Coal geology of the northern Galilee Basin and its implications for coalseam methane investigations

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ABSTRACT

Since the early 1960's when BMR/GSQ field parties began field mapping within the northern Galilee Basin, the stratigraphy of the basin, particularly the Triassic and Late Permian part, has been compared and contrasted with that of the Bowen Basin. These comparisons have been carried considerable distances and considering the scarcity of outcrop and subsurface data points, could be said to be quite tenuous in places. In many cases no attempt was made to correlate or subdivide the strata. The authors have reviewed most of the available data and have developed a workable stratigraphic framework for the northern Galilee Basin. As well, the coal measure correlation and coal seam geometry of the Late Permian along the eastern margin and axis of the Koburra Trough have been assessed. Coal thicknesses of both the Early and Late Permian coal Measures are also shown. Considering coal continuity, volume, and in places rank, the Late Permian coal measures of the northern Galilee Basin has potential for coalseam methane development.

INTRODUCTION

Coal exploration in the northern Galilee Basin began in the early 1900's with workings in coal measures exposed at Galah Gorge and Oxley Creek, near Hughenden (Marks, 1911a & b) and Betts Creek, near Pentland (Reid, 1918). Subsequently, exploration and shaft sinking were undertaken by Mount Isa Mines Ltd (Carter, 1948). It was not until the early 1970's that a systematic exploration drilling program of the exposed eastern Galilee Basin was carried out by the Queensland Mines Department. Since then a number of coal exploration companies have explored and drilled within the basin. This coal exploration as well as the deeper drilling for petroleum by oil companies and Departmental stratigraphic drilling have enabled a much clearer picture of the coal distribution and Permian stratigraphy to emerge.

BASIN SETTING

The Late Carboniferous to Middle Triassic Galilee Basin is a large, relatively shallow, intracratonic basin which developed west of the Anakie Inlier and over the Thomson Orogen (Day *et al.*, 1983) (Figure 1). It is divided into northern and southern parts by the east-west trending Barcaldine Ridge, at approximately latitude 24° south. The northern portion of the basin covers approximately 164 000 km^2 and 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 basin contains two main structural depressions, the Koburra Trough in the east and the Lovelle Depression in the west, separated by the early Palaeozoic Maneroo Platform. The Koburra Trough contains in excess of 2 800m of Late Carboniferous to Middle Triassic strata, and the Lovelle Depression greater than 700m of similarly aged strata (Jackson, *et al.*, 1981).

The northern Galilee Basin is bounded to the east by the Late Devonian-Early Carboniferous Drummond Basin, to the north by the early Palaeozoic Lolworth-Ravenswood Block, to the northwest by the Precambrian Mount Isa Inlier, to the west by the Cambrian-Ordovician Georgina Basin and to the south by the early Palaeozoic Maneroo Platform (Figure 1). The basin is underlain by Precambrian units; probably early Palaeozoic metamorphic and granitic rocks west of the Cork Fault (Hawkins *et al.*, in prep.); probably early Palaeozoic metamorphic rocks of the Thomson Orogen in the central region

(Kirkegaard, 1974, Murray & Kirkegaard, 1978, Evans, 1980); and Late Devonian to Early Carboniferous volcanoclastic rocks of the Drummond Basin in the east (Jackson, *et al.*, 1981, Murray, 1986).

PREVIOUS STRATIGRAPHY

Previous to this paper the stratigraphy of the northern Galilee Basin was the result of work from many diverse and in some aspects unconnected areas. Because this work was so diverse, the authors have decided to include a summary of previous work in an attempt to illustrate the complexity that the stratigraphy of the northern Galilee basin had become.

Late Carboniferous to Early Permian Stratigraphy

Early mapping in the northern Galilee Basin by Vine *et al.* (1965), Mollan *et al.* (1969) and Exon *et al.* (1972) referred to the Joe Joe Formation, the basic unit at outcrop, as being Late Carboniferous to Early Permian in age (Tables 1 & 2). From petroleum exploration drilling the Joe Joe Formation was found to overlie rocks of the Drummond Basin sequence in the eastern part of the Koburra Trough and in the western part, crystalline basement. In the northern part of the Koburra Trough in the Hughenden area, the Late Carboniferous-Early Permian sequence equivalent to part of the Joe Joe Foemation is represented by the Boonderoo beds.

Mollan *et al.* (1969) and Exon *et al.* (1972) also referred to an Early Permian coal measure sequence on the Springsure Shelf and equated this to the Reids Dome beds of the Denison Trough. Within the eastern Koburra Trough and the Lovelle Depression, an Early Permian coal measure sequence was found to overlie the Joe Joe Formation from petroleum exploration drilling (Figure 2). This unit does not outcrop and could only be differentiated from the Late Permian coal sequence by palynology.

Gray and Swarbrick (1975) raised the Joe Joe Formation to Group status (Table 1) and defined the constituent formations in ascending order as, Lake Galilee Sandstone, Jericho Formation, Jochmus Formation and Aramac Coal Measures. Palynology indicates that the Aramac Coal Measures are the same age as part of the Reids Dome beds of the westren Bowen Basin.

Late Permian Stratigraphy

The Late Permian sedimentary rocks of the Galilee Basin are basin-wide, but within the southern part, south of the Barcaldine Ridge, coal is relatively rare (Figure 3). In the Lovelle Depression the Late Permian sequence ranges from approximately 700m to at least 1450m deep and has been intersected by only a few petroleum exploration wells. Because of this, discussion of the stratigraphy of the Late Permian sequence is mainly centred on the Koburra Trough.

Initial work on the Late Permian sequence within the Galilee Basin was by BMR/GSQ field mapping parties in the Springsure Shelf area (Mollan *et al.*, 1969 & Exon *et al.*, 1972). Because of the similarity in age and lithology of the exposed sequences in the Springsure Shelf and southern Koburra Trough areas with the Denison Trough of the Bowen Basin, the stratigraphic nomenclature of the Denison Trough was carried across the Nebine Ridge into the Galilee Basin. This mapping was supported by both the coal and petroleum explorationists who drilled within the basin. In the southern Springsure Shelf/Koburra Trough area the Late Permian was divided, in ascending order, into the Colinlea Sandstone, Peawaddy Formation, Black Alley Shale and Bandanna Formation (Table 1).

In the northern and northeastern parts of the Koburra Trough, in the Hughenden-Pentland area, the Late Permian was initially referred to as the 'Betts Creek Series' by Reid (1916). This sequence was later informally renamed and redefined by Vine *et al.* (1964) as the Betts Creek beds. The inference was that the Colinlea Sandstone, Peawaddy Formation, Black Alley Shale and Bandanna Formation, to the south, were equivalent to the Betts Creek beds (Table 2). Casey (1970) also addressed the problem of Late Permian stratigraphy in the northern part of the Koburra Trough. He stated that there was little lithological correlation between the strata from petroleum wells drilled within the trough and the rock units outcropping along the eastern margin. His stratigraphy was similar to that used by Mollan *et al.* (1969).

Gray and Swarbrick (1975) divided the Late Permian sequence in the northeastern Galilee Basin into the Colinlea Sandstone correlative overlain by the Bandanna Formation correlative. They showed that the Peawaddy Formation and Black Alley Shale wedged out north of AOD Jericho 1.

Between 1973 and 1978 the Coal Section of the Geological Survey of Queensland (GSQ) drilled a series of bores across strike of the outcropping and subcropping Late Permian rocks along the eastern margin of the trough, from Jericho in the south to Pentland in the north (Carr, 1973a, b, 1974a, b, c, 1976, 1977, 1978; Matheson, 1987a, b). These bores were part of a program by the Coal Section to assess the coal resources of the Late Permian along the eastern margin of the Galilee Basin. In total, 66 bores, including redrills, were completed. Most of these bores were either fully cored or were cored from below the covering Cainozoic rocks (Figure 4).

