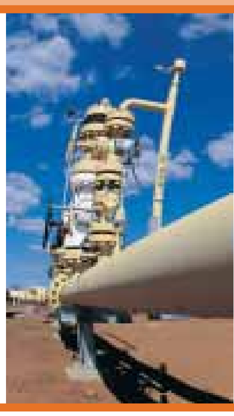
Queensland
Opportunities for petroleum exploration 2007
Geological assessment for potential tenderers

November 2006

Adavale and Georgina Basins Opportunities 2007


Queensland **the Smart State**

Queensland Government
Department of **Mines and Energy**

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In September 2006 the Queensland Government created the **Department of Mines and Energy** by merging sections of the Department of Natural Resources, Mines and Water with the Department of Energy.

The former department is now the Department of Natural Resources and Water. At the time of publication machinery of goverment changes had not been finalised, particularly those associated with the changeover of email and web addresses.

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Department of Mines and Energy
GPO Box 2454
Brisbane Queensland Australia 4001

For copyright enquiries phone +61 7 3405 5563 or fax +61 7 3405 5567

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Library
Level 2, Mineral House, 41 George St
Brisbane Queensland Australia 4000

Phone: +61 7 3237 1435
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Adavale and Georgina Basins

Executive summary

Queensland opportunities for petroleum exploration 2007

About this booklet

This booklet is intended to provide new and existing petroleum explorers with information about areas in the Adavale and Georgina Basins in central and western Queensland that may be available for petroleum exploration under Authorities to Prospect.

These frontier basins have had limited exploration, most of which was conducted during the 1960s. They contain the elements of potentially economic petroleum systems with the potential for both oil and gas.

Available lands over these basins are being assessed by the **Queensland Department of Mines and Energy** with a view to advertising the areas for competitive tender in the first-half of 2007.

The area to be released is likely to exceed 100 000 square kilometres and will represent the largest land release for petroleum exploration in Queensland in the past decade.

Previous calls for tenders gazetted in 2005 and 2006 resulted in the lodgement of 15 and 23 applications respectively, reflecting Queensland's standing as a favourable place to explore for petroleum.

These calls for tenders included areas in the Bowen–Surat and the Cooper–Eromanga Basins. Areas within these basins are also likely to be included in a call for tenders in 2007.

Executive summary

The **Adavale and Georgina Basins** represent a unique petroleum exploration opportunity in Queensland, Australia.

The basins are under-explored by any standard with most serious exploration being undertaken in the 1960s and 1970s. Regional coverage of seismic data is available to enable an assessment of the potential regional geological setting.

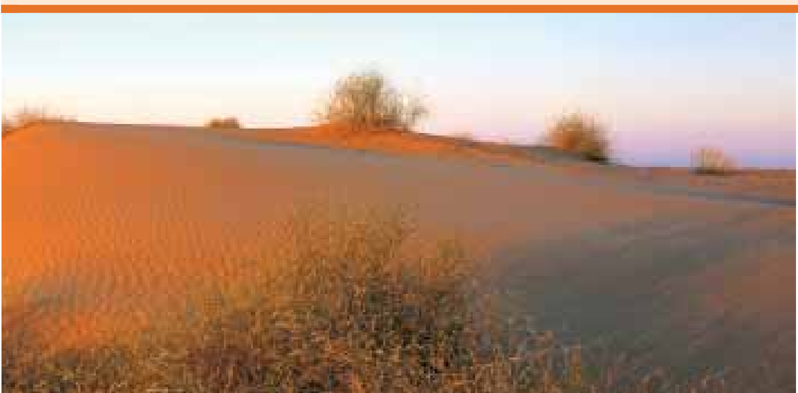
The Adavale Basin contains the small Gilmore gas field and a significant gas flow was recorded from AOD Ethabuka 1 in the Toko Syncline in the Georgina Basin.

Both of these basins contain a mixture of exploration plays ranging from structural traps to stratigraphic traps associated with carbonate facies variations and interbedded carbonate – clastic sequences.

The Adavale and Georgina Basins contain their own unique set of challenges ranging from their location, to the depth of targets and complex geology.

A previously limiting factor in attracting exploration interest in these basins was the absence of infrastructure, particularly pipelines. This is no longer a major issue following the construction of the Ballera to Mount Isa and Cheepie to Barcaldine pipelines.

The continued growth in the Queensland and, in particular, the eastern Australian gas market will assist in the commercialisation of any gas discoveries in the Adavale and Georgina basins.



Adavale and Georgina Basins

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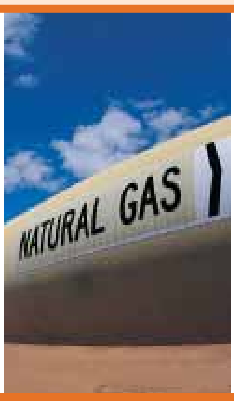


Queensland – geological overview

Queensland contains a number of carbonate basins which are underexplored for petroleum, but contain the elements of potentially economic petroleum systems with potential for both oil and gas.

The oldest such basin is the Neoproterozoic to Ordovician **Georgina Basin** which straddles the Queensland–Northern Territory border and is traversed by the Ballera to Mount Isa gas pipeline.

There are rich source rocks of Middle Cambrian age which in the Toko Syncline are mature for oil except in the deepest part of the syncline, where they are mature for dry gas.

There are large structures associated with fault rollovers plus potential for stratigraphic traps. Vugular porosity in dolomites offers the best chance of carbonate reservoirs within the Ninmaroo and Kelly Creek Formations and Thorntonia Limestone.

There are oolitic sedimentary rocks which may have good primary porosity and interbedded sandstones in the carbonates that contain porosity. Fracture porosity is another possibility (cf. the Palm Valley gas field in the Amadeus Basin).

Fine-grained carbonates and shales provide excellent seals. There has not been a valid test although AOD Ethabuka 1 flowed 7000 m^3/d of dry gas, but was abandoned short of the target depth.

Hydrocarbons have generated and migrated in the Devonian **Adavale Basin**, and there has been some production from one gas field at Gilmore.

Reservoir rocks vary from poor to good, but data on reservoirs are sparse. Fracture porosity may also provide suitable reservoir properties. Seal rocks are present including salt, shale and fine-grained carbonates.

There are areas of suitable source rocks, both carbonate and siliciclastic. A variety of trap types are available ranging from stratigraphic to structural.

Rocks vary in maturity ranging from immature to overmature depending on the variable thickness of the sequences and the different burial depths attained.

Burial and maturation modelling of the Gilmore gas field indicates two main phases of oil and gas generation. Source rocks in the Log Creek Formation were actively expelling hydrocarbons during the Late Devonian.

Stratigraphically higher source rocks expelled hydrocarbons in the Early Cretaceous. Post-mature dry gas is probably continuing to be expelled.



Adavale and Georgina Basins

Queensland – an expanding gas market

Queensland – an expanding gas market

Demand for natural gas in Queensland is met through conventional gas and coal seam gas reserves.

Most conventional gas is drawn from fields within the Cooper and Eromanga Basins in the south and south-west of Queensland with lesser quantities produced from the Bowen–Surat Basins. Coal seam gas is drawn from the Bowen–Surat Basins.

Queensland has over 5500 petajoules of proved and probable conventional and coal seam gas reserves, of which about three quarters are in coal seam gas reserves.

The mid-1990s saw the development of gas fields in the Queensland portion of the Cooper Basin and the construction of the Ballera processing plant.

Development of these fields was in response to the inability of the Bowen–Surat Basin gas fields to meet the growing demand for gas in south-east Queensland.

By 1994, the Queensland gas market consisted of customers on the Brisbane, Roma and Dalby gas distribution networks and the Incitec Plant at Gibson Island.

The market also included the major industrial consumers in Gladstone. Demand was around 16 petajoules a year supplied via the Roma to Brisbane Pipeline from the gas fields around Wallumbilla.

Industrial customers represented around 55% of demand, smaller industrial and commercial users represented around 36% of demand, and residential and small commercial customers made up the remaining 9%.

In 2006, total market demand for gas in Queensland is likely to exceeded 120 petajoules.

Coal seam gas is expected to meet around 50 petajoules of that gas demand – a market share in excess of 36% and a growth in market share of over 33% in five years.

ABARE[1] predicts that over the period 2003-04 to 2029-30, Australia's natural gas consumption will increase by 4.5% per year in the medium-term and by 2.8% over the entire outlook period.

The use of natural gas is expected to double, accounting for 32% of the growth in total national energy consumption.

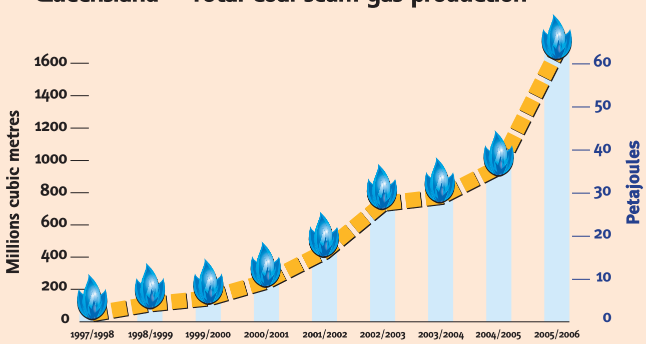
ABARE also predicts that Queensland's gas consumption will almost treble; though noting that much of this growth is expected in the electricity generation sector.

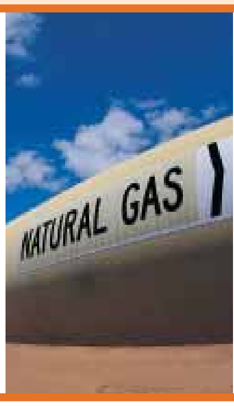
Access to the eastern Australian gas market is limited to a wet gas pipeline from Ballera in south-west Queensland to Moomba in South Australia.

Epic Energy is proposing to construct a common carrier pipeline between these two centres to provide direct access for Queensland-sourced gas into the eastern Australian gas market for the first time. This will expand the opportunities of Queensland producers to market their gas.

Similarly, electricity consumption[2] in Queensland is forecast to grow by 8.8% a year over the next two years.

Queensland – Total coal seam gas production





Adavale and Georgina Basins

Queensland – an expanding gas market

This growth is driven by a strong demand from major new industrial developments with supplementary demand from the growing residential sector. Much of this demand will be met through gas-fired generation.

Investors are recognising Queensland's investment potential, as a State with both a strong economy and significant gas reserves. There is also an acknowledgment that future generation decisions will need to take into account possible requirements to reduce greenhouse gas emissions.

Gas-fired generators are more efficient than coal-fired power stations and produce less greenhouse gas emissions.

Over 600 megawatts of gas-fired generation has come on line since May 2000, in time for the commencement of the 13 per cent Gas Scheme on 1 January 2005.

Projects totalling over 1700 megawatts of gas-fired generation are currently in the various phases of development, including a new gas-fired power station for Townsville.

The $368 million 450 megawatt Braemar Power Station was officially opened on 24 August 2006. The peaking/intermediate power station, west of Dalby, will provide electricity for the summer season of 2006-07. The power station has also designed to incorporate a further three 150 megawatt gas turbine units at a later date.

In October 2005, AGL announced plans to develop a 370 megawatt gas-fired base load power station in Townsville. The power station is expected to consume around 20 petajoules a year. Timing for its construction will be driven by the expanding requirements of the north Queensland energy market, with development scheduled to be completed in the first quarter of 2010.

Overall, the Queensland gas market has a strong future.

Recent announcements by the Australian Government and industry to examine opportunities to increase domestic use of gas, potentially providing up to 70% of all new electricity generating capacity, will further accelerate gas exploration and production and importantly facilitate the construction of new and interconnected pipelines.

1 *Australian Energy, National and State Projections to 2029-2030.* ABARE, October 2005.
2 Queensland Government, *Special Fiscal and Economic Statement.* October 2005

Adavale and Georgina Basins

Call for tender information

Expressions of interest

Anyone can request an area to be made the subject to a call for tenders. Requests should be forwarded to the Manager, Exploration, Mining and Petroleum Strategies.

Legislation

An Authority to Prospect can only be granted from a call for tenders under section 35 of the *Petroleum and Gas (Production and Safety) Act 2004* (the Act).

Requirements for making a tender for an Authority to Prospect, especially in relation to the requirements for an initial work program, are given in sections 37 and 48 of the Act and section 13 of the Petroleum and Gas (Production and Safety) Regulation 2004 (the Regulation).

Information on current call for tenders is available on the Department of Mines and Energy website (**www.dme.qld.gov.au**).

The Act and Regulation can be viewed on the **Office of the Queensland Parliamentary Counsel** website (**www.legislation.qld.gov.au**) or purchased from **Goprint** website (**www.goprint.qld.gov.au**).

Gazette notice

The official call for tenders is published only in the Government Gazette, also available from **Goprint** (**www.goprint.qld.gov.au**).

Making an application

Tenderers must use the 'authority' **approved form** and lodge the tender with the prescribed fee. The form is available from the Department of Mines and Energy website (**www.dme.qld.gov.au**).

The fee is prescribed in Schedule 9 Part 1 of the Regulation. The tenderer should pay the fee at an office of the Department of Mines and Energy and attach a copy of the receipt to the tender.

If the tender is accompanied by the prescribed fee, then the fee must be separate from the tender documents to facilitate issuance of a receipt.

Details of where and when individual tenders must be lodged are provided in the gazette notice.

Work program

The tender application is to include a proposed initial work program for the period stated in the gazette notice.

Guidelines in relation to the contents of an initial work program are available to assist tenderers in preparing their proposed initial work program.

These guidelines are available on the department's website.

Geoscientific information

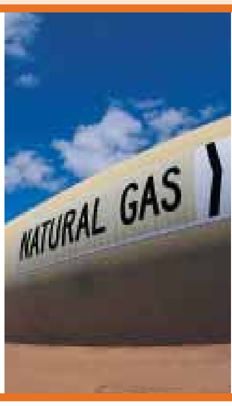
Availability of data in relation to any call for tender area can be determined using the **Interactive Resource and Tenure Maps (IRTM)** system on the Department of Mines and Energy website.

