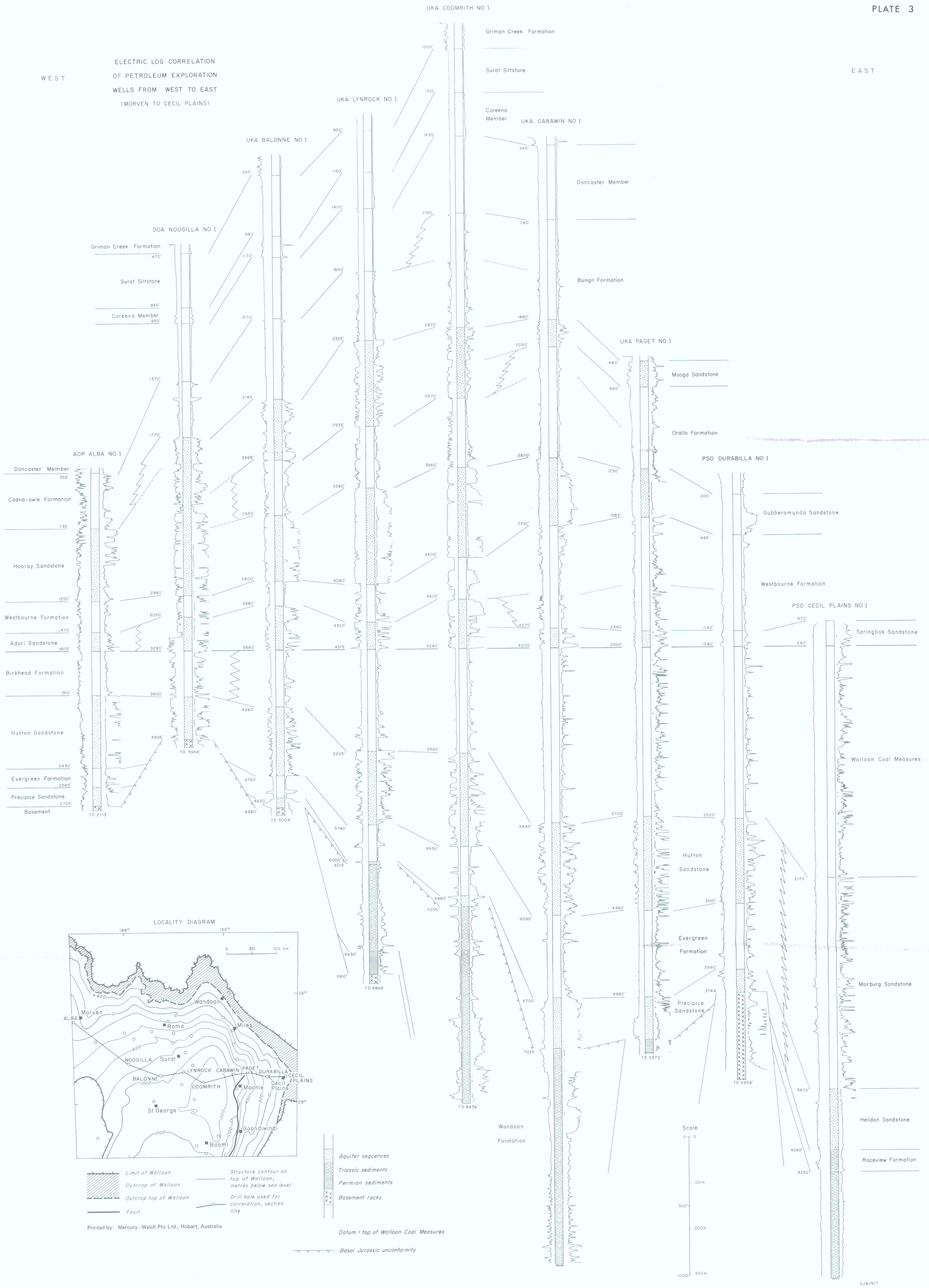
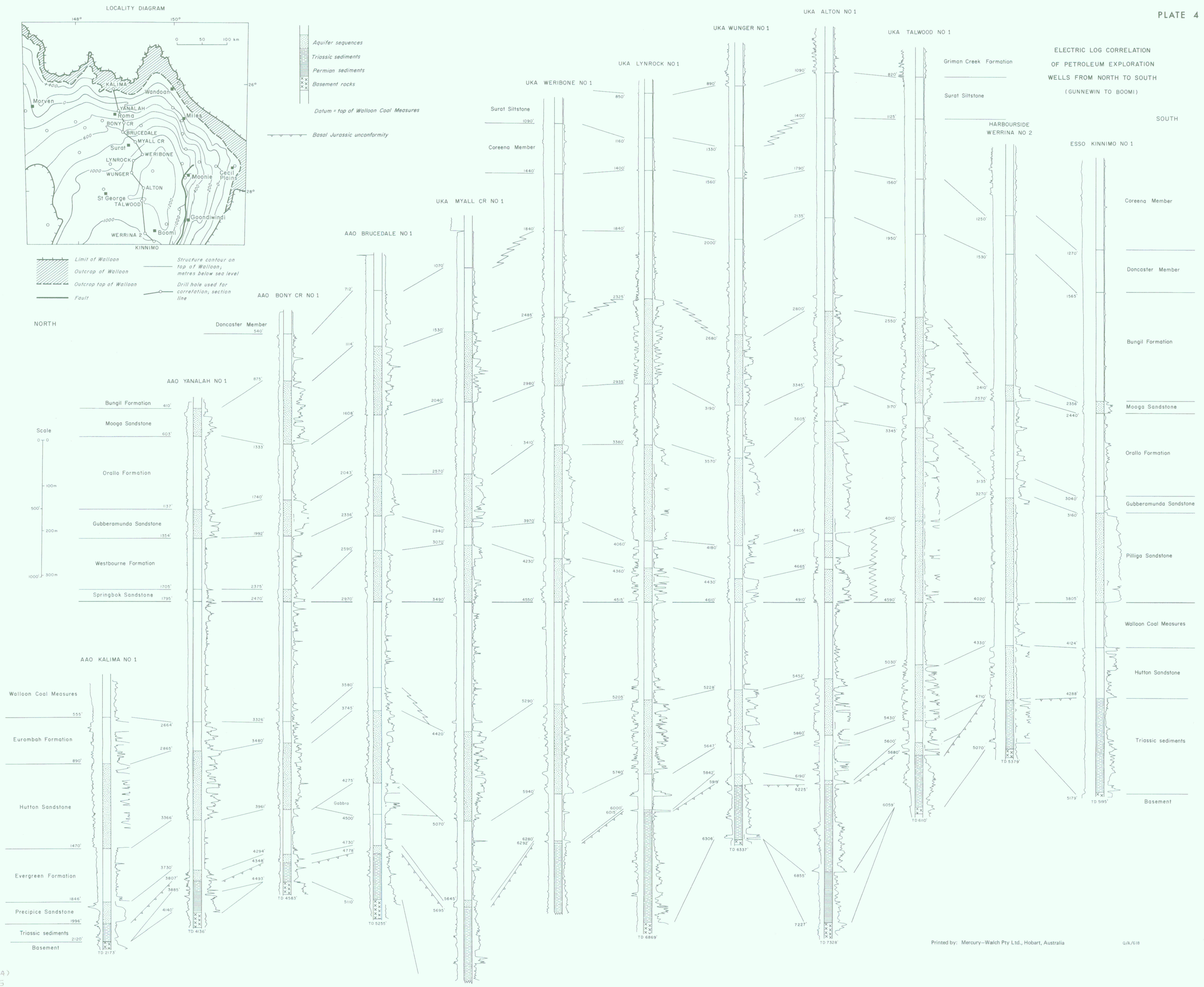

ELECTRIC LOG CORRELATION
OF PETROLEUM EXPLORATION
WELLS FROM WEST TO EAST
(MORVEN TO CECIL PLAINS)
WEST
EAST
AOP ALBA NO 1
DOA NOOGILLA NO 1
UKA BALONNE NO 1
UKA LYNROCK NO 1
UKA COOMRITH NO 1
UKA CABAWIN NO 1
UKA PAGET NO 1
PSO DURABILLA NO 1
PSO CECIL PLAINS NO 1
Griman Creek Formation
Surat Siltstone
Coreena Member
Doncaster Member
Cadna-owie Formation
Hooray Sandstone
Westbourne Formation
Adori Sandstone
Birkhead Formation
Hutton Sandstone
Evergreen Formation
Precipice Sandstone
Basement
Bungil Formation
Mooga Sandstone
Orallo Formation
Gubberamunda Sandstone
Springbok Sandstone
Walloon Coal Measures
Marburg Sandstone
Helidon Sandstone
Raceview Formation
Wandoan Formation
TD 2713'
TD 3944'
TD 5004'
TD 6869'
TD 8436'
TD 5372'
TD 4358'
LOCALITY DIAGRAM
146°
150°
26°
28°
0 50 100 km
ALBA
Marven
Roma
Wandoan
Miles
NOOGILLA
Surat
BALONNE
LYNROCK
CABAWIN
PAGET
DURABILLA
CECIL PLAINS
COOMRITH
Moonie
Cecil Plains
St George
Goondiwindi
Boomi
Limit of Walloon
Outcrop of Walloon
Outcrop top of Walloon
Fault
Structure contour on top of Walloon; metres below sea level
Drill hole used for correlation; section line
Aquifer sequences
Triassic sediments
Permian sediments
Basement rocks
Datum = top of Walloon Coal Measures
Basal Jurassic unconformity
Scale
100m
200m
300m
Printed by: Mercury-Walch Pty Ltd., Hobart, Australia
Q/A/617

PLATE 4

ELECTRIC LOG CORRELATION
OF PETROLEUM EXPLORATION
WELLS FROM NORTH TO SOUTH
(GUNNEWIN TO BOOMI)



Printed by: Mercury–Walch Pty Ltd., Hobart, Australia

Q/A/618

PLATE 5

ELECTRIC LOG CORRELATION OF PETROLEUM EXPLORATION WELLS FROM NORTH TO SOUTH

(WANDOAN TO BOOMI)

