Galilee Basin

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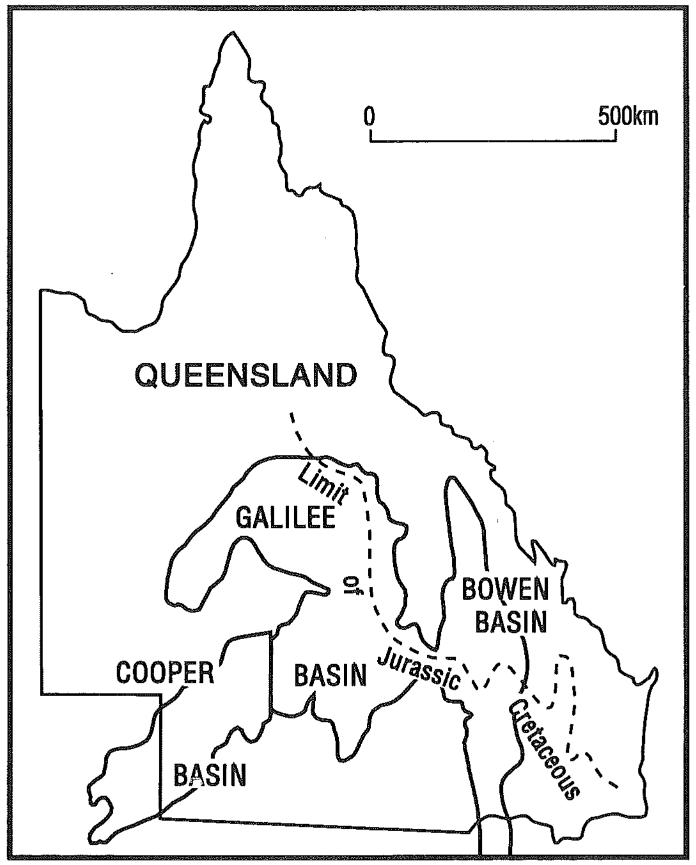

Figure 1. Location, Galilee Basin.

The Galilee Basin covers an area of approximately 247 000 km^2 in central Queensland (Figure 1). It is a totally intracratonic basin and is filled with Late Carboniferous to Middle Triassic sedimentary rocks. These rocks are dominantly of fluvial origin, with minor glacial material occurring towards the base of the succession (Gray & Swarbrick, 1975).

The basin is almost entirely unconformably overlain by the Jurassic-Cretaceous Eromanga Basin. Only along the eastern margin are Permo-Triassic rocks exposed in a long, narrow gently curved belt. The maximum known stratigraphic thickness of the basin is 2818m, penetrated in the Koburra Trough by ENL Lake Galilee 1 (Allen, 1974).

The principal tectonic elements of the basin are shown in Figure 2. The basin is divided into northern and southern parts by the east-west trending Barcaldine Ridge, located at approximately latitude 24° south. The northern part of the basin is subdivided by the Maneroo Platform and its easterly component, the Beryl Ridge, into the eastern Koburra Trough and the western Lovelle Depression. The southern part of the basin is divided into the western Powell (Main) Depression and the Springsure Shelf by the Pleasant Creek Arch.

Exploration within the basin is at a relatively immature stage, with only 50 petroleum wells and stratigraphic bores in the northern part and 53 petroleum wells and stratigraphic bores in the southern part (Figure 3). Coal exploration drilling has been confined to the exposed eastern margin of the basin, with 69 Departmental exploration bores having been drilled and over 1200 shallow coal exploration bores drilled by companies exploring in the Wendouree, Degulla and Pentland areas.

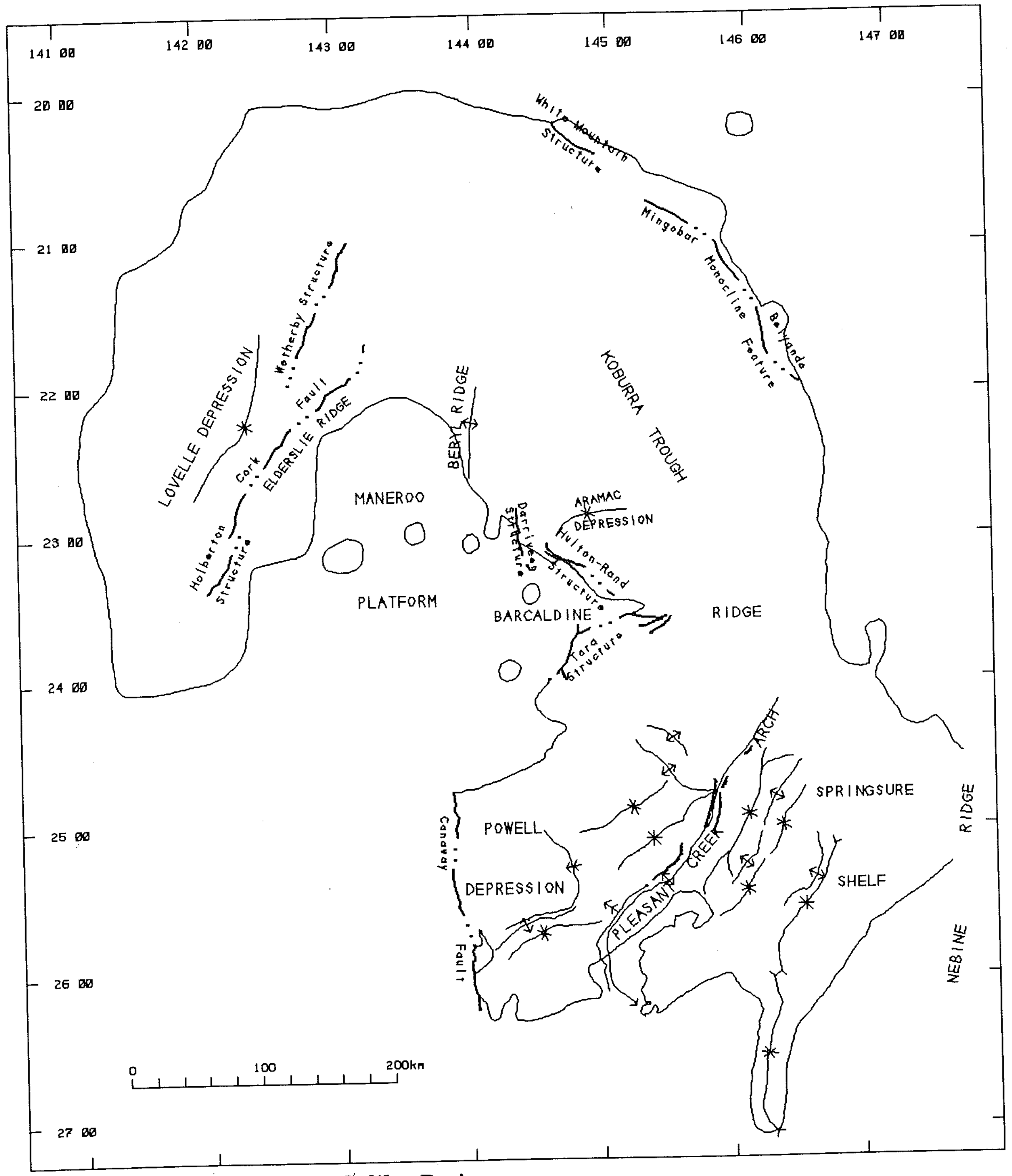

Figure 2. Structural elements, Galilee Basin.