Together with bores drilled by the Coal Section on the Springsure Shelf (Anderson, 1974) and deep stratigraphic wells drilled by the Petroleum Section of the GSQ a clearer picture of the stratigraphy of basin emerged (Gray, 1976). As mapped on the Springsure Sheet, it was found that the Late Permian sequence could be divided into the lowermost quartzose Colinlea Sandstone, overlain by the finer grained and in part, bioturbated Peawaddy Formation and the in part, tuffaceous Black Alley Shale. The uppermost unit comprises interbedded siltstones, mudstones, labile sandstones and thin coal seams of the Bandanna Formation.

Northwards from the Springsure Shelf along the eastern margin of the basin, it appeared that both the Peawaddy Formation and the Black Alley Shale laterally thin and eventually wedge out. Although these formations were logged in coal bores at Lambton Meadows, near Jericho (Carr, 1974), and in GSQ Jericho 1 (Swarbrick, 1974), further north at Wendouree (Carr, 1973) they were not observed. Only the Colinlea Sandstone and Bandanna Formation which were described as having much greater volumes of coal than on the Springsure Shelf (Carr, 1973), persisted.

Coal drilling along the northeastern margin of the basin at Pentland and Milray (Matheson, 1987) and stratigraphic drilling also at Pentland (Gray, 1977) showed that the Late Permian sequence could be equated with the Betts Creek beds, a unit composed of white quartzose sandstone, interbedded siltstone, shale and claystone, coal and carbonaceous shale (Gray, 1977). Between these bores at Pentland and coal bores drilled further south at Degulla (Carr, 1973) no attempt was made to divide the Late Permian sequence intersected in bores at Laglan (Carr, 1974), Moray Downs (Carr, 1974; Matheson, 1987), View Hill (Carr, 1977), Mirtna (Carr, 1976) and Longton (Carr, 1978).

To the west of the coal bores, along the axis of the Koburra Trough and its western margin, a total of 33 petroleum wells and stratigraphic bores have intersected the Late Permian sequence (Figure 4). Most of these intersected coal measures but these were usually undifferentiated, or if the wells were in the southern part of the trough, the Late Permian was referred to as Bandanna Formation and Colinlea Sandstone correlatives.

Since 1973 several companies have been actively exploring for coal in the Wendouree and Degulla areas, and over 900 shallow bores (chip and partially cored) have been drilled to delineate the coal resources of the Bandanna Formation and Colinlea Sandstone. Also from 1979 to 1990 The Shell Company of Australia Ltd drilled over 300 similar bores at Pentland to delineate the coal resources within the Betts Creek beds. In all cases the companies followed the nomenclature established by the Coal Section of the GSQ.

UPDATED STRATIGRAPHY

Early Permian Coal Measures

The coal measures of the Early Permian have now been designated the Aramac Coal Measures (Gray & Swarbrick, 1975) (Table 3). These coal measures have proven difficult to differentiate from the Late Permian coal measures and this can only be achieved by palynology. It should be noted that despite the presence of a time break based on palynology, no readily recognisable unconformity is apparent from examination of fully cored sequences in stratigraphic bores GSQ Muttaburra 1 (Brain *et al.*, 1991) and GSQ Longreach 1-1B (Green *et al.*, 1991). To date only 23 wells/bores have intersected this unit.

The Aramac Coal Measures has been subdivided into: a lower interval of dominantly medium to thickly bedded sub-labile sandstone, and subordinate laminated to thickly bedded mudstone and minor dull coal seams; and an upper interval of quartzose to sub-labile sandstone, laminated siltstone, carbonaceous mudstone and prominent coal seams. Comparisons of coal seam development in the upper interval in both bores revealed that in GSQ Muttaburra 1, 8 seams greater that 0.30m in thickness and averaging 0.76m were intersected, compared with an average thickness of 2.26m for 14 seams greater than 0.30m thick recorded from a similar interval in GSQ Longreach 1-1B. The coal is dull with minor bright bands and tuffs are associated with some seams.

The present day areal distribution of the Aramac Coal Measures is very limited compared with the overlying Late Permian sequence. The former is confined to the western side of the Koburra Trough, adjacent to the Maneroo Platform and to the central portion of the Lovelle Depression, adjacent to the Cork Fault (Figure 2). It would appear that the distribution of these coal-bearing rocks has been controlled by the development of grabens and half grabens. The true depositional extent of the unit cannot be assessed because of mid-Permian erosion.

Late Permian Coal Measures

The present authors have reviewed all the petroleum and stratigraphic well data and a large percentage of the company coal exploration data. From this review a number of anomalies have emerged regarding the present stratigraphy. Because not all coal exploration data have been assessed this presentation can only be regarded as preliminary.

The Late Permian Bandanna Formation, Black Alley Shale, Peawaddy Formation and Colinlea Sandstone are present along the eastern margin of the Galilee Basin from the Springsure Shelf in the south, to at least the Lambton Meadows area. North of Lambton Meadows, the Black Alley Shale appears to pinch out. The other three units continue north to at least the Laglan area where the Peawaddy Formation appears to thin out. The Bandanna Formation and Colinlea Sandstone units are continuous to a least as far north as the Mirtna area. North of Mirtna the Upper Permian sequence is lithologically similar to the Betts Creek beds.

If sandstone lithologies only are used for correlation purposes then the quartzose sandstones of the Colinlea Sandstone are very similar to the sandstones of the Betts Creek beds. However the coal seam architecture offers a different view. Along the entire eastern margin of the northern Galilee Basin the upper and lower coal measures are separated by a thick sandstone unit which does not have a consistent lithology; the boundary between the Colinlea Sandstone and the Bandanna Formation is placed at the top of the last major quartzose sandstone bed and this bed is normally found near the base of the above thick sandstone unit. The upper measures are designated the A and B seams whereas the lower measures are the C, D, E, F and G seams. Carr (1976) found that north of Moray Downs the upper seams are poorly developed and this, with the quartzose sandstone lithology could imply that the Betts Creek beds are equivalent to the Colinlea Sandstone. While this may appear relevant it does not take into account all features. The thick sandstone bed separating the coal measures is present in all bores drilled along the eastern margin and despite the upper coal seams deteriorating north of Moray Downs, they still can be correlated with seams at Moray Downs and to the south. Only at Pentland was the A Seam not intersected in Departmental bores and it is conceivable that these bores were drilled to the east of the A seam subcrop. If this argument is sustained then the Betts Creek beds are equivalent to both the Bandanna Formation and the Colinlea Sandstone and the explanation for the change in sandstone lithology in the northern Koburra Trough can be attributed to a change in sediment source for the Betts Creek beds. This is possible, because to the north and east of the trough lies the Lolworth-Ravenswood Block, a large volcanic, metamorphic province which could have provided source material for the Betts Creek beds. Further south, rocks from the Drummond Basin, now outcropping between the Gallilee and Bowen Basins, may have provided the source for the sedimentary rocks found in the Bandanna Formation in both Permian basins.

COAL SEAM GEOMETRY

Early Permian Coal Measures

There have been only 23 intersections of the Aramac Coal Measures within the basin and only 2 of these with continuous core (Brain *et al.*, 1990, Green *et al.*, 1991). Accordingly, continuity of seams within the Aramac Coal Measures has not been proven. Any attempt to correlate coal seams within the coal measures would not be valid at this time.