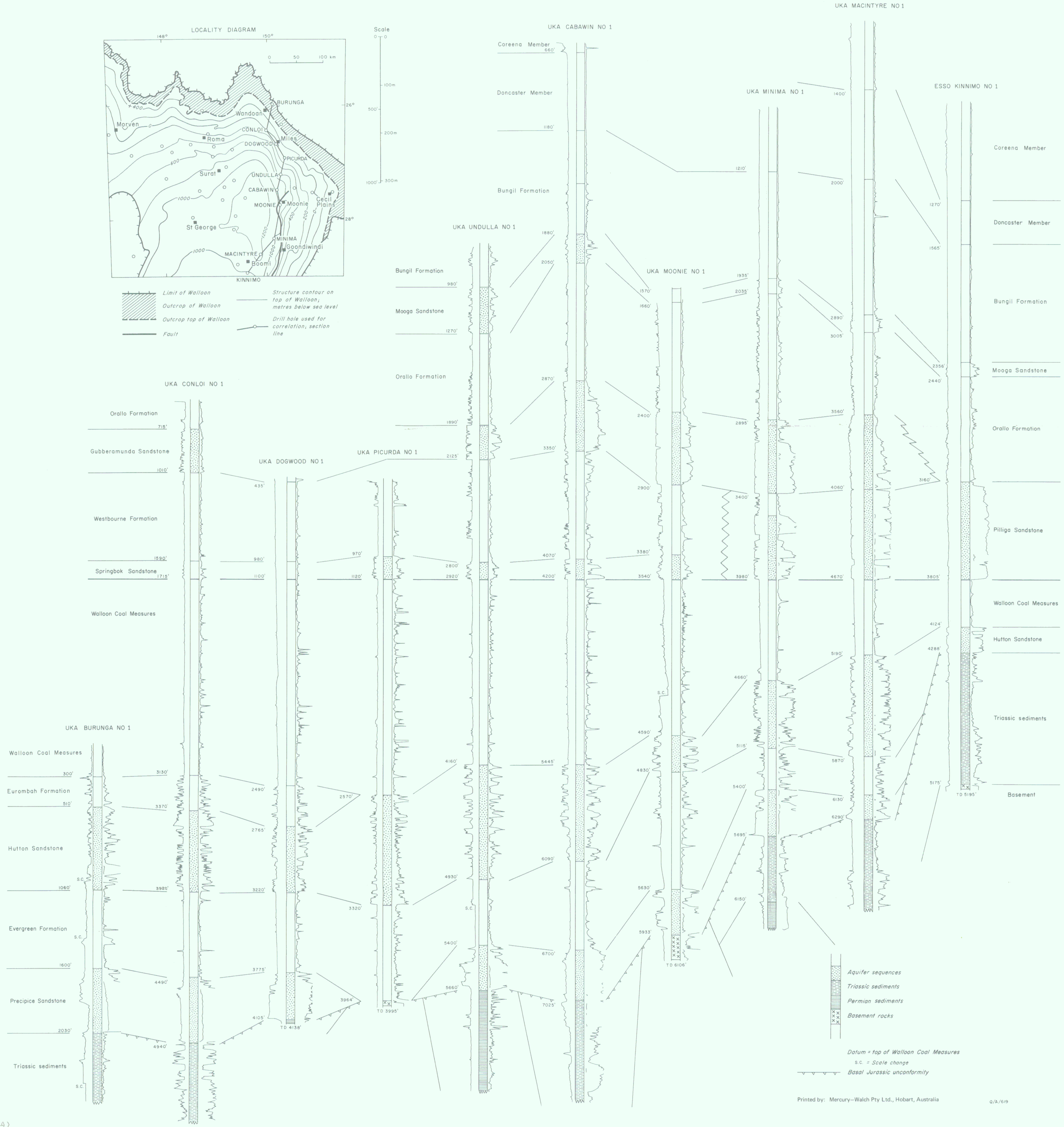


PLATE 6

ELECTRIC LOG CORRELATION OF PETROLEUM EXPLORATION WELLS IN THE SOUTHWEST

(WUNGER NO 1 TO WHYENBIRRA NO 1)

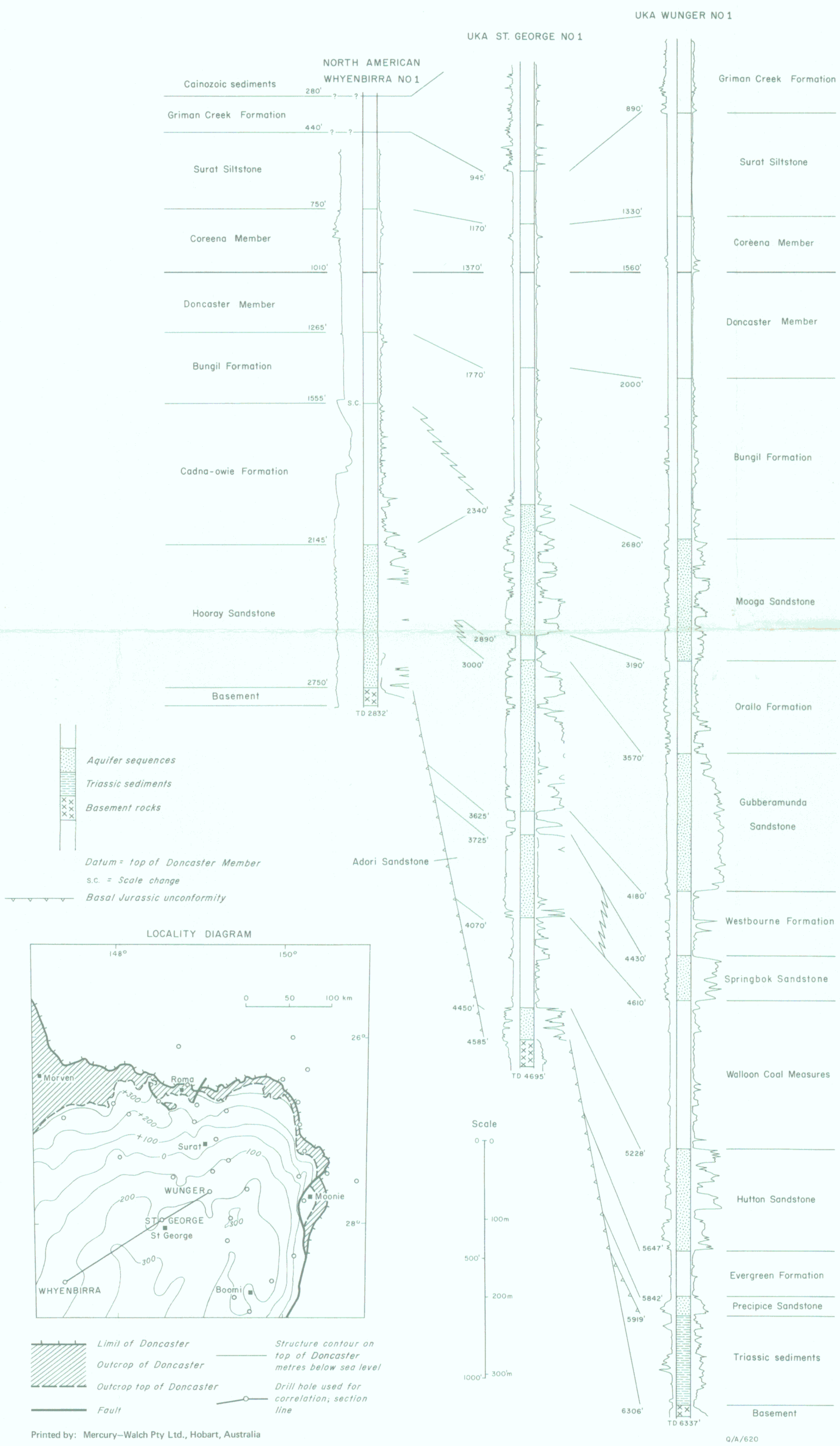


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PLATE 7

ELECTRIC LOG CORRELATION OF PETROLEUM EXPLORATION WELLS IN THE SOUTH

(KINNIMO NO 1 TO SANDY CAMP NO 1)

