To navigate around the basins, click on either the basin name below or an area shown on the map.

- **Beetaloo Sub-Basin**
- **Wiso Basin**
- **Georgina Basin**
- **Amadeus Basin**
- **Pedirka/Simpson Desert/Eromanga Basins**

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THE AMADEUS BASIN 2006

Greg AMBROSE

- Area greater than 170,000 km²
- Large oil and gas fields on production
- 33 wells and 7500 km² of seismic data
- 1 well per 5000km²
INTRODUCTION

The Amadeus Basin (Figure 1) has intermittently been the focus of oil industry activity since the discovery of hydrocarbons in the 1960s culminating in the development of the Ordovician Mereenie and Palm Valley fields in the mid-1980s. These were significant fields and initial reserves at Mereenie were 24 MMSTB of oil and 462 BCF of gas, and at Palm Valley 230 BCF of gas. However, only minor exploration occurred from this time up until 1992 when the last exploration well was drilled. The basin is now a generation behind world standards, not only in terms of exploration activity, but also in terms of applied technology, particularly seismic technology. The current revival of energy prices has seen a resurgence of interest in this ‘sleeping giant’ which covers 170 000 km² with only one well per 5200 km². A watershed in terms of exploration activity is approaching and NTGS has delivered a number of new products that will hopefully facilitate exploration successes in the coming years.

Key geological breakthroughs relevant to the Amadeus Basin and other central Australian Basins were presented at the Central Australian Basins Symposium (CABS) held in 2005. All abstracts have been published and a compilation of final papers should be available by year end 2006 in the proceedings volume (Northern Territory Geological Survey, Special Publication 2). Six key papers delivered at CABS and relevant to the Amadeus Basin are listed below:

6) Gibson, Duddy, Ambrose and Marshall. Regional perspectives on new and reviewed thermal history data from central Australian basins.

Figure 1. Location of the Amadeus Basin. Inset shows map of Texas for areal comparison only.
Subsequent to the CABS Symposium, the latest version of the stratigraphy and related petroleum systems is shown in Figure 2.

Three additional NTGS products, available on CD ROM free of charge, relate to a regional seismic review of leads and prospects (Young Geoconsultants Pty Ltd 2004), a review of the basin’s petroleum source rocks (Marshall 2004) and an overview of the basin’s untapped petroleum potential (Warburton et al 2005).

EXPLORATION HISTORY

Exploration began in the Amadeus Basin in the 1950s with a period of reconnaissance work by the then BMR. The Mereenie Oil and Gas Field was discovered in early 1964 and the Palm Valley Gas Field in 1965. Both of these are in the Ordovician Pacoosta-Horn Valley-Stairway succession. Since then, exploration and scientific study in the basin has largely focused on the Ordovician petroleum system in the northern and eastern part of the basin. (Korsch and Kennard 1991). However, with only 5 wells located away from the central ridge to the south and west, and most recent data in these areas dating back to the 1960s, the greater Amadeus Basin can be considered a ‘greenfields’ area. It is therefore a frontier basin for petroleum exploration.

Encouraging results have been observed that indicate a number of active, but poorly defined older petroleum systems in the Amadeus Basin. The currently uneconomic Dingo gas field is a good example. It is located 80 km south of Alice Springs, and has proven and probable reserves of 25 BCF. Other prospects in the basin, which have recorded small but significant gas flows, but which have been the subject of little (if any) further work, include West Walker, Orange, Magee and Ooraminna.

Current exploration application tenements are shown in Figure 3.

AMADEUS BASIN–STRATIGRAPHY AND GEOLOGICAL HISTORY


The initiation of the Amadeus Basin probably coincided with the onset of Mesoproterozoic rifting, which was associated with the Giles Event (1080–1040 Ma) and may have centred on the Musgrave Province. A number of the resultant northwest-trending faults were reactivated at this time (SRK 2004). This process defined the shape of the basin and location of basement highs. Renewed rifting, related to continued northeast-directed extension, occurred at the commencement of the Neoproterozoic (800–840 Ma) and ultimately lead to the breakup of the Rodinian Supercontinent along the Tasman line (Powell et al 1994). Faults defining the basement fabric were intermittently rejuvenated during later rifting and orogenesis through to the Palaeozoic.

In the Bloods Range region, located in the southwest Amadeus Basin, a thick package of sediments and volcanics (Tjauwata Group) unconformably overlies basement of the Musgrave Province. Incipient rifting at this time resulted in the deposition of quartz-rich sediments, volcanlastic sediments and bimodal volcanics, the Tjuninanta Formation (Close et al 2005). Conformably overlying this succession is the Mount Harris Basalt, which comprises an estimated 1–2 km-thick accumulation of basaltic flows, interpreted to be approximately 1080 Ma in age. The overlying Bloods Range Formation comprises red beds, volcanlastic rocks and fine-grained to conglomeratic clastic rocks. A change from this alluvial / fluvial setting to a shallow-marine–tidal depositional environment (Heavitree Quartzite/Dean Quartzite) marks the onset of the Amadeus Basin succession sensu stricto.

The relationship between the Mesoproterozoic rift succession and the basal Amadeus Basin clastic rocks is contentious and the evidence for continuous rift-sag basin evolution is equivocal; various interpretations are in Close et al 2005. The Neoproterozoic section in the Amadeus Basin averages about 2000 m, increasing to about 3000 m in the northeast. Lindsay (1993) described the stratigraphy of the basin which, together with three basin studies completed for the Northern Territory Geological Survey (Weste 1989) and 6 papers presented at the Central Australian Basins Symposium, form the basis of the following discussion.

NEOPROTEROZOIC

Heavitree Quartzite

Sedimentological and stratigraphical analyses by Lindsay (1993 and 1999) show that basal Amadeus Basin clastic strata resulted from quartz sandstone sedimentation in a shallow, low-gradient ramp setting. Heavily laden braided streams transported quartz clastic material to the basin to be dispersed in a high-energy, shallow-marine environment, forming extensive, sheet-like sand bodies. Clarke (1974) and Dr I Dyson (pers com) have suggested that some of the sandstones resulted from, and were modified by giant storms as shoreface facies prograded across a broad, shallow shelf subjected to tidal amplification. Trough crossbeds show that the main direction of sediment supply was to the north-northwest onto what is now the exposed Arunta Complex. Zircon provenance studies also suggest that the Musgrave Province was emergent at this time (Camacho et al 2002).

Lindsay (1999) showed that the Heavitree Quartzite is relatively uniformly distributed over wide areas of the basin and averages 100–300 m in thickness, grading westwards to 800 m. In the eastern portion of the basin, this author described a major ravinement surface, 20–40 m above the basement contact, which may have regional extent, and which is capped by minor fluvial conglomerate. A distinctive feature of the Heavitree Quartzite is the presence of beds up to 10 m thick, consisting of individual sets of low-angle, sigmoidal crossbeds, which formed in a tidally dominated environment as flow-transverse sand waves.
Figure 2. Stratigraphy of the Amadeus Basin.

Horn Valley - Oil and Gas (Palm Valley and Mereenie fields) (West Walker-1, GIS)

Pertataka Formation - Gas (Dingo and Orange fields)

Aralka Formation - Gas/Oil (Ooraminna-1 gas to surface)

Gillen Member - Gas/Oil (Magee-1 gas to surface)
To the west, data is scarce and there has been only one well intersection, in Magee-1. This well was drilled on a basement high, and the quartzite was only 4.6 m thick and flowed gas to surface at a low rate. From seismic data, Young et al. (2005) interpreted crestal thinning of this potential reservoir over major topographic highs and this could be a major factor controlling large structural / stratigraphic hydrocarbon plays. Silicification inhibits the reservoir potential of the succession, but this may be restricted to the MacDonnell Homocline as a result of fluid movement along deep-seated thrust faults, and more basinal sections may retain better reservoir quality.

**Bitter Springs Formation**

The Bitter Springs Formation comprises three members, namely the Gillen Member, the overlying Loves Creek Member and the topmost Johnnys Creek Member. The thickness of the Gillen Member is highly variable and has been largely determined by intraformational salt movements, which greatly distort the original stratigraphic thickness. The Loves Creek (4–500 m thick) and Johnnys Creek (maximum thickness 380 m) members are less affected.

**Gillen Member**

The contact between the Heavitree Quartzite and the overlying Bitter Springs Formation (Gillen Member) is paraconformable. The following descriptions are based on the work of Lindsay (1993) and Dyson and Marshall (2005). At the base of the Gillen Member, a major transgressive event resulted in the deposition of thick transgressive black shale, which has oil source rock potential and which may be lacustrine in origin. The overlying section comprises stromatolitic dolostone, occasional grey shale and crossbedded sandstone.

An upper evaporitic succession was deposited during a sea level low-stand and can be generalized as a lower dolomite/anhydrite unit, overlain by a thick halite unit, and capped by a dolomite/anhydrite unit (Lindsay 1993). Halite units up to 830 m thick are recognized in wells, but much thicker, remobilised salt layers are recognized on seismic (Figures 4, 5). For example, the Gosses Bluff structure is underlain by over 2200 m of salt (Lindsay 1987) and in the northeast portion of the basin, salt is generally over 1350 m thick.

The Gillen Member has been an important focus for halotectonics in the Amadeus Basin and in an exposed section at Ellery Creek, the unit displays a diapiric habit defined by tectonic breccia, isoclinal folds and sedimentary breccia (Dyson and Marshall 2005). The latter can be correlated over 100 km to the Ross River section and the breccia is interpreted to have been extruded as an allochthonous sheet or tongue of diapiric breccia (viz salt glacier), marking the earliest onset of diapirism in the
Figure 4. Seismic line from the Magee line survey.

Figure 5. Seismic line from the Murphy Range line survey.
Amadeus Basin. All unconformities within the Neoproterozoic and Palaeozoic, some of which are assigned to orogenies and other movements, are best developed adjacent to diapirs and within interpreted salt-withdrawal mini-basins. Sedimentation occurred at various times during the Neoproterozoic to Palaeozoic, in a series of salt nappe complexes and mini-basins that were formed under the influence of gravity sliding and salt withdrawal (Dyson and Marshall 2005).

**Loves Creek Member**

The Loves Creek Member is bounded by erosional surfaces at base and top. This unit was fully cored in Wallara-1 (204 m), and a full intersection also occurs in Murphy-1 (108 m). The Wallara-1 section comprises mainly dolostone in the form of wackestone and packstone, with occasional chert and also rare oolitic beds; stromatolites are common near the top of the unit. Some evaporites are present with anhydrite occurring as beds, nodules and veins. The basal contact with the Gillen Member is deemed unconformable (Lindsay 1993), but sedimentation is continuous with the overlying Johnnys Creek Member.

**Johnnys Creek Member**

This unit varies in thickness up to about 400 m, reflecting in part variable erosion during the Areyonga Movement. In the southern/central portion of the basin, the succession has a distinctive E-log signature and the lowermost unit is a distinctive 60 m-thick brown/red siltstone. The remainder of the succession comprises alternating intervals of dolostone/lime mudstone and brown-grey siltstone, with occasional chert, algal boundstone and glauconitic sandstone near the top of the succession. The unconformity surface with the Areyonga Formation is often marked by development of a rubbly fractured regolith and there is up to 200 m of topographic relief on this surface (Lindsay 1993).

Continued northeast-directed extension and dyke emplacement, related to continued breakup of the supercontinent Rodinia, created a widespread erosional break at the top of the Bitter Springs Formation, which can be correlated to the Adelaide Geosyncline. The Areyonga Formation, which was deposited in an extensional rift regime, is a correlative of the Sturtian glacial succession from the Adelaide Geosyncline, where Rb-Sr dates have yielded an age of approximately 730 Ma. The occurrence of thick glacial successions in the northeast Amadeus and southwest Georgina basins may reflect a rift depocentre in the eastern Arunta Province (M Hand pers com).

**Areyonga Formation / Aralka Formation**

This glaciogenic succession shows marked lithological variation from massive, indurated diamicite/conglomerate to carbonaceous siltstone/shale, feldspathic sandstone and occasional dolostone. A major depocentre was centred on the northeastern portion of the basin and the Arunta Province was a dominant source area. The diamicites were deposited on an intermittent, but extensive ice sheet, which spread over much of the basin as shown by a recent drilling intersection of “Sturtian” diamicites in the far southwest of the basin (Ambrose in prep). Black shales of the Aralka Formation occur in the northeastern portion of the basin and are up to 1000 m thick, being unconformable/disconformable on the Areyonga Formation (Kennard and Nicoll 1986). To date, there have only been sporadic, generally thin well intersections of this unit and the distribution of this potentially important source rock remains uncertain.

**Olympic Formation/Pioneer Sandstone**

The Olympic Formation and its lateral equivalent, the Pioneer Sandstone, disconformably overlie the Aralka Formation and are believed to correlate with Marinoan glacial strata of the Adelaide Geosyncline (Lindsay 1993). In the northeast, the Olympic Formation consists of lenticular units of sandstone, siltstone, conglomerate/diamicite, shale and dolostone, and is up to 190 m thick. To the west, in the Ellery Creek type section, the Pioneer Sandstone consists of intertidal sandstone capped by a “marker” dolostone. It is correlated with the Marinoan Nucaleena Dolostone from the Adelaide Geosyncline.

This unit was not intersected in recent stratigraphic drillholes located in the far southwest of the basin. Equivalent successions may have been eroded during the Souths Range Movement in other areas, where the overlying Pertatataka Formation rests unconformably on the Bitter Springs or Areyonga formations. This was a period of uplift, folding and erosion, intervening between the second glacial succession and thick, extensive marine shale of the overlying Pertatataka Formation. The Souths Range Movement may represent the initial compressive phase of the later, Early Cambrian Petermann Orogeny.

**Pertatataka Formation**

In the eastern portion of the basin, the Pertatataka Formation conformably to unconformably overlies the Olympic Formation, or unconformably overlies the Bitter Springs Formation. It is absent over at least part of the Central Ridge, but is widespread south of this high, where it is 400–500 m thick, and in the past has been referred to as the Winnall Beds, a term that is now redundant. An upward-coarsening regressive cycle in the upper part of the unit can be correlated over a wide area. The succession consists mainly of fine-grained clastics, predominantly red and green shale with minor fine-grained sandstone. Recent drilling in the southwestern portion of the basin intersected 450+ m of red/brown to occasionally grey, silty mudstone, becoming evaporitic towards the top. The succession defines a major regressive, upward-shallowing cycle which in its lower part includes thin, sandy, upward-fining cycles, representing input from turbidity currents.
North of the Central Ridge, the Pertatataka Formation shallows upward into the Julie Formation, which is a widespread, relatively thin succession of ooid grainstone, dolostone and limestone up to 150 m thick. The Pertatataka and Julie formations form a major regressive, upward-shallowing/coarsening cycle beginning with deep-water pelagic and turbiditic rocks that terminate abruptly in oolitic platform carbonates. Major structuring associated with the Petermann Orogeny followed deposition of the Julie Formation.

**Pertaaorrta Group**

The depositional architecture of the Centralian Superbasin suffered major disruption during the Petermann Orogeny (650–530 Ma), when the superbasin suffered major fragmentation. Further rejuvenation of the basement structural fabric affected sedimentation within the Amadeus Basin. Major crustal shortening on the northeastern margin of the Musgrave Province resulted in the deposition of a thick Early Cambrian clastic wedge adjacent to the southwest basin margin.

During the Cambrian, depositional loci moved northwards and sedimentation was concentrated in major sub-basins and troughs north of the Central Ridge. A total of 2800 m of clastics were shed into the Carmichael Sub-basin and 1500 m into the Missionary Plains Trough (Lindsay 1993). These sub-basins may have been bounded by high-angle reverse faults, or by extensional faults, which were later rejuvenated during the Alice Springs Orogeny, thereby masking the structural mechanism. Recently SRK (2004) have defined extensional northwest-trending faults based on regional trends, and the widespread development of Early Cambrian flood basalts north of the basin is indicative of significant underplating. The focus of rifting may have been in the eastern Arunta Province where 20 km of syn-orogenic early Cambrian sediments may have been deposited in the Harts Range area (M Hand pers com).