Late Permian Coal Measures

Since the deep petroleum exploration drilling began during the 1960's, the coal resources of the Late Permian sequence in the Galilee Basin have been surmised to be very large. This supposition implies that the coal seams within the Late Permian are continuous across the basin but there has been no attempt to undertake seam correlation from near outcrop in the east. Along the eastern margin, seams from the Bandanna Formation and Colinlea Sandstone have been tentatively correlated from reconnaissance drilling. The seam nomenclature devised by Carr (1973a, b, 1974a, b, c, 1976, 1977, 1978) and continued by Matheson (1987a, b) was followed by companies exploring in the Wendouree and Degulla areas. Petroleum companies have not attempted to continue this nomenclature deeper into the basin. With the interest now being shown in coalseam methane, very large inferred reserves of methane are assumed to be contained within the Late Permian seams of the basin but continuity of these seams has not been established, as discussed.

Many of the coal exploration bores examined by the authors were found to have been geophysically logged which permitted correlation with the geophysically logged petroleum wells. While the correlation proposed is only preliminary, it appears consistent. There is no identifiable wireline log marker within the Bandanna Formation and Colinlea Sandstone interval but the C Seam at the top of the Colinlea Sandstone has a very distinct character, consisting of a very interbanded top with a clean coal base. Between Degulla and Moray Downs the C seam attains a thickness in excess of 20m and can be readily correlated with other bores (Figure 8).

To the west within the Koburra Trough, the seams intersected by the deep petroleum wells can also be correlated using the same criteria for the eastern margin. Whereas the wells are many kilometres apart, in places greater than 100 kilometres, the seams appear to be sufficiently uniform to enable a fairly consistent correlation (Figure 9). This line of wells can also be related to the section along the eastern margin.

COAL QUALITY AND RESOURCES

Early Permian Coal Measures

Coal rank for the Aramac Coal Measures varies from Rv, max 0.60 to 0.80% in the western part of the Koburra Trough , and from 0.50 to 0.95% in the central area of the Lovelle Depression. Lower than expected reflectance values in the coal measures are attributed to bacterial reduction of organic matter, and the resultant production of lipids which have become incorporated in the humic degradation products (Smith <u>in</u> Green *et al.*, 1991).

Depths in excess of 750m, in both areas, precludes these coals from being mined by open cut methods. Furthermore the quality of these coals is virtually unknown and seam continuity has not been established.

Late Permian Coal Measures

Late Permian coals found within the Galilee Basin have been classified as high ash, subhydrous and lignitious (Callcott *et al.*, 1976) with a rank varying between Rv, max 0.35 and 0.9%. A petrographic study of coal samples from Departmental coal bores (Beeston, 1977) showed the coal to be low rank, subhydrous and to range from thin bright, vitrinite-rich seams in the south to thick, dull inertinite-rich seams in the north. The organic petrology of these coals has implications for coalseam methane. For drainage to take place effectively, methane must diffuse through the coal via a network of natural fractures into the well. Fine fractures are known in vitrinite bands but large interconnecting fractures are required which penetrate both vitrinite and inertinite bands for effective drainage to take place.

Initially there were indications that the Late Permian coals from the Galilee Basin may have been suitable for the manufacture of synthetic fuels and petrochemicals but extensive testing by Dampier Mining Company Ltd showed that the coals were suitable only for steam raising or possibly gasification.

Presently there are no coal mines active within the basin. Two companies have retained Authorities to Prospect (ATPs) in the northeastern part of the Galilee Basin and the Queensland Coal Board carries combined measured and indicated resources of 2585 million tonnes for the Alpha, Kevin's Corner and Pentland areas. The latter was recently surrendered by The Shell Company of Australia Ltd (Queensland Coal Board, 1991).

To date coalseam methane exploration has not been actively carried out within the Galilee Basin. Although there are three current coalseam methane ATPs over areas in the basin, work so far in all three areas has not progressed past office-based studies (Figure 12). Also no quantitative investigations have been undertaken into gas content or quality of the coals found in the basin.

Petroleum exploration within the basin has discovered some conventional gas (ENL Lake Galilee 1 and FPN Koburra 1) which may have been sourced from the coals of the Early and Late Permian coal measures. Whilst it is inferred that vast resources of coalseam methane exist within both coal measures, no studies have been conducted to test this assumption.

CONCLUSIONS

The Bandanna Formation, Colinlea Sandstone and Betts Creek beds of the northern Galilee Basin contain very large resources of coal within as many as seven main coal seams. This coal may also contain very large resources of coalseam methane. Preliminary investigations show that the coal seams of the Late Permian are continuous across the Koburra Trough of the northern basin and that coal volumes are also consistent.

To further clarify the potential of the Late Permian coal measures a systematic exploration program to delineate gas quality, quantity and coal permeability and porosity needs to be undertaken. Using the vitrinite reflectance and coal thickness isopach maps, areas within the northern basin with sufficient maturity and thickness to have generated methane should be targeted (Figure 13).

ACKNOWLEDEMENT

The authors would like to thank Mr A.R.G. Gray who read and reread the paper and offered suggestions about the stratigraphy of the northern Galilee Basin.

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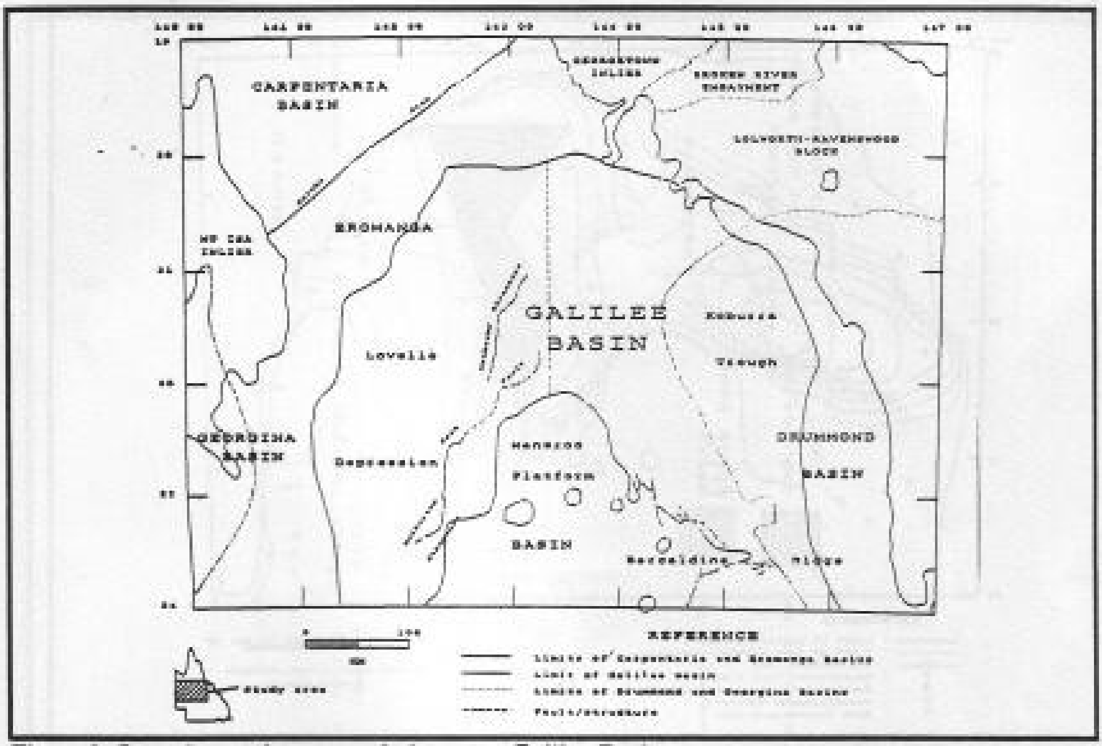