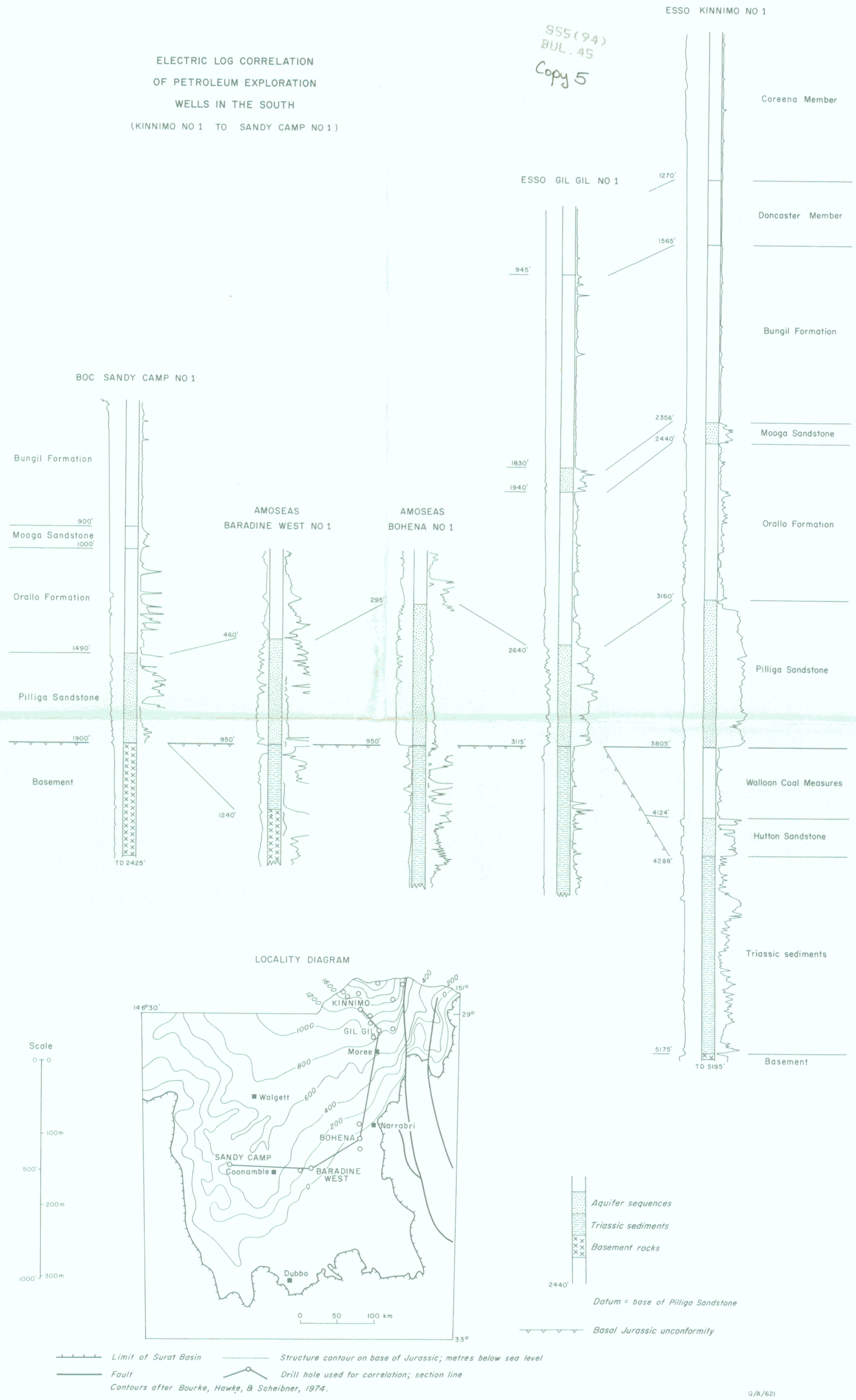
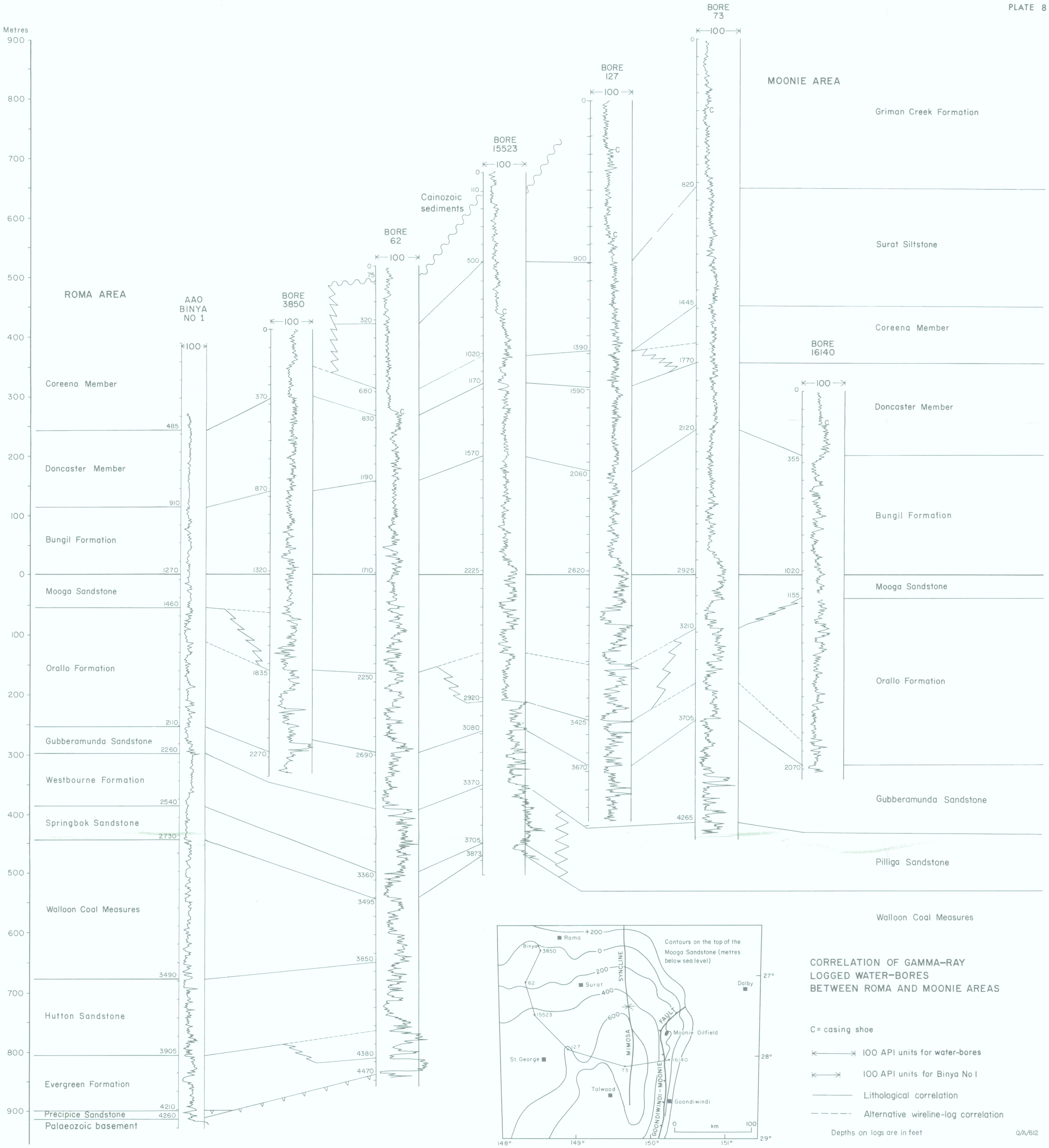


PLATE 8



CORRELATION OF GAMMA-RAY LOGGED WATER-BORES BETWEEN ROMA AND MOONIE AREAS

SSS(94) BUL. 45
Copy 5

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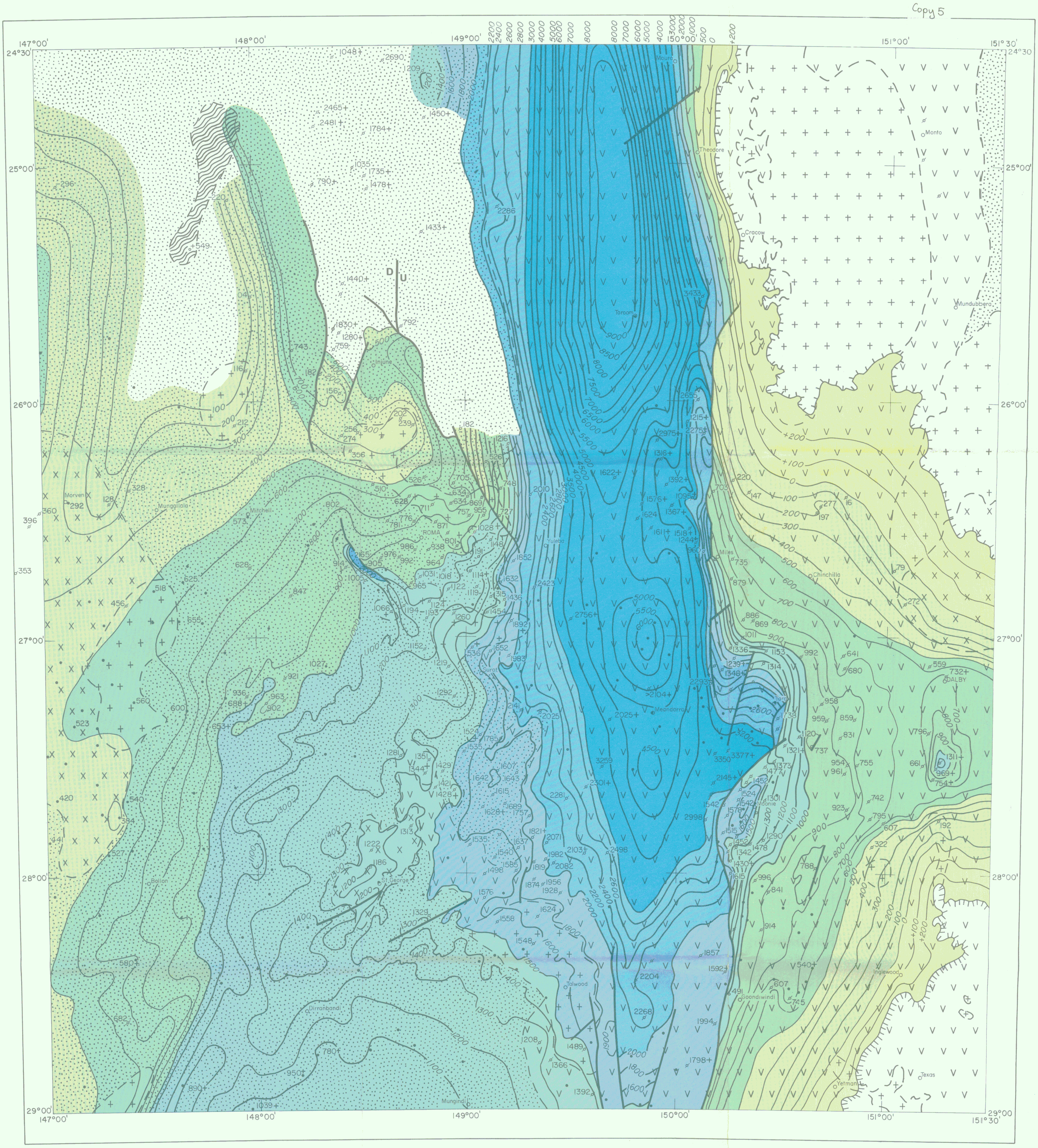
SURAT BASIN