**Arumbera Sandstone**

The basal unit of the Pertaaorrta Group, the Arumbera Sandstone is divided into two depositional successions with maximum thicknesses of 800 m and 500 m, respectively, in the Carmichael sub-basin, although the thickest section is 2000 m in the northeast of this sub-basin (Weste 1989). A disconformity separates the lower and upper Arumbera sandstones, which are late Neoproterozoic and Early Cambrian in age, respectively, both being mainly fluviol-deltaic in origin. The sediments accumulated in three sub-basins, namely the Carmichael in the centre, the Idirriki in the west and the Ooraminna to the east. These depocentres and their connecting troughs lose definition southward towards the Central Ridge, which was an effective buttress to major southward progradation of deltaic successions (Lindsay 1993). However, thin transgressive successions occur in Wallara-1 (90 m) and also Mount Winter-1 (73 m) and East Johnnys Creek-1 (73 m).

The Lower Arumbera Sandstone is conformable with the Julie Formation on the northern basin margin, but an intervening unconformity occurs elsewhere. This unit onlaps the Central Ridge, whereas the southern platform was largely an area of sediment bypass (Lindsay 1993). To the southwest, coarse clastic rocks (Mount Currie Conglomerate) were shed northward into the basin from the Musgrave Province, as a result of major thrusting associated with the Petermann Orogeny and these probably interfered with the Arumbera Sandstone. To the north, major progradation into the Carmichael Sub-basin resulted and a major coarsening-upward cycle developed, capped by fluvial and distirbutary mouth-bar deposits. A mounded facies at the base of the succession may be a lowstand fan (Lindsay 1993).

The Upper Arumbera Sandstone is also a regressive, shallowing-upward deltaic succession capped by shallow-marine carbonate rocks of the Todd River Dolostone. The succession records extensive progradational seismic signatures (clinoforms) and has a maximum thickness of about 500 m near the centre of the Ooraminna and Carmichael sub-basins (Lindsay 1993).

The Arumbera Sandstone is the key reservoir in the Dingo and Orange gas fields and is an important gas target in the northern and southern Amadeus Basin. Details of the Dingo Field are shown in Figure 6.

**Chandler Formation**

The Chandler Formation is a Lower Cambrian carbonate and evaporite succession, and includes organic-rich, foetid, carbonate mudstone, which is a potential petroleum source rock. These sediments were probably deposited during post-Petermann relaxation/extension prior to more regional Cambrian rifting (SRK 2004). The Chandler Formation disconformably overlies the Arumbera Sandstone and a regional depositional model for the unit is in Bradshaw (1991). The succession was probably deposited in a shallow-water, deep desiccated basin in three depositional phases: 1) desiccation and evaporite precipitation; 2) basin flooding and carbonate deposition; and 3) karstification and evaporite precipitation. The western end of the basin is envisaged as the distal end of a salt lake.

Recent drilling suggests the succession is probably absent or very thin west of Magee-1 and Mount Winter-1. Deposition was concentrated in the central-eastern portion of the basin in three north–south-trending facies belts. In the westernmost belt, the Chandler carbonate facies is dominant, comprising relatively thin (10–50 m), areally extensive, black, foetid carbonate mudstone with siltstone, shale and abundant chert. An anoxic, shallow-water, restricted marine environment of deposition has been interpreted (Bradshaw 1991). The section thickens eastward to a mixed carbonate/salt facies up to 500 m thick and the salt ranges in thickness from less than 50 m to over 1000 m. In the easternmost facies belt, evaporites dominate and the thickest well intersection is over 700 m in Bluebush-1. Intraformational salt movements have probably distorted sedimentary isopachs, and extensive salt flowage and dissolution have produced tectonic contacts with numerous older and younger units.
The Tempe Formation disconformably overlies the Chandler Formation and is a shallow-water shelf succession, averaging about 150 m in thickness. It is dominated by a persistent basal sandstone sheet overlain by siltstone and shale, and capped by a dolomite in the Gardiner Range (Kennard and Nicoll 1986). Glaucante and phosphatic skeletal material are abundant. The section also occurs in Wallara-1 (184 m) and Mount Winter-1 (163 m). Conformably overlying the Tempe Formation is the ‘Illara Sandstone’ and it is suggested herein that this term be made redundant and, in future, the ‘Illara Sandstone’ should be included in the Tempe Formation. The latter interfingers to the north and east with the Hugh River Shale and westward with the lower portion of the Cleland Sandstone.

The Giles Creek Dolostone interfingers with the Tempe Formation and disconformably overlies the Chandler Formation. It is conformably and gradationally overlain by the Shannon Formation and to the west, the succession interfingers with the basal part of the Jay Creek Limestone. The Giles Creek Dolostone is only known to the north of the Central Ridge and has a maximum known thickness of 383 m in Wallaby-1. The succession comprises mainly terrigenous-rich carbonate rocks and mudstone/siltstone, often variegated red-brown to green, and minor sandstone. Depositional environments include shallow-marine, tidal flat, intracoastal lagoon, shallow open-shelf and shoal settings. A detailed description of sedimentary environments is in Kennard and Nicoll (1986).

Petermann Sandstone / Deception Siltstone / Cleland Sandstone / Shannon Formation

These stratigraphic units are sometimes lateral equivalents, but the temporal relationships between them are uncertain and hence they are discussed as a whole. The Shannon Formation conformably overlies the Giles Creek Dolostone and reaches a thickness of over 700 m in the northeastern portion of the basin, while progressively thinning to the north and west. The lower Shannon Formation comprises up to 270 m of silty shale with interbeds of thin siltstone and dolostone, deposited in an oxygenated, low-energy marine environment. The upper Shannon Formation is carbonate rich, representing the progradation of peritidal carbonate flats. The main lithofacies are shallow subtidal (ribboned carbonate-mudstone, grainstone and thrombolites),
intertidal (stromatolites) and supratidal evaporitic facies (Kennard and Nicoll 1986). Palaeontological data indicates a Middle Cambrian age for this section.

Across the Central Ridge and on the southern platform, the equivalent Middle Cambrian succession is dominated by fluviatile and overbank facies of the Deception Siltstone and Petermann Sandstone. These are genetically related red-bed alluvial clastics up to 1250 m thick (East Johnnys Creek-1). An equivalent succession in the Idirriki Sub-basin consists of gravelly braided stream deposits of the Cleland Sandstone which reach a maximum measured thickness of over 1000 m. Recent drilling in the southwestern portion of the basin recorded 115 m of red beds (Petermann Sandstone in NTGS LA05 DDO1), comprising a prograding alluvial fan at the base capped by channelised braid-plain deposits with some marine influence (Ambrose in prep).

The Cleland Sandstone outcrops in the western Amadeus Basin and reaches a maximum thickness of 1060 m in the Glen Edith Hills area, where the unit is a medium- to coarse-grained sandstone, which is believed to change facies eastward into the Tempe Formation, Deception Siltstone and Petermann Sandstone.

**Goyder Formation**

The Goyder Formation, which is late Cambrian in age, has a gradational lower contact with aforementioned clastic successions and reaches a maximum thickness of 600 m in the northeastern Amadeus Basin. The unit transgresses the Central Ridge, but generally thins to the south and west, and is only 95 m thick in Mount Winter-1. It is subdivided into lower and upper units, both deposited in shallow subtidal to intertidal environments (Kennard and Nicoll 1986). The lower Goyder Formation is up to 300 m thick and consists of a basai carbonate-clastic unit and overlying sandstone. The upper Goyder Formation consists of up to 300 m of sandstone and siltstone.

An unconformity, denoted by a weathering surface and faunal break (Oaks *et al* 1991, Shaw *et al* 1991), separates the two ‘members’. This break in sedimentation also occurs in the Officer and Ngalia basins and SRK (2004) showed a correlation with sandstone and siltstone.

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An unconformity, denoted by a weathering surface and faunal break (Oaks *et al* 1991, Shaw *et al* 1991), separates the two ‘members’. This break in sedimentation also occurs in the Officer and Ngalia basins and SRK (2004) showed a correlation with the Delamerian Orogeny (510–490 Ma), known locally as the Bloods Range Movement. However, the Delamerian Orogeny is only weakly expressed in the Amadeus Basin and no significant folds or fault movements are interpreted in central Australia (SRK 2004).

**LARAPINTA GROUP**

The Larapinta Group is herein informally divided into upper and lower successions bounded by major unconformities, comprising in total seven formations that range in age from latest Cambrian to Silurian. The group is marked at the base by a significant unconformity within the Goyder Formation, clearly denoted by seismic data and biostratigraphy (Lindsay 1993), and related to the Bloods Range Movement. This marks the first time the Central Ridge failed to partition a depositional phase into sedimentary regimes (Lindsay 1993).

The top unconformity bounding the lower Larapinta Group probably relates to the Rodingan Movement (Shaw *et al* 1991, Walley *et al* 1991). This deformation denotes initial compression associated with the Alice Springs Orogeny, which in places, has formed an erosion surface at the base of the Carmichael Sandstone. However, this erosion surface, while representing a major time break, is paraconformable over large areas of the missionary Plains Trough and Carmichael Sub-basin, and the relationship to basin orogenesis remains uncertain (Lindsay 1993). The upper Larapinta Group, comprising the Carmichael and Mereenie sandstones, is bounded at the top by a major unconformity related to the Pertnjara Movement of the Alice Springs Orogeny.

During the Ordovician, shallow-marine conditions prevailed, mostly in the tidal range, and clastic sedimentation came into dominance (Lindsay 1993). During the mid–late Ordovician, northeast–southwest intracratonic extension opened a broad rift basin connecting the Canning, Amadeus and Warburton basins to the proto-Pacific Ocean, forming the Larapintine Seaway (Walley *et al* 1991). The basin was asymmetrical at this time and most formations thicken to the present north-central margin of the basin, while onlapping the southern margin. The group’s average thickness is 1030 m and reaches a maximum of 2100 m at the northern boundary of the central portion of the basin; southwards there is a progressive depositional overstep up through the stratigraphic section. An important oil reservoir, the Pacoota Sandstone, is gradational with the underlying upper Goyder Formation and is progressively overlain by the Horn Valley Siltstone, Stairway Sandstone and Stokes Siltstone. The final phase of clastic sedimentation is defined by the Carmichael and Mereenie sandstones.

The group is of economic importance in that the succession includes the basin’s only commercial petroleum system, viz the Horn Valley Siltstone source rock, which is responsible for attendant petroleum production from the Pacoota and Stairway sandstones.

"**LOWER**" LARAPINTA GROUP

**Pacoota Sandstone**

The Pacoota Sandstone, which is Late Cambrian to Early Ordovician, is described in detail by Deckelman *et al* (1992), and the following discussion draws heavily on this study. The succession accumulated in response to thermally induced, regional basin subsidence which was in part affected by halokinesis in the Neoproterozoic Bitter Springs Formation. It appears that from this time on, the Central Ridge ceased to be a pivotal barrier to clastic sedimentation. The sandstone is up to 800 m thick in the
central-north of the basin and thins progressively southward to its depositional limit. The depositional setting was largely shallow marine, with subordinate non-marine deposition occurring in response to sea level fluctuations.

Initial deposition formed upper shoreface quartz sandstone, succeeded by a tidally influenced clastic succession in the north-central and northeastern parts of the basin. Major upward-coarsening cycles overstep one another southwestward. Subsequent westward transgression formed transitional fluvial to shallow-marine deposits. Braided streams eroded a northwestern hinterland and deposited sheets of mudstone, conglomerate and arkose which in turn, grade upward into estuarine mudstone and shoreface quartz arenite. Rising sea levels instigated a west-southwestward transgression, which resulted in an overlying section of lower shoreface clastic rocks, offshore marine clastic rocks and minor limestone. The final phase of Pacoota deposition responded to further slow, southwest-directed, marine transgression. Additional quartz arenite and subarkose accumulated at the shoreface, whereas dark grey/black shale/siltstone was deposited offshore.

The Pacoota Sandstone constitutes the main reservoir in the Mereenie and Palm Valley fields and is an important oil and gas target in the northern Amadeus Basin. Details of these fields are shown in (Figures 7, 8, 9).

Horn Valley Siltstone

The Horn Valley Siltstone contains the most important source rocks in the Amadeus Basin. The succession is of Arenigian age and was deposited on a relatively deep-marine shelf, where the black shale component of the succession was presumably deposited under euxinic bottom conditions. The unit has gradational contacts with both the underlying Pacoota Sandstone and the overlying Stairway Sandstone. A maximum thickness of 120 m is recorded in the western McDonnell Ranges, from where the succession thins to the south, west and east, which follows the depositional configuration for the Larapinta Group as a whole.

The base of the succession is defined by the first dolomitic limestone above the Pacoota Sandstone; this unit is rich in conodonts and nautiloids. An overlying black shale with minor limestone is up to 40 m thick. There follows up to 35 m of interbedded marl and shelly limestone with occasional black shale. In Temp Vale-1, this section includes thin storm beds made up of coquina at the base, grading to calcilutite, with dark grey mudstone capping the cycle (Kennard and Nicoll 1986). The uppermost Horn Valley Siltstone marks a transition from black shale and siltstone to fine sandstone. The contact with the Stairway Sandstone is arbitrarily placed where the sand component becomes dominant.

Stairway Sandstone

This sandstone succession lies conformably on the Horn Valley Siltstone, except in the south where the upper unit progressively overlaps older rocks. The Stairway Sandstone is Lower Ordovician (Llanvirnian) and is gradationally overlain by the Stokes Siltstone. The formation isopach largely mimics those of the underlying Horn Valley and Pacoota successions; a maximum isopach of 550 m is recorded in the north-central part of the basin, gradually decreasing to the east, west and south. A tripartite subdivision (Kennard and Nichol 1986) is applied in this area comprising: 1) a lower massive/crossbedded sandstone with pyrite ooids, capped by a quartz pebble horizon (60 m); 2) A middle unit containing black shale, siltstone, fine-grained sandstone and phosphorite (200 m); and 3) an upper unit containing thinly bedded, fine-grained sandstone with interbeds of siltstone and mudstone (300 m).

Stokes Siltstone

The Stokes Siltstone is of Middle Llanvirnian age and defines a succession of fine clastics reaching a thickness of 650 m in the north-central part of the basin, thinning southward and westward. The depositional environment had become more saline by this time and intertidal, supratidal and hypersaline conditions prevailed (Kennard and Nicoll 1986). The dominant lithologies are shale and siltstone with occasional evaporites. The lack of organic matter indicates a restricted, rather than open marine environment, suggesting that the eastern Larapintine seaway closed at this time (Walley et al 1991).

“Upper” Larapintine Group

Carmichael Sandstone

An erosion surface at the base of the Carmichael Sandstone masks a major change in the evolution of the Amadeus Basin from an extensional to a compressional setting, despite some doubts about the regional continuity of this surface. This erosion surface corresponds to the Rodingan Movement of the Alice Springs Orogeny, which was coincident with the onset of convergent subduction at the eastern margin of the Australian continent (SRK 2004). This marked the demise of the Larapintine Seaway, as deltaic sedimentation prevailed, with progradation from source areas in the northwest and southeast (Lindsay and Korsch 1991). The Carmichael Sandstone is believed to be Late Ordovician in age and comprises a reasonably continuous red/brown sandstone, siltstone and mudstone succession up to 150 m thick in the southern part of the basin.

Mereenie Sandstone

The Mereenie Sandstone is largely gradational with the underlying Carmichael Sandstone, but marked onlap of older Palaeozoic units occurs in the northeast portion of the basin, where there was uplift during the Rodingan Orogeny. The succession spans
Figure 7. Mereenie oil and gas field. a, schematic west-east cross-section showing distribution of hydrocarbons; b, south–north cross-section over Mereenie structure; c, map of Mereenie structure at top reservoir level.
Figure 8. Palm Valley Gas field. Palm Valley structure at top reservoir level, showing pipelines and wells.

Figure 9. Palm Valley Gas field. Schematic cross-section.
the Late Ordovician to Early Devonian and reaches a thickness of about 900 m in the axis of an extensive east–west-trending depocentre. Three major units occur in the Mereenie Sandstone; a lower aeolian succession with evidence of ephemeral lakes is overlain by a locally developed fluvial unit, in turn capped by an upper aeolian sandstone displaying large dune crossbedding (Lindsay 1993).