STRATIGRAPHY

The stratigraphic succession of the Galilee Basin is partly related to stratigraphic successions in the Cooper and Bowen Basins, with each basin having experienced a hiatus during some part of the middle Permian (Figure 4). Major coal deposition occurred in the Galilee Basin during the Early Permian in the Aramac Coal Measures, as well as during the Late Permian in the Colinlea Sandstone and Bandanna Formation and their correlatives and the Betts Creek beds.

Coal development within the basin is concentrated in the northern part. South of the Barcaldine Ridge coal seams are thin and sporadic. Detailed stratigraphic descriptions of the individual units are given in Gray & Swarbrick (1975) and Hawkins & others (1993).

Late Carboniferous and Early Permian

The Late Carboniferous and Early Permian Joe Joe Group was defined by Gray & Swarbrick (1975) as "that succession of formations which is unconformably overlain by the Colinlea Sandstone and its lateral correlative, and unconformably overlies strata of the Adavale and Drummond Basins or other pre-Late Carboniferous rocks". The Joe Joe Group is divided into four formations, in ascending order: the Lake Galilee Sandstone, the Jericho Formation, the Jochmus Formation and the Aramac Coal Measures.

Lake Galilee Sandstone

The basal unit of the Galilee Basin is the Lake Galilee Sandstone, defined by Gray & Swarbrick (1975). This unit has been completely intersected in only three petroleum exploration wells, located

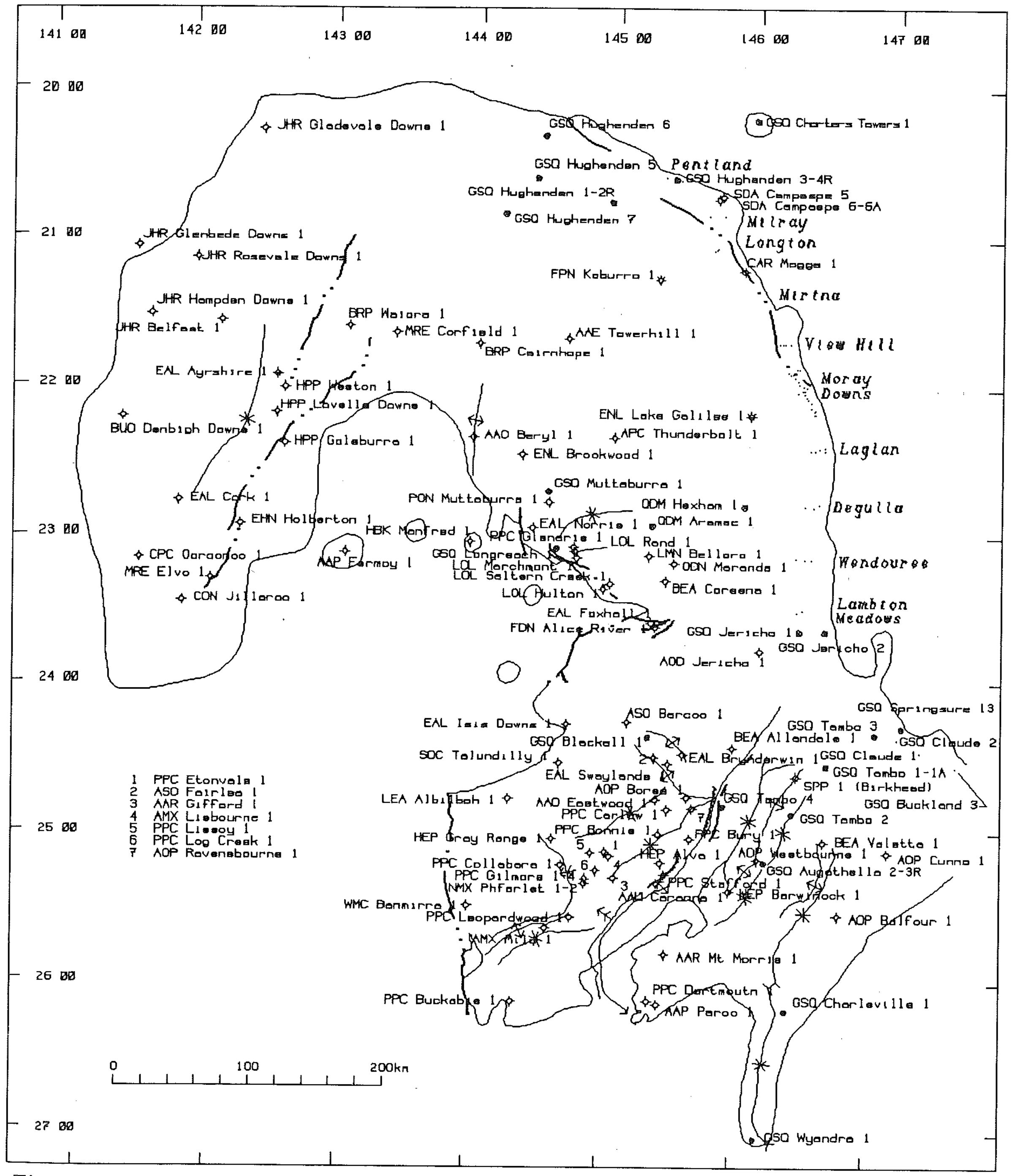

Figure 3. Wells/bores, Galilee Basin.

along the axis of the Koburra Trough, and appears to be confined to the Koburra Trough of the northern Galilee Basin (Figure 5). The Lake Galilee Sandstone consists of mainly grey, fine to medium grained quartzose sandstone, with minor dark grey and black mudstone (Hawkins & others, 1993).

Jericho Formation

The Jericho Formation overlies the Lake Galilee Sandstone in the Koburra Trough (Gray & Swarbrick, 1975), but in the southern part of the basin it is the basal unit of the sequence (Figure 6). The Jericho Formation has not been recognised in the Lovelle Depression.

The Jericho Formation consists dominantly of mudstone and siltstone with subordinate sandstone. Near the Barcaldine Ridge, the unit contains localised thick and thin conglomerate beds (Hawkins & others, 1993). Within the middle of the unit a sequence of mainly interbedded siltstone, mudstone and shale containing red zeolites is recognised and defined as the Oakleigh Siltstone Member (Gray & Swarbrick, 1975). The siltstone, mudstone and shale are dark grey and green, very hard, siliceous, strongly banded and varved.