Scale 1:1000 000

Q/A 503

20 10 0 20 40 60 80 100 KILOMETRES
10 0 20 40 60 MILES

V V — Volcanics and sediments of the 'Kuttung Formation' and equivalents

Sandstone, siltstone, shale, and their metamorphosed equivalents: Timbury Hills Formation and Wandella Formation

+ + — Granite and granodiorite

X X — Schist and gneiss

Gabbro and ultrabasic rocks

Outcrop margin of basinal sediment

Geological boundary

Fault

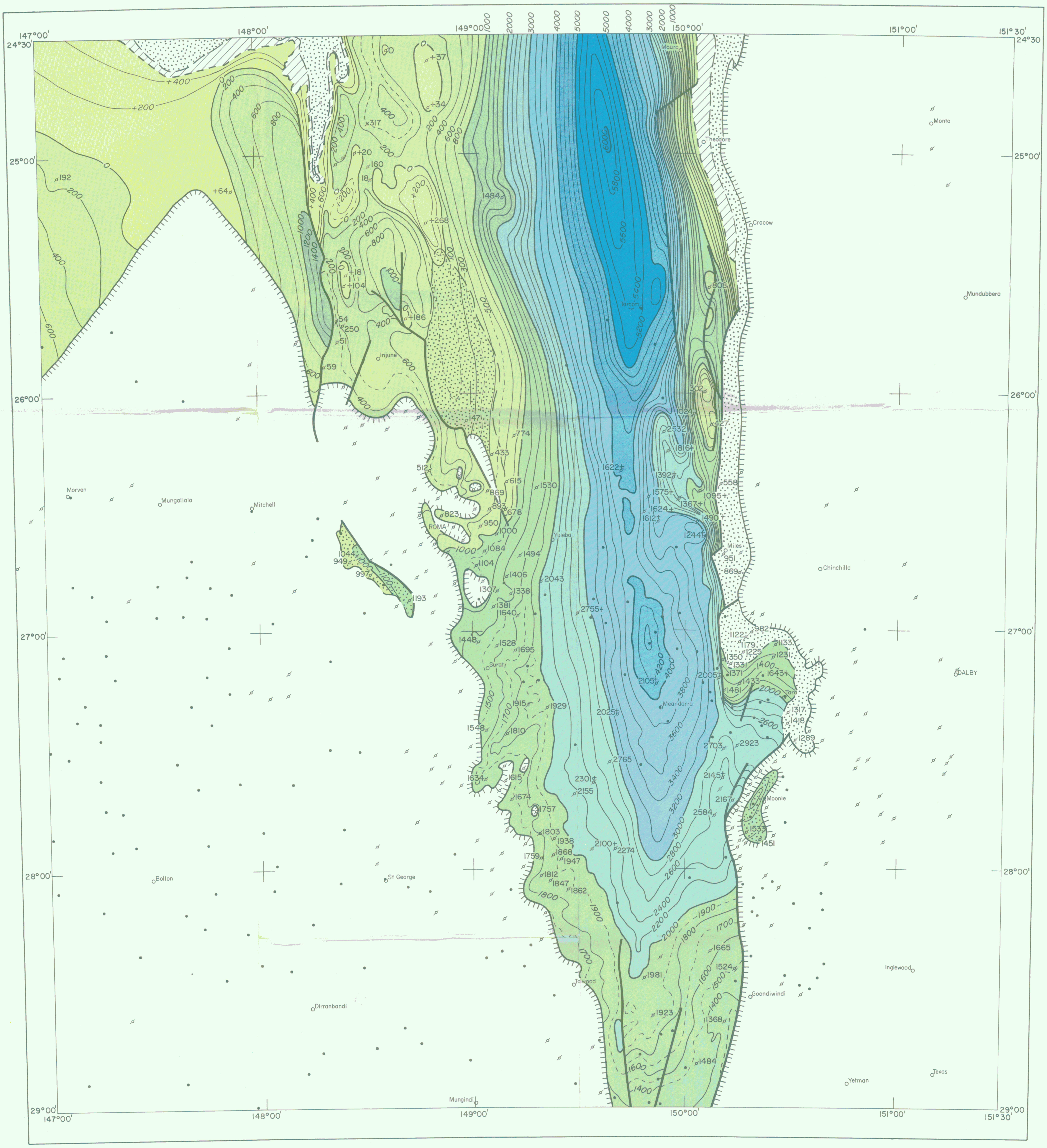
≥1000 m / <1000 m — Structure contours (below sea level)

Petroleum exploration well

Wireline-logged water bore

Plate 9 Structure contour, top of basement.

SURAT BASIN



Scale 1:1000 000

Q/A 504

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10 0 20 40 60 MILES

Lower Permian alone present

Upper Permian outcrop

Limit of Permian sediments

Base of Upper Permian

Top of Permian in outcrop

1000m
800m
700m
Structure contours (below sea level)

Fault

Petroleum exploration well

Wireline-logged water bore

Plate 10 Structure contours, top of Permian sequence

SURAT BASIN

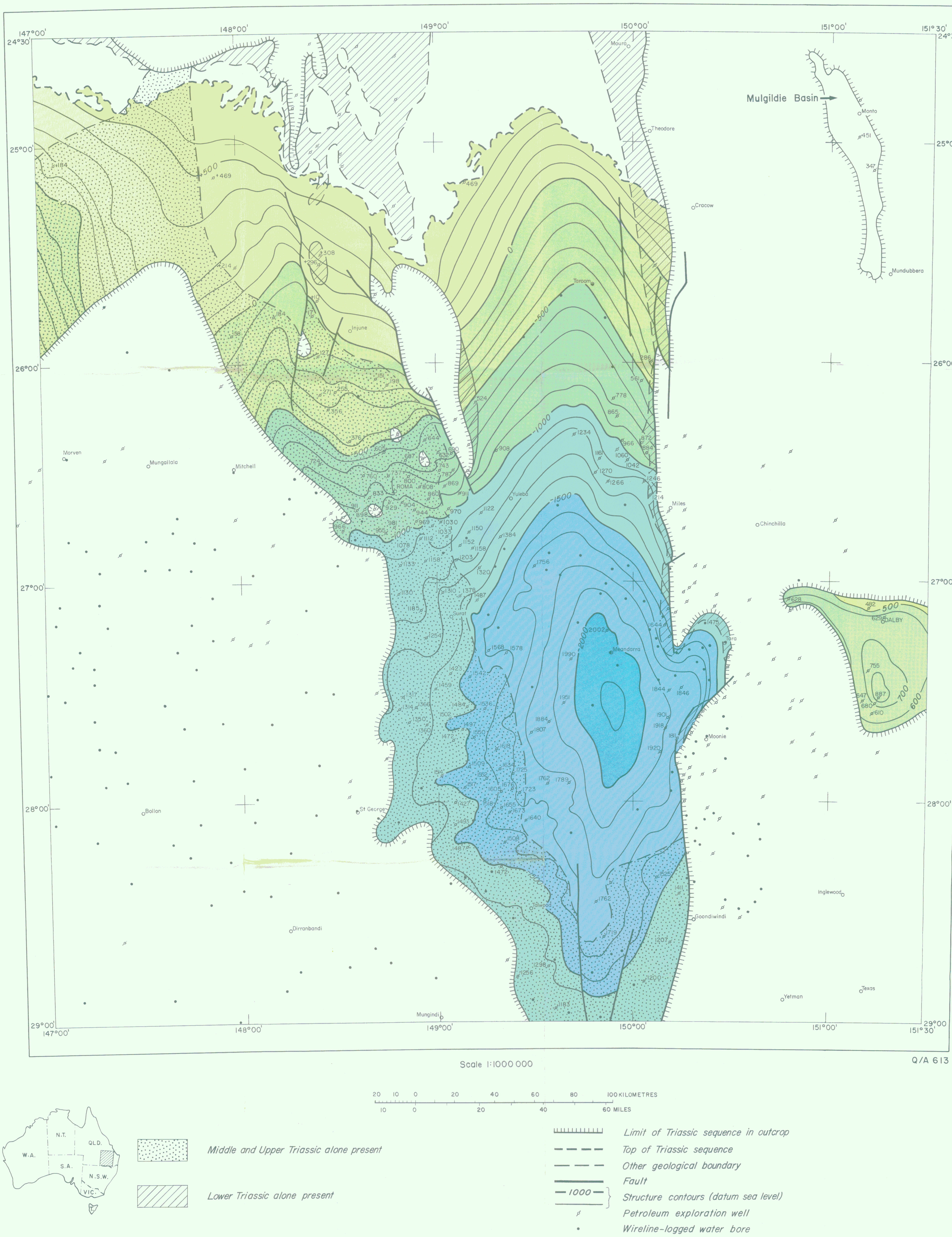
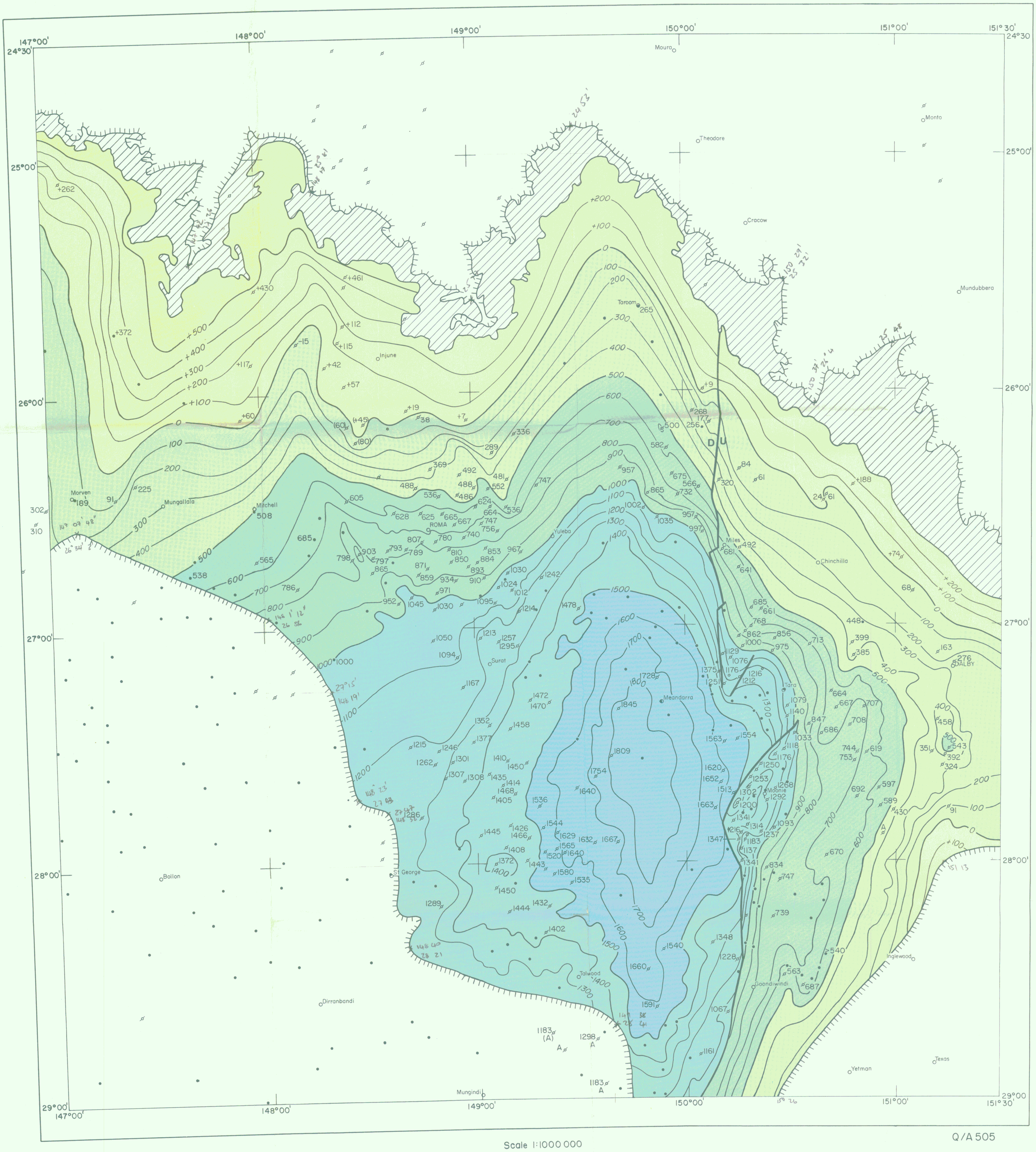