PERTNJARA GROUP

The mid-Devonian marked a period of convergent subduction on the eastern margin of the continent, and coincident structuring in central Australia occurred during the Alice Springs Orogeny. Earliest orogenesis occurred during the Rodingan Movement, but the later Pertnjara Movement (395–375 Ma, Haines et al 2001) is denoted by synorogenic deposition of the Pertnjara Group and its equivalents in the Amadeus, Georgina and Wiso basins. In the Amadeus Basin, this group comprises an upward-coarsening, foreland basin succession which unconformably overlies the Mereenie Sandstone and spans the Middle to Late Devonian.

During the Pertnjara Movement, major exhumation of the Arunta Province was accommodated in a series of south-directed thrusts, resulting in the formation of an extensive, thick clastic wedge in the northern Amadeus Basin (Pertnjara Group). The basal part of the succession (Parke Siltstone) has a maximum thickness of 1000 m and consists of mainly fluvial/alluvial, lithologically immature siltstone and sandstone with occasional lacustrine influence (Kennard and Nicoll 1986). This unit gradually coarsens upward to a succession of litho-feldspathic quartz sandstone deposited in upward-finling fluvial/alluvial cycles, as sediment was swept off the Arunta Province (Hermannsberg Sandstone). This unit is up to 1000 m thick in the northern portion of the basin and the sandstone become more mature in composition to the south and east.

Syn-orogenic, coarse alluvial conglomerate of the Brewer Conglomerate rest unconformably to conformably on the Hermannsberg Sandstone, reaching a thickness of 3000 m in the north of the basin. The succession formed as a syn-orogenic molasse formed by deposition on coalescing piedmont alluvial fans, coincident with south-directed deformation on the rising northern margin of the basin.

The final phase of the Alice Springs Orogeny, convergent deformation during the Carboniferous, is known as the Mount Eclipse Movement (340–310 Ma, Haines et al 2001). This corresponds to the Kanimbilan Orogeny beneath the Cooper–Eromanga Basin and convergent subduction at Australia’s eastern margin (SRK 2004). The direction of compression was probably northeast–southwest, but there was no coincident syn-orogenic sedimentation in the Amadeus Basin. Synorogenic deposition occurred to the north in the Ngalia Basin (Mount Eclipse Sandstone), and associated folding and thrusting of Amadeus Basin successions occurred to the south.

During the later phases of the Alice Springs Orogeny, uplift of the Musgrave Province resulted in deposition of Devonian continental clastics (Finke Group) described in detail by Jones (1973) and Edgoose et al (2002). Inboard of the southeastern basin margin, coarse alluvial facies of the Finke Group (Polly Conglomerate) are up to 400 m thick. The overlying Horsebend Shale forms a variably thick, discontinuous sheet over a much wider area of the southeastern basin. Both this unit and the Langra Formation were sourced from the south and interfinger northward with the Pertnjara Group. Distal facies of the Brewer Conglomerate (Idacowra Sandstone) occur in this area, where there is also minor deformation of the Finke Group; this indicates structural overprint during the latter phases of the Alice Springs Orogeny, which effectively marked the close of sedimentation in the basin.

NEW DATA/ONGOING INVESTIGATIONS

Interpretation of aeromagnetics

New aeromagnetic data clearly differentiate Amadeus Basin strata from the underlying crystalline basement. The data have enabled the identification of over 100 untested antiformal structures, 60 of which were not recognised prior to acquisition of the new aeromagnetics.

These features are the subject of continuing study and provide a great advantage to petroleum explorers in that little regional seismic is required to locate target structures underlying sand dunes etc. By leveraging this new aeromagnetics data, now provided free-of-charge by NTGS, more exploration funds can be directed at detailed seismic programs over target structures to enable definition of closure, crestal location and in some cases stratigraphic criteria.

During 2004, a basement study was completed by FrogTech Pty Ltd (formerly SRK Consulting), using the new magnetic data (Ham and Griffin 2004). This study has been useful in attempting to match the tectonic development of the Arunta and Musgrave provinces with that of the intra-basinal sediments that comprise the Amadeus Basin. This modeling gave an estimation of the depth to magnetic basement and the ‘container shape’ of the basin.

Seismic studies

The seismic interpretation report undertaken by Young Geoconsultants Pty Ltd (2004) brought all data held in the NTGS data repository together, and as a result, NTGS can now provide all seismic data available, interpreted at key stratigraphic horizons, which has now been incorporated into a Kingdom Suite project, and a substantial report to the public. This study was also presented at the CABS Symposium in 2005. These data and interpretations provide an extremely comprehensive base for explorers operating in the Amadeus Basin and the study was presented at the CABS Symposium in 2005. A detailed paper will
be published in the CABS proceedings volume later in 2006. The study also made available a regional seismic shot point base map for the entire basin. The highlight of the study was the elucidation of the highly prospective Heavitree Quartzite sub-salt play and the definition of multi-TCF structural/stratigraphic plays at this level in the southern Amadeus Basin. Examples of seismic lines from this area occur in Figures 4 and 5.

**Charge and migration modelling**

An investigation into the possible charge/migration history from various Amadeus Basin wells (e.g. Tempe Vale-1, East Johnnys Creek-1, Alice-1) is underway. New information is derived from Quantitative Grain Fluorescence (QGF), Quantitative Grain Fluorescence Extract (QGF-E), and Grains Containing Oil Inclusions (GOI), all of which are patented CSIRO techniques. These results have indicated the presence of possible palaeo/residual oil columns and also migration pathways in a number of wells. Compilation of a final report will commence in 2006.

**Halotectonics**

The Amadeus Basin was interpreted by Dyson and Marshall (2005) as a halotectonic basin where sedimentation occurred dominantly in a series of salt nappe complexes formed under the influence of gravity gliding, gravity spreading and salt withdrawal. Both the Gillen and Chandler salt successions have undergone halokinesis forming a myriad of potential petroleum traps. Relevant papers will be published in the CABS proceedings volume in late 2006 and studies will be ongoing this year.

**Geohistory modelling**

Recent papers by Gibson *et al* (2004, 2005) have reviewed the thermal history of the Amadeus Basin, utilizing new and existing maturity data and Apatite Fission Track Analysis (AFTA). The results indicate that up to four synchronous post–Early Carboniferous cooling episodes occurred in the Amadeus, Georgina and Pedirka basins, and these events were probably even more widespread, but have not been evaluated in other areas. In the northern Amadeus Basin, peak palaeotemperatures associated with each of these events decreased with each progressively more recent episode. In the northern Amadeus Basin, cessation of hydrocarbon generation from the Horn Valley Siltstone (Ordovician) occurred in the Late Carboniferous to Early Permian (Figure 10).

In the southern Amadeus Basin, maturity data from Wallara-1 (Figure 5) and Murphy-1 indicate regional unroofing of the basin, suggesting that hydrocarbon generation from Neoproterozoic successions was more pervasive than previously recognized. For instance, MPI-generated VRo values from Wallara-1 indicate that the Aralka and Bitter Springs formations (Loves Creek Member) lie in the oil window (VRo= 1.1) at current depths of 1300 m. This suggests that a significant portion of sediment load has been eroded, probably during the Tertiary, and negates earlier notions of increasing maturation from south to north across the basin. Similarly, in Murphy-1, shale in the Bitter Springs Formation shows maturities through the gas window at current depths of less than 3000 m (C Boreham pers com), also suggesting erosion at this location.

**CONSULTANTS EXPLORATION OVERVIEW AND RESOURCE ASSESSMENT**

A major overview of the basin, sponsored by NTGS and several operators, reviewed international analogies, salient aspects of the exploration history, and also both risked and unrisked petroleum reserve potential. The study was carried out by consultancy group, Fault Seal and was published as NTGS Record 2005-004 (Warburton *et al* 2005). The main conclusions are summarized below:

1) The Amadeus Basin is a producing basin, which by world standards is vastly underexplored.
2) Exploration statistics are favourable: 33 exploration wells have yielded 2 oil/gas discoveries, 5 technical gas discoveries which flowed gas to surface, and 13 exploration wells which were drilled off-structure.
3) **The commercial success rate is 11%**
4) **The technical success rate is 40%**
5) Reservoir quality and trap definition are major exploration hurdles.
6) Approximately 300 mmbl BOE have been discovered by 33 exploration wells.
7) Exploration technology dates back to the 1980s and the basin is a generation behind modern exploration methodologies. Tight 2D seismic grids are generally absent and there are no 3D grids in the basin.
8) Exploration finding costs are low at between US$0.5–1.3 per BOE.
9) Assuming a success rate of 11% for existing leads and prospects, then the risked “yet-to-find” reserves stand at 634 mmbl BOE or 3.9 TCF of gas. This also assumes all leads and prospects contain deterministic potential hydrocarbon volumes.
Figure 10. a, Wallara-1 and; b, Tyler-1 burial history models.
10) Five petroleum systems are recognized in the basin. The Ordovician Horn Valley Siltstone is most prospective, yielding 42% of the potential YTF reserves. The Gillen Member Petroleum System may contain 25% of future reserves and commercial viability would be enhanced by high Helium contents (eg Magee-1 gas flow comprised 6% Helium).

11) High-density 3D seismic is needed to optimize pre-drill locations.

12) An analogous petroleum province in Pakistan suggests the application of 3D seismic may provide the breakthrough to define and deliver remaining reserves.

**SUMMARY OF PLAY TYPES**

- Four-way dip closed over-thrust anticlines (Mereenie, West Walker) and 4-way dip closed anticlines (Palm Valley, Dingo) are the most common tests of Ordovician, Cambrian and Precambrian sections.
- Only one sub-thrust play has been tested (Undandita-1 and -1A), and these wells exhibited live oil and gas shows. Others are present throughout the basin.
- A Bitter Springs Formation–Heavitree Quartzite pinch-out play, analogous to the giant Proterozoic fields of the Eastern Siberian Basin and Sichuan Basin, has been tested by only one well, Magee 1, in the southeast of the basin (flowed gas at 2 km depth).
- Thrust-related traps, both in the hangingwall and footwall.
- Combination evaporite/stratigraphic/structural traps.

Untested play types (after Marshall 2005)

- There is an abundance of untested combination structural/stratigraphic plays (Figure 11). In this respect, the limitations are only that new interpretations are required on existing data to delineate preservation or thinning of units around structural features.
- Approximately one dozen salt diapirs are noted in outcrop in the southwestern part of the basin, where there is possible development of a Bitter Springs/Neoproterozoic petroleum system. These structures have not been studied, or officially documented, since the 1960s. Opportunities exist for diapir-related petroleum plays in these and other undocumented areas.
- Fault seal-dependent prospects have not been tested.
- Existing leads and prospects are shown in Figure 12. These do not include newly defined anticlinal trends shown on Figure 13.
- Over sixty new anticlinal structures have been recognised on newly acquired regional aeromagnetics.
- Aeromagnetic data are available online free-of-charge from NTGS.
- Combination evaporite/stratigraphic/structural traps.
- Huge conventional gas plays, such as Murphy South (Young Geoconsultants Pty Ltd 2004). However, fracture porosity is likely to be a key component of the play.

**Figure 11. Conceptual play cross-sections, central Amadeus Basin (diagram not to scale).**
Figure 12. Conceptual play cross-sections, central Amadeus Basin (diagram not to scale).

Figure 13. Amadeus Basin - interpreted structure in first vertical derivative magnetics.
AMADEUS BASIN PETROLEUM PROSPECTIVITY – CURRENT STATUS

- There are 4 viable petroleum systems operating in the Amadeus Basin, of which the Horn Valley Siltstone (Ordovician) and Gillen Member (Neoproterozoic) are most important.
- The Horn Valley Siltstone is probably only generative north of the Central Ridge and complacency regarding its remaining potential there is misplaced. This petroleum system is still only sparsely explored considering: 1) only one play type (ie 4 way dip closures) has been addressed; 2) existing seismic grids are very primitive and drilling has been generally sparse; and 3) only large oil and gas fields have been discovered and there have been no attendant small- to moderate-sized oil discoveries, as one would predict. The northern part of the basin is areally extensive and structurally complex and it is believed the incumbent Ordovician petroleum (oil) system has been vastly undersold and retains considerable potential for moderate-sized oil fields.
- The Gillen Member of the Bitter Springs Formation provides the second best target petroleum system in the basin and although gas charge was probably widespread there is potential for oil near the basin’s margins. Helium deposits in the target reservoir, the Heavitree Quartzite, would probably be dependant on deliverability from fracture porosity, but will provide commercial options in the case of a discovery. Regional blanket seal, provided by Gillen Member salt, together with the fact that multi-TCF-sized leads have already been defined, but await seismic detailing, both point to a bright future for this play.
- Two upper Neoproterozoic petroleum systems, the Pertatataka Formation and Aralka Formation appear to be largely gas prone, but data is very limited. Residual oil stains below the Chandler Formation salt seal in Finke-1 hint at the possibility of oil charge from this part of the section, but once again data is very sparse.
- New aeromagnetics data over the basin defines almost all the antiformal structures in the region, as well as being definitive of basement topography, thus largely negating the need for expensive regional seismic grids. Future exploration will require tight 2D/3D grids to confirm closure and a crestal location. Structural/stratigraphic plays will emerge as more data is acquired, hopefully verifying some of the very large leads already defined near the basin’s southern margin.
- There is considerable existing infrastructure and burgeoning resource projects in the Northern Territory will provide future gas markets. In the case of large gas discoveries, there will be: 1) potential to tie into the national gas grid via Moomba; 2) potential to provide feedstock for gas-to-liquids production; and 3) the possibility of contributing to future LNG exports from Darwin.
- The Palm Valley to Darwin gas pipeline and the new transcontinental railway line provide key infrastructure, which will improve the viability of upcoming resource projects throughout the Northern Territory.

REFERENCES


THE BEETALOO SUB-BASIN 2006

Greg AMBROSE
Matthew SILVERMAN

- 21,000 km² of prospective area
- 11 oil wells
- 2700 km of seismic data
INTRODUCTION

The Beetaloo Sub-basin is a Mesoproterozoic–Neoproterozoic intra-cratic sag basin unconformably overlying the western portion of the much larger McArthur Basin (Figure 1). The McArthur Basin contains a Mesoproterozoic sedimentary succession, deposited in several troughs bounded by normal faults; these were reactivated at least twice during the Neoproterozoic along compressional and strike-slip faults, after deposition of the Beetaloo Sub-basin succession.

- The Beetaloo Sub-basin includes the relatively young Mesoproterozoic–Neoproterozoic Roper Group, which is unconformably overlain by relatively thin sheets of Cambrian volcanics.
- This intra-cratic sag basin covers an area of 21 000 km²; it is relatively undisturbed structurally and has not been subjected to significant heat/stress regimes, although the centre of the basin has probably passed through the gas window.
- The Beetaloo Sub-basin succession contains thick, oil-prone source-rock successions, which are in the oil window over large areas of the basin and probably gas-mature in the main depocentre.
- The basin seismic coverage comprises 2700 line km of modern seismic and eleven oil exploration wells.

STRUCTURE AND TECTONIC ELEMENTS

- The Roper Group reaches a thickness of 3000 m in the central basin, which is an approximately oval, broad gentle depression (Figure 2).
- The main structural highs in the basin trend north–south, parallel to the Walker Fault Zone (eg the Arnold Arch), whereas subordinate structures trend east–west and appear to have been formed by compressional strike-slip fault systems. The Arnold Arch suffered major uplift and erosion immediately prior to deposition of the Jamison Sandstone, the base of which marks a regional unconformity.
- The latest compressional event occurred in the late Middle to Late Proterozoic, and strongly affected the Daly Waters Arch, but not the Arnold Arch.
- Overall tectonism in the Beetaloo Sub-basin has been relatively mild so that structurally, the basin resembles many much younger productive basins around the world, eg the Williston Basin, Canada. It is apparent that some of the structures in the basin predate oil migration.

Figure 1. Location of the Beetaloo Sub-basin. Inset shows map of Texas for areal comparison only.
Roper Group stratigraphy is summarised in Figure 3. A schematic cross-section of the basin is shown in Figure 4.