Jochmus Formation

The Jochmus Formation overlies the Jericho Formation in the eastern and southern parts of the basin and is the basal unit in the western part of the

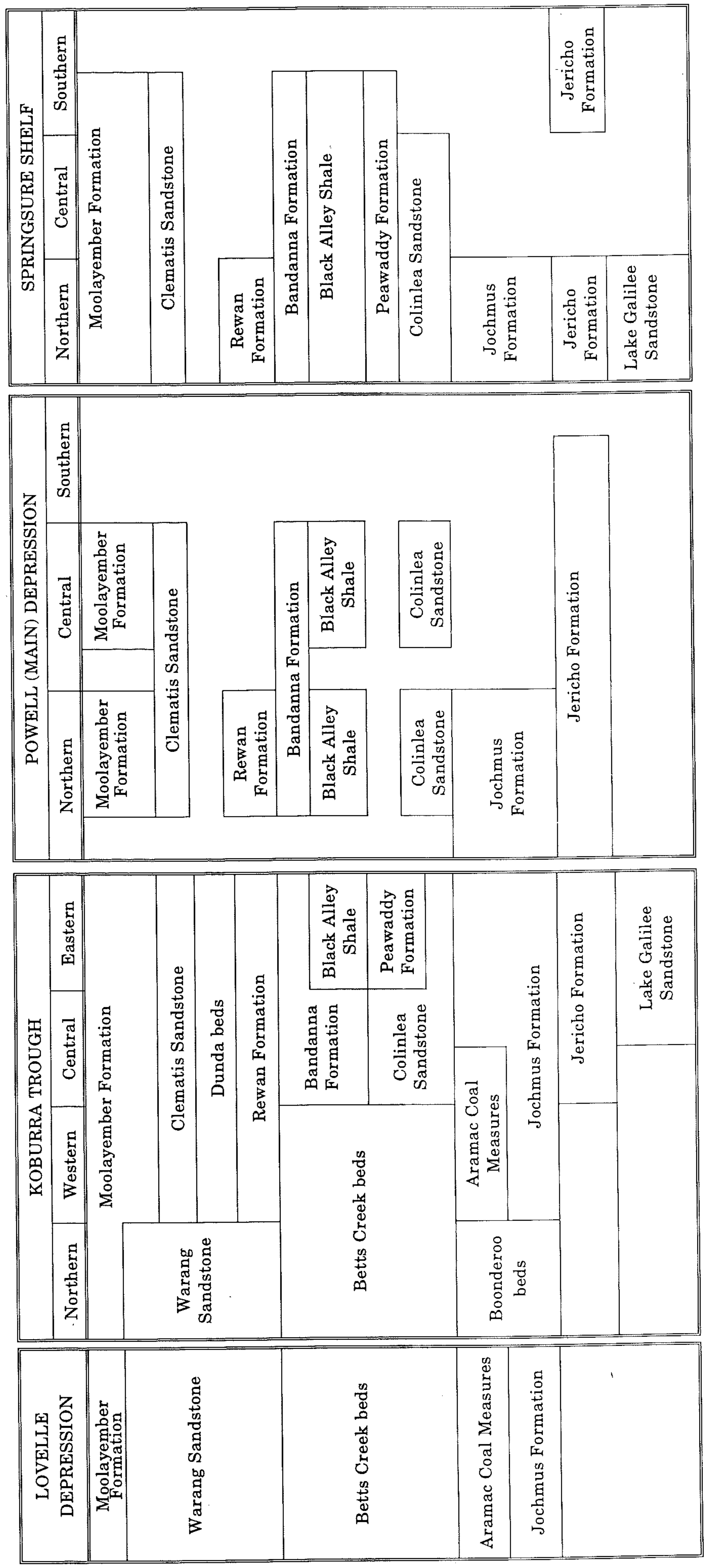

Figure 4. Stratigraphy - Galilee Basin.

Figure 5. Areal extent of the Lake Galilee Sandstone.

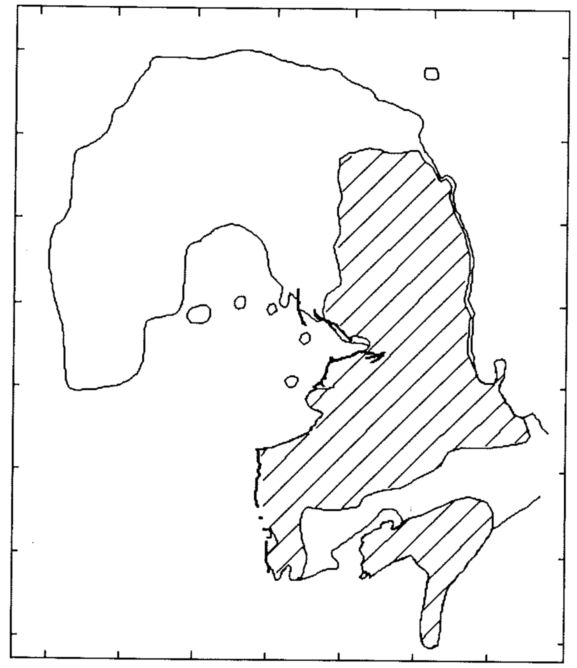

Figure 6. Areal extent of the Jericho Formation.

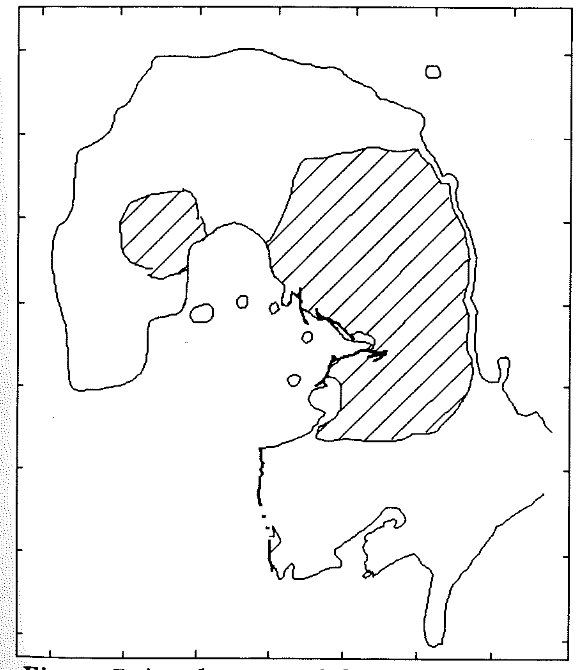

Figure 7. Areal extent of the Jochmus Formation.

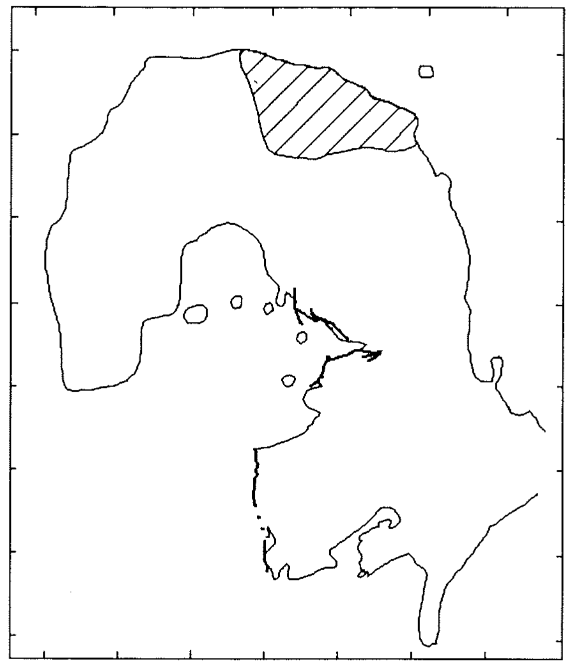

Figure 8. Areal extent of the Boonderoo beds.

basin (Figure 7). As defined by Gray & Swarbrick (1975) it can be divided into 3 units; a basal unit consisting mainly of sandstone, a middle unit made up dominantly of tuff and mudstone and an upper sandstone unit. The middle unit has been defined as the Edie Tuff Member.

Sandstones in the Jochmus Formation are generally light grey to green, and more rarely brown and reddish, fine to medium grained, labile and locally conglomeratic. Siltstones are light to medium grey and grey-green, hard, brittle and carbonaceous. Mudstones are grey-green, silty, tuffaceous in part and carbonaceous (Gray & Swarbrick, 1975).