Plate II Structure contours, top of Triassic sequence

SURAT BASIN



Scale 1:1000 000

20 10 0 20 40 60 80 100 KILOMETRES
10 0 20 40 60 MILES

Contour interval 100m (below sea level)

Limit of the Evergreen Formation

Top of outcrop of the Evergreen Formation

Fault

Outcrop of Evergreen Formation

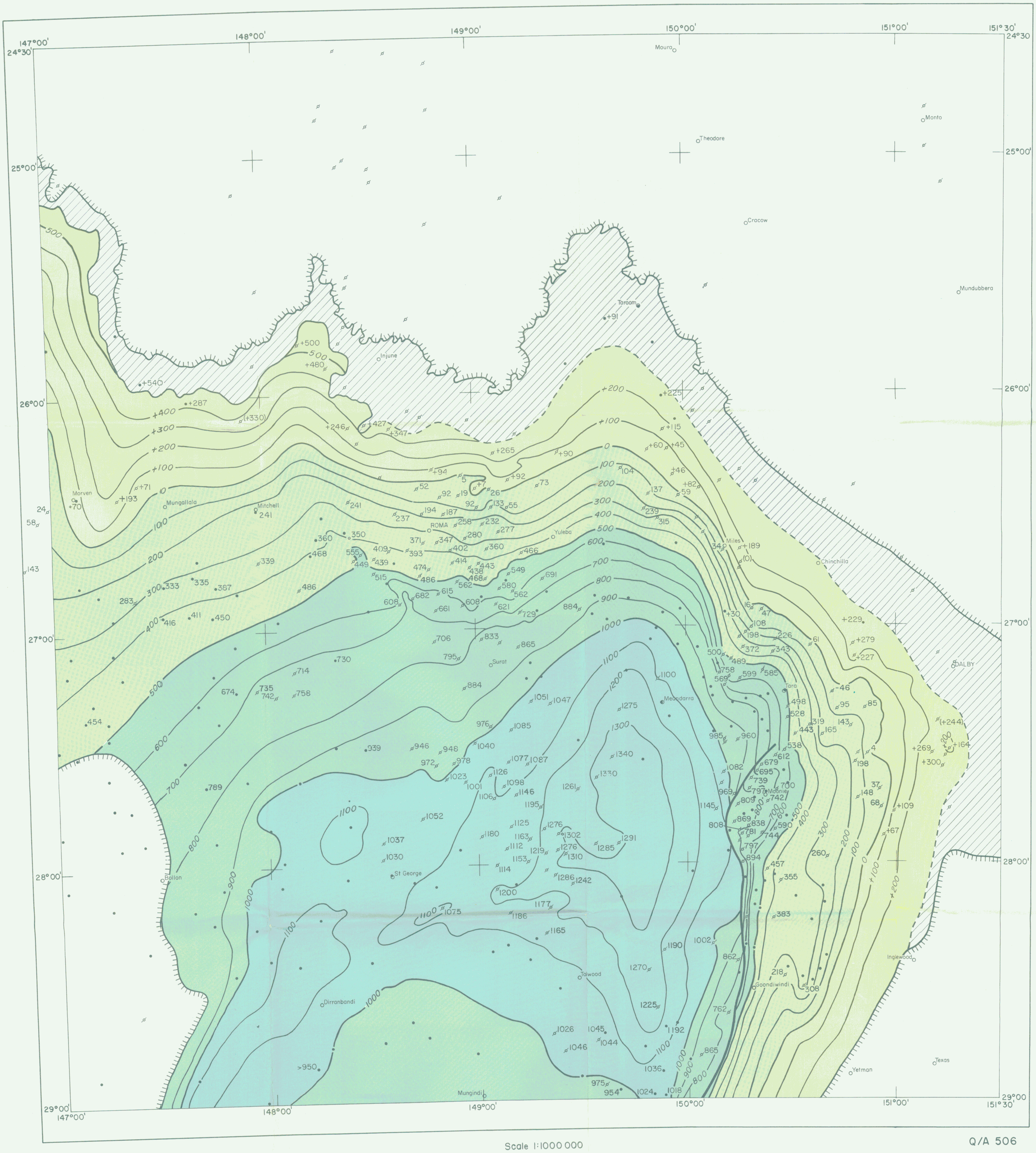
Petroleum exploration well

Wireline-logged water bore

A *Evergreen Formation absent*

Plate 12 Structure contours, top of Evergreen Formation

SURAT BASIN



Scale 1:1000 000

Q/A 506

20 10 0 20 40 60 80 100 KILOMETRES

10 0 20 40 60 MILES

Contour interval 100 m (below sea level)

Limit of Walloon Coal Measures (=Birkhead Formation)