- Key source intervals are enriched in microbial/algal organic matter. The oldest source rock is the Velkerri Formation, which has an age of about 1.43 Ga (Warren et al 1998). This formation is up to 1150 m thick and previous workers have adopted a tripartite subdivision of organic-rich units, where TOC levels commonly exceed 4% and occasionally reach 8%.
- The Moroak Sandstone and Bessie Creek Sandstone form viable reservoir targets immediately above and below this source rock, respectively. The Moroak Sandstone has yielded significant recoveries during DSTs, indicative of viable permeability, and measured porosities are in the range 6–19%, but reservoir quality is strongly depth-dependant. The underlying Bessie Creek Sandstone has not been intersected in the Beetaloo Sub-basin, but is expected to be widespread and some DST results on the basin’s margins indicate the potential for reservoir-quality sandstone.
The overlying Kyalla Formation is restricted to the heart of the Beetaloo Sub-basin, where it reaches a thickness of about 730 m. TOCs are generally less than 2%, but range up to 9%, and the overlying Jamison Sandstone is the main reservoir target, in addition to the Moroak Sandstone.

High TOCs in source rocks, the recovery of live oil on DSTs in two wells and the presence of many other oil and gas shows, all testify to the generation of oil and gas in the basin. Some parts of the basin are actively in the oil window.

The main caveat for successful exploration in the Beetaloo Sub-basin is the preservation of hydrocarbons over hundreds of millions of years. In this regard, RobSearch (1992) have suggested that the period of maximum burial and generation of hydrocarbons occurred in the Cambrian, some 600–800 million years later than other estimates. In shallower parts of the basin, major petroleum systems could be actively generating and expelling hydrocarbons at much younger ages. These assertions would suggest any oil/gas pools would have a far greater chance of survival than previously thought and there are several younger analogous petroleum systems in other petroleum-bearing basins around the world, eg in Siberia, China and Oman.
CONCLUSIONS

The Beetaloo Sub-basin is a Mesoproterozoic depocentre including some highly productive petroleum systems which have generated billions of barrels of oil. Some uncertainties still exist re the geological timeframe over which hydrocarbon pools could have been preserved, but this could be far less than previously thought.

A new exploration player to Australia, US company Sweetpea Corporation, holds almost all of the basin either under legal title or under application, and this company is seeking farmines to continue their work program, which has already included a basin study and seismic reprocessing.

REFERENCES

The Georgina Basin 2006

Greg Ambrose
Peter Putnam

- 100,000 km² of prospective area
- 18 wells (no valid tests)
- Numerous oil shows
- 750 km of seismic data
- 1 well per 5500 km²
This contribution addresses key aspects of the geology and hydrocarbon potential of the southern Georgina Basin, an area exceeding 100 000 km². The southern Georgina Basin includes a Middle Cambrian petroleum system that, to date, has attracted little exploration, largely due to a dearth of modern seismic data, of which there is only 750 line km. In addition, only 18 exploration wells have been drilled, none of which has tested a valid structural closure. Electric log data, together with seismic, core, and newly acquired aeromagnetic data, facilitate simplification of the existing stratigraphy and allow the construction of regional isopachs based on lithostratigraphic units, correlatable over hundreds of kilometres, which in turn, enable an improved reconstruction of basin history and tectonic controls.

SOUTHERN GEORGINA BASIN – STRATIGRAPHY AND GEOLOGICAL HISTORY


INTRODUCTION

The Georgina Basin is the largest Neoproterozoic–Palaeozoic basin on the North Australian Craton (Figures 1, 2, 3). During the Neoproterozoic, it was contiguous with the Amadeus Basin to the south, forming a northern component of the Centralian Superbasin. Late Neoproterozoic to Early Cambrian orogenesis (Petermann Orogeny) partitioned these two basins when the Mesoproterozoic Arunta Province became largely emergent, except for a deep, narrow graben in the Harts Range area. The Georgina Basin comprises a succession of Neoproterozoic, Cambrian and Ordovician–Devonian carbonate and clastic sediments up to 5000 m in thickness (Figures 4, 5), deposited in a broad northwest–southeast depression covering an area of 325 000 km². This article describes the geological history of the southern Georgina Basin, which is prospective for hydrocarbons, and which covers an area of about 100 000 km².
Figure 2. Southern Georgina Basin study area.

Figure 3. Tenement application areas within the Southern Georgina Basin (current as of the 1st March 2006).
Figure 4. Stratigraphy of the Southern Georgina Basin.

Figure 5. Regional surface geology, including outcrops and major tectonic elements, of the Southern Georgina Basin.
Ten basin phases/tectonic events have shaped the Georgina Basin during the Neoproterozoic and Palaeozoic (Teasdale and Pryer 2002). The most important of these were the Petermann Orogeny (Late Neoproterozoic–Early Cambrian) and the Alice Springs Orogeny (Late Ordovician–Early Carboniferous). Neoproterozoic half-grabens are recognized on seismic data and thicken southward towards the Alice Springs Orogeny thrust front (Teasdale and Pryer 2002). In the southern Georgina Basin, the Palaeozoic is relatively shallow (<2 km deep) and the depositional surface topography was relatively subdued. The basin was unroofed during the latest Alice Springs Orogeny, with further erosion occurring during the Tertiary.

Intracontinental deformation in central Australia, formed in response to plate margin processes to the east, was limited compared with major orogenesis recognized in the Amadeus Basin. The southern Georgina Basin overlies the Altjawarra and Dulcie basement terranes (Figure 6, Teasdale and Pryer 2002), which have mainly resisted Palaeozoic compression, largely preserving Neoproterozoic half-graben fill, Cambrian platformal carbonate rocks and Ordovician–Devonian rift/foreland clastic successions. The relevant depocentres for these three mega-successions show some lateral displacement, as the basement structural fabric was rejuvenated through time. For instance, the Dulcie Syncline in the south of the basin focused Ordovician–Devonian sedimentation, but the thickest Middle Cambrian section occurs in an area north of the syncline. Lithostratigraphic relationships of the Palaeozoic succession in the Toko and Dulcie synclines are shown in Figure 7.

Figure 6. Tectonic elements and basement terrane emphasising the distribution of granites beneath the Southern Georgina Basin.

Figure 7. Schematic diagram showing stratigraphic relationships in the Southern Georgina Basin, including the Dulcie and Toko synclines.
NEOPROTEROZOIC

During the early Neoproterozoic, Australia was part of the Rodinia Supercontinent, which included Gondwana and North America. The Amata Dyke “event” (820 Ma) marked the onset of Neoproterozoic rift-related sedimentation in the Centralian Superbasin. This basin phase was dominated by east-northeast–west-southwest extension with approximate northwest-trending normal fault systems accommodated by northeast-trending transfer zones (Teasdale and Pryer 2002). The basin is interpreted to be a northwesterly extension of the Adelaidean Rift System. In the Arunta Province, the sediments that filled the main part of this rift basin are probably now part of the highly deformed and metamorphosed Harts Range Complex (Buick et al 2005).

Neoproterozoic half-grabens in the southern Georgina Basin were infilled by marine siliciclastics and at least one glacial interval. Thick half-graben fills are recognized on seismic sections in the Baldwin-1 and MacIntyre-1 areas, and other depocentres have been described by Tucker et al (1979) and Dunster et al (in press). Latest Neoproterozoic sediments are assigned to the Mopunga Group, which in the southern Georgina Basin comprises three units, namely the Elyuah and Grant Bluff formations, and overlying silty turbiditic rocks of the Elkera Formation (Ambrose et al 2001). The Elkera Formation correlates well with the lower Arumbera Sandstone in the Amadeus Basin, indicating a connection between these basins at this time. In the south/southeast of the Georgina Basin, the Elkera Formation is unconformably overlain by earliest Cambrian sediments of the Mount Baldwin Formation.

The Neoproterozoic succession on the southwestern margin of the basin is dominated by siliciclastic facies, with the Amesbury Quartzite at the base. This is overlain unconformably by glacial diamictite of the Boko Formation and the Oorabra Arkose; these two units probably represent the younger “Marinoan” glacial episode (Haines 2005). The overlying succession comprises up to 800 m of synorogenic sediments of the Mopunga Group, which formed coincidentally with the Petermann Orogeny. The lowermost unit of the Mopunga Group consists of black mudstone of the Elyuah Formation, which grades into the Grant Bluff Formation; these units are overlain by immature clastic rocks and evaporites of the Elkera Formation, which is capped by siliciclastic rocks of the Central Mount Stuart Formation. The latter consists of immature clastic sediments, which fed into the basin from the northwest, parallel to structural trends (Haines 2005); these sediments were deposited in a fluvial-deltaic complex with increasing marine influence to the east.

EARLY CAMBRIAN

Mount Baldwin Formation / Adam Shale

The regional continuity of the Neoproterozoic Centralian Superbasin was terminated by the 550 Ma Petermann Orogeny. Early Cambrian sediments in the Georgina Basin were probably deposited in a distal foreland/sag setting adjacent to the Petermann Orogen. There is a plethora of stratigraphic names applied to the early Cambrian sediments in the literature, which need rationalizing, eg Andagera Sandstone, Mount Baldwin Formation, Sunhill Arkose, Adam Shale, Octy Formation, Rising Sun Conglomerate, Neutral Junction Formation, etc. In the Northern Territory, the name Mount Baldwin Formation is applied herein to the earliest Cambrian sediments, which represent a full spectrum of alluvial fan-delta facies, varying from proximal conglomeratic facies through to distal siltstone/mudstone successions (Eyre 1994). Upward-coarsening, alluvial clastic successions were shed off the Arunta Province and the maximum recorded thickness is about 300 m.

The Mount Baldwin Formation fan-delta succession was subdivided into four units by Eyre (1994), which overall represent a coarsening-upward succession proximal to the Arunta Province source area. This coarse-grained, clastic succession interfingers with finer, tidally influenced distal facies to the north. The Mount Baldwin Formation probably correlates with the upper Arumbera Sandstone in the Amadeus Basin, but these depocentres were separate from the Early Cambrian onwards. To the east, the succession interfingers with the Adam Shale, which is dominantly a marine shale containing minor quartz sandstone interbeds.

Red Heart Dolomite / Errarra Formation.

These successions conformably overlie Early Cambrian clastic rocks and mark the onset of marine conditions, denoted by characteristic archaeocyathid-bearing dolostone with a variable clastic content. The Red Heart Dolostone is up to 92 m thick (Phillip-2), but its lateral extent is not well defined. In Phillip-2, the unit consists of a red dolostone that interfingers with 25 m of micaceous shale at the base. It is not widespread in drillholes and deposition appears to have been controlled by irregularities and undulations in the basin topography. Clastic content increases towards the basin margin, where the Red Heart Dolostone interfingers with the Errarra Formation on the southwestern margin. In its type section (Freeman 1986), the Errarra Formation is 129 m thick, comprising vuggy, micritic archaeocyath-bearing dolostone (23 m), overlain by sandstone and chert (36 m), capped by grey dolostone (67 m).

MIDDLE CAMBRIAN

Early interpretations of the Middle Cambrian stratigraphy suffered from a labyrinth of stratigraphic names, often based on sporadic, weathered outcrops. This confused nomenclature, together with erroneous facies relationships, has been rationalized by subsurface mapping using modern seismic, E-logs and core data (Ambrose et al 2001). Revamping the stratigraphy of the
Middle–Late Cambrian has resulted in the development of more comprehensive geological models, which in turn, establishes a new stratigraphic framework for petroleum and minerals exploration (Ambrose and Putnam 2005, in prep).

**Thorntonia Limestone**

The Thorntonia Limestone is a sheet-like, dolomitised limestone, with subordinate black shale, which was deposited during a major transgression spanning the Ordian and early Templetonian stages of the early Middle Cambrian. It was deposited in a range of peritidal to restricted, shallow subtidal environments (de Keyser and Cook 1972). The succession is unconformable on earlier Cambrian successions and maintains a thickness of 50–100 m over most of the basin (Ambrose et al 2001). Significantly, the thickest successions occur close to the western basin margin (150 m in Ammaroo-1, -2) and also on the eastern basin margin (150 m in Bradley-1), suggesting the unit extended well beyond the current eroded basin margins.

The base of the Thorntonia Limestone is locally a siliciclastic basement wash up to 30 m thick comprising basement-derived sandstone, siltstone and quartzite dolostone, and an initial thin conglomerate (Elkedra-3, Owen-2). The bulk of the Thorntonia Limestone is light to dark grey dolostone, mainly dolomudstone and dolowackestone, punctuated by minor dolostain. Nodular evaporite and evaporite dissolution collapse textures are common, as are marine invertebrate bioclasts, stylolites, fractures, pyrite and secondary porosity due to dolomitisation. Dark grey to black shales, usually 0–20 m thick, occur near the top of the unit and are carbonaceous and pyritic, constituting good-quality petroleum source rocks. Locally, on the southwest basin margin, a linear, fault-controlled trough defines a thickened succession (150 m), which contains about 90 m of black bituminous limestone and shale (P Kruse, NTGS pers com).

The top of the Thorntonia Limestone is a regional unconformity marked by karstification and occasional development of phospathic hard grounds, but there is little evidence of differential erosion during this major break in sedimentation. This important unconformity also occurs to the west in the Wiso Basin.

**Arthur Creek Formation**

The Arthur Creek Formation, which spans the late Middle Cambrian, reflects an initial rapid, basinal transgression succeeded by a gradual regression, on which were superimposed upward-shoaling and upward-shaling cycles (USCs), responding to shoreline regression and transgression, respectively. Facies interpretations suggest that the initial deepening event was regional in extent, covering most of the Georgina Basin. There followed the development of a carbonate ramp succession, which prograded southeastward towards the main basin depocentre in the Toko Syncline. Over most of the southern Georgina Basin, the Arthur Creek Formation is 200 to 400 m thick (Figure 8), increasing to about 800 m in the Toko Syncline (Ambrose et al 2001).

Ambrose et al (2001) and Ambrose and Putnam (2005) informally subdivided the Arthur Creek Formation into upper and lower stratigraphic units, based on electric log responses and lithology. The section has excellent oil-prone source rocks in the lower unit, which are overlain by potential sandstone and oolitic/grainstone reservoirs (upper Arthur Creek/Steamboat Sandstone) in the eastern portion of the basin. The lower and upper Arthur Creek Formation were deposited in outer and middle–inner carbonate ramp settings, respectively.

The lower Arthur Creek Formation is dominated by USCs, related to turbidites/debrites and storm-generated tempestites, which form an important stratigraphic petroleum play in the southern Georgina Basin. The section in Todd-1 defines an excellent reference section for the basinal succession, dominated by USCs, in contrast to a proximal well (MacIntyre-1), which is dominated by stacked, regressive upward-shoaling cycles. Recent studies, based largely on seismic, E-log and core data, focused on the Arthur Creek petroleum system and related structural/stratigraphic plays (Ambrose et al 2001, Ambrose 2002, Ambrose and Putnam 2005, Boreham and Ambrose 2005, Volk et al 2005, Duddy et al 2005).

**Lower Arthur Creek Formation (outer ramp)**

The base of the Arthur Creek Formation occurs at a major unconformity, separating this unit from the underlying Thorntonia Limestone. The lower Arthur Creek Formation (outer ramp/basinal facies) is 279 m thick in Todd-1. The basal part of the succession comprises a massive/finely laminated to thinly bedded, anoxic, organic-rich, partly dolomitite shale (“hot shale”), up to 25 m thick, which was deposited via aggradation of pelagic/hemi-pelagic organic sediment on the outer ramp. This unit, which has excellent source rock potential, was deposited sheet-like over most of the southern Georgina Basin and has correlatives further north on the basin’s northern shelf. This transgressive “hot shale” grades upward into a slightly less carbonaceous, laminated to thinly bedded turbidite succession, comprising mainly thin, graded, organic-rich, dolomitite siltsite beds. In the top 100 m of the lower Arthur Creek Formation, these cycles thicken and are frequently interrupted by thin beds of intraclast breccia, interpreted as debris flows. As regression proceeded, accompanied by subtle, eustatically driven shoreline oscillations, the sub-tidal ramp facies prograded from the north and west of the southern Georgina Basin, towards the main basin depocentre in the area of the Toko Syncline. The lower Arthur Creek Formation contains very rich algal/microbial, oil-prone source rocks over a wide area, and their distribution and maturity are discussed in Ambrose et al (2001). This is the most important petroleum system in the basin, as well as providing regional seal to the underlying Thorntonia Limestone.
Figure 8a-h. Palaeozoic isopachs of the Southern Georgina Basin.
Upper Arthur Creek Formation (middle-inner ramp)

The upper Arthur Creek formation consists of largely pale-coloured, peritidal, carbonate rocks, dominated by dolomudstone with subordinate dolograinless and oolitic/peloidal sediments. The basal contact with the lower Arthur Creek Formation is sometimes gradational, but is often marked by a USC, usually 5–10 m thick, which may denote a ravinement surface on a semi-regional scale. A good example occurs in Hacking-1, where the cycle comprises a thin (<20 cm) basal packstone lag, containing carbonate pebbles and granules, and also fossil fragments. Carbonaceous laminae increase in frequency up through the cycle, against a background lithology of silty dolomudstone. This unit correlates with a 7 m-thick breccia (debricle) in Owen-2, which is a viable reservoir target. The Buah Formation in Oman is an important analog; this succession includes hydrocarbon reservoirs formed on a Neoproterozoic, distally steepened, storm-dominated carbonate ramp (Cozzi et al. 2004), very similar to the ramp facies described herein.