Figure 1. Location and structural elements, Galilee Basin

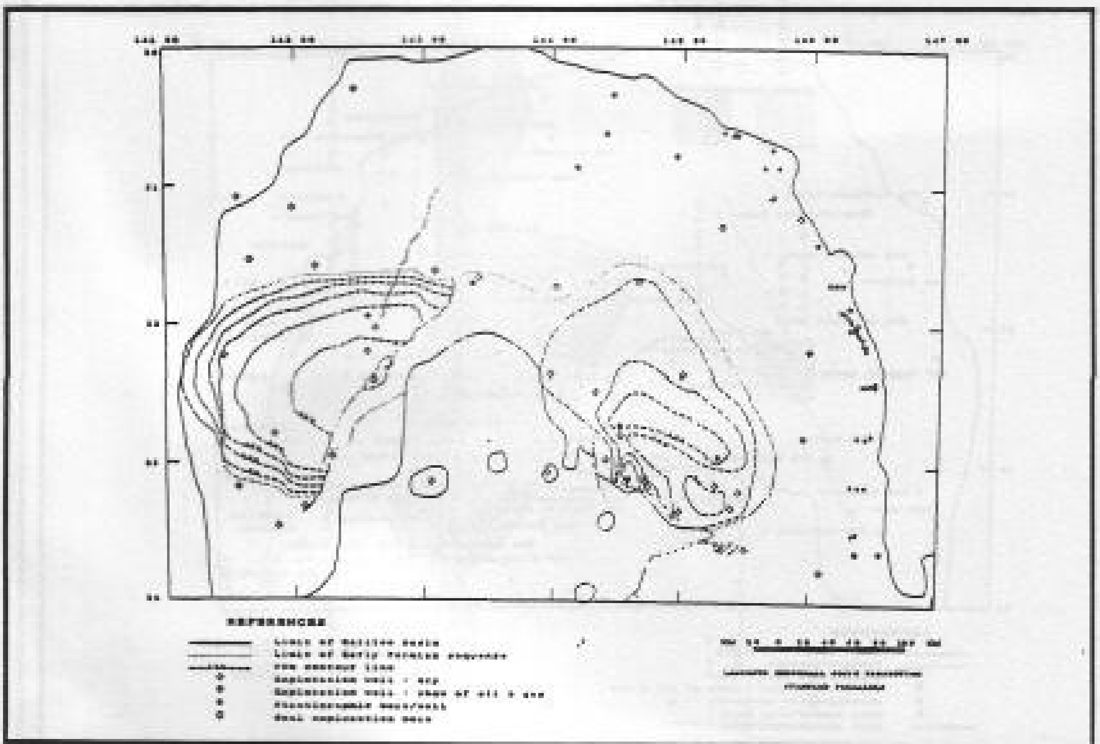

Figure 2. Areal extent and thickness Early Permian coal measures, Galilee Basin

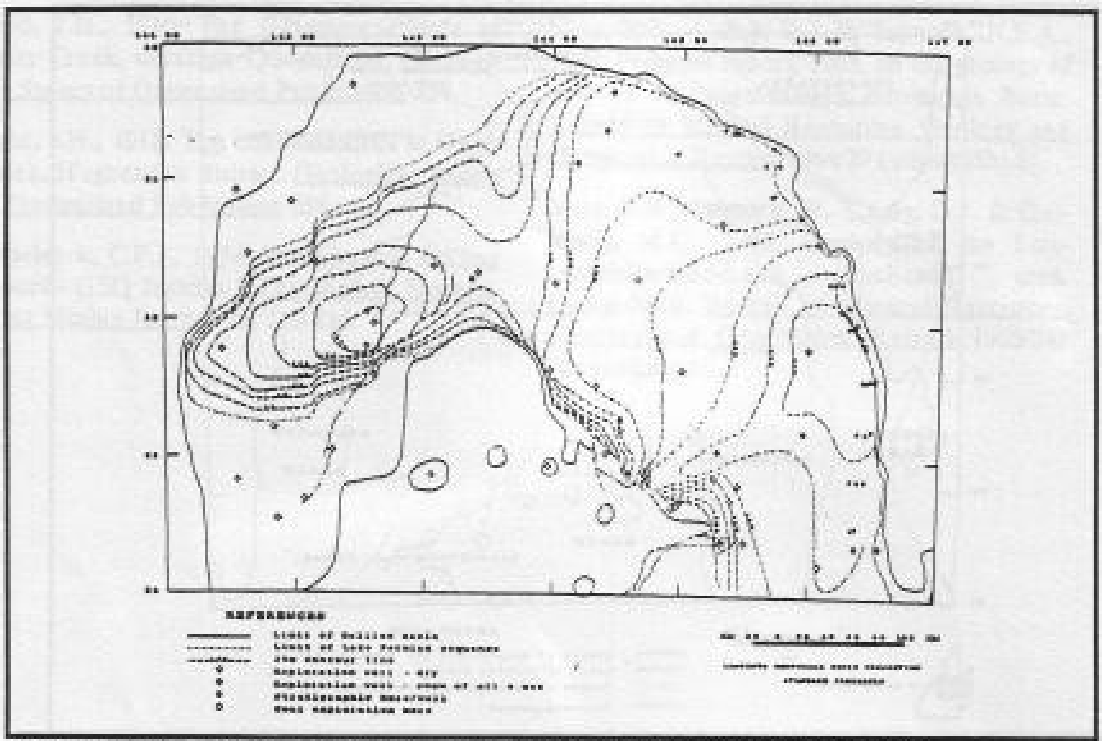

Figure 3. Areal extent and thickness, Late Permian coal measures, Galilee Basin