Outcrop top of Walloon Coal Measures

Fault

Outcrop of Walloon Coal Measures

Petroleum exploration well

Wireline-logged water bore

Plate 13 Structure contours, top of Walloon Coal Measures

SURAT BASIN

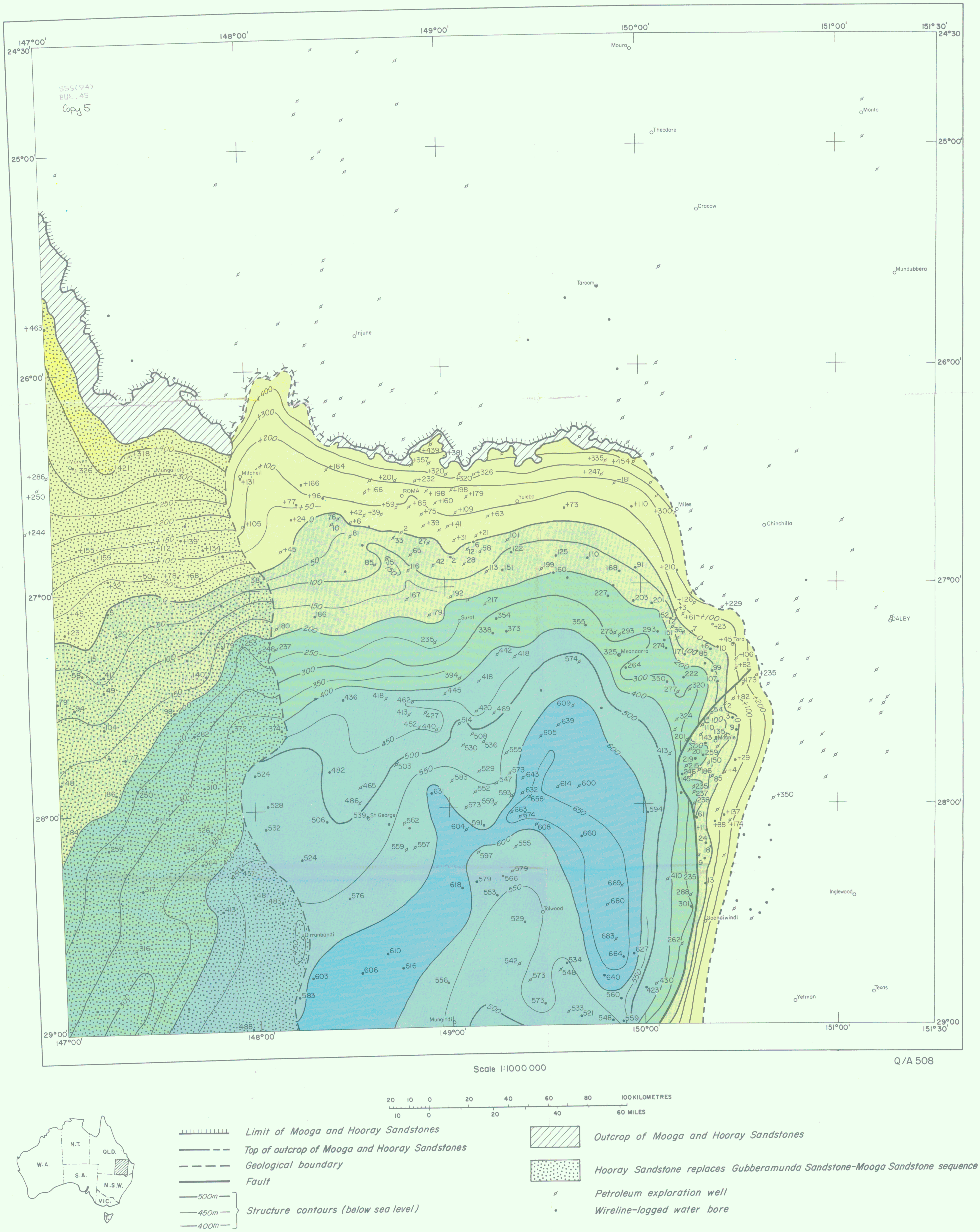


Plate 14 Structure contours, top of Mooga and Hooray Sandstones

SURAT BASIN

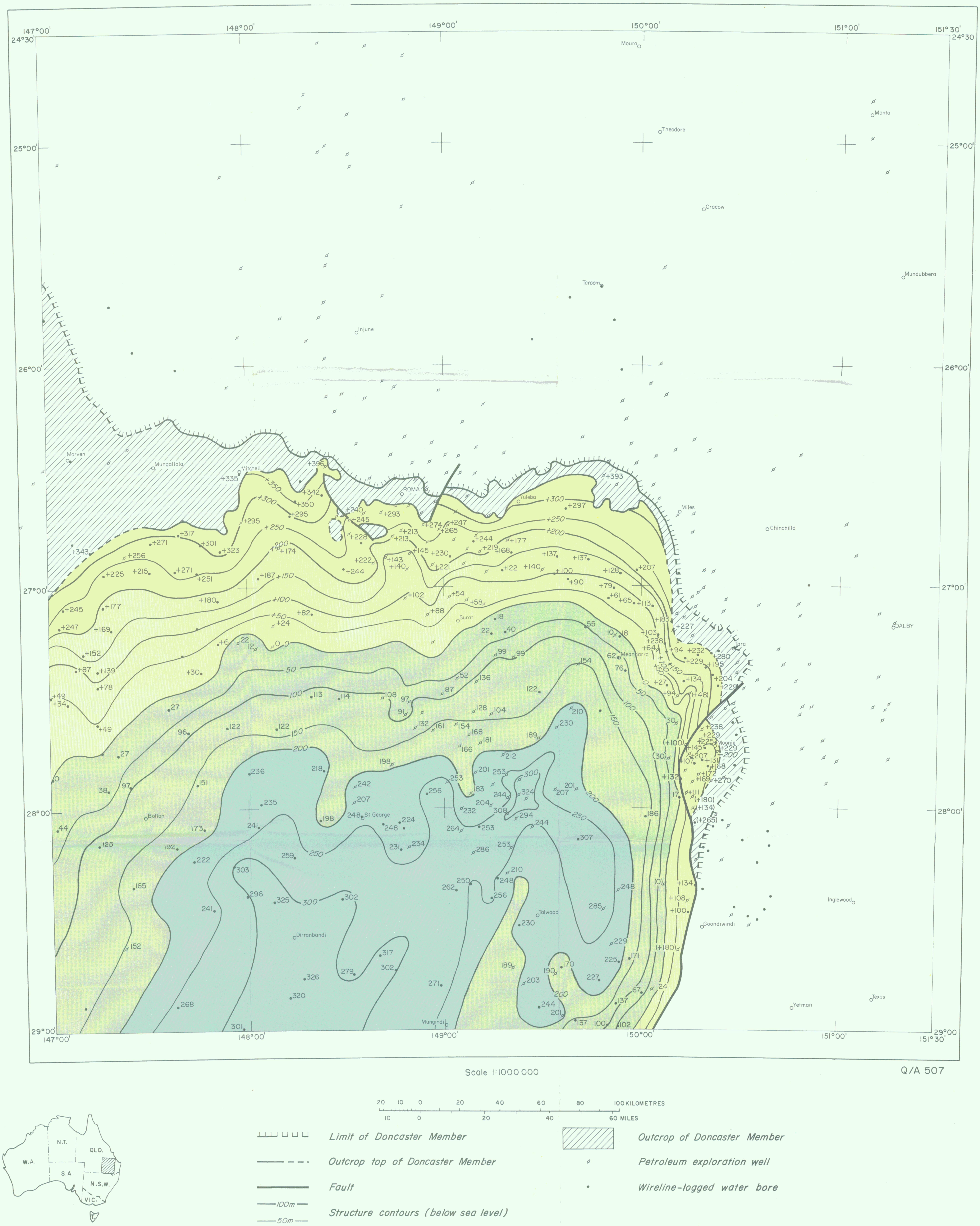
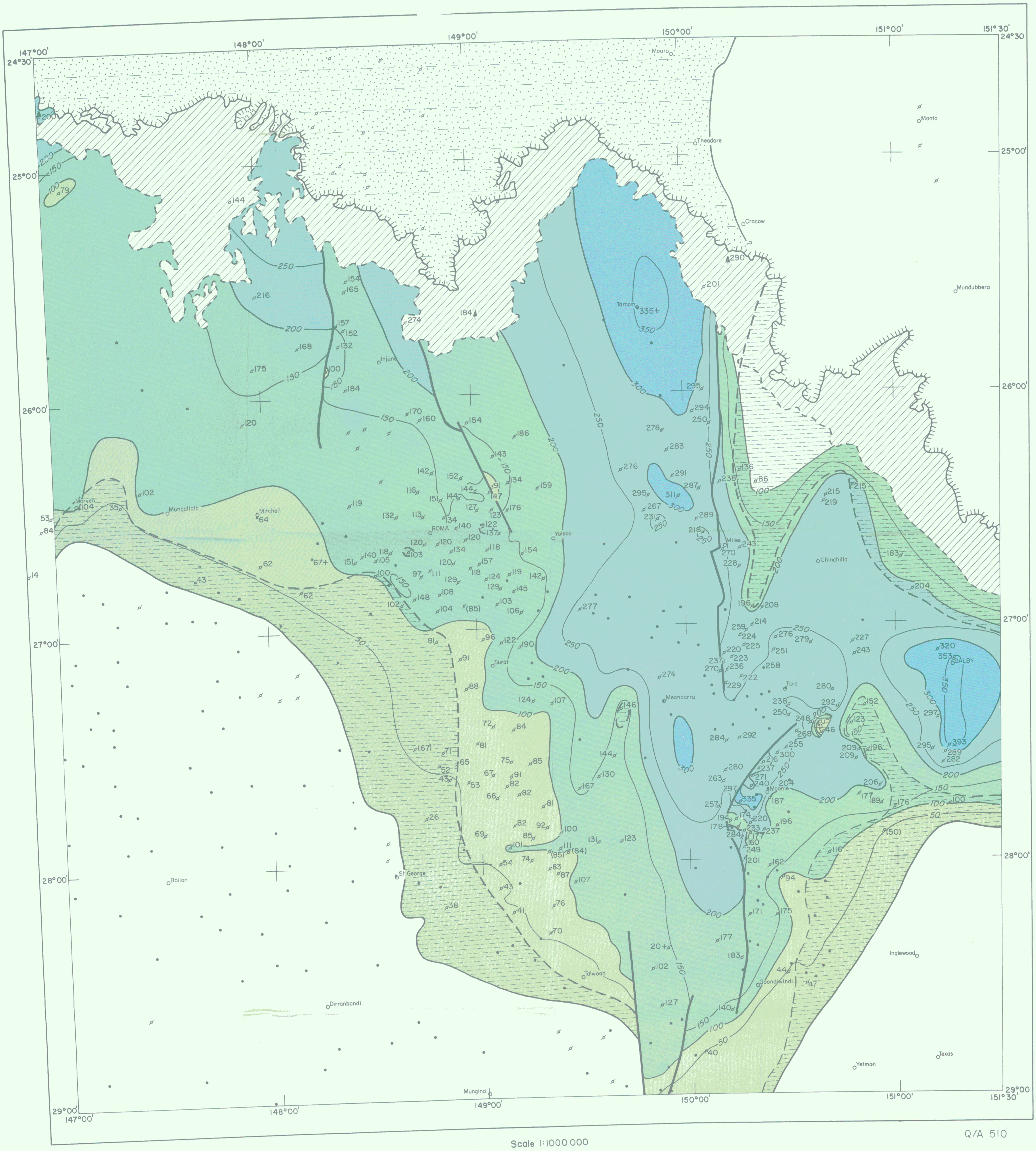


Plate 15 Structure contours on the top of the Doncaster Member (Wallumbilla Formation).

SURAT BASIN



Scale 1:1000 000

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10 0 20 40 60 MILES

W.A. N.T. QLD. S.A. N.S.W. VIC.