Stacked USC gamma log cycles are common in the middle ramp facies of the upper Arthur Creek Formation and range from 5–20 m in thickness. They are well demonstrated in Todd-1 and comprise buff to yellow-brown, stylolitic dolostone at the base, grading via finely laminated (carbonaceous laminae) dolostone into wispy, laminated, silty dolostone at the top. They are interpreted as distal tempestite cycles deposited on the middle ramp below storm wave base. The rate of sediment supply outpaced production of accommodation space, as reflected by prograding clinoforms described by Harrison (1979). Some USCs show marked lateral continuity, sometimes up to 100 km, as confirmed by core studies and E-log correlations; related oil plays were described in Ambrose and Putnam (2005). These deposits may have formed as storm-influenced, prodelta turbidite fans deposited on the middle ramp. Associated channel and fan facies are recognised on seismic and provide opportunities for the stratigraphic entrapment of hydrocarbons. One seismically defined channel is about 100 m thick and a few hundred metres across. Overlying strata draped over the channel probably reflect differential compaction over a sandstone body embedded in fine-grained carbonate rocks. This channel facies may be a feeder to related fan facies recognized nearby on seismic (Ambrose and Putnam 2005), but neither facies has been drilled and exact stratigraphic relationships are uncertain.

Adjacent to the western basin margin, stacked, laterally extensive upward-shoaling/coarsening cycles replace USCs as the dominant depositional signature. These are demonstrated in MacIntyre-1 (Ambrose and Putnam 2005), where the upper Arthur Creek Formation comprises six upward-shoaling cycles, varying from 20–50 m in thickness. Several of the cycles demonstrate a full gradation from subtidal marine (organic rich dolomitic shale) → intertidal (algal boundstone, nodular limestone) → shoreline (coquina, grainstone) → supratidal (thin anhydrite beds). A thin, highly permeable shoal-grainstone, developed at the top of cycle-5, is a prospective reservoir target. This facies could also form at the top of other shoaling cycles, where there was sufficient winnowing, and may be prospective for hydrocarbons.

Steamboat Sandstone

The Steamboat Sandstone is a near-shoreline calcareous/siliciclastic sandstone, interbedded with oolitic carbonate rocks, which interfingers with the top portion of the upper Arthur Creek Formation. The unit is extensive and is usually about 70 m thick east of the Putta Putta Fault, which marks the margin of the Altjawaiarra Basement Terrane and appears to define the eastern limit of the sandstone. At this time, the western basin margin appears to have been relatively passive with little contribution of clastics to the ramp, which were mainly sourced from the north and east. Reservoir quality decreases from the Ross-1/Owen-2 area (Ø = 5–17%, K = 0–20 md) into the basin at Todd-1 (Ø = 5–10%, K = 0–5 md). The sandstone interfingers with, and sometimes erodes into upper Arthur Creek carbonate rocks, occasionally down to the level of the "hot shale". The Steamboat Sandstone marks the first contribution of quartzose sand to the basin in the Middle Cambrian, perhaps reflecting minor uplift in surrounding basement terranes. This unit may be disconformable with the overlying Chabelowe and Arrinthrunga formations, but the contact usually looks conformable in cored section.

Seismic character, lithology and the areal distribution of the Steamboat Sandstone suggest, in most part, a prograding strand plain/barrier system; in Todd-1, upward-coarsening shoreline sandstone clearly overlies middle ramp carbonate rocks. A cored reference section for the Steamboat Sandstone occurs in Owen-2, where the unit comprises 50+ m of fine- to very fine-grained, well sorted, feldspathic sandstone, commonly cemented by dolomite and quartz overgrowths. The terrigenous clastic rocks grade to partly oolitic, sandy dolomite/limestone, deposited in upward-coarsening cycles. A near-shoreline depositional environment is inferred, and the sandstone shows ripple cross-lamination and is moderately bioturbated. In the more terrigenous sedimentary rocks, porosity is up to 15% with permeability up to 95 md. Porosity in the sandstone is largely intergranular and there are analogies with the Jurassic Smackover Formation in the Oaks field in Louisiana (Erwin et al. 1979). There, barrier island complexes, deposited as coalescing bars in shoaling-upward cycles, are up to 250 m thick and comprise oolitic carbonate facies and rhodolitic grainstones.

Several major channel facies, recognized on seismic at the level of the Steamboat Sandstone/upper Arthur Creek Formation, probably record submarine channels rather than fluvial systems. They are genetically related to near-shoreline facies of the Steamboat Sandstone, which interfinger with the top Arthur Creek Formation, and probably tap clastics brought to the shoreline by fluvial systems. The best seismic example of a submarine channel occurs at SP 870-930 on seismic line 89-205 (Figure 9). This facies has characteristics of a mixed erosional/depositional submarine channel and both lateral accretion and thalweg elements are recognized (Ambrose and Putnam 2005). The channel shows a suite of erosional architectural elements, such as scours and cut downs, and probably contains coarse-grained clastic fill, but this facies has not been drilled. Topmost, flat-lying reflectors may record fine-grained siltstone/shale/carbonate mudstone, related to channel abandonment or depositional backfill. This
facies is up to 50 m thick compared with the lower coarse channel-fill, which is about 90 m thick. Surfaces of lateral accretion reflect at least a degree of channel sinuosity during the infilling phase. The channel, which is about 1.5 km across, is erosive to the level of the Middle Arthur Creek Formation and a levee bank is preserved on the southern side. The position of the channel appears to be controlled by basement tectonic architecture, which has left a subtle footprint in the overlying Palaeozoic succession, as the channel bifurcated around a major basement high on its northern side. Similarly, this basement footprint seems to have also captured an overlying Ordovician–Devonian channel system at the same location. This subtle basement control may be important in defining structural/stratigraphic petroleum plays (Ambrose and Putnam 2005).

Arrinthrunga Formation

As accommodation space filled, the Arthur Creek Formation was succeeded by a thick Late Cambrian interval of mixed carbonate and siliciclastic sediments (Arrinthrunga Formation), deposited in an extensive and intermittently emergent epeiric sea (Kennard 1981). The basal contact is sharp on electric logs, but is often gradational in core, where the contact is often marked by the sudden disappearance of bioturbation and fossil remains, reflecting a sharp increase in salinity. Terrigenous sediment input recurs in the medial Arrinthrunga Formation, as quartzic dolostone and minor quartz sandstone of the Eurowie Sandstone Member was deposited under sabkha conditions (Nicolaides 1995). The top Arrinthrunga Formation was subjected to major erosion during the Delamerian Orogeny and the thickest remaining section is 700 m in the Dulcie Syncline.

Chabelowe Formation (Hagen Member)

Many Palaeozoic basins worldwide show a progression from an antecedent ramp to a flat-topped platform. This is true in the Georgina Basin, where inner ramp facies of the Upper Arthur Creek Formation are in sharp contact with overlying peritidal sedimentary rocks of the Chabelowe Formation (Hagen Member), which in turn interfinger with the lower part of the Arrinthrunga Formation to the east.

The Chabelowe Formation was deposited in an intermittently exposed epeiric sea, where the lack of depositional geometries excluded progradation of systems tracts, and the depositional style was one of aggradation. The basal Hagen Member of the Chabelowe Formation includes near-shoreline facies at the base (well sorted crossbedded grainstone, ooid banks), overlain by stromatolitic dolostone, succeeded in the western portion of the basin by supratidal evaporites (semi-regional seal), in turn, overlain by red beds of the upper Chabelowe Formation (regional seal). The basal recrystallised dolostone was, in many cases, originally a grain-supported porous carbonate sand, prior to multiphase cementation. Over a wide area of the basin, the upper red bed succession forms a regional seal and no live oil shows have been recorded above this seal.
The Delamerian Orogeny (520–480 Ma) caused extensive deformation in the Adelaide Rift, but its influence in Central Australia appears to have been relatively minor. However, some of the major faults in the southern Georgina Basin were rejuvenated at this time. In particular, Hunt-1, which was drilled on the up-thrown side of the Putta Putta Fault, records Ordovician Tomahawk Beds resting unconformably on upper Arthur Creek Formation. The Arrinthuranga Formation was completely eroded during the Delamerian Orogeny at this location. This fault marks the western margin of the Altjawarra Basement Terrane, but the extent of structural rejuvenation in the basement fabric during Delamerian deformation remains uncertain; probably only major structures were affected.

During the mid–late Ordovician, northeast–southwest intracratonic extension opened a broad rift basin, forming the Larapintine Seaway, but this did not extend to the Georgina Basin. South of the Georgina Basin, evidence of deep crustal Ordovician extension is now exposed in the Harts Range Complex (Teasdale and Pryer 2002). During this time, within the basin (Toko Syncline), extension resulted in the deposition of marine clastic rocks in a platformal environment (Tomahawk Beds/Nimmaroo Formation, Kelly Creek Formation, Coolibah Formation, Nora Formation, Carlo Sandstone, Mithaka Formation and Ethabuka Formation). Minor normal faulting is interpreted in the Toko and Dulcie Syncline areas (Teasdale and Pryer 2002). Ordovician extension was terminated at about 450 Ma by the onset of convergent subduction at Australia’s eastern margin, corresponding to the earliest phase of the Alice Springs Orogeny in central Australia (Rodingan Movement). The total thickness of the Ordovician section above the Nora Formation is uncertain because of erosion at this time. It has been suggested by Ambrose and Putnam (2005) that Ordovician sediment loading may have initiated oil generation in the southern Georgina Basin, but later unroofing of the basin has removed the evidence.

The recognition of grainstone shoals over a wide area on the western side of the basin indicates that shoreline facies were developed laterally, probably as detached sheets, tens of kilometres wide. A shoreline stratigraphic play, defined by pinchout of shoreline sands to the west onto the Tennant Inlier, was described in Ambrose et al. (2001), Ambrose (2002) and Ambrose and Putnam (2005). Significant oil shows occur at this level (up to the evaporite seal) over part of the southwestern Georgina Basin and these are described by Volk et al. (2005).

**Ordovician–Devonian Sedimentation (Delamerian/Alice Springs Orogeny)**

The Delamerian Orogeny (520–480 Ma) caused extensive deformation in the Adelaide Rift, but its influence in Central Australia appears to have been relatively minor. However, some of the major faults in the southern Georgina Basin were rejuvenated at this time. In particular, Hunt-1, which was drilled on the up-thrown side of the Putta Putta Fault, records Ordovician Tomahawk Beds resting unconformably on upper Arthur Creek Formation. The Arrinthuranga Formation was completely eroded during the Delamerian Orogeny at this location. This fault marks the western margin of the Altjawarra Basement Terrane, but the extent of structural rejuvenation in the basement fabric during Delamerian deformation remains uncertain; probably only major structures were affected.

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The second major phase of deformation during the Alice Springs Orogeny, the Pertnjara Movement (395–375 Ma), resulted in basin orogenesis, and the southern margin of the basin formed at this time as basin was thrust over Neoproterozoic–Ordovician sediments (Teasdale and Pryer 2002). Syn-orogenic sedimentation occurred in a foreland setting in the southern parts of the basin (Dulcie Sandstone/Cravens Peak beds). Although the original thickness of the resulting sedimentary pile is not known, it is likely this loading event could have been involved with oil-generation in the southern Georgina Basin.

The final phase of convergent deformation is known as the Mount Eclipse Movement (340–310 Ma). There was significant exhumation of the Arunta Province at this time, as most of the province underwent sinistral transpression (Teasdale and Pryer 2002). Only minor reactivation of older structures along the southern margin of the basin occurred and no syn-orogenic Carboniferous sediment is preserved in the basin.

**Tomahawk Beds/Nimmaroo Formation**

The Tomahawk Beds (Ordovician) unconformably overlie the Arrinthuranga Formation and comprise a clastic-dominated succession deposited in a littoral to sublittoral environment on a middle to outer marine shelf (Stidolph et al. 1988). The maximum preserved thickness in the study area is 327 m in Phillip-2. The formation contains mainly medium- to coarse-grained, calcareous and glauconitic sandstone, with thin carbonaceous silty shale comprising up to 45% of the section. Thin interbeds of quartz-rich dolarenite and calcarenite are also present. To the east in the Toko Syncline, the Tomahawk Beds interfinger with the Ninmaroo Formation and no syn-orogenic Carboniferous sediment is preserved in the basin.

**Kelly Creek Formation/Coolibah Formation/Nora Formation/Carlos Sandstone/Mithaka Formation/Ethabuka Sandstone**

In the Dulcie Syncline, a thin succession of Kelly Creek Formation comprises fresh-water/aolian clastic rocks. These conformably overlie the Tomahawk Beds and are, in turn, disconformably overlain by the Dulcie Sandstone (Devonian). To the southeast in the Toko Syncline, the deposition of extensional Ordovician clastic successions (Kelly Creek Formation, Coolibah Formation, Nora Formation, Carlos Sandstone, Mithaka Formation, Ethabuka Sandstone) was terminated by compression associated with the Rodingan Movement (earliest Alice Springs Orogeny) and hence, the original thickness of the sedimentary pile is uncertain.

**Dulcie Sandstone/Cravens Peak Beds**

In the Toko Syncline, deposition of the Cravens Peak Beds occurred during the Pertnjara Movement of the Alice Springs Orogeny and this unit correlates with the Dulcie Sandstone deposited to the west. There followed mild folding and reverse faulting associated with the latter phases of the Alice Springs Orogeny (Mount Eclipse Movement) and hence, the original thickness of the sedimentary pile is uncertain.

Erosion of a thin, Mesozoic/Tertiary cover succession resulted in scattered remnant outcrops in the southernmost part of the basin.
HYDROCARBON PROSPECTIVITY

Introduction

The Middle Cambrian succession in the Georgina Basin contains potentially prolific marine source rocks with expulsion signified, in part, by the abundance of oil and gas shows. The most important potential source rocks occur in the lower Arthur Creek Formation, particularly the basal ‘hot shale’ facies. This facies ranges in thickness up to 60 m (Elkedra-3) and often grades upward into thinly bedded potential source rocks, extending up to 100 m above the basal ‘hot shale’. Total organic carbon (TOC) contents are commonly between 0.5% and 10% and rarely range up to 16%. The organic material is microbial with high initial hydrogen content (Hydrogen Indices 600–800) and total yield (S1+S2) ranging up to 57 kg/t. The shale extends over about 50 000 km² and a Russian research group estimated that 40 billion tonnes of hydrocarbons have migrated from these rocks in the southern Georgina Basin (SIBGEO 1991a, b, 1992). The shales grade from being immature in the north to overmature on the southern basin margin.

Source rocks and maturation

The most important source rocks occur in the outer ramp/basinal facies of the lower Arthur Creek Formation and the upper portion of the Thorntonia Limestone; these are discussed in Questa (1994), Ambrose et al (2001) and Boreham and Ambrose (2005). The distribution of oil- and gas-mature source rocks is shown in Figure 10. There is evidence that the importance of Thorntonia Limestone source rocks near the top of this unit has been underestimated in the past. New palaeontological studies on the southwestern margin of the basin indicate that the Thorntonia Limestone thickens markedly into local fault-controlled half-grabens (eg, in Ammaroo-2; P Kruse, NTGS, pers com 2004). The thickened section includes 90 m of additional black carbonaceous limestone, which, when compared with adjacent wells, vastly enhances the oil source potential of this area. Hydrocarbon generation probably occurred during Ordovician to Carboniferous sediment loading.