These maps provide information on the data density, including seismic lines and petroleum wells. The system can be used to assess possible overlapping tenure issues, including coal and oil shale mining tenements.

Open file company reports, including seismic survey and petroleum well reports relating to the tender areas, can be obtained through the department's **Queensland Digital EXploration Reports (QDEX)** system.

Seismic data from open file seismic survey reports can be obtained by contacting the Geoscientist (Seismic Data Management), Exploration Data Centre, 68 Pineapple St, Zillmere, on telephone +61 7 3863 8714.

Further geological and geophysical data relevant to any area can be purchased from the **Geological Survey of Queensland**.



Adavale and Georgina Basins
Key contacts details

Natural Resources, Mines and Water
Information Centre
Level 2, Mineral House
41 George Street, Brisbane Qld 4000
Phone: +61 7 3237 1435
Website: www.dme.qld.gov.au
Sales: sales@nrm.qld.gov.au

Geological Survey of Queensland
Phone: +61 7 3006 4666
Website: geological_info@dme.qld.gov.au

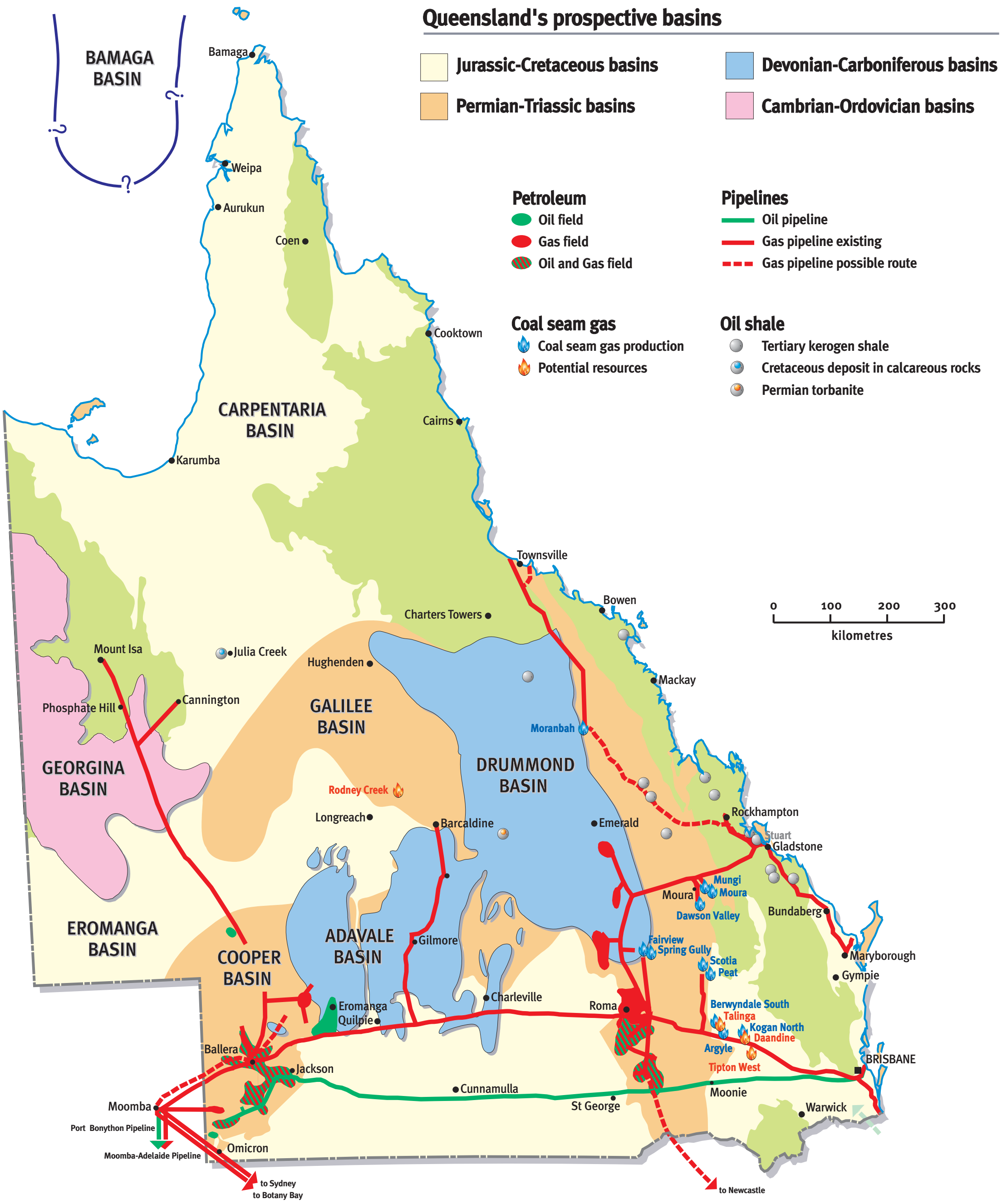
Expressions of interest
Manager, Exploration, Mining and Petroleum Strategies
GPO Box 2454, Brisbane Qld 4001
Email: petroleum@dme.qld.gov.au

Goprint
371 Vulture Street
Woolloongabba Qld 4102
Locked Bag 500
Coorparoo DC Qld 4151
Phone: +61 7 3246 3500
General enquiries: mail@goprint.qld.gov.au
Sales: sales@goprint.qld.gov.au

Office of Queensland Parliamentary Counsel
Website: www.legislation.qld.gov.au/OQPChome.htm

Adavale and Georgina Basins

Figure 1: Queensland's prospective basins



For current interactive information on resource and tenure maps (updated daily) connect to: www.nrm.qld.gov.au/mines, then click on interactive maps.

Queensland Government
Department of Mines and Energy

Adavale Basin

Geological setting

John Draper, Mike Mckillop and Kinta Hoffman

The Adavale Basin has received only sporadic exploration interest since it was actively explored in the 1960s. The Gilmore gas field demonstrates that hydrocarbon generation and accumulation has occurred.

The Adavale Basin is a structurally-complex Devonian age basin that occurs in southern Queensland. There have been three major depositional phases with fluvial, deltaic, marine and evaporite deposition occurring in the basin.

The key element for successful exploration in this basin is to be able to accurately predict reservoir quality in this deep and complex basin.

Location

The Adavale Basin shown in Figure 1 has produced from one gas field, Gilmore. The basin was actively explored in the 1960s but became a secondary target with the discovery of oil and gas in the Cooper and Eromanga Basins.

The basin can be considered a frontier area as the geological setting and structural history of the basin are in need of revision.

Controls on carbonate and clastic deposition are poorly understood, resulting in the poor definition of reservoir trends.

The depth to most targets (>2000 metres) has been a limiting factor to exploration. The basin has been described most recently by Draper and others (2004) and McKillop and others (in press).

Geological setting

The Adavale Basin overlies rocks of the Neoproterozoic to early Palaeozoic Thomson Fold Belt, made up of steeply dipping, low-grade metasediments of turbidite origin (Passmore and Sexton, 1984; Murray 1990, 1994; Draper, 2006).

The Adavale Basin initially developed in the mid–late Early Devonian as an intracontinental volcanic rift or extensional basin (Finlayson and others 1988, Hoffmann 1988, Evans and others 1990, Murray 1990, 1994).

The latter author discounted previous suggestions that volcanics at the base of the succession were related to a west-dipping subduction zone (Murray 1986) or that the basin formed as a back-arc basin west of a volcanic arc along the Nebine Ridge (Remus and Tindale 1988).

Powell (1984) proposed a regime of dextral transtension for eastern Australia during the Late Silurian–Early Devonian and compared it with the Basin and Range Province in the southwestern USA.

Evans (1982) and Evans and others (1990), on the other hand, indicated a sinistral shear-stress regime along the palaeo-Pacific/Panthalassan margin. The latter reversed to dextral in the latest Carboniferous as Pangaea switched from a clockwise to an anticlockwise rotation.

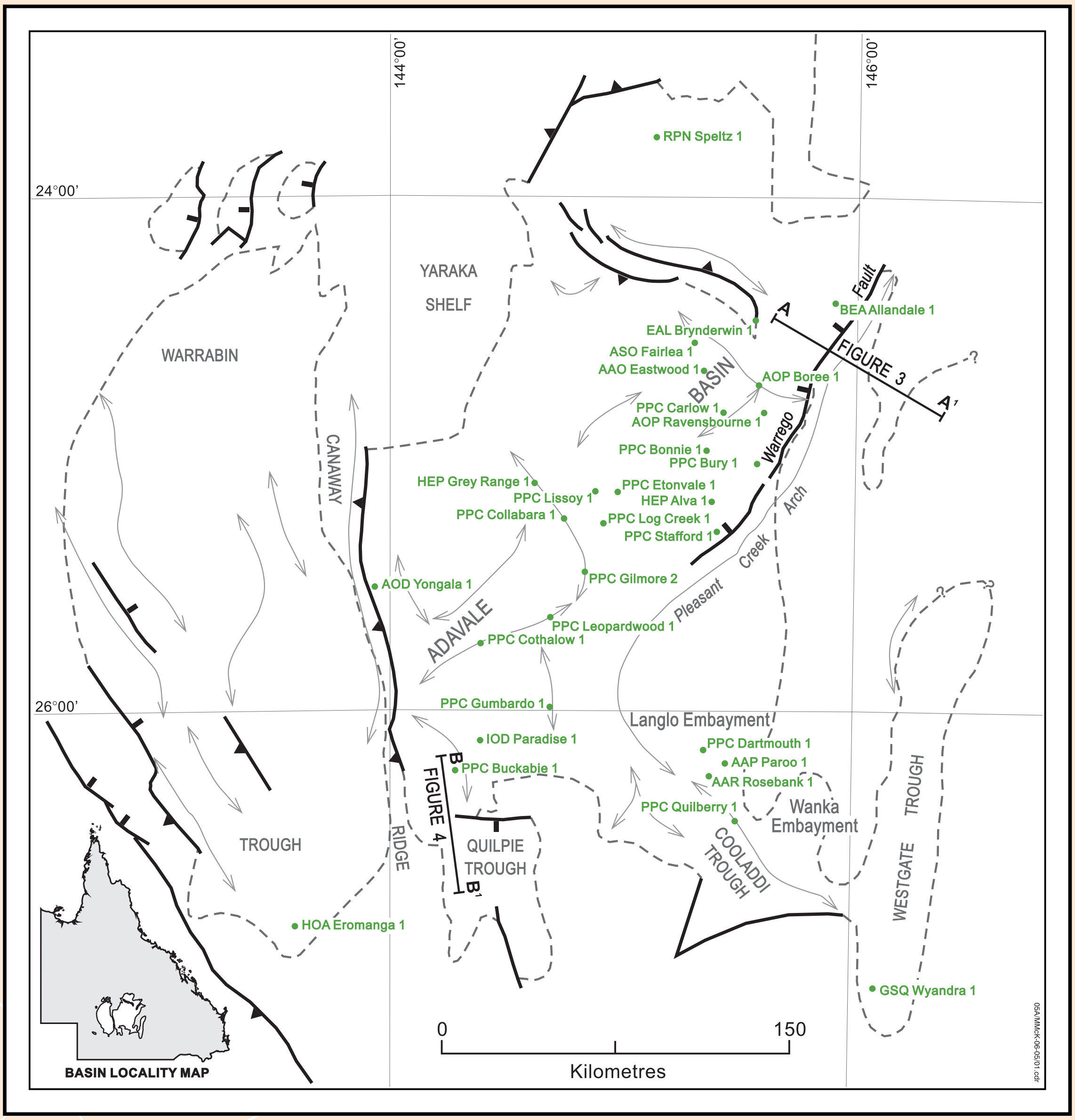
This new stress regime effected the widespread formation of sedimentary basins in the latest Carboniferous (300 Ma) as a prelude to the deformation, in eastern Australia, of the mid-Permian–late Middle Triassic Hunter-Bowen Orogeny (Draper and McKellar 2002, McKellar in press, and references cited therein).

The extensional tectonism that formed the Adavale Basin and Warrabin Trough during the Early Devonian involved widespread block faulting, with the north–south-trending Canaway Ridge (Figure 2) forming a major structural feature that physically separated these two areas of Devonian sedimentation in the early stages of basin formation and development (Finlayson and others 1988, Hoffmann 1988, 1989a,b).



Adavale Basin

Figure 2: Adavale Basin and Warrabin Trough



Adavale Basin

Geological setting

Evans and others (1990) and Finlayson and others (1990) related the extensional terrain to a westerly-dipping, crustal detachment fault.

Hoffmann (1988, 1989a,b) recognised on seismic reflection profiles a series of half-grabens and grabens (Figure 3) on both sides of the Canaway Ridge. These features are presumably related to the initial volcanism (Gumbardo Formation) in the basinal system.

Evans and others (1990) submitted that, following this extension, the Adavale Basin became a foreland basin in the early Middle Devonian, with repeated basement thrusting from the south-east, causing deepening towards that direction and culminating in a major compressional orogeny in the mid Carboniferous.

Widespread earth movements associated with this mid Carboniferous (~330–320 Ma) event are represented by the 350–330 Ma Kanimblan Orogeny in south-eastern Australia and the 320 Ma Alice Springs Orogeny in central Australia (Scheibner and Veevers 2000, Veevers 2000).

The Adavale Basin was terminated and deformed at this time, with thrusts and regional-scale folds some tens of kilometres in wavelength (Figure 4).

During the ensuing mid to late Carboniferous, these anticlinal features were eroded in excess of 3000 m in places. As a result of this deformation and erosion, most of the troughs were detached from the main basin and from one another (Passmore and Sexton 1984, Finlayson & others 1988, Hoffmann 1988, Remus and Tindale 1988).

For the Devonian basins overlying the central Thomson Fold Belt in Queensland, this orogenic event has been termed the Quilpie Orogeny (Finlayson and others 1990, Finlayson 1990).