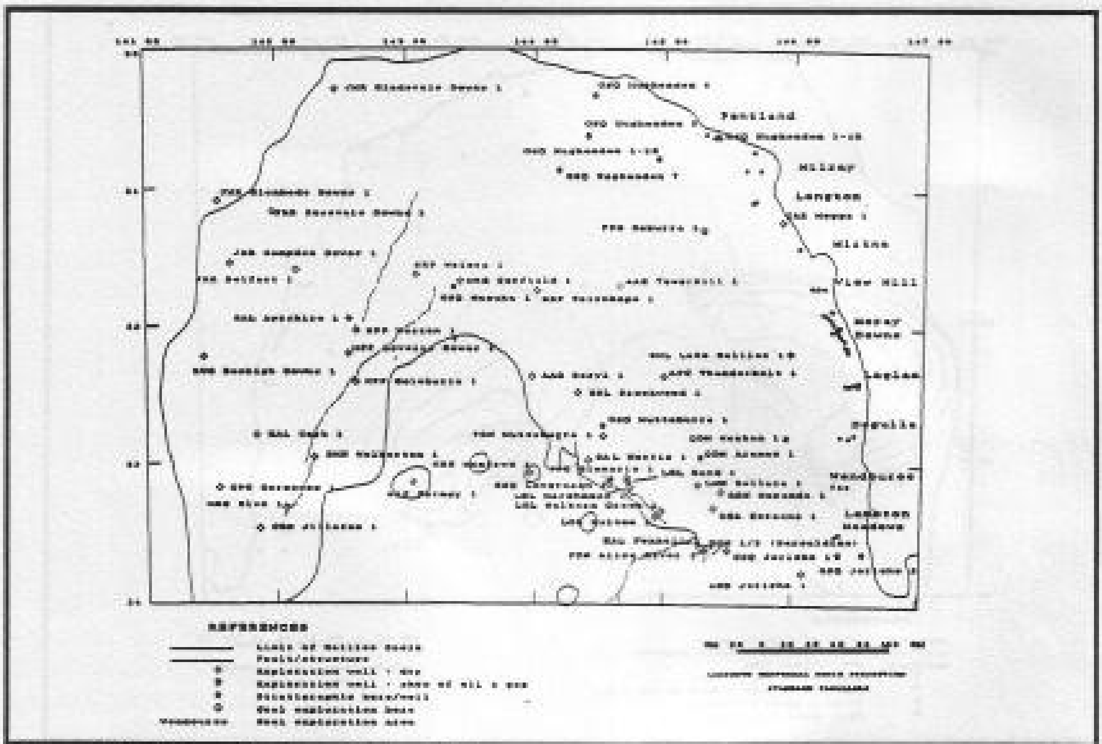

Figure 4. Well/bore location, Galilee Basin

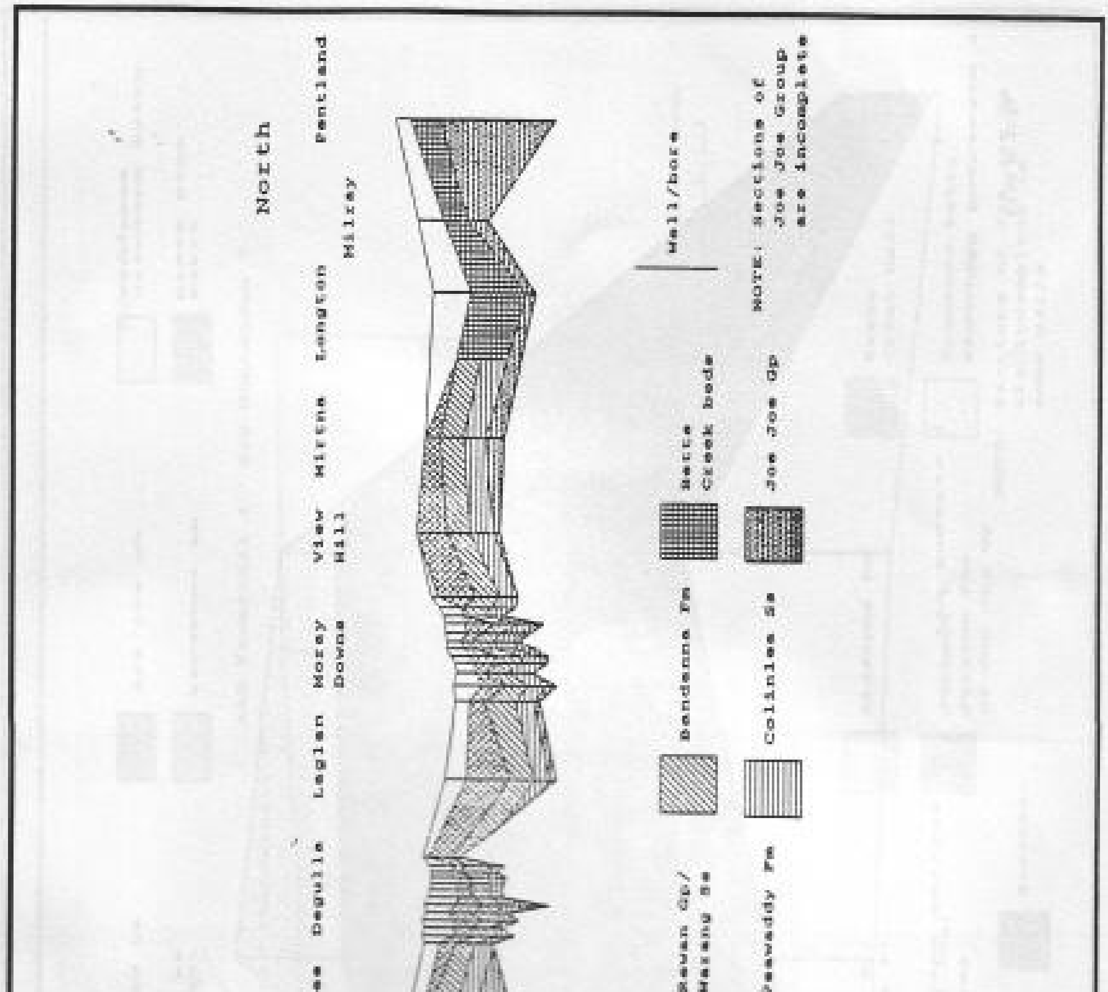

Figure 5. Stratigraphic section - eastern margin Koburra Trough, Galilee Basin

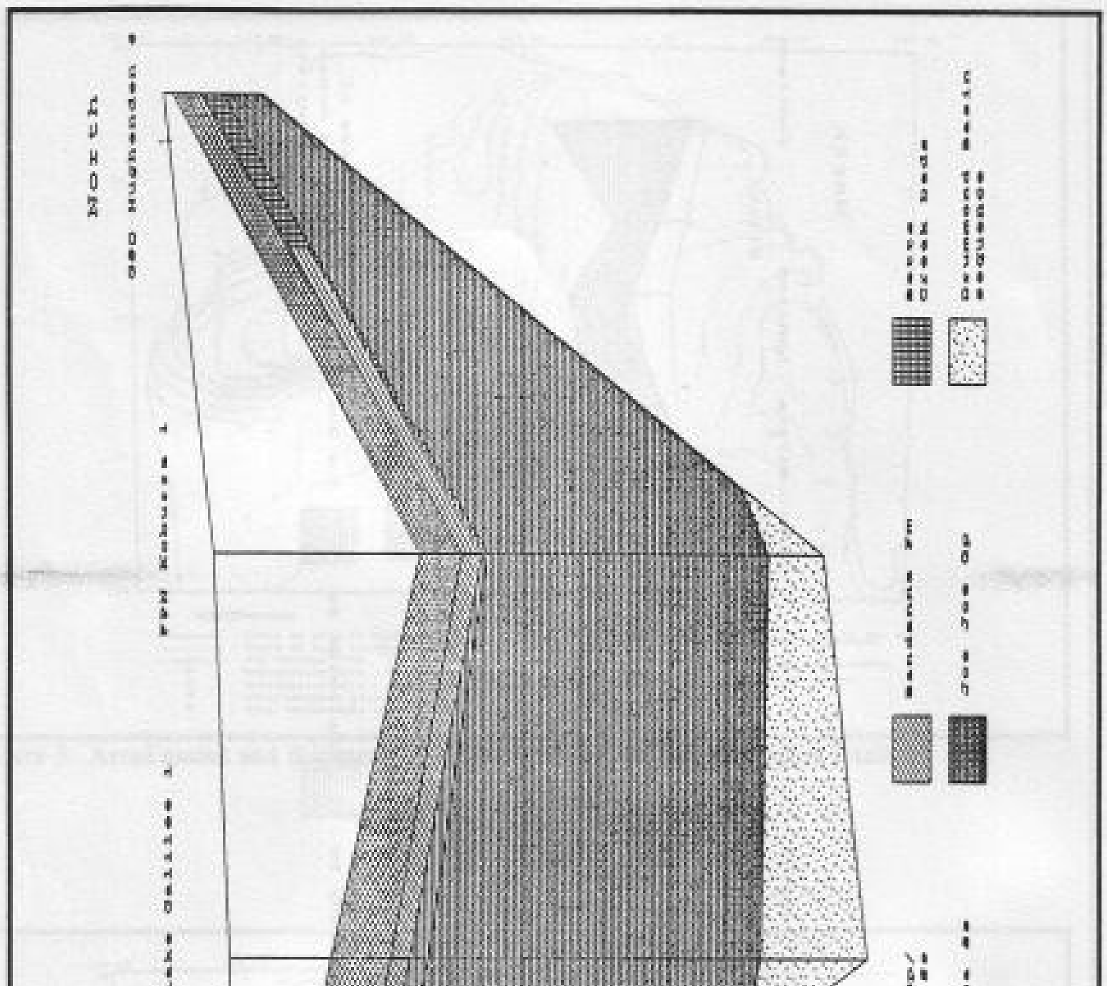

Figure 6. Stratigraphic section - axis Koburra Trough, Galilee Basin