In the Dulcie Syncline, the relatively thin Arthur Creek Formation section and absence of lower Arthur Creek Formation source rocks suggest that basinal dips were to the north during the Middle Cambrian, and that there was considerable basin unroofing of the Ordovician–Carboniferous succession in the Ammaroo-2/Elkedra-7 area, and indeed, over much of the southern Georgina Basin, in the latter stages of the Alice Springs Orogeny.

Figure 10. Present-day basin geothermal gradients and maturation distribution in the Southern Georgina Basin.
Reservoir and seal

In the southern Georgina Basin, the main target reservoir/seal couplets are:

1. Thorntonia Limestone. Basin-wide regional seal is provided by basal Arthur Creek Formation organic shale.
2. Sandy tempestite/debris flows in the upper Arthur Creek Formation middle ramp facies, as seen in Owen-2. Semi-regional seal is provided by marine silty carbonate capping this USC.
3. Upper Arthur Creek Formation shoals, developed in upward-shoaling/coarsening cycles; these are best developed in MacIntyre-1 and adjacent wells on the western basin margin. Vertically stacked transgressive marine silty/shales at the top of each cycle provide semi-regional seal.
4. Oolitic and calcareous sandstone developed in upward-shoaling/coarsening cycles in the Steamboat Sandstone. Seal for this reservoir is uncertain, but could reside in cemented grainstone/evaporite/boundstone lithologies, found in the top of the Arthur Creek Formation and overlying Hagen Member.
5. Thick submarine channel facies (Figure 9), submarine fans and abandoned channels; these facies are completely encased in tight carbonate rocks deposited on the Arthur Creek middle ramp.
6. Near-shoreline basal Hagen Member oolitic grainstone and calcarenite occur on a regional scale and were important migration pathways. In the western portion of the basin, thickly bedded evaporites provide effective regional seal. In the central-eastern basin, Chabelowe Formation red beds provide regional seal.

Play types

Stratigraphic and structural play types are discussed in Ambrose et al (2001), but a combination of recent seismic interpretation, new geothermal history modelling (Gibson et al 2005, Duddy et al 2005) and basement structural mapping using airborne magnetics data (Teasdale and Pryer 2002, Duffett and Dunster 2005) have yielded several new exploration strategies.

Recent basin modelling indicates that Middle Cambrian source rocks over much of the southern Georgina Basin, including the Toko Syncline, entered the oil window during the Ordovician to Carboniferous. In deeper parts of the basin, this could have occurred prior to folding/faulting associated with the latest phase of the Alice Springs Orogeny, which unroofed much of the southern Georgia Basin. Thus, structural plays associated with the Ordovician Delamerian Orogeny and early Alice Springs Orogeny are attractive targets, as are early-formed, Middle–Late Cambrian structural/stratigraphic traps.

Thin, highly permeable reservoir plays (described below) have very sparse well control, which, however, broadly defines viable source, reservoir, seal, and structural/stratigraphic avenues for entrapment, in what is essentially a tight succession. Much thicker, seismically defined, submarine turbidite channel and fan plays are large volumetrically, but this facies is completely untested by the drill.

A discussion of these main play types occurs below:

1. **Steam Boat Sandstone shoreline plays.** This review of the limited seismic coverage in the southern Georgina Basin has delineated numerous anomalous, lenticular seismic signatures within the Steam Boat Sandstone, which are believed to be a combination of beach ridge/barrier, tidal/distributary channel facies and deltaic sediments, formed on the inner shelf above wave base.

2. **Upper Arthur Creek Formation middle ramp clastics.** Previously described submarine channels and fans that formed on the middle ramp are shown in Figure 9. Control on facies distribution is poor, given the sparse seismic grid, but most of these features occur east/southeast of MacIntyre-1, and interpreted channel trends have been mapped out in the Baldwin/Hunt area. These facies may possess enhanced porosity, as a result of relatively strong current activity, but there is a complete lack of well control.

   Zones of basement subsidence could have acted as sediment funnels, focusing sand accumulation; for example, a submarine fan is recognised on seismic on the downthrown side of the Putta Putta Fault, which has a long history of Palaeozoic structural growth, probably extending back to the Precambrian. Adjacent submarine channels erode up to 150 m into the Arthur Creek Formation and tap into oil-mature source rocks of the outer ramp facies (lower Arthur Creek Formation), providing an ideal oil-charge scenario. Basin unroofing at the end of the Alice Springs Orogeny dictates target depths for this play of 300–1000 m and, given the predicted thick reservoir columns proposed, stratigraphic entrapment could reach hundreds of millions of barrels of oil.

3. **Upper Arthur Creek Formation shoal.** MacIntyre-1 is the reference well for an important grainstone shoal play within the upper Arthur Creek Formation. This well records six stacked upward-shoaling cycles, with porous shoreline grainstones, capping cycle 5, providing an excellent, if thin, target reservoir. This shoal can be correlated between MacIntyre-1, Ross-1, Hunt-1, Baldwin-1, Lucy Creek-1 and Cockroach-1, an area exceeding 20 000 km². Moderate to excellent reservoir quality occurs in Baldwin-1, Ross-1 and also MacIntyre-1, where an excellent reservoir (> 1 Darcy permeability) recorded significant oil shows. Capping these thin reservoirs are evaporitic beds of variable thickness, in turn, overlain by transgressive marine shale (of the succeeding cycle), which together provide semi-regional seal. This shoal/seal couplet has wide lateral extent, but the distribution of the topmost reservoir-quality grainstone is uncertain. However, the retention of excellent secondary porosity/permeability,
which is unusual in the Arthur Creek Formation, suggests that early hydrocarbon saturation in vuggy grainstone inhibited more advanced cementation. Some structural control could have resulted from subtle drape over basement fault blocks, facilitating winnowing by wave action. These data suggest stratigraphic/structural oil plays (eg up-dip MacIntyre-1) could be established, with a minimal amount of seismic, targeting thinly bedded, but highly productive grainstones at depths of around 500 m. Given the large possible areal extent of these thin reservoirs, stratigraphic entrapment could result in significant oil fields.

4 Upper Arthur Creek Formation middle ramp debris flow (tempestite facies). In Owen-2, the terrigenous input into the Arthur Creek Formation section is relatively enhanced, due to proximity to the basin margin. Owen-2 is also the reference well for a stratigraphic play that targets a sandy debris flow, formed on a ravinement surface that marks the base of the upper Arthur Creek Formation. The target reservoir is a breccia unit (7 m thick), in sharp contact with an underlying silty, very fine-grained, tight, calcareous quartz sandstone, where the presence of synaeresis cracks suggests a nearshore environment (Martins and Baker 1992). The overlying breccia contains limestone and sandstone clasts (<15 cm) in a limestone/sandstone/siltstone matrix, cemented initially by calcite, in turn, replaced by dolomite. Porosity is low (<2%), except at the base, and pores are often lined and stained by bitumen. Typically for the Arthur Creek Formation, oil migration occurred via secondary porosity related to dissolution of late burial, void-filling dolomite cement, which occurs in the basal 2.5 m of the breccia. Porosity and permeability range up to 10% and 95 md respectively. This subtidal intraclastic breccia is matrix-supported at the top and clast-supported at the base, and is crudely upward-fining, with top seal provided by laterally extensive marine calcareous, dolomitic siltstone. Importantly, this depositional cycle and the associated top seal can be correlated on electric logs over a wide area, but well control is extremely sparse. The extent of this play is uncertain, but structural/stratigraphic traps could be significant at target depths of 400–900 m. The proximal portion of the fan complex would provide the best opportunities for reservoir development, as more distal wells to the south appear to be tight (eg Hacking-1, Todd-1).

5 Hagen Member shoreline play. A shoreline grainstone/calcarenite facies at the base of the Hagen Member is widespread in the southern Georgina Basin and presents opportunities for stratigraphic entrapment on the margins of the Tennant Region (Ambrose et al 2001, Ambrose 2002). The Elkedra-7 stratigraphic hole is a useful reference well, which documents a fully-cored section of reservoir, source and seal lithologies. Excellent oil shows occur in the lower Hagen Member, beneath a thick evaporite (anhdrite) seal. A 10 m-thick residual oil column is indicated by studies of comparative residual fluorescence, using a technique developed by CSIRO, termed quantitative grain fluorescence (Volk et al 2005). The potential trap is breached by erosion in this area; however, the play is prospective elsewhere on this basin margin, where top evaporite seal and stratigraphic pinchout of reservoir-quality Hagen Member grainstone shoals are preserved. Oil-mature lower Arthur Creek Formation shale and Thorntonia Limestone source rocks are widespread in the area near the surface, having expelled oil prior to unroofing of the basin during later phases of the Alice Springs Orogeny. A key component of the play is the lateral extent of the evaporite seal.

GEORGINA BASIN PROJECT OUTLINES

Papers presented at the Central Australian Basins Symposium (CABS)

- Carbonate ramp facies and oil plays in the Middle/Late Cambrian, southern Georgina Basin, Australia (Ambrose and Putnam).
- Oil families from the Middle–Late Cambrian, southern Georgina Basin, Australia (Boreham and Ambrose).
- The Georgina Basin: constraints on the hydrocarbon generation history from Fission Track Analysis (AFTA) (Duddy, Gibson and Ambrose)
- Southern Georgina Basin architecture and mineral potential: results from integrated geophysical interpretation and GIS analysis (Duffett and Dunster 2005).
- Cryogenian to Early Cambrian stratigraphy and depositional history of the southwest margin of the Georgina Basin, central Australia (Haines).
- Petroleum migration in the Georgina Basin: Evidence from the geochemistry of oil inclusions and bitumens (Volk, George, Kempton, Liu, Ahmed and Ambrose).

ONGOING AND FUTURE PROJECTS

- Basin and thermal modelling to be fine-tuned (AFTA, MPI maturity data).
- Enhanced interpretation of depositional models from seismic and electric logs.
- Stratigraphic drilling (Steamboat Sandstone target).
- Fluid inclusion analysis (GOI).

PREVIOUS EXPLORATION HISTORY

- 100 000 km² includes 18 exploration wells, 750 line km of seismic data and one well per 6000 km².
- No valid structural tests, due to dearth of modern seismic data.
- 1990s well and seismic data and recent aeromagnetics never before fully integrated. Six new papers relevant to the basin were delivered at CABS.
CAMBRIAN BASIN ARCHITECTURE

- Two stratigraphic E-log markers (basal ‘Hot Shale’ of the Arthur Creek Formation and top Hagen Member) provide the basis for stratigraphic interpretation.
- The resultant simplified stratigraphy has regional extent.
- Major structural growth occurred during Arthur Creek time, whereas the Thorntonia Limestone and Arrinthunga Formation are sheet-like units.
- Intra-Arthur Creek shoals are correlatable between MacIntyre-1 and Baldwin-1 (50 km).
- The sand content of the Arthur Creek Formation increases to the north (Mulga-1). The Steamboat Sandstone becomes an important reservoir over a wide area of the southern Georgina Basin in near-shoreline, delta and channel facies.
- The basal Arthur Creek ‘Hot Shale’ is correlatable for over 300 km and covers an area of 80 000 km².

Figure 11. Stratigraphic cross-section between Randall-1 and Todd-1.

Figure 12. Stratigraphic cross-section between Huckitta-1 and Mulga-1.
**HYDROCARBON POTENTIAL (SOURCE)**

- ‘World-class’ source rock occurs in the basal Arthur Creek Formation (Middle Cambrian); up to 16% TOC.
- Anoxic microbial, oil-prone shale up to 25 m thick occurs at the base of the gross source interval in the lower Arthur Creek Formation, which is up to 115 m thick (Figure 13).
- Lower Arthur Creek source rocks cover an area of 50 000 km²; about 40 billion tons of liquids have been expelled (SIBGEO 1991a, b, 1992).
- Lower Arthur Creek source rocks also provide regional seal to the Thorntonia Limestone.

**Figure 13.** Source rock distribution: lower Arthur Creek Formation and Thorntonia Limestone.

**Figure 14.** Black laminated, organic-rich shale (potential source rock) of the basal Arthur Creek Formation (‘Hot Shale’), overlying Thorntonia Limestone from Ross-1 (934.3 m).

**Figure 15.** Isopach map and maturation distribution of gross source rock interval within lower unit of the Arthur Creek Formation in the Southern Goergina Basin.
HYDROCARBON POTENTIAL (RESERVOIR)

- One primary target in the basin is the platformal Thorntonia Limestone, which has been subjected to karstification at the top of the unit; secondary porosity relates to vugs, fractures and dissolution.
- A second primary target is Steamboat Sandstone shoreline facies, including delta lobes, channels and shoals.
- The Thorntonia Limestone/Arthur Creek Formation is a regional reservoir/source-seal couplet which can be mapped over 80,000 km².
- Upper Arthur Creek Formation grainstone ‘shoals’ provide additional targets.
- Hagen Member ‘shoals’ are prospective on the southwestern margin of the basin.

**Figure 16.** Van Krevelen diagram: Owen-2.

**Figure 17.** Van Krevelen diagram: Ross-1.

**Figure 18.** Highly porous and permeable subtidal shoal dolograinstone bed of the Thorntonia Limestone, NTGS 99/01.

**Figure 19.** Vugular porosity associated with karsted Thorntonia Limestone dolostone; 940.2–947 m depth in Ross-1.
Figure 20. Thin section photomicrographs of Cambrian reservoirs. **a**, Vuggy porosity in bioclast dolograinstone, medial Thorntonia Limestone, 565.4 m depth in NTGS 99/1; **b**, Interstitial porosity, modified by dolomitisation, in peloidal intraclast dologranstone of Upper Arthur Creek Formation, 638.9 m depth in MacIntyre-1; **c**, Interstitial porosity, modified by dolomitisation, in peloid grainstone of Hagen Member, 888.4 m depth in Randall-1.

**MATURATION MODELLING**
- Arthur Creek Formation source rocks grade from immature in the north to over-mature near the southern margin of the basin, where high-temperature granites in the basement have affected maturation history in the Baldwin–Hunt area (Figure 10).
- Maturation modelling is complicated by a complex geothermal history and uncertainties related to the amount of erosion at major unconformities.
- Ongoing AFTA analysis and MPI maturation studies will help unravel the geothermal history and, in particular, the importance of an Ordovician thermal event recognised in the Arunta Province to the south.

**HYDROCARBON PLAY TYPES**
- Stratigraphic plays shown in Figure 21 are dependant on architecture of clastic facies occurring in the basin. These facies, which fall into the upper Arthur Creek and Steamboat units and include possible distributary channel, deltaic, submarine channel and submarine fan facies are described in more detail above and in Ambrose and Putnam (2005).
- Numerous four-way dip closure leads are indicated by existing seismic data; these need to be matured to prospect status. Structures associated with the Delamerian Orogeny are most attractive.
- Previous exploration wells either lacked any seismic control or were located on sparse seismic grids. None of the wells tested a confirmed structural closure. The timing of oil migration versus structuring is being reviewed; results will be released at the Central Australian Basins Symposium (CABS).
- Structural plays away from the Toko Syncline are likely to target oil. Structural plays on the western faulted margin of the Toko Syncline are likely to be gas charged.

**HAGEN MEMBER STRATIGRAPHIC PLAY**
- The Hagen Member ‘shoal’ onlaps the southern margin of the Tennant Region and overlying massive anhydrite provides vertical seal. The basin has been unroofed in this area.
- Source and bottom seal are provided by Arthur Creek petroliferous shales, which are in the peak oil-generation window.
- Excellent oil shows occur in the Hagen Member ‘shoal’ and the Thorntonia Limestone (Elkedra-7), both of which onlapse onto basement up-dip.
- There is evidence for an isolated aquifer system in this area. Oil samples show no evidence of biodegradation or water washing.
- Further north, excellent oil shows were encountered in Elkedra-2.
- The Hagen Member ‘shoreline play’ extends for over 300 km east–west across the southern Georgina Basin’s gently ramped flank.
- The basin is largely undisturbed and these ancient shoreline traps, with regional anhydrite seal, should not have been breached or flushed.
Figure 21. Schematic diagram showing hydrocarbon play types in the Palaeozoic of the Southern Georgina Basin.