It is worth noting that Haines and others (2001), in a study in central Australia, recognised three phases of the Alice Springs Orogeny: a Late Ordovician event, an Early to Late Devonian event, and a mid Carboniferous event.

These three events correspond broadly to the events associated with the Adavale Basin. The Warburton Basin rocks in the Thomson Fold Belt were probably folded in the Late Ordovician or Early Silurian; the Adavale Basin formed during the Early to Late Devonian; and the final folding phase that affected the basin occurred in the mid Carboniferous.

The Alice Springs Orogeny was caused by episodic, north–south convergence, though how this impacted on the Devonian basins in Queensland is not known and requires investigation. The Thomson Fold Belt was thrust over the Lachlan Fold Belt in the mid Carboniferous (Russell Korsch, personal communication, 2006).

Strata contained within the basin are variously covered by unconformably overlying sedimentary rocks comprising the latest Carboniferous–Middle Triassic Cooper and Galilee Basins and the Late Triassic–mid Cretaceous Eromanga Basin.

Figures 3 and 4: Geology

Figure 3: Seismic Line EAL Y81A-1149

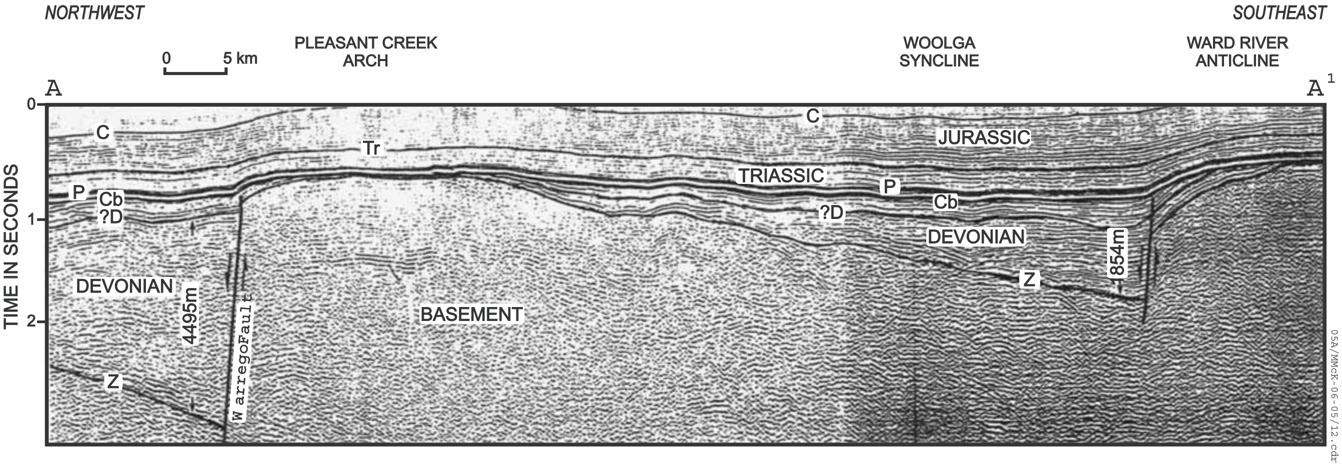
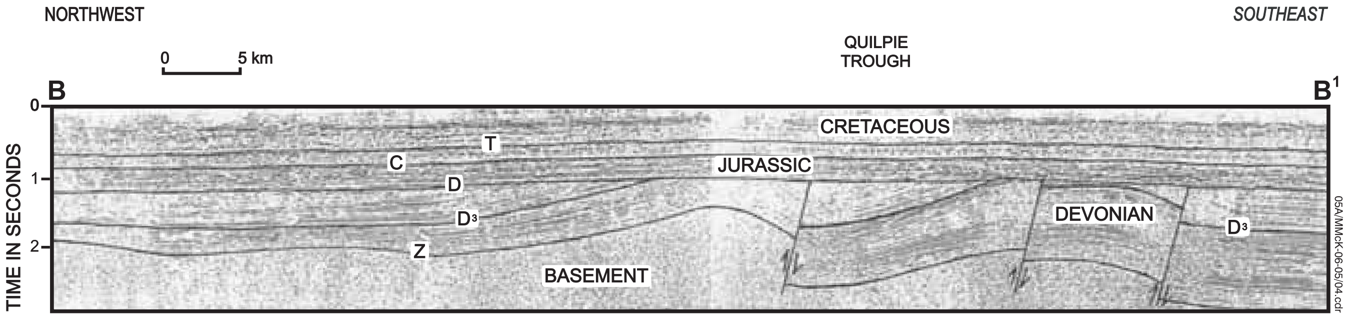
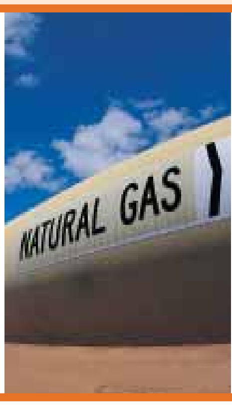


Figure 4: WMC Quilpie Q85-6





Stratigraphy

Early Devonian

Structural deformation plus the paucity of wells penetrating the sequence create difficulties in compiling a lithostratigraphic framework for the basin. Biostratigraphic correlations are limited by the endemic nature of the marine faunas and the patchy distribution of well-preserved palynomorphs.

Nonetheless, palynological zonation, complemented by two, U-Pb zircon dates from the basal, non-palyniferous unit in the basin, the *Gumbardo Formation*, have afforded a reasonable level of chronostratigraphic control.

The stratigraphy is shown in Figure 5 and discussed in detail in McKillop and others (in press). The Gumbardo Formation was deposited under continental conditions in a developing rift basin.

It was redefined (McKillop and others, in press) to exclude previously included volcanic rocks, now known from U-Pb zircon dating to be of Early Ordovician age.

So restricted, the formation embraces interbedded acid-volcanic and sedimentary rocks confined, based on isotopic dates, to the Pragian and early–mid Emsian.

Middle Devonian

Unconformably overlying it are the late Emsian *Eastwood beds*, a fluvial unit containing quartzose and sub-labile sandstone interbedded with siltstone and mudstone.

Possible early Eifelian unconformity separates these strata from the mid–late Eifelian to earliest Givetian *Log Creek Formation*, which consists of feldspatho-lithic and quartzose sandstone, siltstone, mudstone, conglomerate and minor limestone.

The Log Creek Formation was deposited initially as a fluvial sequence, but, following a marine transgression, deposition occurred in a range of environments, from fluvial to deltaic and shallow marine. Also associated with the marine transgression was deposition of the late Eifelian to early–mid Givetian *Bury Limestone*, the lower part of which is laterally equivalent to the upper Log Creek Formation.

The Bury Limestone encompasses packstone, wackestone, calcareous siltstone and mudstone, and minor siliciclastic rocks.

Containing a diverse fauna, it was deposited in lagoonal, reef and offshore environments. Overlying the Log Creek Formation and laterally equivalent to the upper, but not the uppermost, Bury Limestone is the early Givetian *Lissoy Sandstone*.

Coastal to marginal marine in character and comprising feldspathic sandstone and minor siltstone and conglomerate, the Lissoy Sandstone further reflects the marine transgression, with the Bury Limestone continuing to represent the offshore environment.

These circumstances culminated, subsequently in the late early to early mid Givetian, with deposition of a widespread transgressive-regressive sequence, the *Cooladdi Dolomite*.

This unit overlies the Lissoy Sandstone and part of the Bury Limestone. Where the Cooladdi Dolomite is absent above the Bury Limestone, it is not clear whether the unit was either eroded or not deposited.

Dolomitisation of the Cooladdi Dolomite is postulated to have occurred, approximately in the mid Givetian, both prior to, and during the time of, deposition of the halite-dominant *Boree Salt*, largely at the onset of a broad-scale hiatus and under conditions of saline reflux and tectonically-controlled basin restriction.

Late Devonian

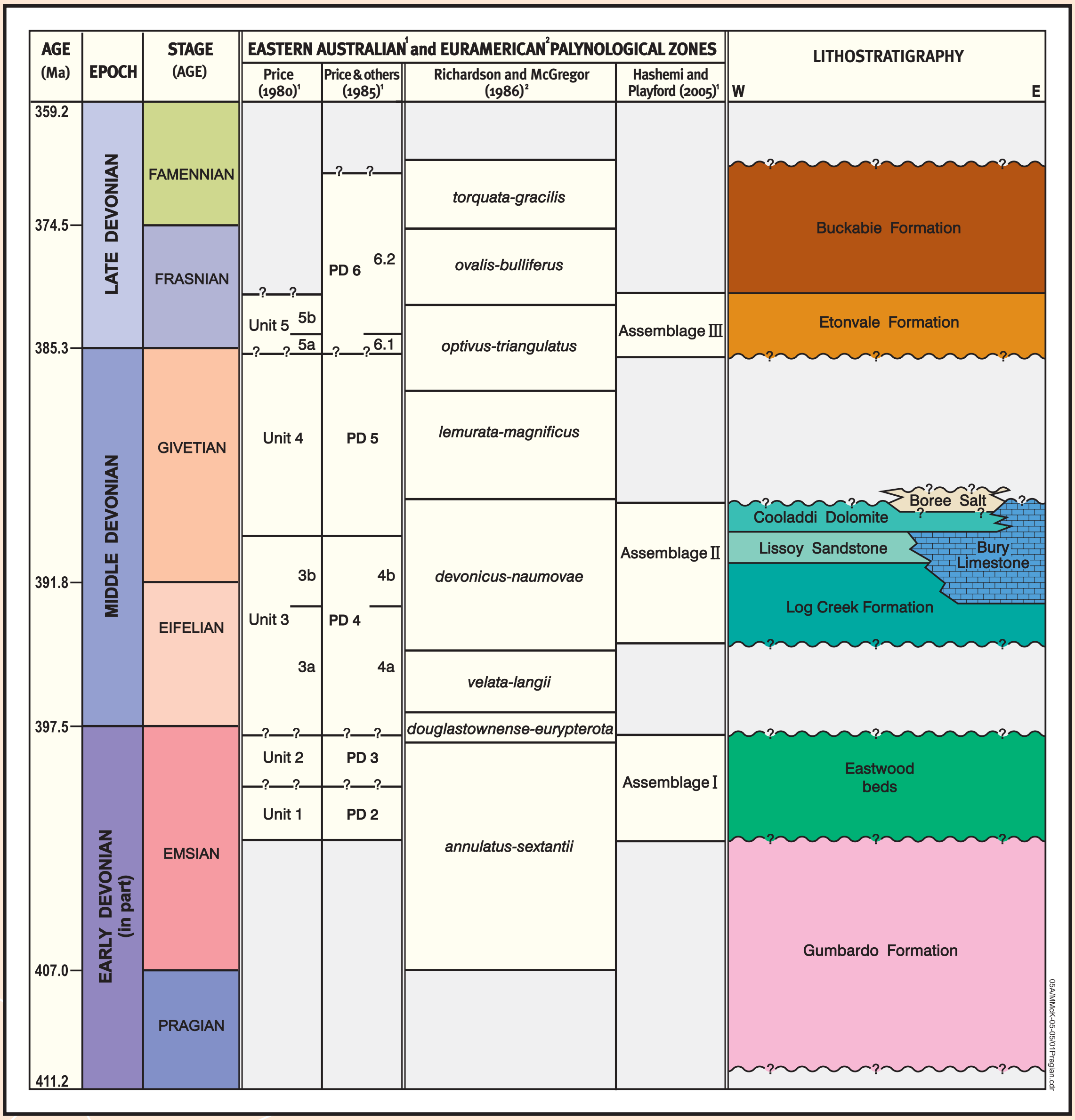
Unconformably overlying the Cooladdi Dolomite, Boree Salt and the Bury Limestone are quartzose sandstone, mudstone, shale and minor limestone of the latest Givetian–early Frasnian *Etonvale Formation*, the deposition of which occurred in a fluvial to marginal marine environment under arid conditions.

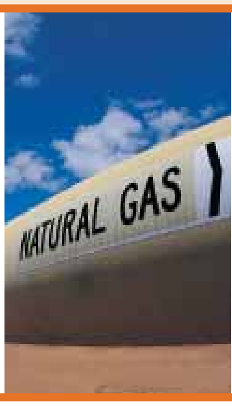
The basin's uppermost unit, with red beds of quartzose sandstone and mudstone of fluvial origin, is the mid–late Frasnian to mid Famennian *Buckabie Formation*.



Adavale Basin

Figure 5: Age scale





Structural Geology

Remus and Tindale (1988), based on seismic stratigraphic-sequence analysis, subdivided the succession in the Adavale Basin into three stratigraphic sequences that were said to broadly correspond to phases of tectonic evolution (rift, extension, convergence).

Convergence during the Middle Devonian – mid Carboniferous was said to have involved the lower two sequences in a westward propagating thrust system. Evans et al. (1990, p.86) proposed a somewhat comparable sequence subdivision of the Adavale Basin.

They, however, differentiated 'four sequences that reflect phases of evolution of the Adavale Depression': an initial extensional phase, and three subsequent phases of foreland thrusting during the remainder of the Devonian, which climaxed in the major mid Carboniferous event.

Foreland-basin initiation was associated with the Log Creek Formation (assigned by Remus and Tindale to their phase of extension), the basin deepening to the south-east in response to crustal loading.

This was said to be followed by an interval of tectonic quiescence (encompassing the third sequence) when the Bury Limestone and Cooladdi Dolomite were deposited (incorporated in the 'Middle Adavale Sequence' of Remus and Tindale).

The second phase of foreland thrusting was linked by Evans and co-workers to the fourth sequence embracing the Etonvale and Buckabie Formations.

Their third stage of foreland thrusting was delimited by the terminal mid Carboniferous compression.

The initial rifting led to the formation of a series of half-grabens and grabens on both sides of the Canaway Ridge, this being identified in seismic-reflection profiles (Hoffmann 1988).

The relative timing of this extension on both sides of the Ridge is yet to be established, but is assumed to have been concurrent. The troughs on the southern and south-eastern margins of the Adavale Basin, however, do not show any evidence of rifting.