Evergreen Formation alone present

Area of outcrop of isopached sequence

Areas formerly overlain by isopached sequence

Erosional margin of isopached sequence

Top of outcrop of isopached sequence

Inferred depositional margin of isopached sequence

Geological boundary

Fault

50m, 100m Isopachs

Petroleum exploration well

Wireline-logged water bore

Measured section

Plate 16 Thickness of Precipice Sandstone and Evergreen Formation

SURAT BASIN

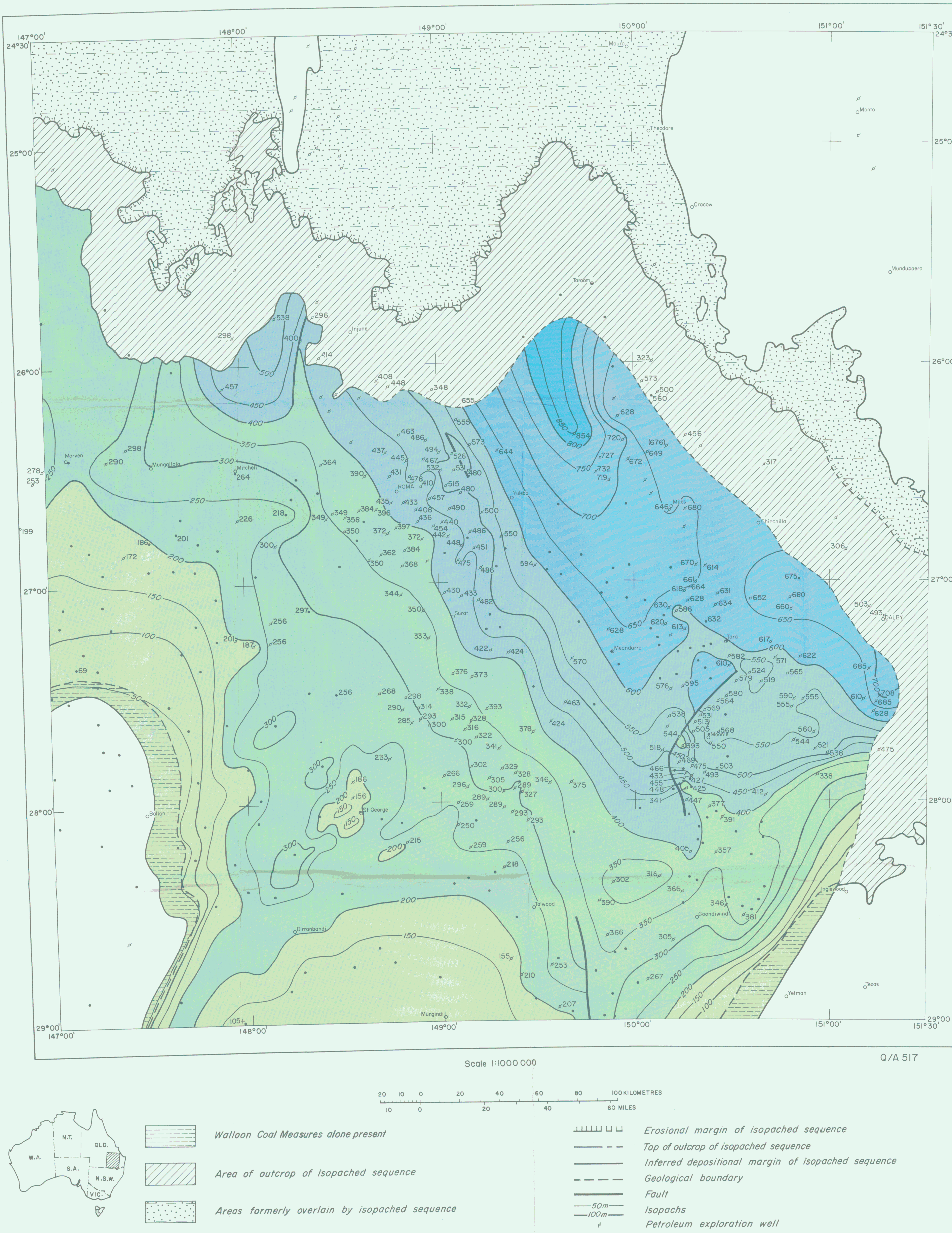


Plate 17 Thickness of Hutton Sandstone and Walloon Coal Measures

SURAT BASIN

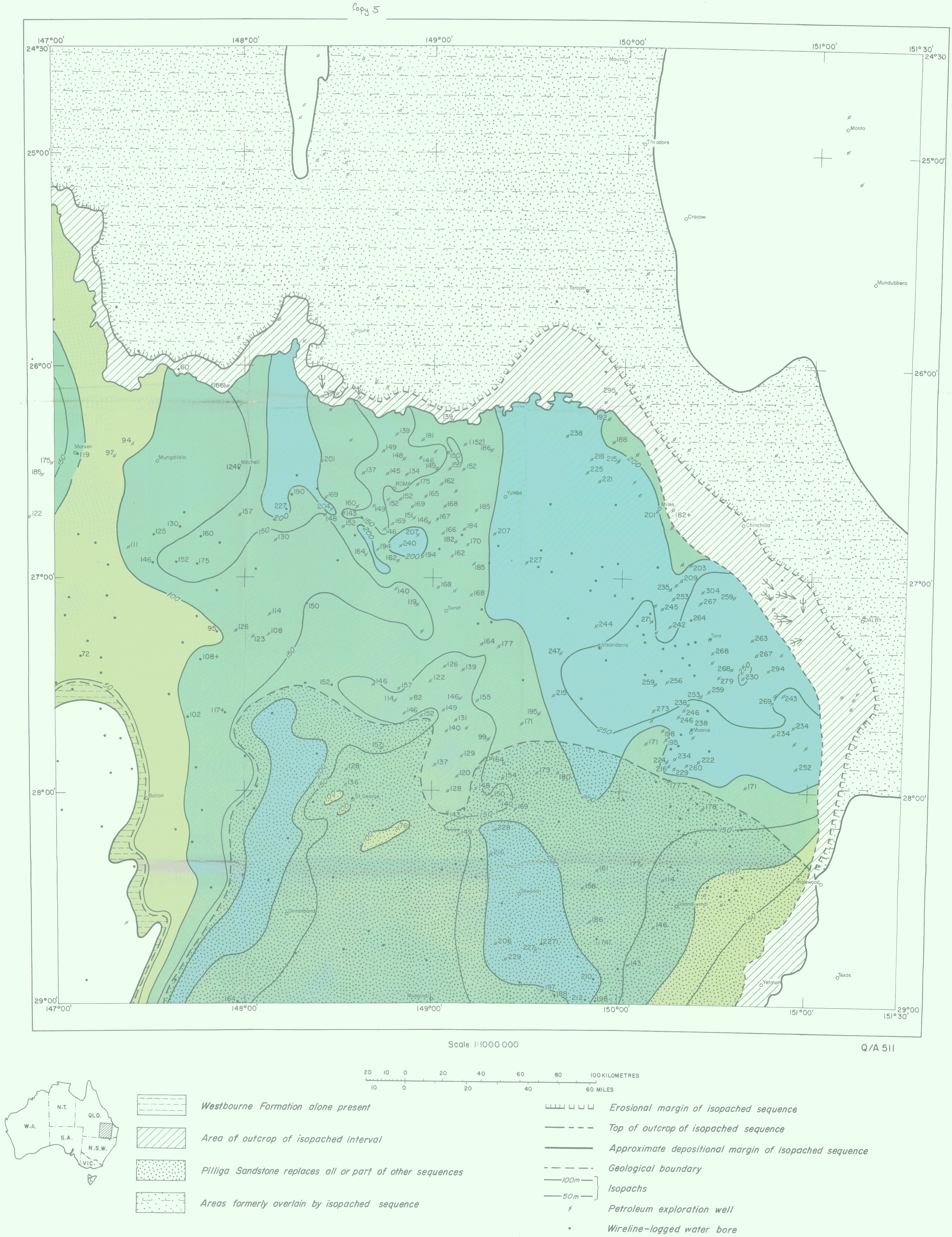


Plate 18 Thickness of Westbourne Formation and Springbok Sandstone (= Pilliga Sst.) interval.