In the north-eastern part of the basin, outcrops and intersections of the Boonderoo beds are lithologically similar in part to the Jochmus Formation (Figure 8) (Gray, 1977).

Aramac Coal Measures

The Aramac Coal Measures is the lateral equivalent of the upper Jochmus Formation, the uppermost unit of the Late Carboniferous-Early Permian Joe Joe Group. The unit is developed on the western side of the Koburra Trough and across the Beryl Ridge into the southern Lovelle Depression of the northern part of the basin (Figure 9).

It comprises a lower, dominantly sandstone unit with minor coal and mudstone and an upper sandstone and subordinate coal unit (Hawkins & others, 1993).

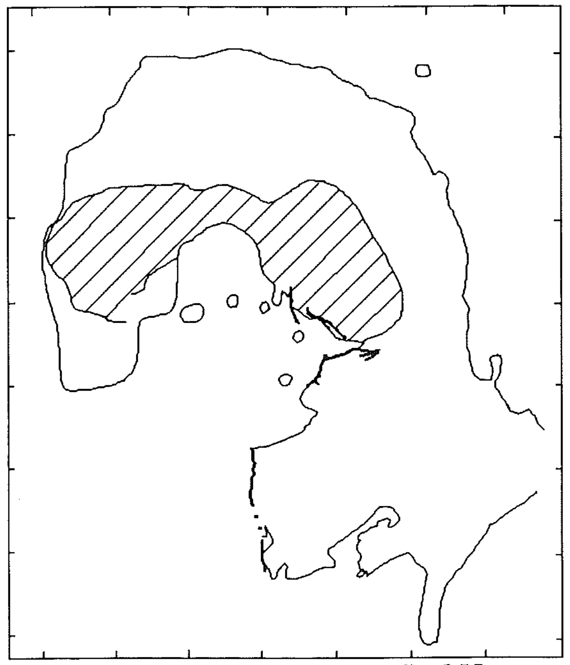

Figure 9. Areal extent - Aramac Coal Measures.

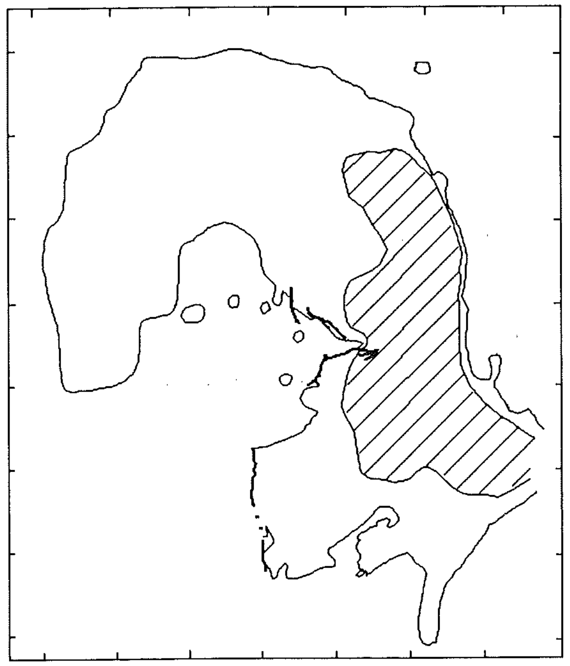

Figure 10. Areal extent - Colinlea Sandstone.

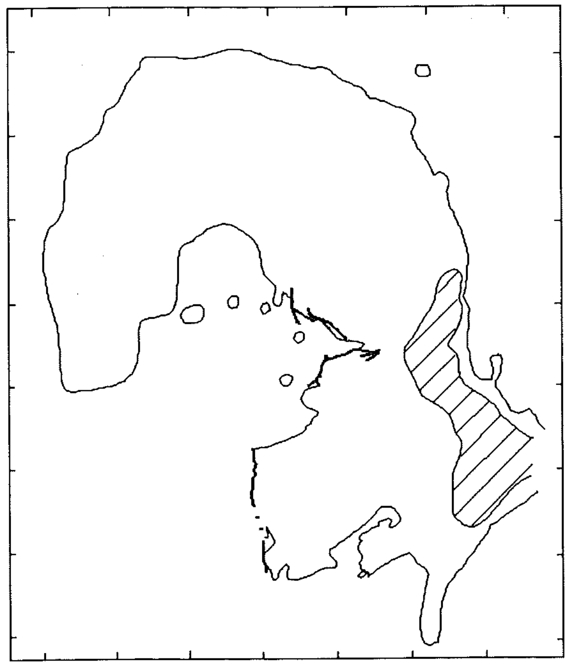

Figure 11. Areal extent - Peawaddy Formation.

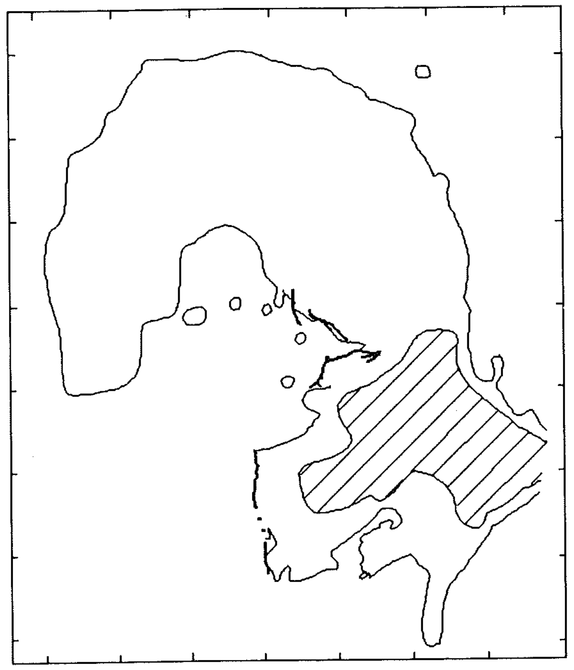

Figure 12. Areal extent - Black Alley Shale.

Late Permian

Colinlea Sandstone and equivalents

The Colinlea Sandstone in the Galilee Basin is continuous, across the Nebine Ridge, with the Colinlea Sandstone of the Bowen Basin. The unit is present over the eastern and south central Galilee Basin (Figure 10). It comprises mainly sandstone, siltstone, mudstone and coal. The sandstone is fine to coarse grained, conglomeratic in part, and sublabile to quartzose (Hawkins & others, 1993). In the southern part of the basin coal is either present in very small proportions or is non-existent.

Peawaddy Formation

Within the Galilee Basin, the Peawaddy Formation comprises mainly sandstone with lesser amounts of siltstone, mudstone and coal. It is only developed on the Springsure Shelf (Figure 11).

Away from the Springsure Shelf, across the Barcaldine Ridge and towards the Pleasant Creek Arch the unit thins rapidly and onlaps the underlying Colinlea Sandstone.

Black Alley Shale

The Black Alley Shale of the central and south-central Galilee Basin consists of dark grey to black shale and siltstone with interbedded light green-grey tuff and fine to very fine, labile sandstone (Gray, 1976). The unit thins over the Barcaldine Ridge into the Koburra Trough, eventually onlapping the underlying Colinlea Sandstone. It occurs, however, over most of the southern part of the basin (Figure 12).