They were initiated as broad depressions, which were subjected to the mid Carboniferous deformation and subsequent erosion (Fig. 4).

The bounding faults of the extensional blocks in the north-east, east and south-east regions of the Adavale Basin show a dip direction towards the Canaway Ridge.

In contrast, extensional faults in the Warrabin Trough dip towards the centre of the trough and form a rift corridor trending north-westerly (Hoffmann 1988, 1989).

The geometry of the *Adavale Basin system* is asymmetric, with the greatest rifting occurring along the eastern and northern edges.

Growth faults in the Adavale Basin have displacements as large as 4500 m in the case of the Warrego Fault, but the syndepositional movement on Warrabin-Trough extensional faults is generally less than 1000 m (Hoffmann 1989).

Although the Canaway Ridge was the site of normal faulting and associated half-graben development, the main activation of the Canaway Fault probably occurred during the mid Carboniferous compressional tectonism.

During this time it was reactivated as a north–south trending reverse fault downthrown to the east (Pinchin and Anfiloff 1986; Hoffmann,1989).

Displacement of the Devonian strata is in the order of 1000 m along it. Finlayson et al. (1988) proposed strike-slip movement must have occurred on the fault to accommodate this north–south compression.

Substantial lateral shortening of several tens of kilometres and vertical movements of several kilometres have also been reported by Finlayson (1990). Finlayson et al. (1988), moreover, have suggested that

detachment faults and ramps accommodated the crustal shortening, allowing the formation of the southern Adavale Basin troughs.

Contrasting opinion by Leven et al. (1990) has discussed the development of the troughs as ramp synclines and ramp basins above mid-crustal ramps, inferring an extensional-stress regime rather than a compressional-stress regime.

The original extensional block edges and/or subsequent uplift have led to the formation of many of the anticlinal features evident today. These features include the Pleasant Creek Arch, Gumbardo Anticline, and Cothalow Arch (Hoffmann 1989; Evans et al. 1990).

The northeasterly-trending Warrego Fault on the eastern side of the main depression forms the bounding fault of a half-graben, which has been rotated towards the Canaway Fault (Hoffmann 1989). This extensional fault has involved in excess of 4000 m of displacement (Hoffmann 1988, 1989).

Hoffmann (1989) demonstrated that Late Cretaceous to Cainozoic deformation was influenced by pre-existing basement features. Areas underlain by rocks affected by Devonian extension show greater displacement than areas with older basement.

Because of the combination of extensional and compressional reactivation of pre-existing faults, it is difficult to define the timing of particular events.

This difficulty is exacerbated by the weathered nature and patchy distribution of the Cainozoic rocks. For the Late Cretaceous to Palaeocene deformation, Hoffmann (1989) postulated east–west and north–south extension as a result of sagging associated with rifting in the Tasman Sea, together with isostatic adjustment.

She attributed a north–south compressional deformation to collision of the Australian and Pacific plates, which resulted in thrust belt development in New Guinea from the Oligocene to mid-Miocene.

An east–west compression, which affected the Canaway Fault, may have occurred between the Miocene and Recent, with uplift of the Eastern Highlands.

Hoffmann (1989) estimated up to 890 m of displacement of Eromanga Basin strata in the Late Cretaceous and Tertiary. Rodgers et al. (1991), using velocity interval data (actual depth versus predicted depth), identified areas of major post-Eromanga Basin uplift. Uplifts of up to 800 m were estimated in the Mount Howitt area.

Features such as the Canaway Ridge and the Pleasant Creek Arch have a topographic expression as a result of these movements.

Exploration history

The Adavale Basin was first recognised in 1958 when Oklahoma Australia Oil Company ran a reconnaissance seismic survey east from Grey Range towards Quilpie (Hightower and Thralls, 1958).

Ensuing investigations were undertaken by petroleum exploration companies, Geoscience Australia (formerly the Bureau of Mineral Resources and the Australian Geological Survey Organisation) and the Geological Survey of Queensland.

To date, 76 exploratory, 15 appraisal and 4 development wells, together with one departmental stratigraphic drillhole (GSQ Wyandra 1), have penetrated the Adavale Basin system and associated troughs.

A considerable number of them were drilled with the intention of exploring/developing the overlying Cooper and Eromanga Basins, with only a few attaining pre-Devonian basement.

Initially, clastic units were the principal drilling target. As the depth of troughs was a limiting factor, the focus of this early exploration was along the series of highs associated with the regionally extensive, northeasterly-trending thrust zone in the region to the immediate east of the Cothalow Arch and the Carlow Arch (Boreham and de Boer, 1996).

Subsequent exploration was directed towards the eastern part of the Adavale Basin and the reef carbonates therein, particularly following Paten's (1977) assessment that they offered the most prospective target.

Phillips-Sunray DX (a joint venture between Phillips Petroleum Company and Sunray DX Oil Company) led the initial exploration, shooting regional seismic and drilling 19 wells in the region east of the Canaway Ridge, commencing in 1961 with Buckabie 1 (Tanner, 1962; Heikkila, 1966; Slanis & Netzel, 1967; Galloway, 1970; Auchincloss, 1976; Harrison and others, 1980; de Boer, 1996).

In 1964, the Gilmore Field, which has been detailed by Benstead (1972), Beddoes (1973) and overviewed by Auchincloss (1976), was discovered when PPC Gilmore 1 flowed dry gas at a rate of 138 753m^3/day.

Ensuing appraisal resulted in the drilling of PPC Log Creek 1, PPC Gilmore 2, PPC Gilmore 3 and PPC Gilmore 4a.

Both Log Creek 1 and Gilmore 2 were unsuccessful, as they did not penetrate the main Gilmore structure, with the former producing minor gas and the latter minor oil (de Boer, 1996). Gilmore 3 and 4a were drilled in the Gilmore closure, also yielding gas.

Strong gas shows and numerous gas flows were also recorded in the field in the underlying Log Creek Formation in both PPC Gilmore 1 and 4a, although subsequent attempts to repeat the flows were unsuccessful (de Boer, 1996). AGA Phfarlet 1 and Phfarlet 2, drilled in 1992, yielded small gas flows from the same interval.

The Gilmore Field was closed in after the initial testing, as its remoteness from pipe-line infrastructure at that time made it uneconomic.

Energy Equity Corporation Ltd recognised the potential of the field and acquired all interests in it between 1988 and 1992.

Commercial production commenced in July 1995, following construction of a peak-loading power station (feeding into the state electricity grid) at Barcaldine to the north and a 240 km gas pipeline from the field to fuel it (de Boer, 1996).

Interconnection now also exists between the Gilmore Field and the south-west Queensland-to-Brisbane gas pipeline (Figure 1).

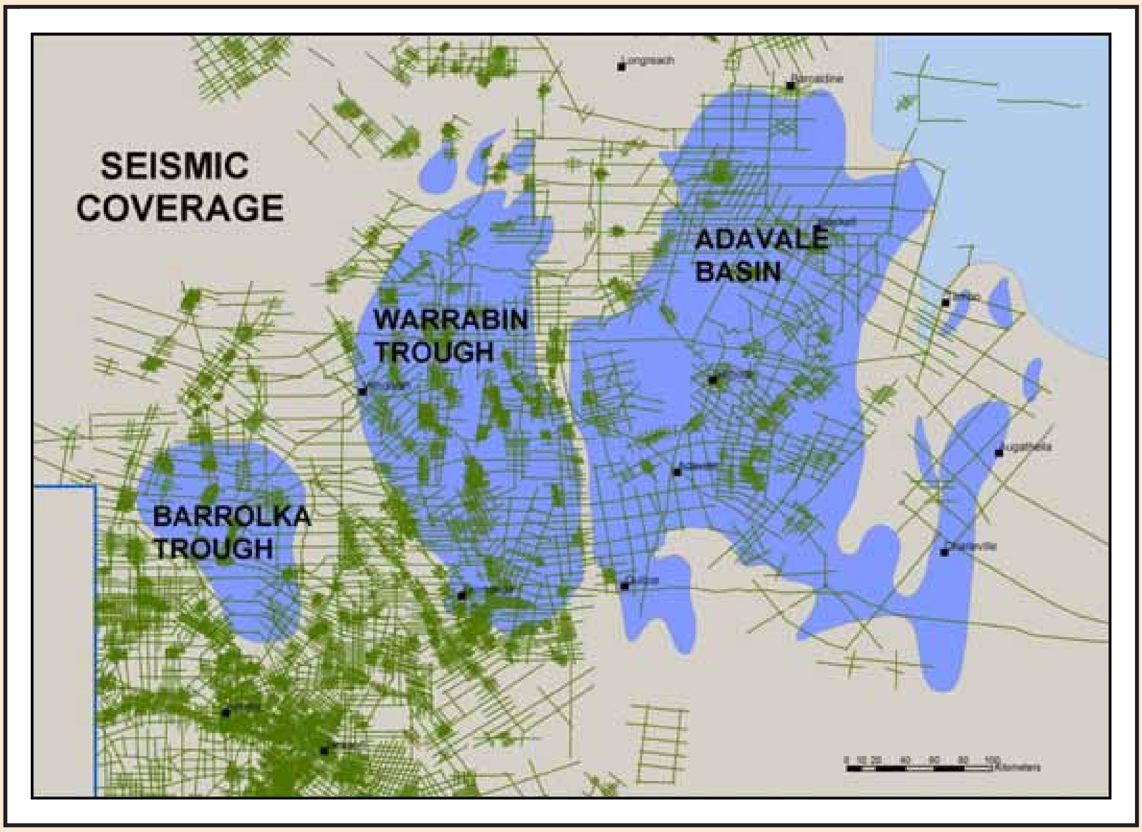
There is a good cover of seismic reflection data available across the entire Adavale Basin system (Figure 6).

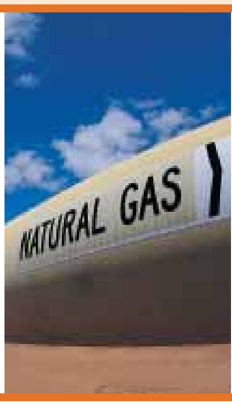
This includes surveys undertaken by petroleum exploration companies and the deep crustal lines (down to 20 seconds TWT) recorded by Geoscience Australia (Bureau of Mineral Resources/Australian Geological Survey Office)[Mathur and Sexton, 1981; Wake-Dyster and Pinchin, 1981].



Adavale Basin

Figure 6: Seismic reflection data





An aeromagnetic survey undertaken for Magellan Petroleum in 1959 delimited the north-eastern margin of the basin (Auchincloss, 1976).

A recent aeromagnetic and radiometric survey was carried out over the Adavale Basin and adjacent Drummond Basin at a 400 metre line spacing by the Geological Survey of Queensland in 1998.

Exploration in the Adavale Basin has also encompassed investigation of the Boree Salt as a source of potash in the manufacture of fertilisers (Bluck and others, 1982).

Curiously, granular salt and salty water have been retrieved from various units in the central and north-eastern Adavale Basin, but not from wells west of the Canaway Ridge.

Presumably, salty water, which may affect wireline-log readings, has its origins in groundwater percolating through evaporitic rocks.

Following the discovery of oil in DIO Jackson 1 in the Eromanga Basin in 1981, there has been little petroleum or mineral exploration in the Adavale Basin system.

Hydrocarbon occurrences

Hydrocarbon occurrences are few, the only discovery being at Gilmore. Initial recoverable gas reserves for the Gilmore gas field were estimated at 588×10^6 m^3 (Passmore and Sexton 1984; Miyazaki and Ozimic 1987), this dropping, as a result of production, to 393×10^6 m^3 in June 2000 (Department of Natural Resources, Mines and Energy, unpublished data).

Drill-stem testing of PPC Gilmore 3 recovered gas at a rate of 232×10^3 m^3/d and traces of oil from the Log Creek to Cooladdi Dolomite interval.

Sub-economic gas flowed at a rate of 566 m^3/d from the Log Creek Formation in PPC Log Creek 1 (Meaney 1996). PPC Gilmore 4a and AGA Phfarlet 1 recovered gas from the Lissoy Sandstone at 77×10^3 m^3/d and 8×10^3 m^3/d, respectively, during drill-stem testing.

Most other occurrences in all units except the Gumbardo Formation have been gas-cut mud/water during well-fluid testing in both the Adavale Basin and Warrabin Trough.

Minor oil shows have been recorded in the Log Creek–Cooladdi Dolomite interval in PPC Gilmore 2 and PPC Gilmore 3.

In the Warrabin Trough, trace condensate and a petroliferous odour were encountered in the Devonian sequence in VIP McIver 1 (Short 1999).

The geochemistry of oils from the Eromanga Basin indicates minor migration of oils from the Warrabin Trough (Boreham and Summons 1999).

Only 126 wells have intersected Adavale Basin and Warrabin Trough rocks and 85 of these penetrated less than 100 m of section. Basement was penetrated by 29 wells.

The Adavale Basin and Warrabin Trough are very much underexplored spatially and vertically. Very little of the section has been tested.

Reservoir

The porosity of the rocks across the entire basin system generally ranges from 0–15%, and horizontal permeabilities vary up to 38.7 mD.

However, porosity readings between 15% and 50.3% have been encountered in the Gilmore gas field in the Buckabie Formation, Lissoy Sandstone and Log Creek Formation with horizontal permeabilities up to 1486 mD.

Undifferentiated Adavale Group rocks in HEP Cranstoun-1 in the Warrabin Trough have porosities up to 21.5% and horizontal permeabilities of up to 511 mD.

The major reservoir unit in the Adavale Basin is the Lissoy Sandstone, but attendant porosity and permeability values for the formation are generally poor (Green 1994).

Production in the three Gilmore wells, however, derives from the near-shore sandstones above the base of the formation (de Boer 1996). These strata, through dissolution of early marine cements, have intergranular porosity, which is facies controlled.