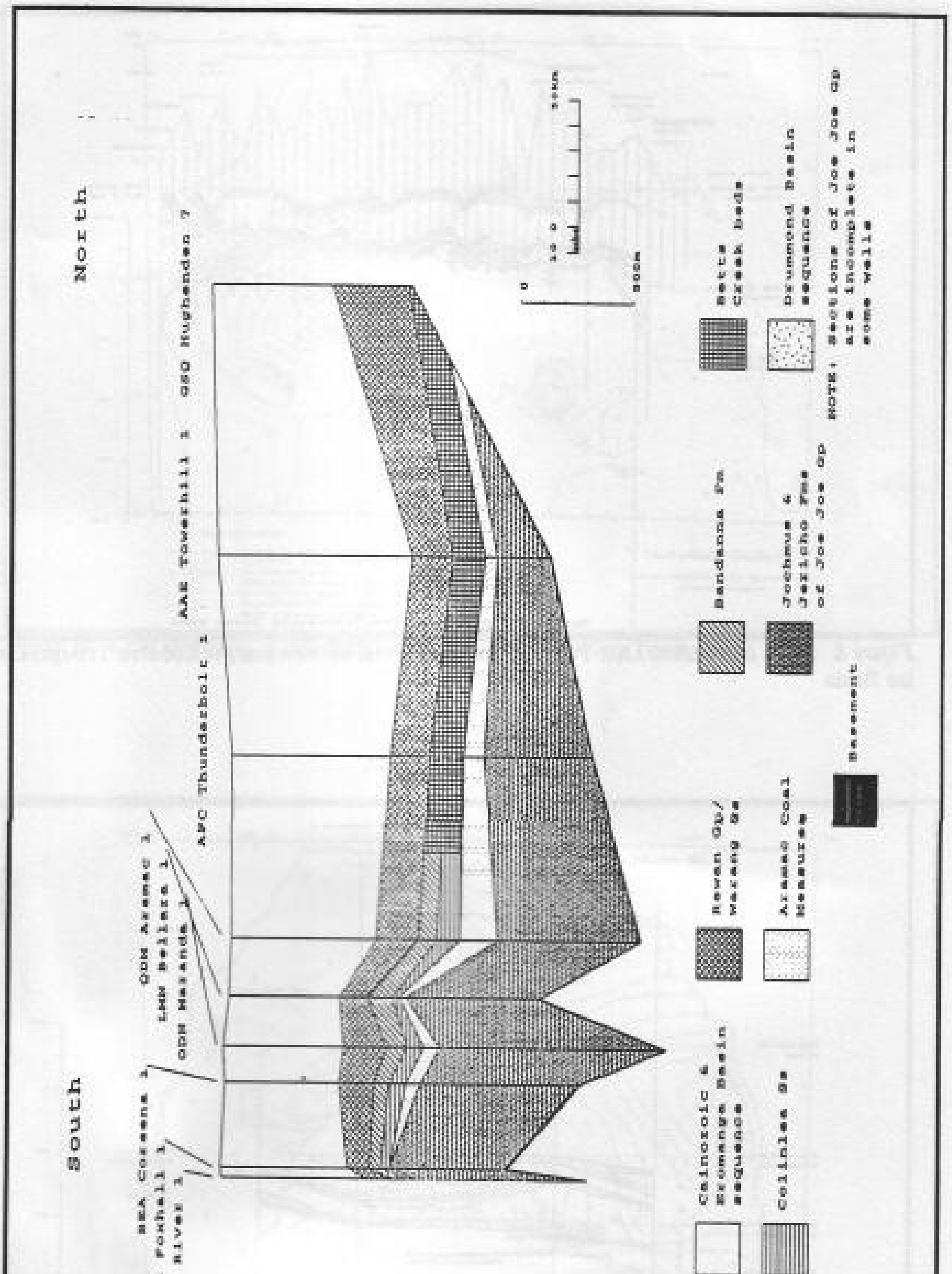

Figure 7. Stratigraphic section - western margin Koburra Trough, Galilee Basin

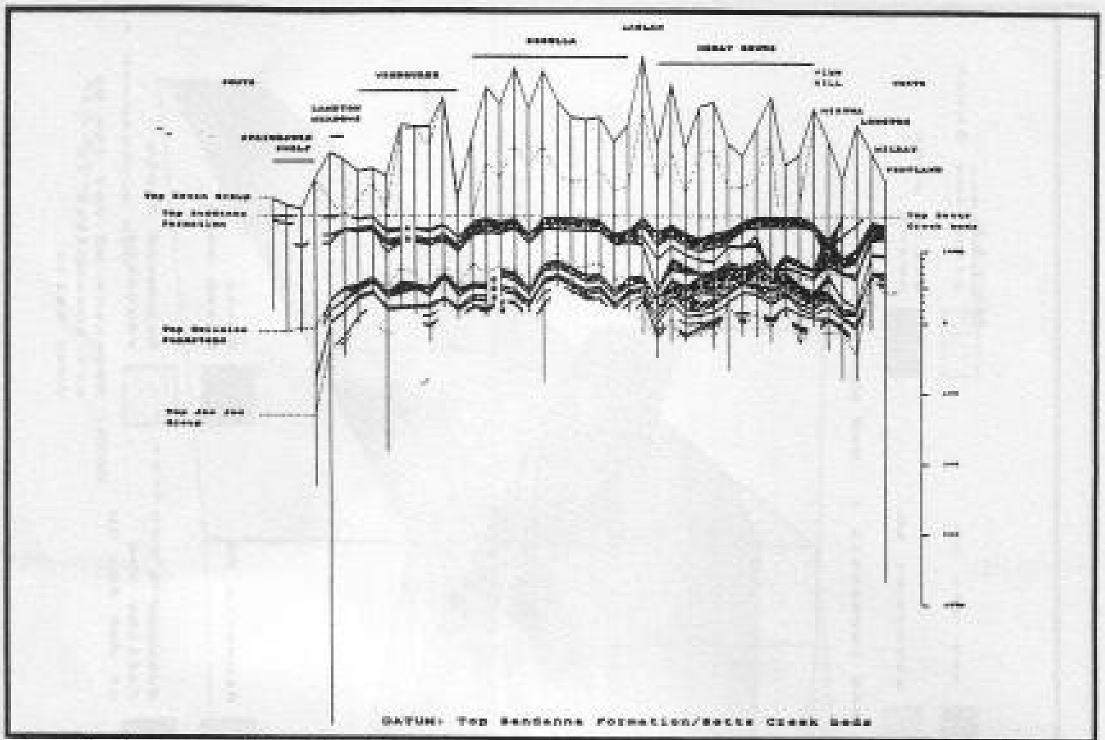

Figure 8. Seam correlation Late Permian coal measures, eastern margin Koburra Trough, Galilee Basin