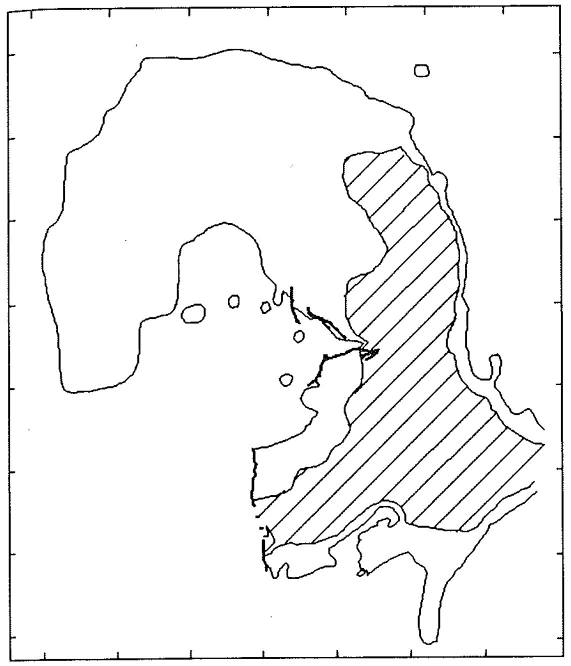

Figure 13. Areal extent of the Bandanna Formation.

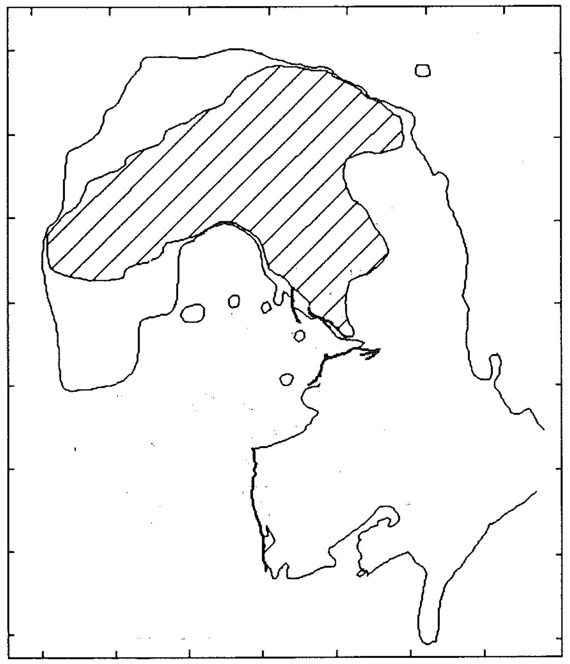

Figure 14. Areal extent of the Betts Creek beds.

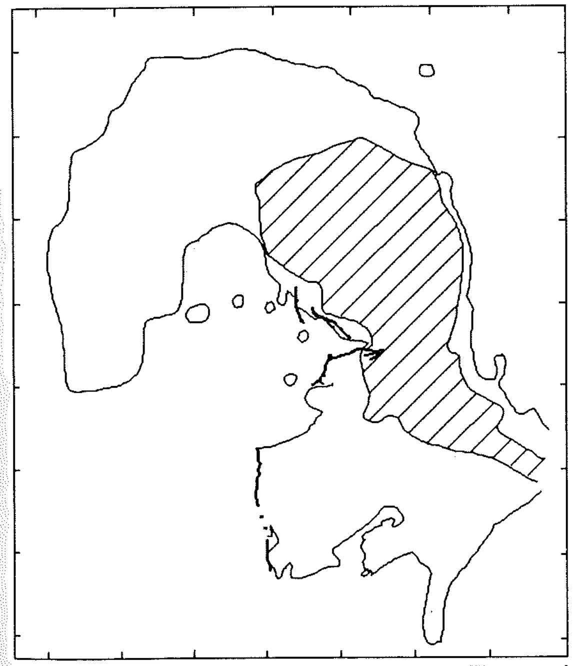

Figure 15. Areal extent of the Rewan Formation.

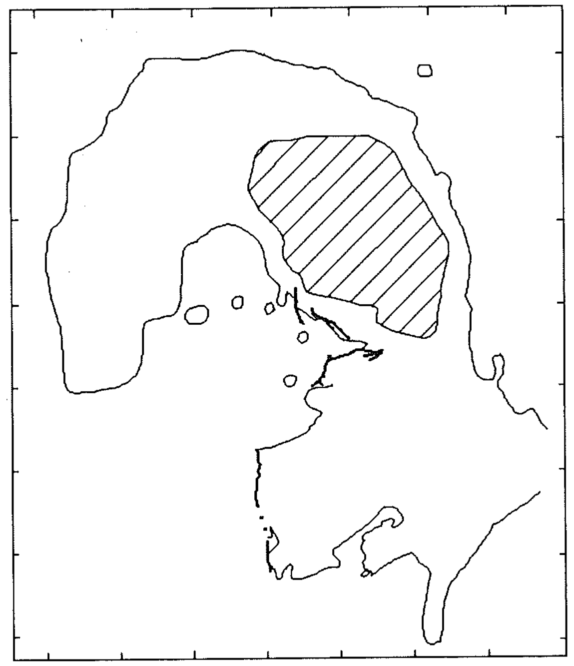

Figure 16. Areal extent of the Dunda beds.

Bandanna Formation and equivalent

The Bandanna Formation of the Galilee Basin consists of an interbedded sequence of sandstone, siltstone, mudstone and coal (Hawkins & others, 1993). Within the southern Galilee Basin, the volume of coal in the unit is substantially lower than that in the northern part of the basin. The unit occurs within the north-eastern and southern areas of the basin (Figure 13).

Betts Creek beds

The Betts Creek beds are the lateral equivalent of both the Colinlea Sandstone and Bandanna Formation. They occur in the northern and western areas of the basin (Figure 14), and comprise sandstone, interbedded siltstone, shale and coal (Hawkins & others, 1993). The sandstone is very fine to coarse and quartzose to sublabile. Along the north-eastern margin of the basin, Departmental coal drilling has indicated that the lithology of the sandstones of the upper part of the Upper Permian coal measures changes from predominantly labile to predominantly quartzose. This change is indicative of a change in sedimentary source, and it has been used to define the provenance of the Betts Creek beds (Scott & Hawkins, 1992).

Triassic

Rewan Formation

The Rewan Formation occurs within the eastern and central areas of the Galilee Basin (Figure 15). Although the sequence has been raised to group status in the Bowen Basin (Jensen, 1975), formation status has been retained in the Galilee Basin by Day & others (1983). The unit consists mainly of interbedded light grey, fine to coarse grained,

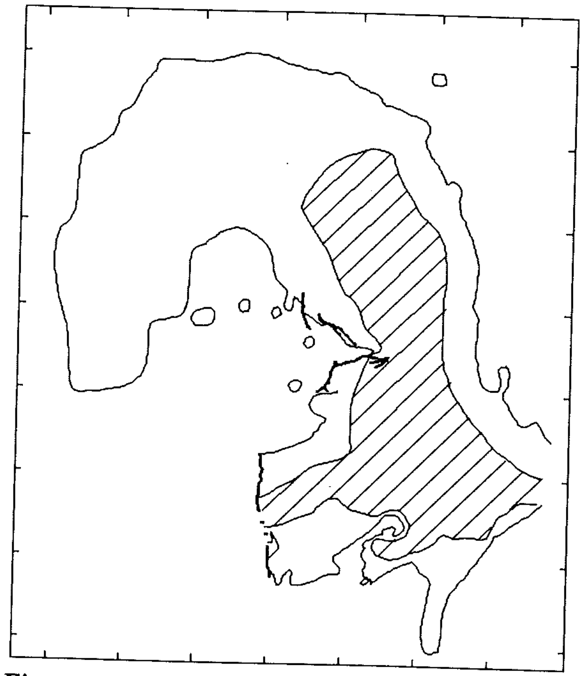

Figure 17. Areal extent of the Clematis Sandstone.