Porosity ranges from 4% to 15%, with measured permeabilities of up to 11.7 mD and water saturations averaging about 40%. Other facies in the Lissoy Sandstone and Log Creek Formation in the Gilmore gas field have low permeability, but with significant storage capacity (de Boer 1996).

Benstead (1972) has indicated that much of the original porosity and permeability has been lost because of fusion of grain boundaries and infill by silica.

He concluded that units with fractures or secondary porosity would be the most prospective. Porosity is well developed in the sandstone member of the Etonvale Formation in PPC Collabara 1, but it yielded only gas-cut salty water.

Traps

There are three main stages of trap development: during deposition, during the mid Carboniferous compression, and during the Late Cretaceous to Tertiary compressional events.

The structural development of the basin has provided many potential traps, such as anticlines associated with thrust complexes and reactivation of bounding faults on extensional blocks.

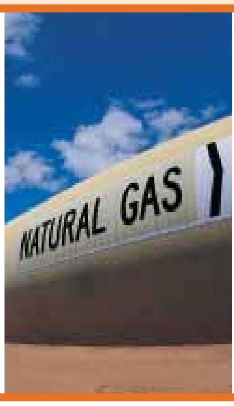
There are also possible stratigraphic traps involving porous rocks (such as sand lenses and reefs) contained within fine-grained impervious strata.

Other potential stratigraphic traps are provided by depositional pinch-outs on uptilted block edges and at unconformable contacts with overlying younger strata.

Moreover, reservoirs and source rocks may be juxtaposed in rift-fill sequences.

The Gilmore structure, embracing the Lissoy Sandstone principal reservoir unit, is a high-relief compressional anticline, which formed during the Kanimblan (Alice Springs/Quilpie) Orogeny, possibly by reactivation of underlying normal faults (de Boer 1996; Boreham and de Boer 1998).

It is bounded to the south-west by the Grey Range Fault, and, to the east, by a series of reverse faults; it is also possibly compartmentalised by internal faulting (de Boer 1996).



Seals

Impermeable strata are generally provided by evaporites and shales which inhibit horizontal or vertical migration of hydrocarbons.

Paten (1977) proposed that, in the Adavale Basin, these lithologies could form the main seal to the underlying, predominantly marine strata.

In PPC Gilmore-1 (in the Gilmore gasfield), the cap rock is represented by the Cooladdi Dolomite (Slanis and Netzel 1967).

Fine-grained clastics within the overlying Cooper, Galilee and Eromanga Basins could provide seals to hydrocarbons expelled and migrating as a consequence of the second phase of petroleum generation or undergoing secondary migration (Figure 6).

Source

The source-rock potential of the Adavale Basin is difficult to determine because of the scarcity of reliable data. Passmore and Sexton (1984) rated the basin as having a low oil prospectivity, but this assessment may have been premature, as an insufficient number of potential source rocks have been sampled for pyrolysis.

Half-graben and graben infills have not been adequately explored, especially in their thickest parts adjacent to growth faults. Drilling to date generally has targeted the uptilted block edges.

However, Devonian strata pinch out on these uptilted edges and, hence, are not representative of the associated half-graben trough sedimentation.

The thicker deposits in the troughs imply faster sedimentation rates and thus vastly better chances of organic matter preservation and possible source rock development.

Passmore and Sexton (1984) rated the quality of source rocks in the entire basin as only fair to poor, with total organic carbon (TOC) values being generally less than 1%.

Higher TOC values have been recorded respectively in the Bury Limestone–Cooladdi Dolomite–Lissoy Sandstone interval and in the Log Creek Formation in PPC Bury-1 and PPC Etonvale-1.

For a source rock to be prospective, clastics require TOC values greater than 0.5 % and carbonates, greater than 0.3%, based on the classification of Tissot and Welte (1978).

Assessment of TOC data shows that the Log Creek Formation, Bury Limestone, Buckabie Formation and undifferentiated Devonian sedimentary rocks of the Warrabin Trough provide the most prospective strata.

TOC values range from <0.3% to 6.65%, which is of particular significance, as Ower and Cooper (1982), in their hydrocarbon source-rock classification, deem rocks with TOC values greater than 1% as good, greater than 2.4% as rich, and in excess of 4% as excellent.

Although wells intersecting the Devonian succession have TOC determinations, only a few have pyrolysis results. Both datasets are required to adequately assess source-rock potential through a comparison of TOC, hydrocarbon generating potential (S2), and Hydrogen Index (HI) for each sample (Peters 1986).

The limited results are nonetheless encouraging:

- Bury Limestone: gas prone (HI); good source richness (TOC); good potential yield (PY); very good hydrocarbon generating potential (S2); and falling within the oil – wet gas maturity zone in PPC Bury-1 and PPC Quilberry-1.
- Log Creek Formation: good source richness (TOC) in PPC Etonvale-1.
- Buckabie Formation: oil and gas prone (HI); good potential yield (PY); good hydrocarbon generating potential (S2); excellent source richness (TOC); and immature to over-mature in PPC Quilberry-1.
- Undifferentiated Devonian strata in the Warrabin Trough: gas prone (HI); very good potential yield (PY); very good generating potential (S2); excellent source richness (TOC); mature for both oil and wet gas in a number of wells (e.g. CON Springfield-1).

Boreham and de Boer (1998) have submitted that dry gas in the Gilmore gas field was sourced from both wet gas accompanying late-stage oil generation and methane derived from a deep, over-mature source (most likely associated with higher temperature, off-structure, Devonian sedimentary rocks).

These authors further maintained that:

- The deep gas source is characterised by a high nitrogen content and isotopically heavy methane and carbon dioxide.
- The maturity level of the wet gas and associated oil are identical (with an equivalent vitrinite reflectance of 1.4% to 1.6 %).
- Oil recovered from PPC Gilmore-2 has been sourced from Devonian marine organic matter deposited under mildly evaporitic and/or restricted-marine conditions.
- The most likely sources of this oil are the basal marine shales of the Log Creek Formation, the algal shales at the top of the Lissoy Sandstone, and the Cooladdi Dolomite.

Two main phases of oil and gas generation have been identified by Boreham and de Boer (1998) from burial and maturation modelling of the Gilmore gas field.

Source rocks in the Log Creek Formation in the lower part of the Adavale Basin succession were likely to have been actively expelling oil and gas in the Late Devonian and Early Carboniferous by the time the upper Buckabie Formation was being deposited (prior to mid-late Carboniferous uplift and erosion).

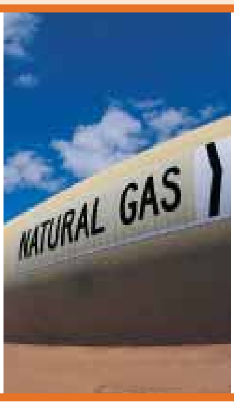
At this time, however, potential source rocks (Cooladdi Dolomite) at higher stratigraphic levels than the Log Creek Formation had not quite reached the stage of initial expulsion, because of lower thermal maturity (corresponding to lower depths of burial).

The second phase of oil and 'associated' gas generation was during the Early Cretaceous when temperatures in the Adavale Basin source rocks exceeded those experienced during the earlier phase.

Primary oil and gas generation was considered to have been almost complete between the Early and Late Cretaceous, but dry gas generation from the deep Devonian source rocks (vitrinite reflectance; *Rv max*›2.5%) is interpreted to have continued to the present time.

Although this gas has a subordinate contribution to the Gilmore gas field, Boreham and de Boer suggested that it may have a marked effect on the redistribution of hydrocarbons, as it can fractionally displace condensable C_{2+} liquids already in the reservoir.

They further suggested that later tertiary migration through structural reactivation of a mobile liquid phase could have given rise to shallower oil and gas reservoirs (if appropriate traps and seals are present).



Any trapped secondary hydrocarbons in the Eromanga Basin would have been affected (e.g. water washing) by the changes in hydrodynamic regimes as the topographically driven basin evolved.

Most formations in the basin are mature for oil generation, with a few units still immature and others having attained over-maturity. Passmore and Sexton (1984) have reported that maturity is unrelated to the present depth of burial.

A heat-flow plot in Boreham and de Boer (1998, fig.18b), based on WinBury software, illustrates elevated heat flow during the inception of the basin, which Passmore and Sexton (1984) attributed to rifting and extensive volcanic extrusion.

Thermal sagging during deposition of the Buckabie Formation resulted in a lower heat-flow gradient (Boreham and de Boer 1998). A subsequent increase in thermal gradient is indicated and these authors attribute this to the result of major tectonic deformation during the mid Carboniferous.

From the latest Carboniferous onwards, there has been a steady rise in the gradient to the present-day value of 94.5 mWm^{-2} (Boreham and de Boer 1998).

Present-day temperature readings from geophysical logs reveal variations across the basin, but with no apparent relationships to known structures or trends.

The northern Adavale Basin is significantly cooler (92°C@ 2613 m) than the current heat regimes occurring in the central area of the basin (117°C@ 2764 m) and the Warrabin Trough (154°C@ 2680 m).

Pitt (1982) has attributed these higher-than-average geothermal gradients to Tertiary deformational events.

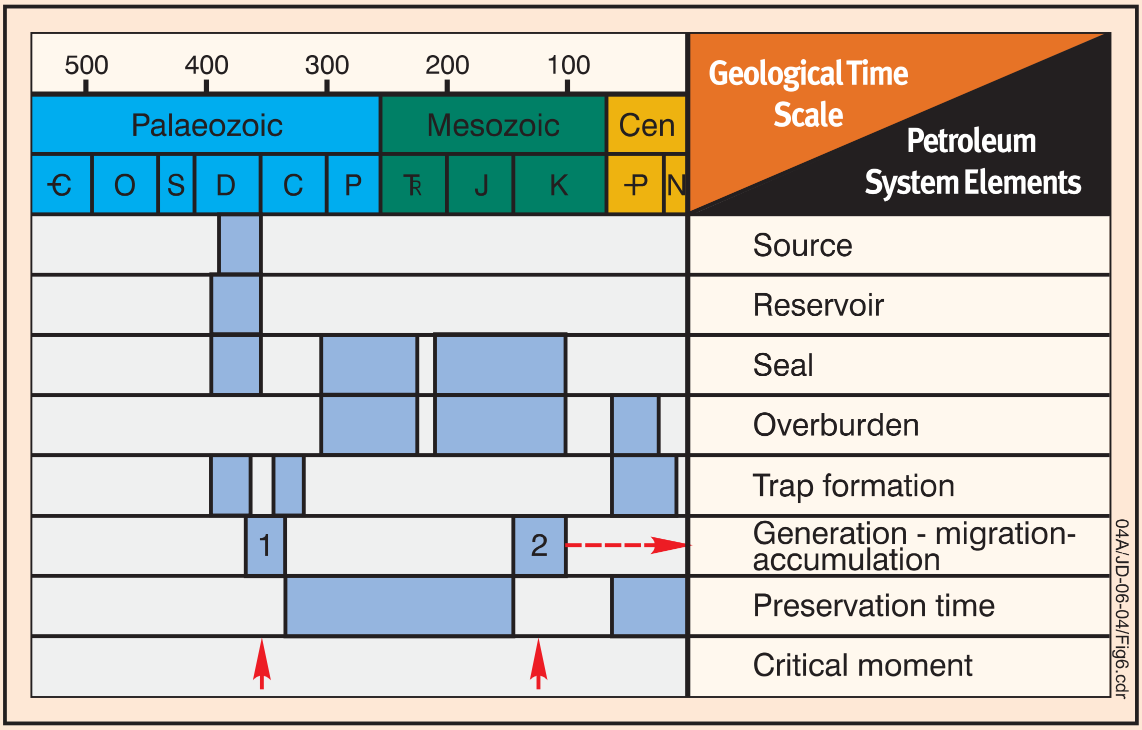
Vitrinite reflectance readings vary significantly within single formations as well as between wells, suggesting that these data may be unreliable.

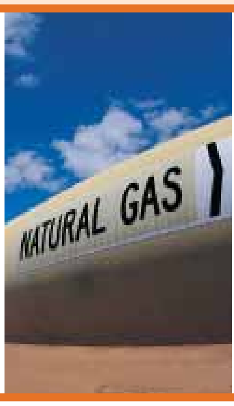
Values provided by one laboratory for the upper 20m of the Log Creek Formation in PPC Etonvale-1 (0.8% to 1.0%) contrast with another laboratory's determinations for the same interval of 1.7% to1.8% (Smith, 1987).

These discrepancies derive from difficulties in selecting suitable coaly material, varying laboratory techniques, operator error or inexperience, and contamination by cavings from overlying strata.

The reflectance data are best compared to Rock-Eval Tmax data in order to determine maturity levels.

Figure 7: Petroleum system





Production

Total gas production from the Gilmore gasfield was 238,981x10^3 m^3 between 1995 and 2002. The gas was used in a power station built at Barcaldine (de Boer, 1996).

Exploration Potential

The petroleum system (Figure 7) for the Adavale Basin, although not fully defined ('hypothetical'), does indicate that the basin is prospective and by extrapolation, the remainder of the Adavale Basin and the Warrabin Trough are also prospective.

Hydrocarbons have been generated and migrated, and there is some production from one field (Gilmore). Although discoveries are few, the Adavale Basin remains under explored.

The Warrabin Trough is almost totally unexplored. Reservoir rocks vary from poor to good, but data on reservoirs are sparse. Fracture porosity may also provide suitable reservoir properties.

Seal rocks are present including salt, shale and fine-grained carbonates. There are areas of suitable source rocks, both carbonate and siliciclastic.

A variety of trap types are available ranging from stratigraphic to structural. Rocks vary in maturity ranging from immature to overmature depending on the variable thickness of the sequences and the different burial depths attained.

Detailed maturity data are sparse. Burial and maturation modelling of the Gilmore gas field (Boreham and de Boer 1998) indicates two main phases of oil and gas generation.

Source rocks in the Log Creek Formation were actively expelling hydrocarbons during the Late Devonian. Stratigraphically higher source rocks expelled hydrocarbons in the Early Cretaceous. Post-mature dry gas is probably continuing to be expelled.