SURAT BASIN

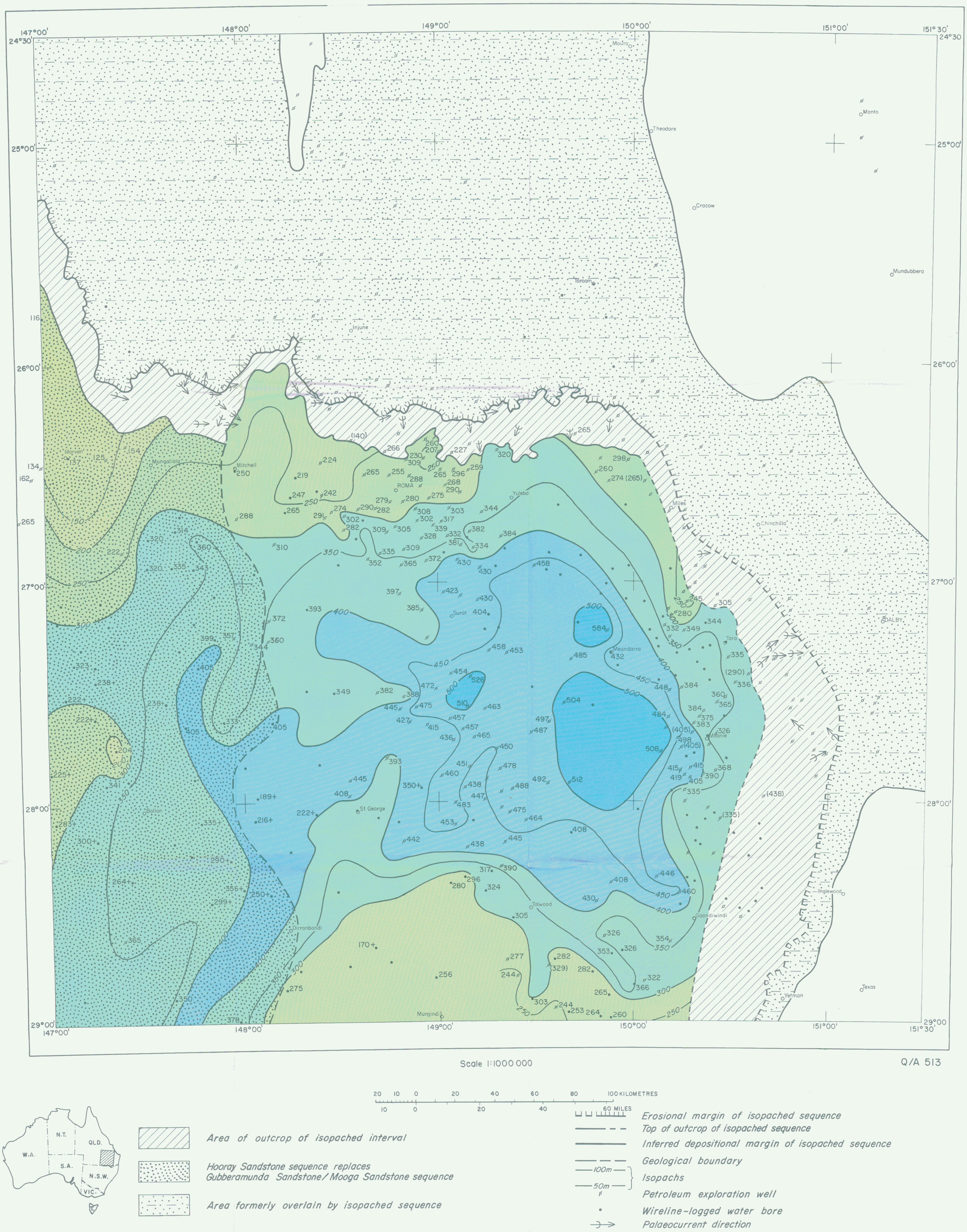
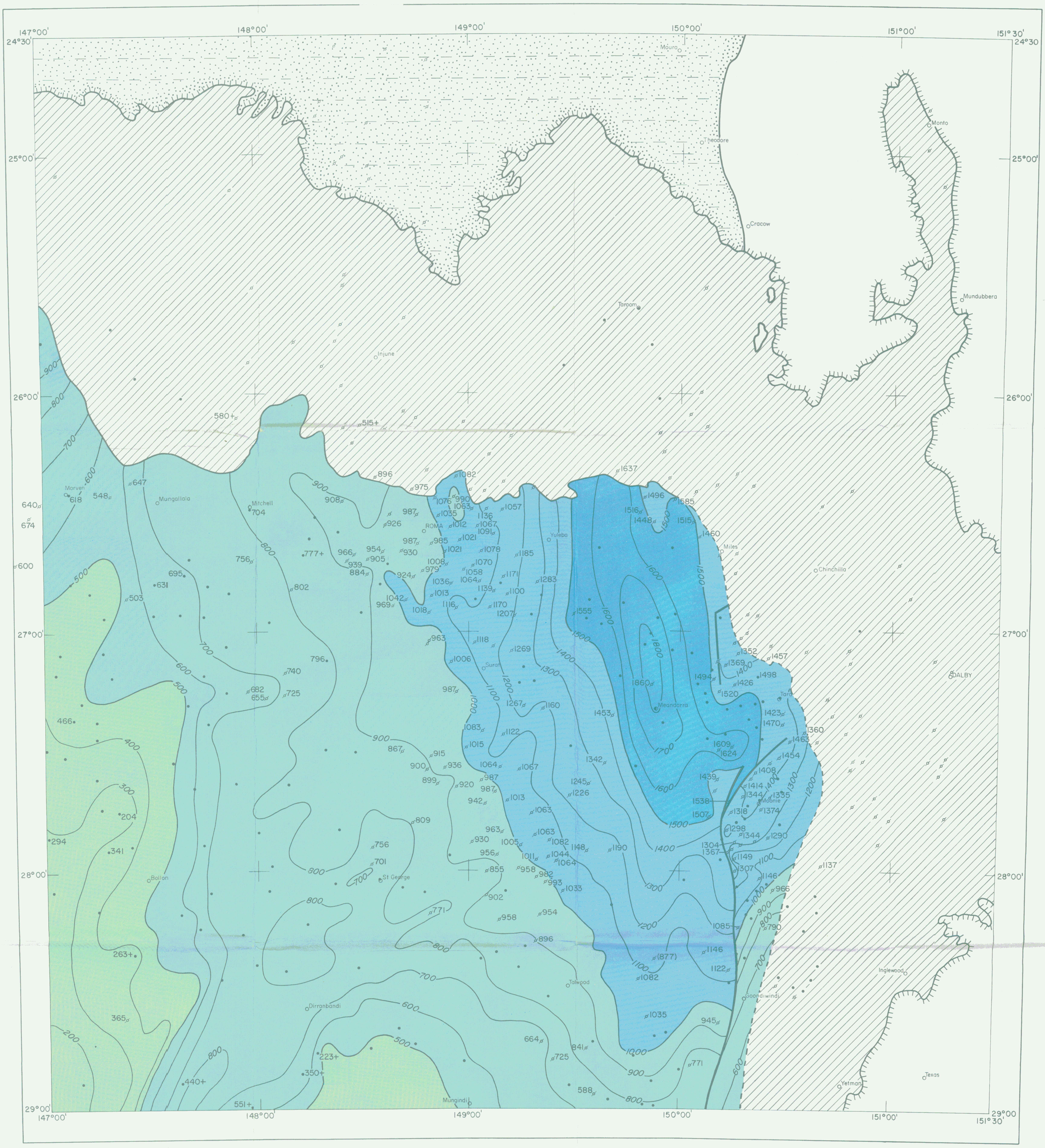


Plate 19 Thickness of Gubberamunda Sandstone/Mooga Sandstone interval (=Hooray Sst)

SURAT BASIN



Scale 1:1000 000

20 10 0 20 40 60 80 100 KILOMETRES
10 0 20 40 60 MILES

Area of outcrop of isopached sequence

Areas formerly overlain by isopached sequence

Erosional margin of isopached sequence

Top of outcrop of isopached sequence

Inferred depositional margin of isopached sequence

Fault

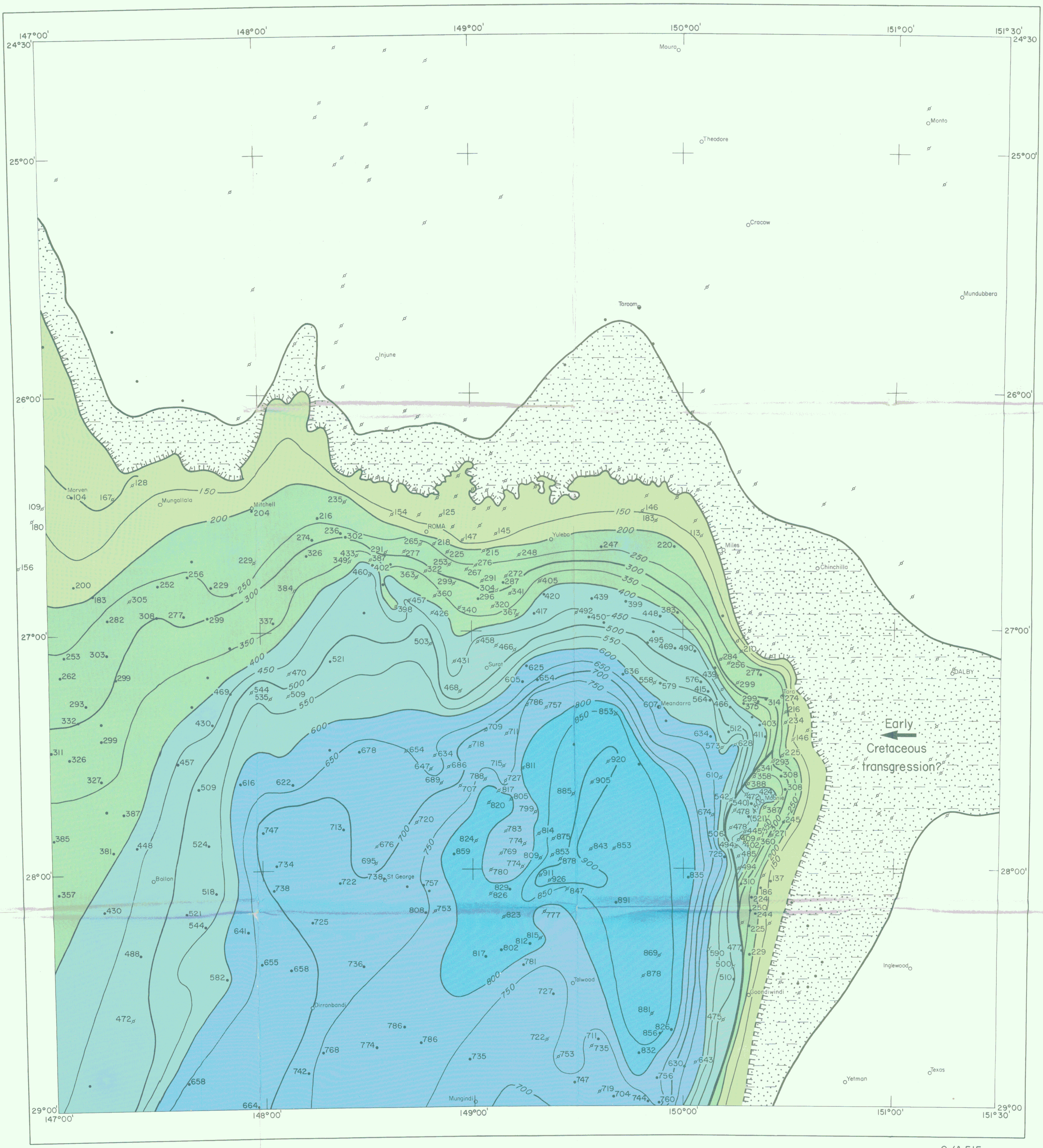
500m
400m
Isopachs

Petroleum exploration well

Wireline-logged water bore

Plate 20 Thickness of non-marine part of Surat Basin sequence (Mooga Sandstone to base of Jurassic)

SURAT BASIN



Scale 1:1000 000

Q/A 515

20 10 0 20 40 60 80 100 KILOMETRES
10 0 20 40 60 MILES

Area formerly overlain by isopached sequence

Erosional margin
Inferred depositional margin of isopached sequence
Fault
50m
100m
Isopachs
Petroleum exploration well
Wireline-logged water bore

Plate 21 Thickness of marine part of Surat Basin sequence (Rolling Downs Gp + Bungil Fm)