Figure 22. Schematic diagram showing showing the facies architecture of the Arthur Creek Formation within the Palaeozoic of the Southern Georgina Basin.
Figure 23. Schematic diagram showing stratigraphic play on the southwestern margin of the Georgina Basin. Main targets are the Hagen Member and the Thorntonia Limestone.

Figure 24. Southern Georgina Basin depth to basement.
There is scope for many other stratigraphic plays in the basin. Those close to the Toko Syncline/Dulcie Syncline will be accessing oil generated in Ordovician times. In more shallowly buried areas, generation from the Arthur Creek Formation was probably much later.

**BASIN ANALOGIES WORLDWIDE**

- A comparison of the Toko Syncline with the Anadarko Basin (southern USA) is in Ambrose (2002). Both are deep, Palaeozoic foreland basins bounded by reverse faults. Both contain extremely rich Cambrian source rock successions (Figure 25).
- There are analogies between the Georgina Basin and the Siberian Platform where production from lower Cambrian carbonates comes from early-formed stratigraphic traps with durable evaporite seals.
- An important analogy in respect to the upper Arthur Creek Formation (middle/inner ramp) is the Neoproterozoic Buah Formation in Oman (Middle East). This unit is a significant gas reservoir interpreted as a distally steepened storm-dominated ramp. Facies include oolitic shale (inner ramp) and storm-dominated mid-ramp facies (Cozzi et al 2004).
- A comparison of potential Cambrian Thorntonia–Arthur Creek reservoirs with productive analogues from the Carboniferous (Mississippian) of western North America and Mexico is in Putnam (2002).

**CONCLUSIONS**

The southern Georgina Basin is a vast greenfields exploration province, with a well density of one well per 6000 km² and there are no tests of proven traps validated by seismic data. It is the daunting size of the basin (100 000 km²) and absence of large structures, rather than its inherent prospectivity that has hindered previous exploration. Previous geological dogma has also harmed perceptions of prospectivity, as has very poor seismic control of previous exploration wells. The lower Arthur Creek Formation and Thorntonia Limestone petroleum systems are pivotal to hydrocarbon charge and there is widespread evidence of significant oil migration.

New basin modelling and petrological evidence suggest that the main phase of oil migration through the Arthur Creek/Hagen carbonates relates to burial during the Ordovician to Carboniferous, depending on the relative thickness of the sedimentary pile. Initial early diagenetic, fabric-destructive dolomite cements eliminated primary porosity and later dissolution porosity appears to be facies-dependent.

**Figure 25.** Major lithologies of the Anadarko Basin (southern USA).
Analysis of existing cores and e-logs has identified thin zones of viable permeability on the Arthur Creek ramp in what is essentially a fairly tight succession and a number of structural/stratigraphic plays have been described. Plays defined by subtle structural control inherited from basement features are primary targets. However, the focus of this article has been the definition of thick potential reservoirs in the middle/inner ramp facies of the Upper Arthur Creek Formation and Steamboat Sandstone, respectively. The recognition, from seismic data, of thick (150+ m), submarine distributary channel and turbidite fan facies at the level of the middle ramp is unusual in this setting and provides a new play in the basin. These unusual facies, which to date, have not been drilled, have potential to include important clastic reservoirs encased in essentially tight carbonate ramp lithologies. In addition, the potential reservoir facies erode into, and are sometimes onlapped by, organically rich source facies of the Lower Arthur Creek Formation, in turn providing an ideal hydrocarbon charge mechanism. Significant unroofing of the Ordovician–Carboniferous section in the southern Georgina Basin during later phases of the Alice Springs Orogeny, has resulted in shallow reservoir target depths of 300–1000 m.

In the current oil price environment, the Georgina Basin offers attractive, cheap entry acreage for explorers targeting ‘greenfield basins’ with shallow oil potential. Deeper gas prospects in the Toko Syncline have a lower risk than the oil plays, given the gas flow from Ethabuka-1, and are of strategic interest, given the burgeoning of gas markets and pipeline grids.

REFERENCES


THE PEDIRKA/ SIMPSON DESERT/ EROMANGA BASINS 2006

Greg AMBROSE

- 73,000 km² of prospective area
- 7 wells
- 2500 km of seismic data
- 1 well per 10,000 km²
Within the Northern Territory, the Pedirka/Simpson Desert/Eromanga basins occupy an area of about 73 000 km² (Figures 1, 2). This area is very sparsely explored with only 7 exploration wells (one well per 10 000 km²) and 2500 line km of seismic data. Tenements (as of March 2006), wells and the main tectonic elements of these basins are shown in Figure 2.

PEDIRKA / SIMPSON DESERT / EROMANGA BASINS – STRATIGRAPHY AND GEOLOGICAL HISTORY


INTRODUCTION

The Pedirka area occupies the Simpson Desert and encompasses four superimposed sedimentary basins, namely the Palaeozoic Warburton / Amadeus basins, the Permo–Carboniferous Pedirka Basin, the Triassic Simpson Desert Basin, and the Jurassic–Cretaceous Eromanga Basin. The northern Pedirka Basin covers an area of 73 000 km² in the Northern Territory and includes seven exploration wells and 2500 line km of seismic (Figures 1, 2). Adjacent basins and pipelines are outlined and testify to the overall isolation of the area, a factor recently offset to some extent by surging oil prices (Figures 1, 3). The most recent studies in the basin (Alexander et al 1996, Ambrose et al 2002, Middleton et al 2005) have updated models on the basin’s petroleum potential, as well as providing new research data. However, the basin has been largely underestimated for the last 20 years and suffered during the 1990s from a complete absence of exploration activity, a period when new exploration axioms were evolving in the analogous Cooper/Eromanga basins to the southeast. Recent exploration in the latter has largely succeeded because of the application of new technology, including extensive 3D seismic, and the fine-tuning of geoscientific models pertaining to petroleum expulsion and migration pathways. It is believed the same approach will succeed in the Pedirka Basin and recently explorers, encouraged by the current high oil price regime, are returning to the Simpson Desert to see if this time, she will give up her spoils.

Figure 1. Location of the Pedirka/Simpson Desert/Eromanga basins. Inset shows map of Texas for areal comparison only.
Figure 2. Tenements (as of the 1st of March 2006), wells and main tectonic elements of the Pedirka/Simpson Desert/Eromanga basins.

Figure 3. Central Australian basins showing significant tectonic elements and the location of fields, wells and pipelines.
The exploration history of the northern Pedirka Basin dates back to the early 1960s when the emphasis was on the Early to Middle Palaeozoic Amadeus Basin succession (McDills-1, Hale River-1). In 1963, the discovery of Permian gas to the south in the Cooper Basin turned attention to successions of similar age in the Pedirka Basin (eg Colson-1). The 1977 discovery of Jurassic and Triassic oil in Poolowanna-1 focused efforts towards younger Mesozoic reservoirs (Thomas-1, Etingimbra-1 and Poeppels Corner-1). There is uncertainty about the veracity of these traps. This is largely related to sparse seismic grids and also to velocity models for the basal Algebuckina Sandstone and the effect on the resultant depth conversion at the level of the main target reservoirs, ie the Poolowanna Formation and also Triassic and Permian targets.

All of the exploration wells in the area predate now-traditional exploration philosophy associated with the Permian/Mesozoic petroleum system, thus prejudicing the early exploration effort and distorting recent views of prospectivity. Interest was revived in the area by a key study (Ambrose et al 2002) which focused on this petroleum system and revealed new key data including:

1) the recognition of multiple reservoir/seal systems within the basal Jurassic Poolowanna Formation.
2) maturation models of salient Permian depocentres using the latest Winbury™ basin modelling software. Newly acquired thermal history data using the latest AFTA technology has refined the maturation history of these Permian depocentres, ie the northern Eringa Trough, the northern Poolowanna Trough and the Madigan Trough. The expulsion histories for these depocentres was defined using composite kinetic models derived for the Cooper Basin.
3) a regional overview of the Permian Purni Formation and the Poolowanna Formation using available data from both South Australia and the Northern Territory. The recognition of a proposed petroleum system equivalent to the lower Patchawarra/Tirrawarra Sandstone source–reservoir couplet in the Cooper Basin (which is equivalent to the Purni Formation/upper Crown Point Formation) was a major advance.

Figure 4. Depth to top Purni Formation, structure contours, well locations and regional tectonic elements.
4) the recognition of a palaeo-oil/gas column in Colson-1 in the Poolowanna Formation changed perceptions regarding hydrocarbon prospectivity.

REGIONAL TECTONIC ELEMENTS AND STRUCTURAL HISTORY

Regional aspects of the structural framework and tectonic elements of the northern Pedirka Basin were summarized by Questa (1990), Alexander et al (1996) and Ambrose et al (2002). Basin-wide tectonic elements and structure at top Permian (Purni Formation) and top Basal Jurassic (Poolowanna Formation) are shown in Figures 4, 5. Both local and regional tectonic elements are shown in Figures 2, 3, respectively, and are discussed below.

McDills Trend / Eringa Trough

The McDills Trend is a northeasterly-trending Palaeozoic ridge that extends for over 100 km, separating the Eringa Trough to the west and the Madigan Trough to the east (Figure 2). It is one of a series of northeasterly-trending anticlinal ridges, bounded by west-side-down, and occasionally by east-side-down reverse faults, all of which display a similar structural history. Other structural ridges in the basin are subparallel to the McDills Trend, but have less vertical displacement. The McDills Trend may have been extensional during the Neoproterozoic and Early Palaeozoic, but compression and wrenching have been dominant, probably since the Middle Ordovician. Compressional tectonism culminated in the Alice Springs Orogeny (Late Ordovician–Early Carboniferous); this was associated with dextral shear and deep-seated flower structures, indicative of wrenching. Major bounding faults were reactivated with tilt reversal at the end of the Early Permian and again at the end of the Triassic (Figures 6, 7). Tilt reversal and differential subsidence changed the prominence of various depocentres, developed west to east across the region. There was also major rejuvenation along the same structural trends during the Late Cretaceous and Tertiary.

The high point on the McDills Trend occurs at the Ettingimbra-1 location and the Permian succession thickens from this point to about 1000 m to the south in Mount Hammersley-1. The ridge plunges gently to the north from Ettingimbra-1 into the western Madigan Trough, before a major plunge reversal occurs where it meets the Hale River High, which is largely bald of Permian strata. East of the McDills High is a complementary elongate depocentre named the Eringa Trough. This is a Permo–Carboniferous feature, which was initiated during the final northwest–southeast compressional phase of the Alice Springs Orogeny (Alexander and Carne 1997). The succession contains up to 1000 m of Permian sediments and a probable 300 m Triassic section, neither of which have been penetrated by drilling.
Figure 6. Diagrammatic west–east structural cross-section across the McDills–Ettingimbra Trend.

Figure 7. West–east seismic line 85NT-03, showing structure across the McDills–Ettingimbra Trend.
The structural framework east to west across the McDills Trend is asymmetric and the high was pivotal during Palaeozoic and Mesozoic sedimentation (Figures 6, 7). Permian thickness and depth of burial in the cognate Eringa and Madigan troughs are similar and the characteristic seismic signature of the Purni Formation in both depocentres is indicative of fluvial floodplain and swamp sedimentation (sandstone, shale and coal). Glacial outwash sandstones of the underlying Tirrawarra Sandstone are predicted in the axes of the Eringa and Madigan troughs, along with onlap onto the margins of the McDills Trend. Significantly, the Purni Formation was severely truncated by uplift and erosion on the eastern margin of the McDills Trend at the end of the Early Permian and again at the end of the Triassic. This resulted in the erosion/non deposition of the Triassic succession on the margins of the Madigan Trough. At this time, there was tilting of the basin and subsidence further to the east, accommodating Middle Triassic continental/lacustrine sediments of the Simpson Desert Basin. The Border Trend may have acted as a hinge at this time and also throughout Jurassic deposition (Questa 1990).

Hale River High / Madigan Trough

The Madigan Trough is a saucer shaped depocentre containing over 1000 m of Permo–Triassic sediments (Figures 4, 5). It is bound to the north by the Hale River Fault Zone which comprises a series of northwest-trending, down-to-basin normal faults, denoting the edge of the Hale River High, which is largely bald of Permian and Triassic sediments. Based on a new interpretation of the Hale River-1 logs, this fault zone also defines the northern limit of cycle 1 of the Poolowanna Formation. These northwest-trending faults are displaced by several hundred feet at the near-top Poolowanna level and their structural grain is contiguous with Precambrian basement trends in the Arunta Province to the north.

Poolowanna Trough / Colson Trend / Thomas Trend

The Poolowanna Trough is a major Triassic–Jurassic–Cretaceous depocentre, which formed in response to easterly epeirogenic tilt and subsidence, after Early Permian sedimentation (Figures 4, 5). In the Northern Territory, this trough comprises several elongate depocentres, segmented by several Palaeozoic ridges extending into its northern reaches. These are the Thomas Trend, the Colson Trend and the Erabena Trend, all of which are defined by north-trending reverse faults downthrown to the east.

Summary of structural history

1. Marine forearc and foreland basin sediments were deposited in the Cambro–Ordovician (Warburton and Amadeus Basin equivalents). Compression probably began in the Middle Ordovician.
2. Compression and foreland basin development occurred during the Middle Devonian–Early Carboniferous Alice Springs Orogeny.
3. Epeirogenic downwarping in the Late Carboniferous to Early Permian was associated with deposition of glaciogene and floodplain-swamp deposits.
4. Mild orogeny occurred at the end of the Early Permian; this was accompanied by tilting of the basin to the east and was followed by deposition of Middle Triassic continental sediments. The Poolowanna Trough was the main depocentre. Purni Formation strata were eroded from the flanks of the major highs, e.g. the McDills Trend.
5. Uplift and erosion occurred in the Late Triassic, as pre-existing structures were rejuvenated. An important thermal event occurred at this time.
6. Cyclic sedimentation affected the basal Jurassic succession and separate reservoir–seal couplets onlapped the underlying topography. Epeirogenic downwarp followed during deposition of Eromanga Basin strata and regional basin tilt was to the southeast. The main locus of sedimentation occurred in the Poolowanna Trough. Drape and compaction occurred over older Palaeozoic highs with associated structural growth recognised in the Jurassic to Early Cretaceous.
7. Rapid burial of the Eromanga Basin occurred during the Cretaceous, with maintenance of a regional southeasterly basin tilt.
8. Sedimentation was terminated in the Late Cretaceous by uplift, weathering and erosion during east–west compression prior to the Palaeocene.
9. During the Oligocene, major uplift and folding affected the Eocene Cordillo Silcrete. Later in the Tertiary, there was tilting and folding of Miocene silcrete, as recorded in South Australia. Further structural rejuvenation occurred during the Pleistocene to Recent.

STRATIGRAPHY AND GEOLOGICAL HISTORY

PRE-PERMIAN

The earliest sediments in the area are a succession of Neoproterozoic to Late Devonian intracratonic sediments of the Amadeus/Warburton basins. These strata occur extensively in the subsurface and onlap Mesoproterozoic gneiss, amphibolite and granite of the Musgrave Province; they are discussed in more detail by Questa (1990). The overlying cover successions are described below and the stratigraphy is summarised in Figure 8. The regional geology is summarised in five structural and stratigraphic cross-sections (Figures 6, 7, 9, 10, 11).
Figure 8. Stratigraphy of the Pedirka/Simpson Desert/Eromanga basins.