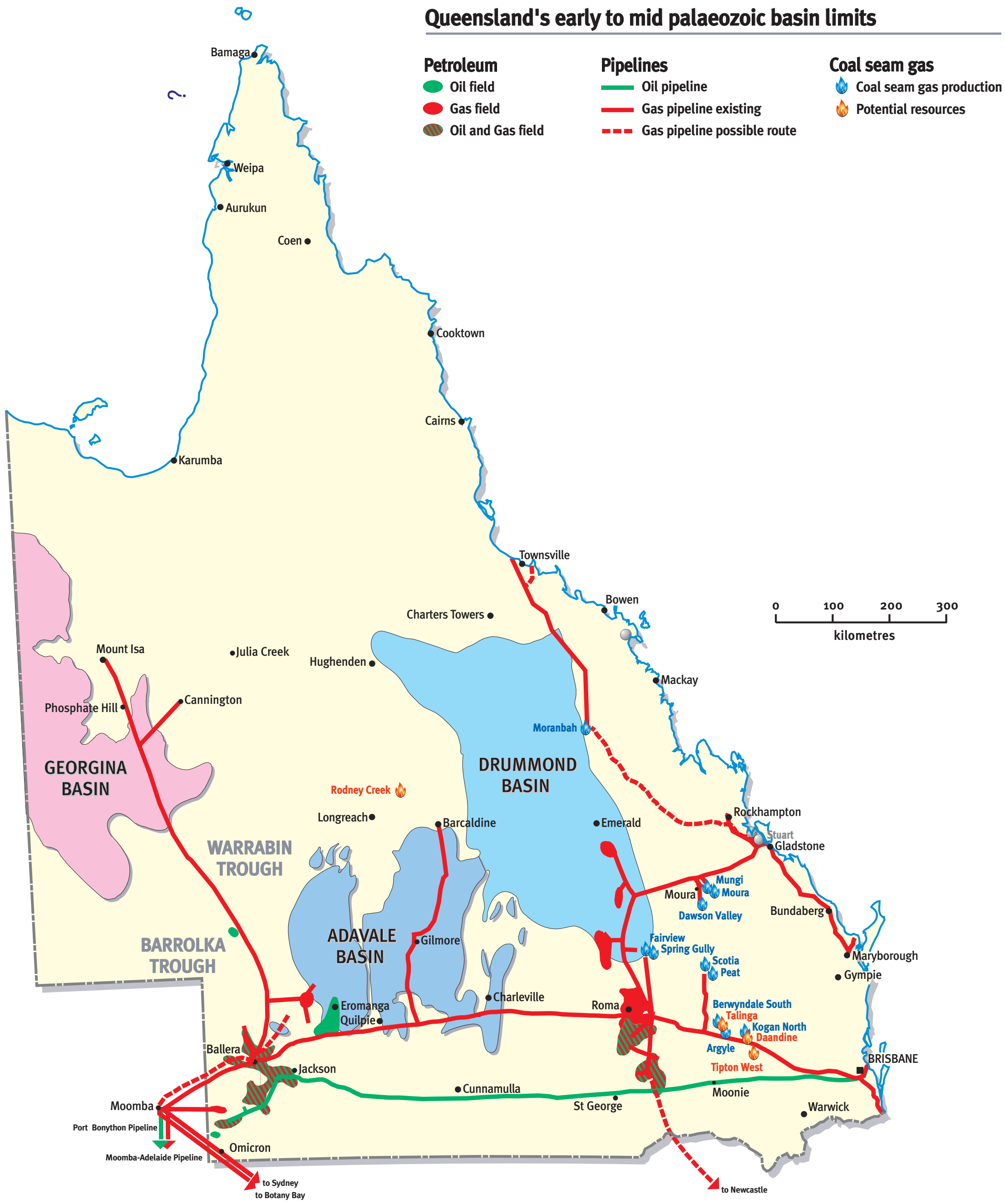
Migration of Adavale Basin hydrocarbons into younger rocks may also have occurred. There is some geochemical evidence for this.

Migration occurred during the Early Cretaceous expulsion. Tertiary migration could also have occurred in the Late Cretaceous when there was major uplift in the area.

Redistribution of any hydrocarbons in the Eromanga Basin would have occurred as the artesian basin evolved.

Adavale and Georgina Basins

Figure 1: Queensland's early to mid Palaeozoic basin limits



For current interactive information on resource and tenure maps (updated daily)
connect to: www.nrm.qld.gov.au/mines, then click on interactive maps.

Queensland Government
Department of Mines and Energy

Georgina Basin

Geological setting

John Draper

The Georgina Basin has received only cursory exploration. There have been a number of gas and oil shows with the most significant being a gas flow of 7000 cubic metres per day (m^3/day) from AOD Ethabuka 1.

The significance of this gas flow was never fully evaluated. This region has recently started to attract renewed interest.

The Georgina Basin is a large intracratonic basin which occurs in both Queensland and the Northern Territory. Smith (1972) and Shergold and Druce (1980) provide overviews of the geology of the basin. Ambrose and others (2001) summarised the geology of the southern Georgina Basin, mainly in the Northern Territory.

As hydrocarbon indications are common and gas has been recovered from one well in the basin, the presence of infrastructure provides an opportunity to explore in a remote and complex area.

Location

The Georgina Basin lies across the Queensland/Northern Territory border (Figure 1).

In Queensland, the basin crops out from north of Camooweal (Undilla sub-basin) to the Simpson Desert (Toko Syncline) and in a belt between Duchess and east of Boulia (Burke River Structural Belt).

The basin continues to the south beneath the Eromanga Basin. The nearest major centre is Mount Isa.

Although several major bitumen highways cross the basin the bulk of vehicle access is on dirt roads and station tracks. As some of the tracks traverse black soil plains they can become impassable in wet weather.

The Ballera to Mount Isa gas pipeline traverses parts of the basin and will underpin the continued development of new mines and the mineral processing industries in north-west Queensland.

Geological setting

The Georgina Basin is a Neoproterozoic to Palaeozoic basin which formed on a basement comprising three major Proterozoic blocks, the Arunta Complex, the Mount Isa Inlier and the 'Aljawarra Craton' (Tucker and others, 1979).

The south-western most block in Queensland, the Arunta Complex, is represented by minor granite outcrops along the Toomba Fault.

Unpublished U-Pb SHRIMP dating of granites along the Toomba Fault in Queensland shows a felsic crustal event at 1795±17Ma and a magmatic event at 1744±7Ma (Berents & Rutley, 1996).

Undated granites occur in AOD Mirrica 1, PAP Netting Fence 1 and GSQ Mount Whelan 1. A mid Ordovician deformation event has been identified in the eastern Arunta Complex (Miller and others, 1998); this event may have affected the Georgina Basin.

Airborne geophysical surveys carried out in 2006 provide additional information on the geology of the area.

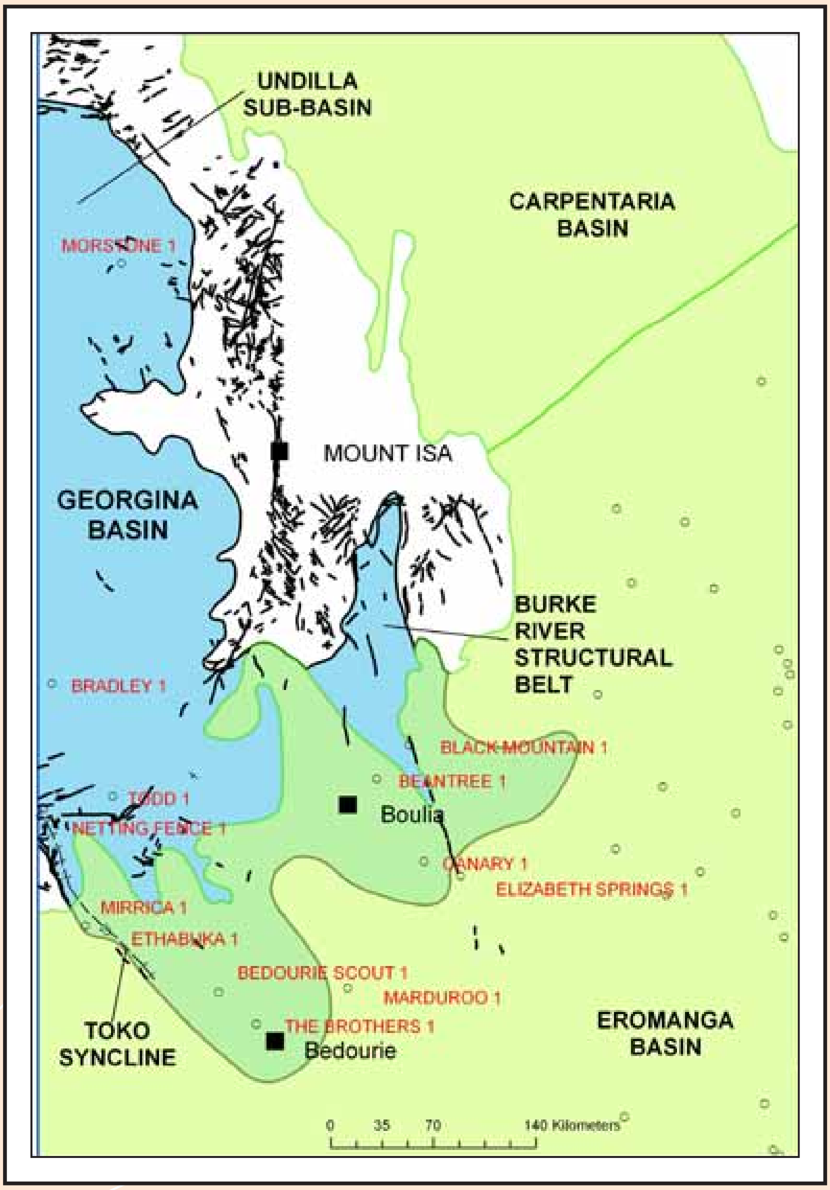
The south-eastern Georgina Basin is underlain by rocks of the Mount Isa Inlier (Blake, 1987; Wellman, 1992) which are exposed on the Duchess 1:250 000 Sheet.

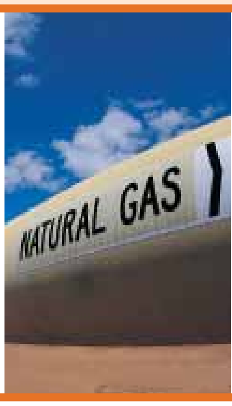
Recent airborne geophysical surveys by the Australian Geological Survey Organisation (AGSO) on Boulia and Springvale 1:250 000 sheet areas provide additional information on the nature of the Mount Isa Inlier rocks beneath the basin.

The northern Georgina Basin in Queensland is underlain by rocks referred to as the 'Aljawarra Craton' by Tucker and others (1979). These rocks probably belong to the Tennant Creek Province.

The behaviour of the basement blocks resulted in quite variable geological histories in different parts of the basin. The Toko Syncline trends north-west reflecting the trends in the Arunta Complex whereas the Burke River Structural Belt runs almost north–south reflecting the trends of the Mount Isa Inlier.

Figure 2: Location of Georgina Basin and Toko Syncline





The Neoproterozoic rocks form part of the Centralian Superbasin (Walter and others, 1995) which includes the Amadeus, Georgina, Ngalia, Officer and Savory Basins. The Centralian Superbasin spans a period from Neoproterozoic (from about 800Ma) to Early Cambrian.

The separate depositional centres in the Georgina Basin have a rift-like aspect. Some of this may be superimposed Early Cambrian rifting.

Early Cambrian rocks are restricted to the southern Georgina Basin and are a mixture of carbonate and siliciclastic rocks. Middle Cambrian sedimentation occurs throughout the basin whereas Late Cambrian units are restricted to the southern parts of the basin.

By the early Ordovician, deposition was restricted to the Toko Syncline area where it continued until the mid Ordovician. Early to Middle Devonian rocks were deposited in the Toko Syncline area which was then thrust, and folded by the Alice Springs Orogeny.

Jurassic to Cretaceous rocks of the Eromanga Basin were deposited and are preserved in the southern Georgina Basin and in the northern part of the basin. A number of Tertiary units overlie the Georgina Basin.

Stratigraphy

Neoproterozoic

The Neoproterozoic rocks of the Hay River area on the western side of the Toko Syncline have been described by Walter (1980). He recognised four tectosomes which have subsequently been correlated with the four supersequences of the Centralian Superbasin (Walter and others, 1995).

The poorly exposed Yackah beds are the oldest unit and belong to supersequence 1. The Yackah beds are unconformably overlain by the Yardida Tillite, which is part of supersequence 2. Supersequence 3 rocks, the Black Stump Arkose and the Wonnadinna Dolomite, unconformably overlie the Yardida Tillite.

Unconformably overlying Supersequence 3 rocks are the Gnallan-A-Gea Arkose and the overlying Grant Bluff Formation of Supersequence 4.

A basin containing a thick succession of Neoproterozoic rocks has been defined by gravity and seismic beneath the Toko Syncline (Tucker and others, 1979; Harrison, 1980; Lodwick and Lindsay, 1990). The contents of this basin will remain speculative until sampled by drilling.

On the eastern side of the Toko Syncline, the Sun Hill Arkose may correlate with the Black Stump Arkose. A thin tillite sequence in GSQ Mount Whelan 1 may correlate with the Yardida Tillite.