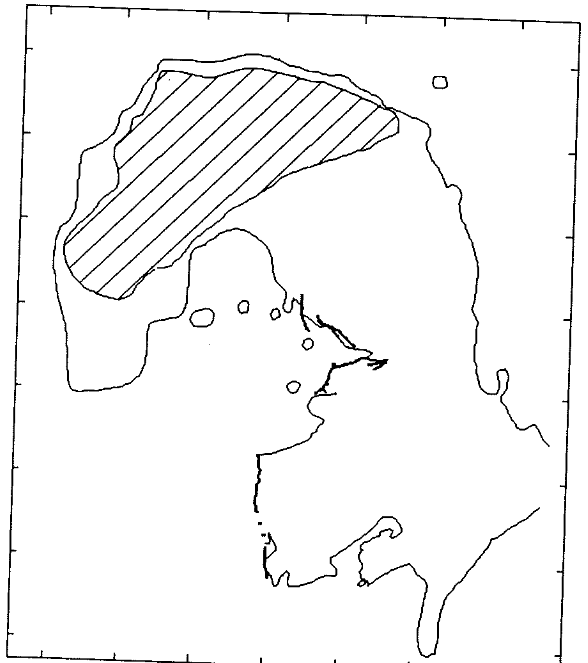

Figure 19. Areal extent of the Warang Sandstone.

sublabile to labile, in part quartzose sandstone, grey and green siltstone and mudstone (Hawkins & others, 1993).

Dunda beds

The Dunda beds were identified by Vine & others (1965), Olgers (1970) and Vine & Doutch (1972) from outcrop along the central margin of the basin. In the subsurface, the unit is restricted to southern and central Koburra Trough area (Figure 16). The sequence comprises light grey, olive-grey, and yellow-grey, fine to coarse grained, poorly sorted, quartzose to labile sandstone and varicoloured mudstone and siltstone (Hawkins & others, 1993). The lower half is dominated by sandstone while the upper half is dominated by mudstone.

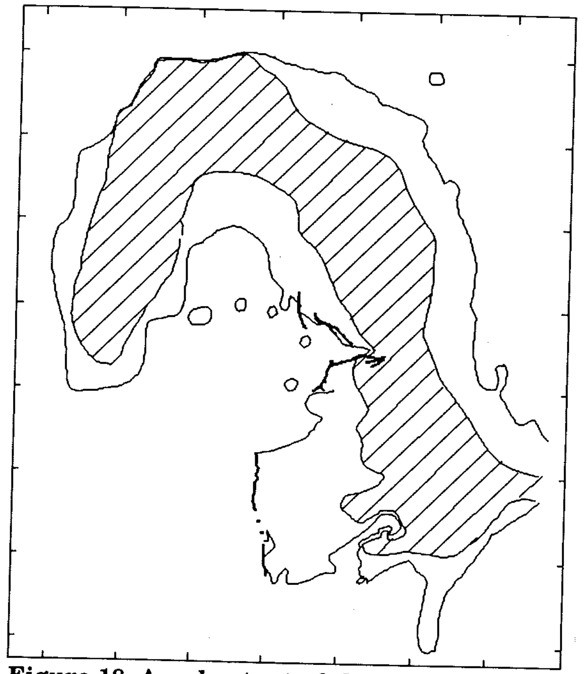

Figure 18. Areal extent of the Moolayember Formation.

Clematis Sandstone

The Clematis Sandstone, originally named by Jensen (1926) in the Bowen Basin, has been mapped along the north-eastern margin of the Galilee Basin by Vine & others (1965) and Senior (1973); it has recognised and mapped in the subsurface by Casey (1970) and Vine (1973, 1976).

Within the basin the unit is confined to the eastern and southern central regions (Figure 17). As with the Rewan Formation, formation status has been retained for the Clematis Sandstone in the Galilee Basin even though it has been raised to group status in the Bowen Basin (Jensen, 1975). The unit consists mainly of light grey, friable, fine to very coarse-grained, angular to subrounded quartzose sandstone with lesser amounts of grey or brown siltstone and mudstone (Hawkins & others, 1993).

Moolayember Formation

The Moolayember Formation was originally described in the Bowen Basin (Reeves, 1947; Hill & Denmead, 1960) and was mapped in outcrop along the eastern margin of the Galilee Basin by Exon (1970), Vine & Doutch (1972) and Senior (1973). The sequence is found within the eastern and western areas of the basin (Figure 18). The Moolayember Formation, in the subsurface, comprises green, grey, brown, purple and red mudstone with minor siltstone and some medium to coarse-grained, pebbly sandstone (Hawkins & others, 1993).

Warang Sandstone

The Warang Sandstone occurs within the northern and western parts of the northern Galilee Basin (Figure 19). It was originally mapped at outcrop by Vine & others (1964) where it forms the rugged topography of the White Mountains and the Great Dividing Range along the north-eastern margin of the Galilee Basin. The unit consists of white to light grey and light green-grey, medium to very coarse grained, poorly sorted, quartzose to sublabile sandstone, interbedded siltstone, mudstone/shale and conglomerate (Gray, 1977). Palynology suggests that the Warang Sandstone is a correlative of the upper Rewan Formation, Clematis Sandstone and lower and middle Moolayember Formation (McKellar, 1977).

Major Coal-bearing Sequences

Aramac Coal Measures

Structure

The Aramac Coal Measures, as mentioned above, is developed only within western and central parts of the northern Galilee Basin. The deepest intersection has been in the Lovelle Depression in HPP Lovelle Downs 1 (1600m), whilst the shallowest has been in the southern Koburra Trough in LMN Bellara 1 (757m). Development of the Aramac Coal Measures appears to have been dependent on fault movements (Hawkins & others, 1993); in both the Lovelle Depression and the Koburra Trough, the coal measures developed within assymetrical troughs formed by faulting.

The Aramac Coal Measures is thickest on the south-western margin of the Koburra Trough in GSQ Longreach 1-1B (265.2m) and thinnest in the southern Koburra Trough at LMN Bellara 1 (31.0m) (Figure 8). Generally the unit is consistently thickest in the Lovelle Depression and thin over the Beryl Ridge to thicken again in the south-western Koburra Trough.

Depositional environment

The Aramac Coal Measures are considered to have formed in a braided stream environment (Hawkins & others, 1993). The lower, coal-poor sequence represents a deposit from braided streams flowing at the distal margins of fans while the upper, coal-rich sequence represents the peat swamp phase. During this period tectonism declined, vegetation flourished and there was an expansion in the depositional sites. The Aramac Coal Measures represent a change in the climate of the Galilee Basin from essentially cold, dry, alkaline conditions with glacial influence depicted by the Joe Joe Group rocks to warm, humid, acid conditions.

Coal facies

As mentioned above the Aramac Coal Measures can be divided into two intervals: a lower interval dominantly consisting of sandstone with minor mudstone and coal and an upper interval of sandstone and subordinate coal (Hawkins & others, 1993). The greatest development of coal in the unit is on the western side of the Cork Fault in the Lovelle Depression where, in HPP Lovelle Downs 1, the formation reaches a thickness of 272.0m and the aggregate coal thickness is 60.0m.