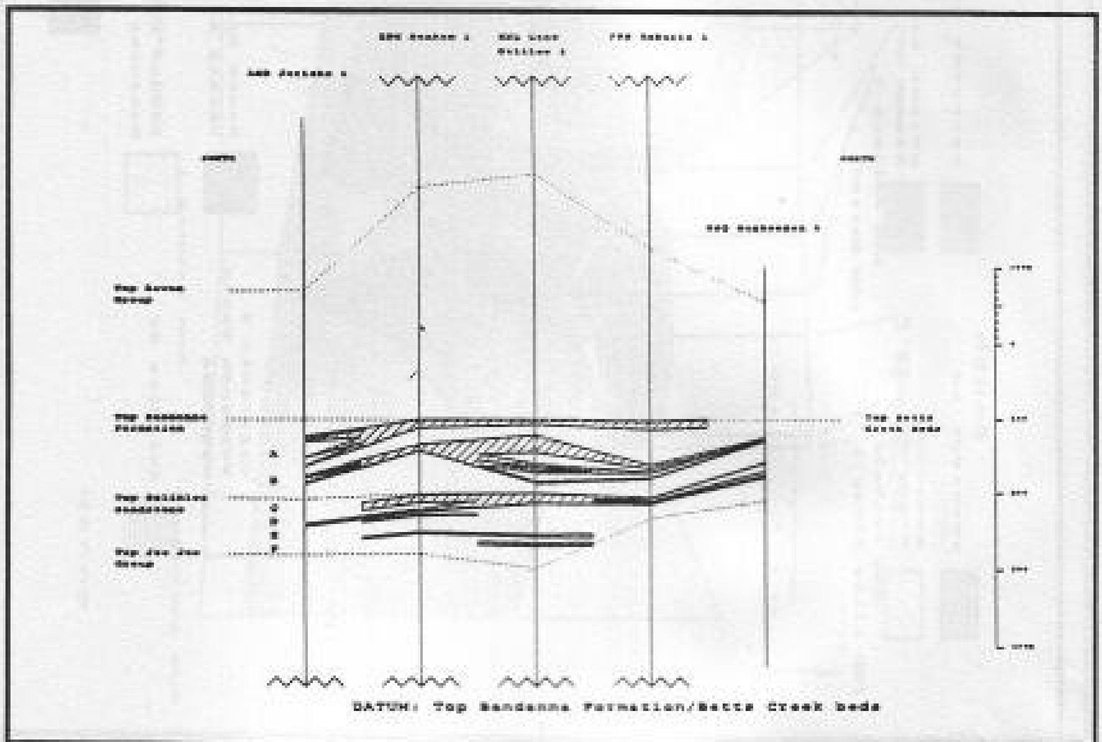

Figure 9. Seam correlation Late Permian coal measures, axis Koburra Trough, Galilee Basin