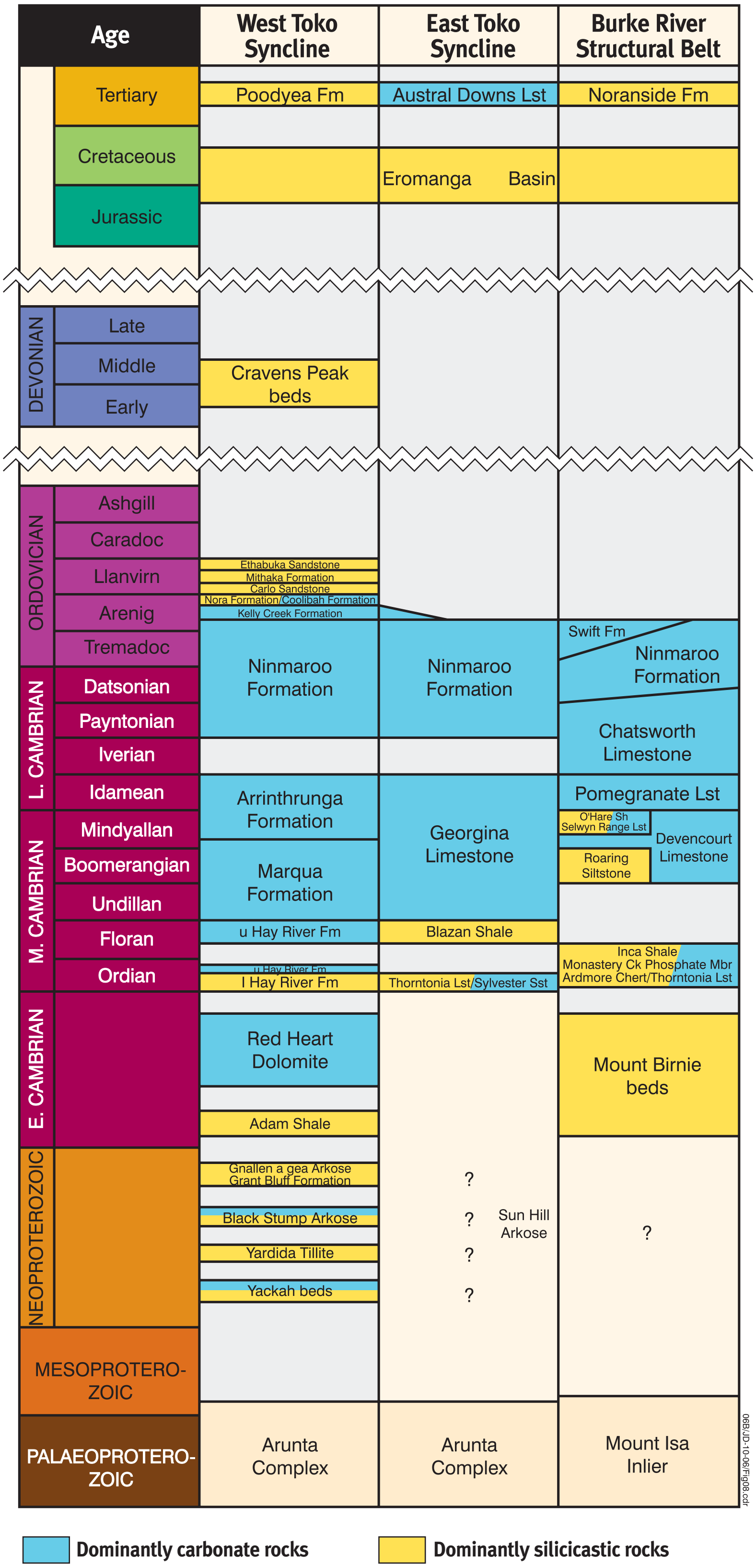
Petroleum wells in the southern Burke River Structural Belt have intersected Neoproterozoic rocks. Tillites, diamictites, varves and dolomites have been described, but no work has been undertaken to correlate these rocks with revised stratigraphy in the Field River area. Dating of the fine-grained sedimentary rocks provided ages between 790–600Ma (Compston and Ariens, 1968).

Cambrian

Early Cambrian

In the Hay River area on the western side of the Toko Syncline (Figure 2), the oldest Cambrian unit is the Adam Shale which comprises bioturbated red and green shale and sandstone.

Figure 3: Stratigraphy of the Georgina Basin, Queensland



Disconformably overlying the Adam Shale is the Red Heart Dolomite which has a basal sandstone and arkose interval. A late Early Cambrian age is indicated by the acritarchs and archaeocyathans in the unit.

The Sylvester Sandstone on the eastern side of the Toko Syncline may be Early Cambrian or form part of the basal Middle Cambrian sequence.

The Mount Birnie beds in the Burke River Structural Belt likewise may be Early Cambrian or earliest Middle Cambrian.

Early Cambrian rocks are not known in the northern Georgina Basin (Undilla sub-basin).

Middle Cambrian - Late Cambrian

Middle Cambrian rocks are widespread representing the most extensive phase of deposition (Southgate and Shergold, 1991). To the west of the Toko Syncline, the lower Hay River Formation unconformably overlies the Red Heart Dolomite (Figure 3).

Ambrose and others (2001) equate the lower Hay River Formation with the Thorntonia Limestone. There is a significant hiatus within the formation but its areal extent in the Toko Syncline is unknown.

The Marqua Formation conformably overlies the Hay River Formation and is itself overlain by the Arrinthunga Formation. Ambrose and others (2001) extended the descrotion of the Arthur Creek beds in the Northern Territory to encompass the upper Hay River Formation and the Marqua Formation.

In the eastern Toko Syncline, the base of the Middle Cambrian is marked by the Thorntonia Limestone (Figure 3). The 8 metre thick black shale which overlies the Thorntonia Limestone, has been correlated with the Blazan Shale and the upper Hay River Formation.

The overlying Georgina Limestone ranges in age from Middle to Late Cambrian. The relationship between the Arrinthrunga Formation/ Marqua Formation and the Georgina Limestone in the eastern Toko Syncline is not well defined. However, the Georgina Limestone is probably the deep-water facies of the other two units (Green, 1985).

Both the Arrinthrunga Formation in the west and the Georgina Limestone in the east are unconformably overlain by the latest Cambrian Ninmaroo Formation which is predominantly early Ordovician and is discussed below.

The succession in the Burke River Structural Belt is very different to that in the Toko Syncline both in terms of the contained rock types and the time of the major unconformities (Figure 3). The basal Middle Cambrian unit is the Thorntonia Limestone which is unconformably overlain by the Beetle Creek Formation, the main phosphate bearing unit.

The Inca Formation unconformably overlies the Beetle Creek Formation and is itself separated by a significant hiatus from the Devoncourt Limestone.

The Devoncourt Limestone, in its lower part, is laterally equivalent to the Roaring Siltstone. The upper part is a correlative of the Selwyn Range Limestone and O'Hara Shale.

The earliest Late Cambrian Pomegranate Limestone conformably overlies the Devoncourt Limestone. The youngest Cambrian unit is the Chatsworth Limestone.

The Ninmaroo Formation in the Burke River Structural Belt is conformable on the Chatsworth Limestone unlike in the Toko Syncline where it unconformably overlies the older units.

In the Undilla sub-basin, there are a number of Middle Cambrian units, but no Late Cambrian. Thorntonia Limestone, Beetle Creek and Inca Formation are present.

These are overlain by predominantly limestone units (Age Creek Formation, Currant Bush Limestone, V Creek Limestone and Mail Change Limestone).

Ordovician

Ordovician rocks are restricted to the southern part of the basin. The oldest Ordovician unit is the Ninmaroo Formation which extends across the Toko Syncline and the Burke River Structural Belt (Figure 3).

This unit has been described in detail by Radke (1980, 1981, 1982) and at Black Mountain by Shergold and others (1991).

In the Burke River Structural Belt, the Ninmaroo Formation is overlain by the Swift Formation, a regolith derived by karstification of the Ninmaroo Formation.

A karst surface is also developed on the Ninmaroo Formation in the Toko Syncline area where the Kelly Creek Formation unconformably overlies the Ninmaroo Formation. The Coolibah Formation conformably overlies the Kelly Creek Formation.
The remaining Ordovician rocks in the Toko Syncline belong to the Toko Group (Draper, 1980).

The oldest unit in the group is the Nora Formation which is followed by a conformable succession including the Carlo Sandstone and Mithaka Formation. The youngest unit in the group is the Ethabuka Sandstone.

Devonian

The Devonian Cravens Peak beds are preserved on the western side of the Toko Syncline. The stratigraphy of these rocks was described by Draper (1976) and Turner and others (1981).

A tentative age of Emsian to Eifelian was ascribed to the unit at the time and a simple stratigraphic sequence described.

Subsequent improvement in the knowledge of the biostratigraphy of Devonian fish (Young, 1996) indicates a more complex picture with an unconformity dividing the beds into two units.

Jurassic-Cretaceous

The southernmost parts of the Georgina Basin are overlain by the Eromanga Basin and outliers of Eromanga Basin occur throughout the basin. The geology of the north-west Eromanga Basin was described by Mond and Harrison (1978).

The basal unit in the area is the Hooray Sandstone which crops out in the Toko Syncline and Burke River Structural Belt. It is possible that the upper part of the unit mapped as Hooray Sandstone may contain the Cadna-owie Formation as the unit, previously mapped as Longsight Sandstone, was renamed the Hooray Sandstone by Mond and Harrison (1978).

The Longsight Sandstone as defined by Casey (1959) contained two distinct facies, a lower fluvial facies and an upper glauconitic marine facies. The latter may be equivalent to the Cadna-owie Formation. The marine Rolling Downs Group overlies the Hooray Sandstone/Cadna-owie Formation.

Cainozoic

Cainozoic fluvial or lacustrine units include the Podyea Formation, Mount Coley Sinter, Austral Downs Limestone, Marion Formation, Noranside Formation, Springvale Formation and the Horse Creek Formation. Most of these units are discussed in Paten (1964) and Mond and Harrison (1978).

Structural geology

Burke River Structural Belt

In general, structural movement in the Burke River Structural Belt was limited and was dominated by vertical movements. Timing of these movements is difficult owing to the gap in deposition from the Early Ordovician to the Late Jurassic.

The youngest movement was a southward tilting during the Cainozoic, and broad folding. The Eromanga Basin has been folded in broad open folds possibly during the Early Tertiary. Minor faulting also occurred.

The impact of the Devonian Alice Springs Orogeny is difficult to isolate as the Burke River Structural Belt runs almost north–south and any impact would have been minimal because of the orientation of the basement block to the direction of compression.

Strike-slip movement could be expected and several authors, for example Casey (1968) and Radke (1982) have suggested this or wrench-thrust movement. Likewise, the mid Ordovician movement cannot be quantified. Normal faulting and formation of domes may have occurred then.

Anderson and others (2004) recorded magnetic events during the Late Ordovician–Early Silurian and Early Devonian, supporting the view that the Burke River Belt was affected by movements at these times.

Normal faulting occurred during deposition of the Middle Cambrian units and several unconformities are present. The Early Cambrian or late Neoproterozoic rifting event in northern Australia may be represented by basalt in the Burke River Structural Belt.

The Neoproterozoic units were also deposited in a rifted basin. The main defining faults, such as the Pilgrim Fault, are older faults associated with the Mount Isa Inlier.

Toko Syncline

The Toko Syncline area has a more complex structural history than the Burke River Structural Belt with the dominant structural elements being associated with the Devonian Alice Springs Orogeny.

Northward directed thrusting caused right-lateral wrenching along the north-west trending Toomba Fault which is a fundamental basement structure (Harrison, 1980). Palaeozoic strata is upturned, overturned or folded to the north-east of the fault. The Toko Syncline is asymmetric, wedge-shaped, and lies between the Toomba Fault and the northward–trending Bedourie Block which is part of the Mount Isa cratonic block.

Dating of the deformation is based on the Devonian sedimentation. The uppermost conglomeratic part of the Cravens Peak beds is interpreted to be syn-depositional and it contains reworked Neoproterozoic rocks. These rocks are Eifelian or younger (Middle Devonian) although subsidence started in the Emsian.

There is an erosional unconformity within the Middle Ordovician Ethabuka Formation associated with broad regional folding. A number of unconformities exist in the Cambrian rocks, but these have little structural significance. Likewise, the structural significance of breaks in the Neoproterozoic rocks is not known.

The Tertiary and Cretaceous movements observed in the Burke River Structural Belt are also present in the Toko Syncline area.

Exploration history

Exploration to 1978 is summarised in Draper and others (1978). Between 1962 and 1964, four petroleum wells were drilled in the Burke River Structural Belt, one in the Undilla sub-basin, one in the Toko Syncline and two in the Bedourie Block.

Since then, two wells have been drilled in both the northern and southern Toko Syncline. AOD Ethabuka 1, drilled in the southern Toko Syncline in 1973 was the only one with a significant show, flowing gas at a rate of 7000 m3/d.

Seismic surveys have been of a regional nature and were restricted to the Toko Syncline. Surveys have been conducted by Bureau of Mineral Resources (BMR) and petroleum exploration companies (Harrison, 1979; Lodwick and Lindsay, 1990). The most recent survey was in 1999 (CR 31626).