In the Koburra Trough, the greatest coal development is on the south-western margin, along the Maneroo Platform. In GSQ Longreach 1-1B, the unit is 265.2m thick with an aggregate coal thickness of 29.0m.

Coal from the Aramac Coal Measures is grey to black, brittle and predominantly dull (Gray & Swarbrick, 1975). Smith (*in* Green & others, 1991) attributed the anomalously low vitrinite reflectance values in the Aramac Coal Measures in GSQ Longreach 1-1B to bacterial reduction of the peat, producing lipids which were incorporated into the humic degradation products.

Coal quality and potential

As there have been only two cores cut in the Aramac Coal Measures, there has been little analytical work done on the coals. Analyses of vitrains from GSQ Longreach 1-1B (Green & others, 1991) reported the following properties (air dried basis):

Moisture	3.4%
Volatile Matter	39.0%
Fixed Carbon	56.8%
Ash	0.8%
Specific energy	34.88 MJ/kg

Because of the depth to the coals in the Aramac Coal Measures, there appears to be little potential for mining. However the Aramac Coal Measures is considered a major source for both coal seam methane (Durie & others, 1992) and petroleum (Hawkins, 1978)

Bandanna Formation, Colinlea Sandstone and Betts Creek beds

Structure

The Bandanna Formation, Colinlea Sandstone and Betts Creek beds crop out along the eastern margin of the basin (Figures 10, 13 & 14). Both the Bandanna Formation and Colinlea Sandstone thin over the Barcaldine Ridge into the southern Galilee Basin, with coal development within these two formations decreasing to a minor component south of the Barcaldine Ridge. The Betts Creek beds are best developed within the main depo-centres of the northern part of the basin, the Koburra Trough and the Lovelle Depression, and thin across the Beryl Ridge. Coal development is related to formation thickness, and coal is thickest where the unit is thickest.

Depositional environments

The strata of the Late Permian coal measures were deposited in fluviatile-dominated environments. Only freshwater microflora, spores, pollens and rare macroflora have been recovered from the Late Permian units (Hawkins, 1976). Sedimentary structures found in core, such as small scale cross-stratification (Hawkins, 1976), and in outcrop, such as trough cross-stratification (Vine & others, 1965) as well as the presence of significant coal seams, indicate that the Late Permian sequence was deposited in environment controlled by a major river system with associated peat swamps. Exactly where in this system, however, is a moot point. Wells (1989) listed the interpretations of a number of authors; these ranged from alluvial plain to delta plain. A piedmont facies was also suggested by Vine & others (1964).

Hawkins & others (1993) have suggested a three phase division of the Upper Permian sequence. The earliest phase, the lower Aramac Coal Measures and Colinlea Sandstone, was deposited in an alluvial plain environment dominated by southerly and easterly flowing rivers. Associated with these rivers were peat swamps. The river borne sediments would have been sourced from the rocks of the volcanic and metamorphic provinces to the north of the basin margins (Scott & Hawkins, 1992).

The second phase was associated with a reduction in stream gradients and a rise in relative sea level. This led to a marine incursion into the southern and central regions of the basin, and hence to deposition

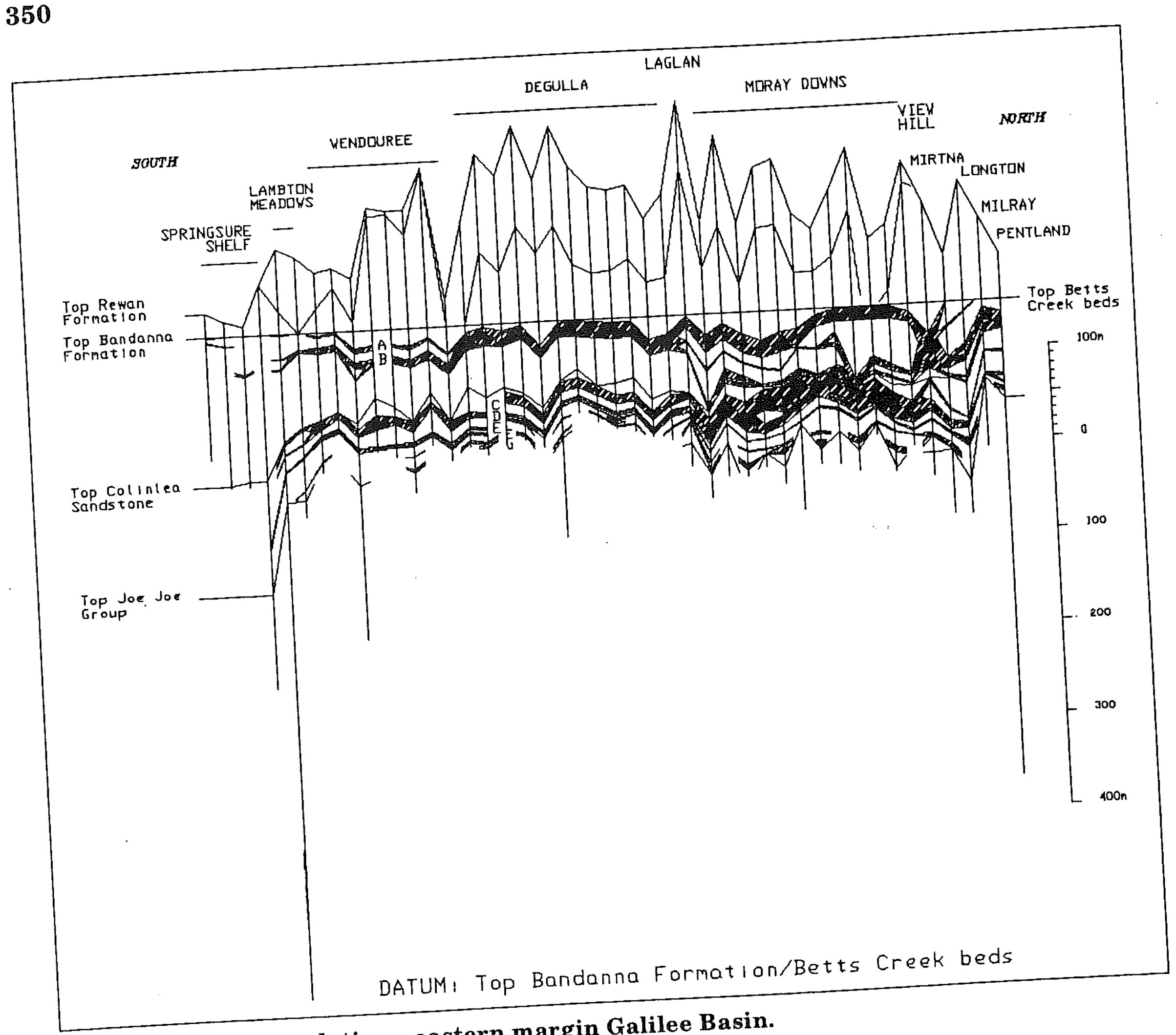

Figure 20. Seam correlation - eastern margin Galilee Basin.

of the Peawaddy Formation and the Black Alley Shale.

The final phase of sedimentation in the Late Permian saw a return to fluvial conditions. The only difference was that in the central and southern areas the rivers carried sediment from a volcano-lithic province, producing the labile sandstone based Bandanna Formation, while to the north and west the original sediment source areas continued to provide volcanic and metamorphic based material.