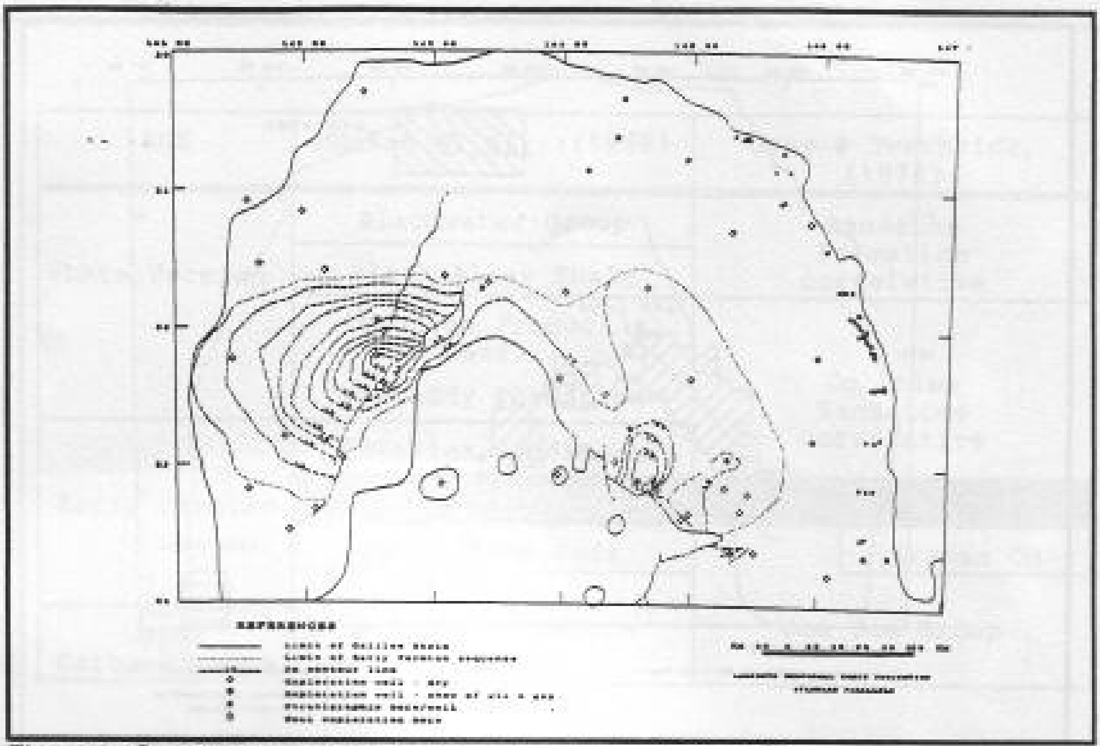

Figure 10. Coal thickness, Early Permian coal measures, Galilee Basin

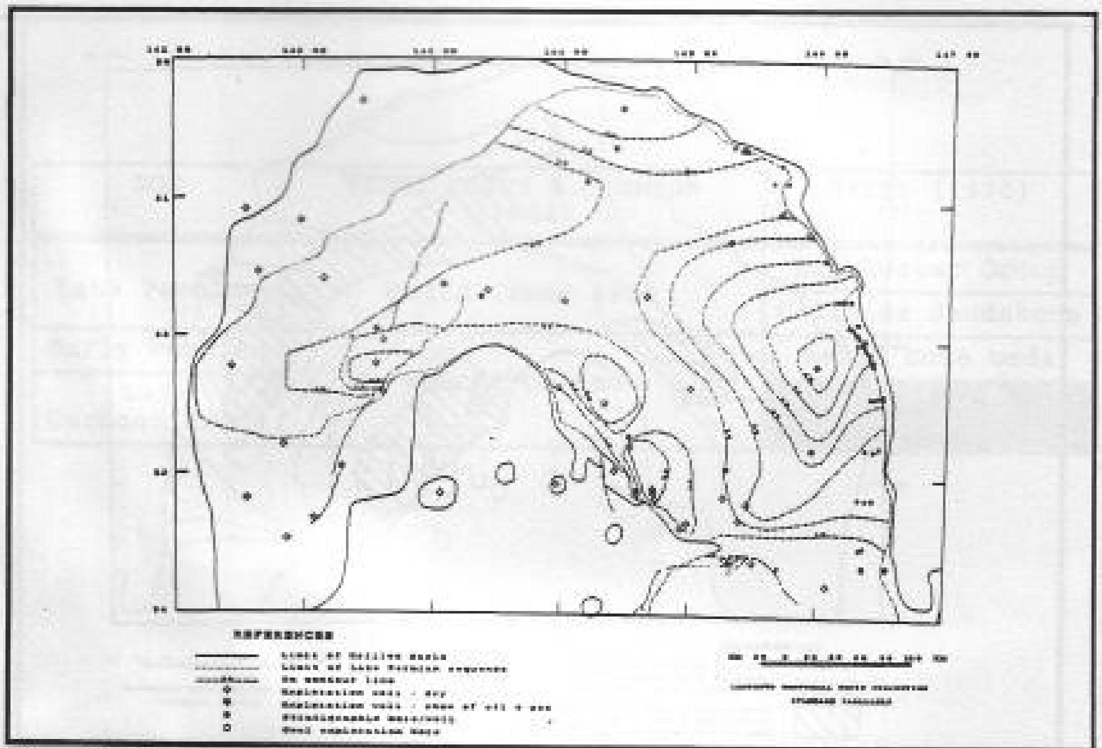

Figure 11. Coal thickness, Late Permian coal measures, Galilee Basin

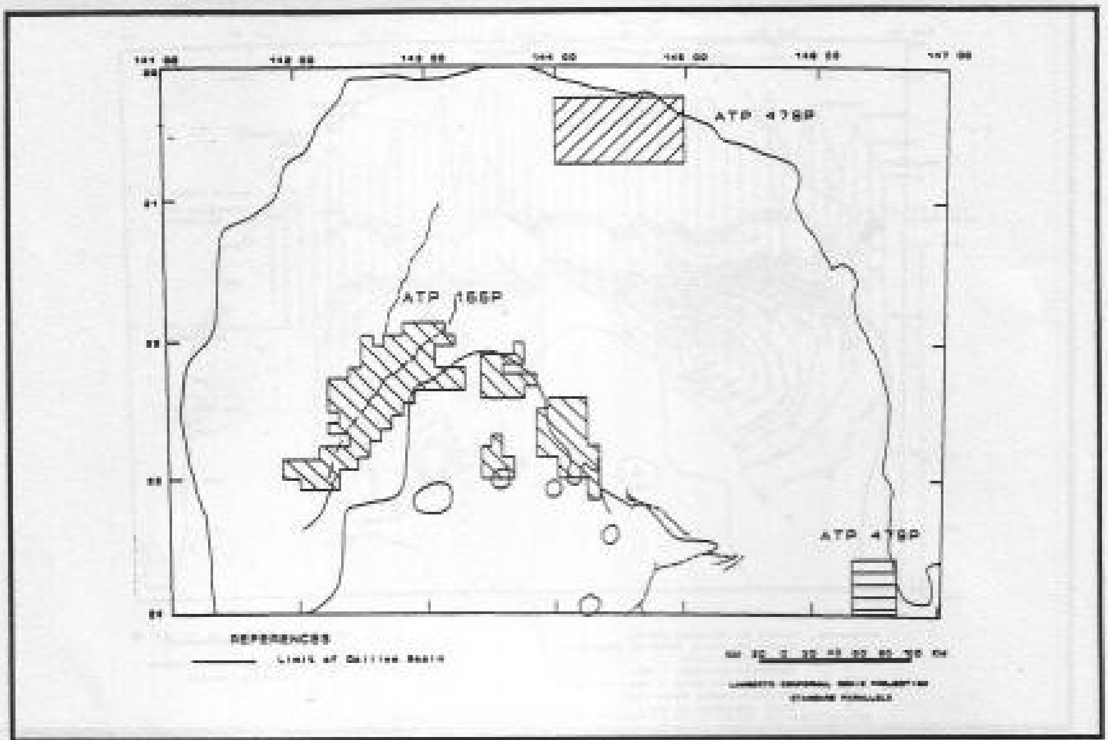

Figure 12. Coalseam methane Authorities to Prospect, Galilee Basin

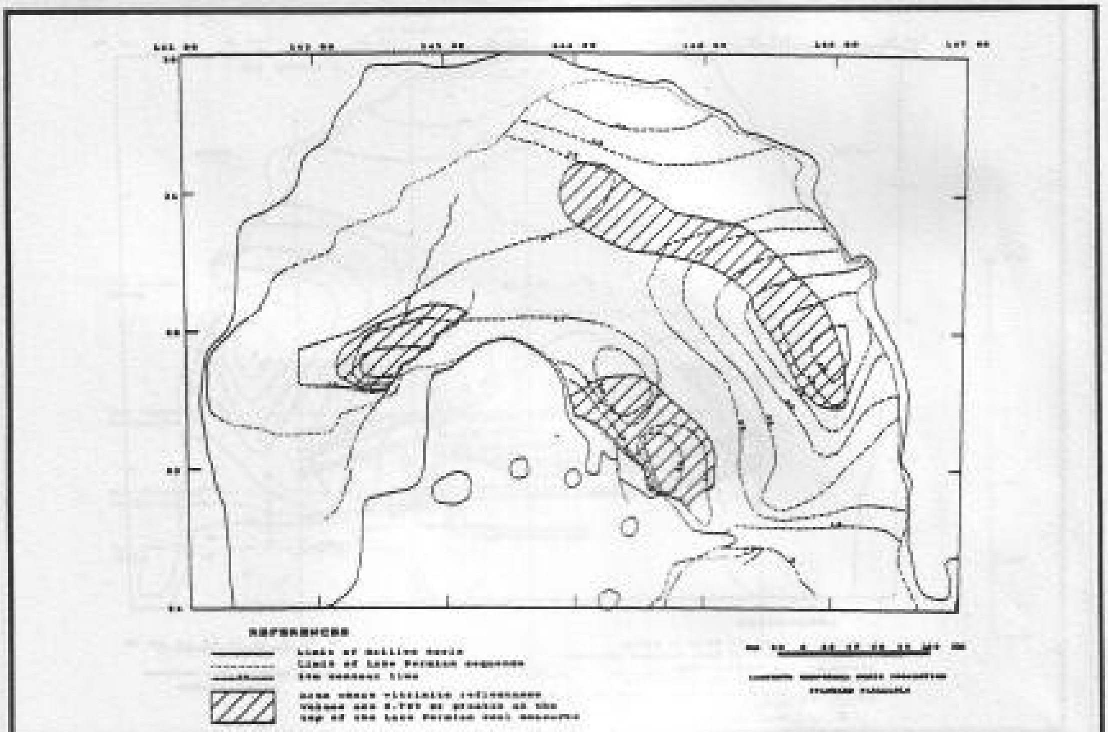

Figure 13. Coalseam methane potential areas, Late Permian coal measures, Galilee Basin

AGE	Mollan et al., (1969)	Gray & Swarbrick, (1975)
Late Permian	Blackwater Group	Bandanna Formation correlative
	Black Alley Shale	
	(Mantuan *Productus* Bed) Peawaddy Formation	Colinlea Sandstone correlative
Early Permian	Colinlea Sandstone	
	Reids Dome Beds	Aramac CM
Upper Carboniferous	Joe Joe Formation	Joe Joe Group

Table 1. Early stratigraphy of the Carboniferous-Permian of the southern part of the northern Galilee Basin

AGE	VINE, CASEY & JOHNSON (1964)	CASEY (1970)
Late Permian	Betts Creek beds	Blackwater Group
		Colinlea Sandstone
Early Permian	Boonderoo beds	Reids Dome beds
Late Carboniferous		

Table 2. Early stratigraphy of the Carboniferous-Permian of the northern and northeastern parts of the northern Galilee Basin

AGE	LOVELLE DEPRESSION	KOBURRA TROUGH		EASTERN MARGIN			SPRINGSURE SHELF
Late Permian	Betts Creek beds	Betts Creek beds	Bandanna Formation	Betts Creek beds	Bandanna Formation	Bandanna Formation	Bandanna Formation
						Black Alley Shale	Black Alley Shale
			Colinlea Sandstone		Colinlea Sandstone	Peawaddy Formation	Peawaddy Formation
						Colinlea Sandstone	Colinlea Sandstone
Early Permian	Aramac Coal Measures	Aramac Coal Measures	Aramac Coal Measures	Joe Joe Group			Joe Joe Group
Late Carboniferous	Joe Joe Group	Joe Joe Group	Joe Joe Group				

Table 3. Revised stratigraphy northern Galilee Basin