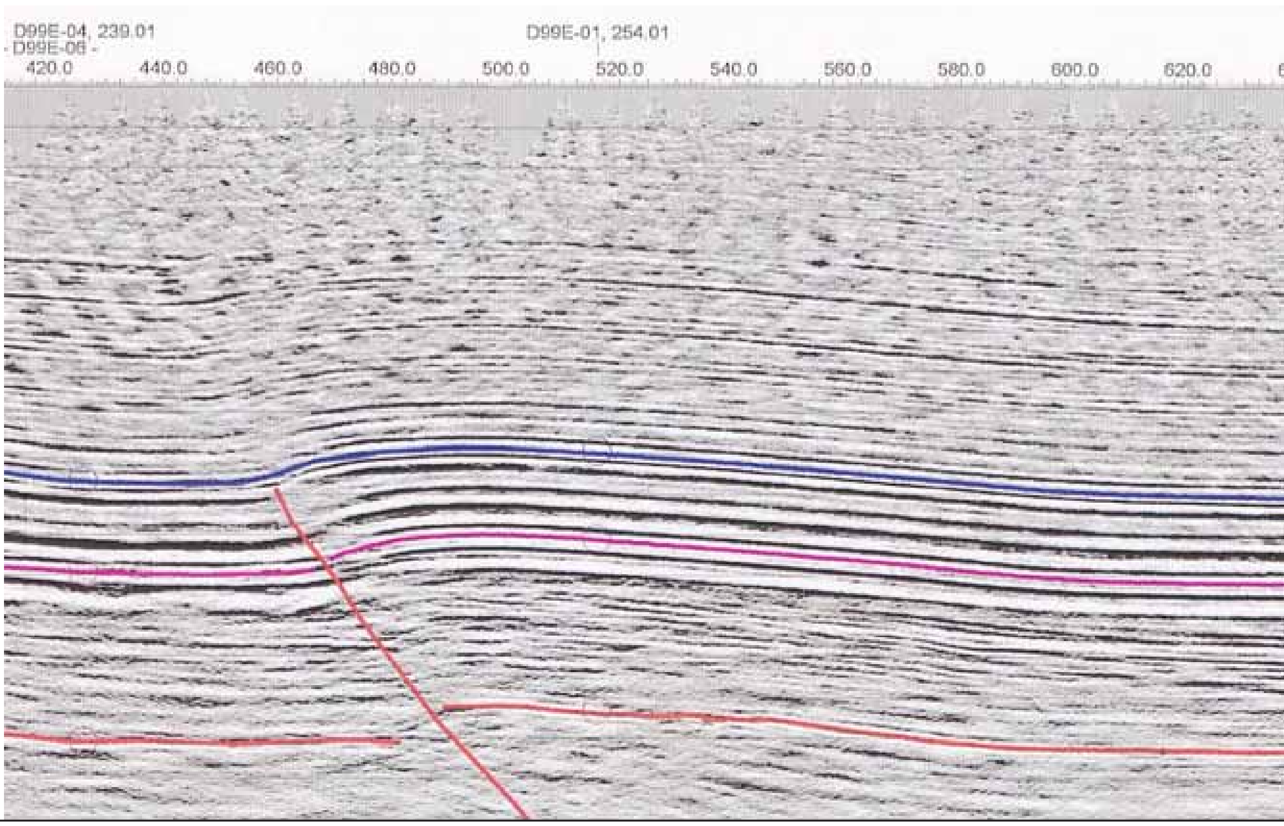
The area is covered by regional gravity and airborne datasets from AGSO and a number of local, more detailed gravity and magnetic surveys have been carried out by exploration companies.

In 1997 AGSO flew detailed magnetic and radiometric surveys of the Boulia and Springvale 1:250 000 sheet areas which include much of the Burke River Structural Belt.

In 2006, detailed airborne surveys were flown by the Queensland Government over the Toko Range area. A gravity survey is planned for the same area in 2006/07.

Figure 4: Seismic line across part of the Ethabuka structure

- blue – top kelly formation : pink – top Georgina limestone : red – basement
- AOD Ethabuka 1 did not penetrate the Kelly Creek Formation



Hydrocarbon occurrences

Burke River Structural Belt

No hydrocarbons were observed in any of the petroleum wells drilled in the Burke River Structural Belt. Residual oil contents up to 0.17 % have been recorded from outcrop samples (Draper and others, 1978). Radke (1982) has described bitumen and bitumen staining in the Ninmaroo Formation.

Toko Syncline

There are numerous shows in or adjacent to the Toko Syncline. The most significant hydrocarbon shows have been in the Toko Syncline where AOD Ethabuka 1 flowed dry gas from the Coolibah Formation at 7000 m3/d.

Owing to drilling problems, this well was abandoned before reaching its reservoir target in the Ninmaroo Formation and considerably short of the Middle to Late Cambrian source rocks. PAP Netting Fence 1 contained bitumen and minor gas in the Nora Formation, Ninmaroo Formation, Georgina Limestone and the Middle Cambrian rocks. AOD Mirrica 1 produced only minor gas from Cambrian rocks.

GSQ Mount Whelan 2 recorded bitumen in the Coolibah Formation (Green and Balfe, 1980). PGA Todd 1 contained bitumen and oil staining with minor gas from the Ninmaroo Formation down to the Thorntonia Limestone. PGA Bradley 1 also contained minor oil occurrences.

It is clear from the degraded nature of the hydrocarbons that water flushing has occurred, although in AOD Ethabuka 1, flushing is restricted to the mid Ordovician portion of the succession.

Reservoir

Randal (1978) identified three aquifer types in the Georgina Basin — sandstones, fractured reservoirs and carbonate reservoirs. The Carlo Sandstone is the best reservoir but is also a major aquifer. Porosities and permeabilities are generally very low in carbonate rocks but are higher in some dolomites (Draper and others, 1978).

Vugular porosity in dolomites offers the best chance of carbonate reservoirs with the Ninmaroo and Kelly Creek Formations and Thorntonia Limestone.

There are also oolitic sedimentary rocks and interbedded sandstones in the carbonates that contain porosity (Radke and Duff, 1980; Radke, 1982). Fracture porosity is another possibility but the predication of its distribution is difficult.

Traps

A number of different trap types are present. Anticlinal traps occur adjacent to the Toomba Fault and in the Burke River Structural Belt.

The Ethabuka and Mirrica structures along the Toomba Fault have been drilled but the wells may not have been optimally located for these to be valid tests.

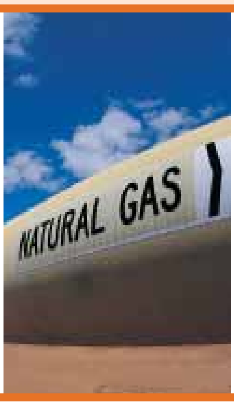
PPC Black Mountain 1 tested a domal structure in the Burke River Structural Belt without success. Stratigraphic traps are likely where the carbonate units thin to the north-west in the Toko Syncline area and a shelf-to-slope transition may occur.

Lateral facies changes in the Burke River Structural Belt could also provide stratigraphic traps. Another possible trap style is against the unconformity below the Eromanga Basin where karst development or suitable reservoir rocks are present.

Seals

Siltstones and mudstones of the Mithaka and Nora Formations are suitable cap rocks in the Toko Syncline. Within carbonate units, zones lacking in permeability may occur locally to form effective seals.

In the Burke River Structural Belt, the fine-grained units such as the Chatsworth Limestone lack permeability and would be good cap rocks.



Source

Burke River Structural Belt

Little is known about the source rock potential in the Burke River Structural Belt. Total organic carbon (TOC) values indicate that the Chatsworth Limestone (0.12%) and the Pomegranate Limestone (0.16 %) (Draper and others, 1978) have the best source potential.

Shergold and Walter (1979) report a TOC value of 2.82% from the Inca Shale and values from 0.19% to 1.51% from the Beetle Creek Formation.

Conodont Colouration Alteration Indices (CCAIs) of 1–1.5 indicate that the sequence is not overmature (Radke, 1982).

Toko Syncline

Jackson (1982) concluded that the Ordovician had little source potential and that the Neoproterozoic rocks were barren in the Toko Syncline.

However, the Middle and Late Cambrian units contain source rocks with the Georgina Limestone having the better quality source rocks, rating fair to very good, with EOM values up to 2000 ppm.

Jackson suggested that in the deeper part of the Toko Syncline, maturity for oil is reached in the mid-Ordovician, and that the Middle Cambrian was still in the gas generation zone.

The time of peak hydrocarbon generation could not be determined. Kress and Simeone (1993) considered that the Georgina Limestone in the northern Toko Syncline was marginally mature to mature and of poor to fair organic richness.

A TAI of 2.25 to 2.50 suggest maturity for early oil generation. This suggests that only in the deeper part of the Toko Syncline is maturity for oil generation exceeded.

Exploration potential

Hydrocarbon generation has occurred in the Georgina Basin and overmaturity has not been reached. Traps, reservoirs and seals are present (Figures 5–7).

However, flushing has affected much of the basin so that only those areas unflushed are prospective.

Burke River Structural Belt

Little is known about the extent of flushing in the Burke River Structural Belt. Maturity levels are suitable and there is evidence that generation has occurred (Radke, 1982).

Reservoir rocks are the major problem as the dolomitic units of the Ninmaroo Formation are either at the surface and karstified or covered by Eromanga Basin rocks.

Migration into the Eromanga Basin is a possibility. The Thorntonia Limestone occurs at depth, but reaches a thickness of only 20m. Fractured reservoirs associated with normal and ?wrench faulting are another possible target.

Toko Syncline

The deeper part of the Toko Syncline is still within the gas generation zone (Figure 5). The structural traps have not all been tested and the recovery of gas in AOD Ethabuka 1 showed the potential of this play concept.

Migration of both oil and gas could have occurred from these deeper older rocks, into stratigraphic traps associated with the prograding shelf slope transition.

In AOD Ethabuka 1 the early Ordovician and Cambrian rocks are not flushed further enhancing the prospectivity of the subsurface Toko Syncline.

Figure 5,6,7: Petroleum system

Figure 5: Georgina Basin – Burke River Structural Belt

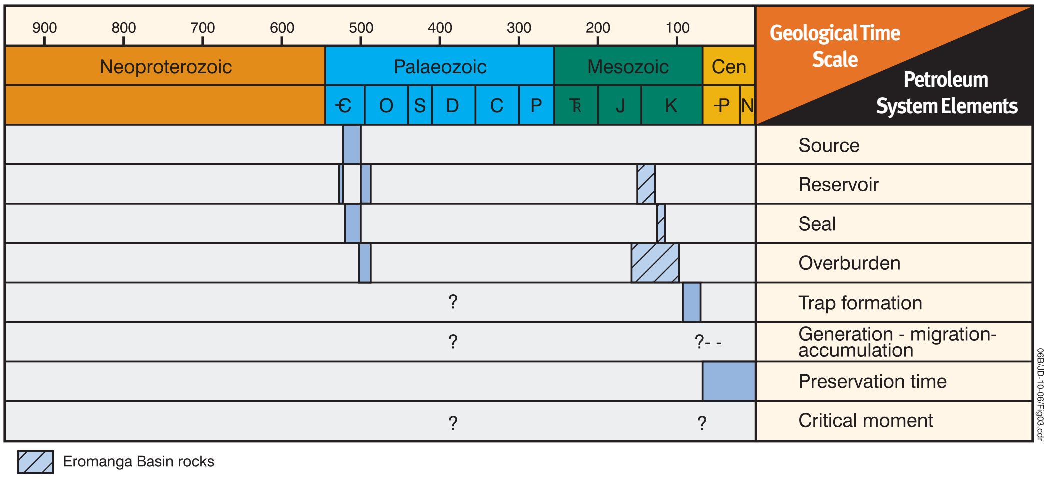


Figure 6: Georgina Basin – Toko Syncline

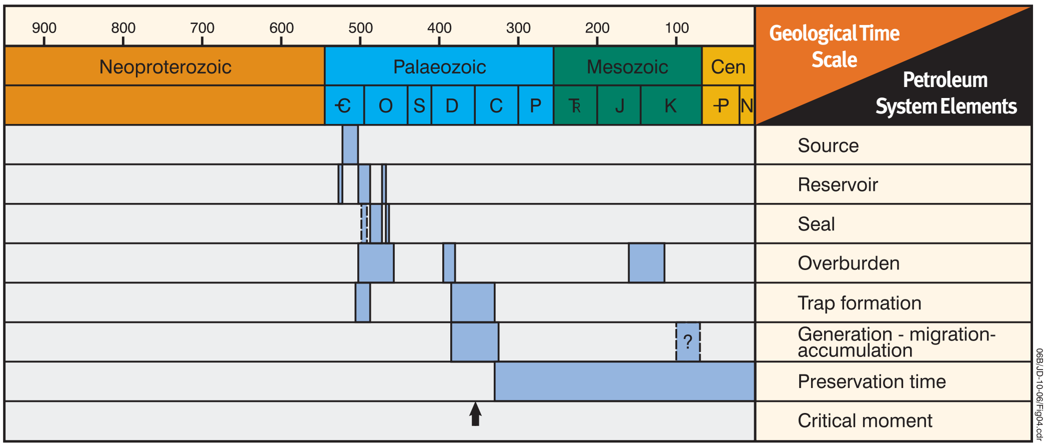
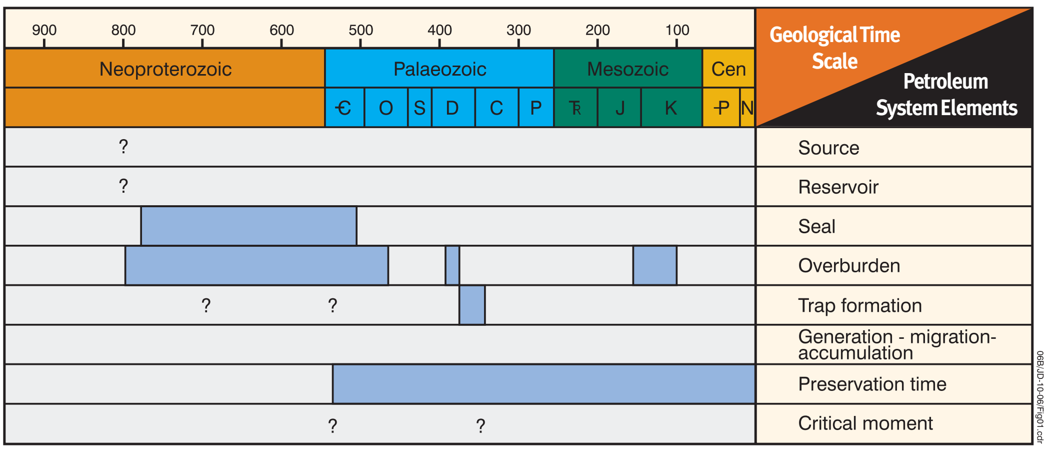


Figure 7: Georgina Basin – Neoproterozoic



Neoproterozoic

Little is known about the Neoproterozoic rocks beneath the Toko Syncline and Burke River Structural Belt (Figure 6).

They are likely to be mature to overmature. Although these rocks are not highly prospective for oil or gas, the presence of oil and gas in rocks of similar age in the Amadeus Basin suggests that they are worthy of further investigation.

Production

There is no production to date from the Georgina Basin.

Adavale and Georgina Basins

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