Coal facies

Coal is present in three units of the Late Permian sequence; the Bandanna Formation, the Colinlea Sandstone and the Betts Creek beds. Along the eastern margin and into the Koburra Trough, at least, the seams are continuous (Figure 20) (Scott & Hawkins, 1992). Within the southern part of the basin the coal facies, however, is very poorly developed.

There are three areas of maximum coal development, the Lovelle Depression, the western margin of the Koburra Trough along the Beryl Ridge, and within the Koburra Trough (Figure 11, Scott & Hawkins, 1992). The seams range in thickness from 0.15m to over 20m, with a maximum aggregate coal thickness of 45m. Petrographic analysis of coals from the eastern margin of the Koburra Trough has shown the coals to be low rank and subhydrous, ranging from thin, bright seams in the south to thick, dull seams in the north (Beeston, 1977).

Coal quality and potential

Only along the eastern margin of the northern Galilee Basin is coal from the Late Permian coal measures shallow enough to be mined. The coal seams are designated A through to G with most being relatively clean. The C seam includes numerous grey and fawn mudstone and siltstone bands. The coal itself is mainly dull, particularly in the lower seams in the north, but some bright bands are also present. The seams have a low dip to the west and south-west, generally at <5°, and the sequence is relatively undisturbed.

The coal along the eastern margin of the Koburra Trough has been classified as high volatile bituminous C under the ASTM classification, and is subhydrous with a low sulphur content. A typical proximate analysis (air-dried basis) of a relatively clean seam would be:

Moisture	9.1%
Volatile Matter	29.4%
Fixed Carbon	46.2%
Ash	15.3%

The average specific energy is about 22 to 23 MJ/kg and the crucible swelling number is either 0 or ½.

There are currently only two Exploration Permits for coal within the Galilee Basin. Total Measured and Indicated Resources for these two areas, and another which has been relinquished by the company, are 1675 and 910 million tonnes respectively (Queensland Coal Board, 1990).

Although coal was found in the Galilee Basin more than 80 years ago, none has yet been mined commercially. One of the many drawbacks to mining development is the basin's geographical isolation. Even if any export product was viable and a market available, the nearest port to a proven deposit is Abbot Point, some 430km by rail from Pentland in the northern part of the basin. The nearest railhead at present from any economic deposit between the Northern and Central Railways is Blair Athol which is some 180 to 200km away by an unsealed access road. Mining infrastructure is therefore completely lacking. Over and above these problems is the excessive thickness of Tertiary and Quaternary deposits, which would add considerably to the cost and difficulties of open cut mining.

The coal in the Galilee Basin has no coking potential, and is suitable only for use as an energy source. Its subhydrous nature and relatively low vitrinite content render it unsuitable for conversion processes. The coal from some of the better quality seams could be burned without beneficiation, but water supply for preparation plants would pose a problem if some of the dirtier seams were eventually to be worked.

Coals of the Upper Permian formations may have the potential to act as a source and a reservoir for methane, which could be produced as coal seam gas. A number of companies have begun exploration into the potential of coal bed methane within the Galilee Basin.

Another potential use for some of the coal from the Upper Permian formations is as oil shale. Such material, found as cannel coal and torbanite, is located in the Colinlea Sandstone to the south-east of Alpha, on the Springsure Shelf. The area is presently held under an Exploration Permit — Minerals (EPM) with the principal aim of producing approximately 3000 barrels of oil products on site per day for consumption in the central Queensland region (Madre, 1987). Total Measured plus Indicated Resources of 90 million barrels of shale oil are estimated to be available. Oil yields from the torbanite are high and range from 200 to 650L/t, while the enclosing cannel coals yield from 20 to 250L/t.

REFERENCES

ALLEN, R.J., 1974: Hydrocarbon significance of Upper Palaeozoic sediments associated with the Koburra Trough, Galilee Basin. *APEA Journal*, **14**, 59–65.

BEESTON, J.W., 1977: The petrography and rank of some shallow coal seams on the eastern flank of the Galilee Basin. *Queensland Government Mining Journal*, **78**, 264–267.

CASEY, D.J., 1970: Northern Eromanga Basin. *Geological Survey of Queensland, Report*, **41**.

DAY, R.W., WHITAKER, W.G., MURRAY, C.G., WILSON, I.H. & GRIMES, K.G., 1983: Queensland Geology. *Geological Survey of Queensland Publication* **383**.

DURIE, R.A., HAWKINS, P.J. & KUKLA, G.T., 1992: The Galilee Basin coal measures: A potential methane resource ? — A case for a well planned, integrated exploration and R & D programme. *Proceedings of the Symposium on coalbed methane research and development in Australia*, **1**, 81–97.

EXON, N.F., 1970: Tambo, Queensland. *1:250 000 Geological Series - Explanatory Notes*. Bureau of Mineral Resources, Canberra.

GRAY, A.R.G., 1976: Stratigraphic relationship of Late Palaeozoic sediments between Springsure and Jericho. *Queensland Government Mining Journal*, **77**, 146–163.

GRAY, A.R.G., 1977: Stratigraphic drilling in the Hughenden 1:250 000 Sheet area, 1974-75. *Queensland Government Mining Journal*, **78**, 382–392.

GRAY, A.R.G. & SWARBRICK, C.F.J., 1975: Nomenclature of Late Permian strata in the northeastern Galilee Basin. *Queensland Government Mining Journal*, **76**, 344–352.

GREEN, P.M., McKELLAR, J.L., CARMICHAEL, D.C. & SMITH, R.J., 1991: Stratigraphic drilling report - GSQ Longreach 1-1B. *Queensland Resource Industries Record* **1991/20**.

HAWKINS, P.J., 1976: Facies analysis and economic significance of Late Permian strata in the northern Galilee Basin. *Queensland Government Mining Journal*, **77**, 15–32.

HAWKINS, P.J., 1978: Galilee Basin - review of petroleum prospects.*Queensland Government Mining Journal*, **79**, 96–112.

HILL, D. & DENMEAD, A.K., (Editors), 1960: The geology of Queensland. *Journal of the Geological Society of Australia*, **7**.

JENSEN, A.R., 1975: Permo-Triassic stratigraphy and sedimentation in the Bowen Basin, Queensland. *Bureau of Mineral Resources Geology and Geophysics, Australia, Bulletin* **154**.

JENSEN, H.I., 1926: Geological reconnaissance between Roma, Springsure, Tambo and Taroom. *Geological Survey of Queensland Publication*, **277**.

MADRE, D.A., 1987: The Alpha Oil Shale deposit, the resource and its potential. *Proceedings of the 4th Australian Workshop on Oil Shale*. Brisbane, December, 1987.

McKELLAR, J.L., 1977: Palynostratigraphy of core samples from the Hughenden 1:250 000 Sheet area, northern Galilee and Eromanga Basins. *Queensland Government Mining Journal*, **78**, 393–399.

OLGERS, F., 1970: Buchanan, Queensland, 1:250 000 Geological series. *Bureau of Mineral Resources Geology and Geophysics, Australia, Explanatory Notes* Sheet SF/55-6.

QUEENSLAND COAL BOARD, 1990: Queensland Coals. 8th Edition.

REEVES, F., 1947: Geology of the Roma district, Queensland, Australia. *American Association of Petroleum Geologists Bulletin*, **31 (8)**, 1341–1371.