**Permian Sedimentation (Pedirka Basin)**

The Pedirka Basin and its associated depocentres, the Eringa and Madigan troughs and the northwestern Poolowanna Trough, date back to the Alice Springs Orogeny (Late Devonian–Early Carboniferous). The Permo–Carboniferous record is dominated by widespread glaciation and basal diamictites (Crown Point Formation), which were previously thought to be disconformably overlain by intracratonic sediments of the Early Permian Purni Formation (Youngs 1975). However, this interpretation recognises regional development of glacial outwash sandstones at the base of the Purni Formation (ie lower Patchawarra Formation equivalent), which are believed to be equivalent to the Tirrawarra Sandstone of the Cooper Basin. Thus the equivalent of the highly productive lower Patchawarra/Tirrawarra Sandstone petroleum system of the Cooper Basin can be shown to be widespread in the Pedirka Basin (**Figure 5**). An important reference section occurs in Mount Hammersly-1 in South Australia, which includes the Purni Formation (286 m), the Tirrawarra Sandstone (197 m) and the Crown Point Formation (504 m; **Figure 10**).
The basal Permian unit, the Crown Point Formation, is a dominantly glacial succession, comprising extensive diamicite, glacial-fluvial outwash, ripple laminated sandstone and siltstone, together with thick shale and varved successions. Coarse sandstone, conglomerate and diamicite are common around palaeohighs, whereas basinal areas focused shale and varved sedimentation. The succession is thickest in the Eringa Trough and 701 m of clean sandstone and siltstone was encountered in Mount Hammersley-1; these are believed to represent glacio-lacustrine deposits.

**Purni Formation / Tirrawarra Sandstone equivalent**

The Purni Formation conformably overlies the Crown Point Formation, being a depositional continuum following the termination of glaciation in Sakmarian time. Youngs (1975) subdivided the Purni Formation at Mokari-1 and Purni-1 into three members with a total maximum thickness of 350 m in Mokari-1 and 286 m in Mount Hammersley-1. The lowest member comprises thinly interbedded sandstone and siltstone, with minor carbonaceous shale and conglomerate. This facies resulted from a predominantly low-energy, meandering-fluvial depositional system. The middle member, which is believed to be both a stratigraphic and depositional facies correlative of the Tirrawarra Sandstone in the Cooper Basin, comprises thick (200 m in Mount Hammersley-1) glacial outwash sandstone, displaying both fining-upward and coarsening-upward GR log motifs. The sandstone is medium-grained to conglomeratic, massive to cross-bedded and kaolinitic, with occasional carbonaceous interbeds (Questa 1990). The upper member consists of paludal/floodplain deposits, comprising very fine- to fine-grained carbonaceous sandstone and interbedded siltstone, shale and coal. This succession is probably thicker than the lower two units combined in the Eringa Trough.
**Triassic Sedimentation (Simpson Desert Basin)**

Triassic sedimentation was preceded by compressional reactivation of older fault systems during the Late Permian–Early Triassic. This formed the structural configuration of the Triassic Simpson Desert Basin, which was a precursor to the later Jurassic–Cretaceous Eromanga Basin. At this time, a regional southeasterly tilt was then imposed and this accommodated Triassic sedimentation in several troughs, the main depocentre being the southern Poolowanna Trough, where at least 300 m of Triassic sediments are preserved.

The Simpson Desert Basin succession lies unconformably on Palaeozoic and Precambrian rocks and, in places, overlaps the Permian Purni Formation. There was probably a time break with the overlying Poolowanna Formation, but this did not entail significant erosion. It is suggested herein, on the basis of new log correlations and limited palynology, that the Walkandi and Peera Peera formations, comprising the Triassic succession in the Simpson Desert Basin, correlate with the Arrabury Sandstone and Tinchoo Formation, respectively, in the Cooper Basin. In both cases, a disconformity is interpreted at the intervening contact.

**Walkandi Formation**

The basal Triassic unit (Walkandi Formation) spans the Early and Early Middle Triassic and was deposited on a peneplaned surface, resulting from erosion at the end of the Early Permian. The succession consists largely of red beds at the base, which, in more basinal sections, grade upward to a slightly carbonaceous shale/siltstone succession. The thickest drilled section occurs in Poolowanna-1 (175 m). To date, exploration drilling has not encountered any significant source or reservoir rocks, but the unit is an important regional seal.

Lithologically, the Walkandi Formation consists of interbedded shale, siltstone and minor sandstone, all varying in colour from grey-green/maroon to brick red. Sandstones are generally very fine-grained to fine-grained, with poor reservoir characteristics. The depositional facies is probably that of a shallow ephemeral lake and cores show evidence of subaerial desiccation and pedogenesis (Moore 1986).

**Peera Peera Formation**

The Middle to Late Triassic Peera Peera Formation was previously thought to be in depositional continuum with the underlying Walkandi Formation. However, Ambrose (in prep) reports an important sequence boundary (?disconformity) at the contact, reflecting a regional drop in the base level of erosion. This new stratigraphic breakdown allows a greater insight into the evolution of the Simpson Desert Basin, especially in regards to the distribution of reservoir, source and seal in the Peera Peera Formation.

The Peera Peera Formation comprises a thick, broadly upward-fining, alluvial/lacustrine succession, up to 220 m thick (Poolowanna Trough). This extends eastward across the Birdsville Track Ridge and north to the Colson–Madigan Trough area, but is absent on the Hale River High. The disconformity at the base of the Peera Peera Formation is marked by an important sequence boundary, represented by a regional sheet sandstone up to 20 m thick. This basal reservoir formed in response to a sharp drop in the base level of erosion, followed by a more gradual rise in base level, responding to rising sea levels to the north and east. This pervasive upward-fining alluvial cycle has regional extent, probably representing the first regional reservoir/seal interface in the Peera Peera Formation.

In more basinal wells, basal sandstone of the Peera Peera Formation is overlain by increasingly fine-grained parasequences. These denote upward-fining alluvial/fluvial cycles in the lower part of the formation. There is a gradation to upward-coarsening parasequences, as the deposition of lake shoreline and deltaic deposits responded to a rising base level of erosion. Relatively thick, carbonaceous lacustrine shales and occasional thin coals cap the cycle on a regional scale and constitute an important regional source/seal. The contact with the Poolowanna Formation is marked by thick braid-plain sandstone in the overlying Poolowanna Formation, which has a characteristic “blocky” log signature.

In the Simpson Desert Basin, a major unconformity exists between the Early Permian Purni Formation and the Early–Middle Triassic Walkandi Formation, but there is no analogous orogenesis recorded in the Cooper Basin. In contrast, in the Cooper Basin, the lower Triassic red bed succession (Arrabury Formation) is in sedimentary continuum with the late Permian Toolachee Formation and its major depocentres are coincident with Permian Troughs (ie, the Nappamerri and Patchawarra troughs; Powis 1989). An important unconformity separates the Arrabury Formation and overlying Tinchoo Formation, which corresponded to a dramatic shift of the Triassic depocentre to the north as this new depositional phase was initiated. The Tinchoo Formation is, in fact, a precursor of the Eromanga Basin depositional regime (Powis 1989). In contrast, in the Simpson Desert Basin, well and seismic data clearly indicate that the Walkandi and Peera Peera Formation depocentres were largely coincident and represent a precursor to the Eromanga Basin regime.
JURASSIC / CRETAKEOUS SEDIMENTATION

Eromanga Basin

Uplift and erosion in the Late Triassic preceded deposition of the Eromanga Basin succession, although the evidence indicates that this was very minor in basinal areas. Regionally, this succession comprises laterally continuous sheet sandstones of fluvial origin (Hutton Sandstone, Adori Sandstone, Namur/Hooray Sandstone), with intervening overbank and lacustrine–swamp deposits, viz Poolowanna Formation, Birkhead Formation, Westbourne Formation and Murta Member of the Hooray Sandstone. These pervasive shaly units provide source and seal to varying degrees throughout the Eromanga Basin, but only the Poolowanna and Birkhead formations occur in the Pedirka area, and then intermittently.

In the Eromanga Basin, cyclical deposition of erosive sheet sandstones, each reflecting a rapid drop in the base level of erosion, relate to a fall in sea level to the northeast, and the basal contacts represent subtle disconformities. In a general sense, the intervening shales are of continental origin and reflect landward ponding of drainage lines responding to transgressive marine events to the northeast, in the area of the Carpentaria Basin. However, over much of the Pedirka area, the Jurassic Algebuckina Sandstone is dominant and represents a condensed, sand-prone fluvial succession, laterally equivalent to the Poolowanna/Hutton/Birkhead/Adori/Namur/Westbourne/Hooray/Murta/Cadnaowie sections that occur in deeper South Australian and Queensland portions of the basin.

In the Eromanga Basin, the basal Jurassic Poolowanna Formation is an important target for hydrocarbons. In the Northern Territory, this unit can be divided into two stacked upward-fining cycles, each being 50–100 m in thickness (Figures 4, 5, 9, 10). The cycles are pervasive and progressively onlap the basin margins and local palaeo-highs, whereby the uppermost cycle (cycle 2) overlaps the basal cycle 1. The base of each cycle is marked by stacked channel sandstones of various thicknesses, which fine upward into finer-grained crevasse splay sandstones, which culminate in siltstones and shaly coals, interpreted as overbank facies, which compartmentalise the reservoirs. Both of these cycles fine upward, whereby basal fluvial sandstones reflect a rapid fall in the base level of erosion, and the transition to overbank facies relates to progressive ponding of drainage lines.

It is interpreted that the Poolowanna Formation is disconformably overlain by thick continental sandstone of the Algebuckina Sandstone, which is, in turn, overlain by the marginal-marine Cadna-owie Formation, comprising fine-grained sandstone, siltstone, and claystone, with minor limestone. The onset of full marine conditions during the Early Cretaceous is represented by the Wallumbilla/Toolebuc/Allaru/Mackunda succession. In the Late Cretaceous, non-marine conditions prevailed and the Winton Formation was deposited in a fluvial-floodplain environment. It was during Winton Formation sediment loading that most hydrocarbon generation is believed to have occurred.

HYDROCARBON PROSPECTIVITY

Thick, oil-prone and -mature Early Permian successions (up to 600 m thick) are widespread in the Madigan and Northern Poolowanna troughs. The Triassic Peera Peera Formation is a mixed oil–gas source rock in these depocentres. Above these source intervals, sheet-like Eromanga Basin (Mesozoic) successions offer reservoir/seal configurations. Post-Early Permian and Late Triassic episodes of regional tilting to the southeast dictate that the most deeply buried Permian source rocks occur on the southeastern basin margin, where they are probably in the late stages of oil generation. The Early Permian Purni Formation/Tirrawarra Sandstone source/reservoir couplet is correlated with the prolific Patchawarra/Tirrawarra petroleum system found in the Cooper Basin (see Figure 3).

REGIONAL TECTONIC ELEMENTS

- The main depocentres are the Northern Eringa Trough, Madigan Trough, and northern Poolowanna Trough.
- Prospective Trends: Northern McDills Trend, George Nose, Samuel Nose, Northern Poolowanna Trough, and Colson-1 and Thomas-1 trends.
- Madigan Trough: 600 m of Purni Formation (source rocks are in the oil window).
- Northern Poolowanna Trough: 200–300 m of Purni Formation east of Colson (source rocks are in the oil window).

Summary of structural history

- Late Devonian–Early Carboniferous Alice Springs Orogeny (thrusting and wrenching).
- Early Permian tilting to the southeast.
- Late Triassic uplift and tilting to the southeast.
- Late Cretaceous compression.
- Mid-Tertiary compression.
PETROLEUM SYSTEMS

- A basal Jurassic petroleum system (Poolowanna Formation source) is proven at Poolowanna-1, where there were significant oil recoveries. A limited Triassic petroleum system is also active in this area. Intra Poolowanna reservoirs are the main target.
- The Triassic Peera Peera Formation is a mixed oil–gas petroleum system, which recovered minor gas and condensate in Poolowanna-1.
- An Early Permian (Purni Formation) petroleum system is indicated by the presence of a residual/palaeo-oil column in Colson-1 (Figure 12). The Purni/Tirrawarra Sandstone and Jurassic reservoirs are the main targets.
- The hydrocarbon potential of the Palaeozoic succession is unknown.

Figure 11. Vitrinite reflectance profiles across the Pedirka/ Simpson Desert/ Eromanga Basins. Note southeast tilt of the Permian Basin.

Figure 12. Colson-1, Poolowanna Formation palaeo-oil column. QGF reflects palaeo-oil saturation as does GOI: QGF-E represents current/recent oil saturation, compatible to solvent extraction used by geochemists, but the volatile HC components/contaminants are removed prior to QGF-E analysis. P’GOC and P’OWC refer to palaeo-gas-oil and oil-water contacts. ROWC, residual oil-water contact. RO, residual oil. Arrows indicate current oil migration pathways. Staining and fluorescence cut (Cit) are from well completion report. Hydrocarbon charge history: initially charged with oil and gas (QGF), lost, remnant oil/minor re-charge, oil migration (QGF-E).
Figure 13. Geohistory plot, Madigan Trough. Late Cretaceous sediment loading (Winton Formation) initiated oil from the Purni Formation.

Figure 14. Hydrocarbon generation plot. Madigan Trough. Late Cretaceous sediment loading (Winto Formation) initiated oil expulsion from the Purni Formation. Pre-Tertiary structures are thus the most attractive targets.
Figure 15. Geohistory plot, northern Poolowanna Trough. Late Cretaceous sediment loading (Winton Formation) initiated oil generation from the Purni Formation.

Figure 16. Hydrocarbon generation plot, northern Poolowanna Trough. Oil and gas expulsion from the Purni Formation occurred during late Cretaceous sediment loading. Pre-Tertiary structures are thus the most attractive.
PLAY TYPES

- Primary targets are numerous undrilled four-way dip closures. Those structures displaying pre-Tertiary structural growth are favoured. There are attractive reservoirs in the Early Permian to Jurassic succession, ie the Tirrawarra Sandstone equivalent and Poolowanna Formation.
- Stratigraphic plays occur largely on the flanks of major structural highs applying to the Poolowanna Formation, Peera Peera Formation and Tirrawarra Sandstone equivalent (Figure 17).

![Figure 17](image1.png)

**Figure 17.** Schematic west–east cross-section through the Eringa and northern Poolowanna/Madigan Troughs, showing hydrocarbon migration pathways and potential oil plays.

PERMIAN LEADS AND PROSPECTS

- The Northern Poolowanna Trough and Madigan Trough are Permian oil and gas? kitchens, as indicated by hydrocarbon shows in Colson-1, Thomas-1 and Oolarinna-1. There are numerous undrilled pre-Tertiary 4-way dip closures, some with coincident geochemical anomalies.

![Figure 18](image2.png)

**Figure 18.** VR’ maturity indications and isopach values for the Permian.
JURASSIC LEADS AND PROSPECTS

- Jurassic-sourced oil occurred in Poolowanna-1. Oil charge occurred during the Tertiary in the southern Poolowanna Trough.
- The Jurassic Poolowanna Formation is only marginally mature over most of the area, but some early oil generation may have occurred in the Madigan Trough and northern Poolowanna Trough.

**Figure 19.** VR maturity indications and isopach values for the Jurassic.

MADIGAN TROUGH STRUCTURAL PLAYS (EXAMPLE)

- Structural plays in close proximity to the Permian Madigan Trough source “kitchen” are highly prospective, but require more seismic data.
- Important intersections of northwest- and northeast-trending faults occur north of the Hooray Prospect.
- Hangingwall fault plays, downflank from Hale River-1, would target Poolowanna and Permian sandstones faulted against Palaeozoic rocks. New data indicate that Hale River-1 is bald of Permian sediments, thus facilitating a potential hangingwall fault trap/stratigraphic onlap play on the downthrown side of the Hale River Fault Zone.

SIMPSON PROSPECT

- The Simpson structure is an old Palaeozoic high that shows a marked thinning of the Permian and Jurassic successions (Figures 20, 21, 22). However, the structure does not have the dominant Tertiary reactivation seen in other barren structures (eg Etingimbra-1) and is far closer to the proposed source area.
- Deep-seated Palaeozoic faults control the Simpson structure.
- 20 ms of Jurassic thinning over the structure suggests downflank stratigraphic potential and palaeo-closure.

BASIN ANALOGIES

- Numerous geological analogies with the southern Cooper Basin.
- Early Permian and Jurassic stratigraphy in the Pedirka Basin area is similar to that in the southern Cooper Basin (Patchawarra Trough: Figure 3).
- The Gidgealpa–Merrimelia Trend (southern Cooper Basin) is analogous to the McDills Trend in the Pedirka Basin.
Figure 20. Simpson Prospect near top Poolowanna Formation (TWT), showing the location of seismic lines 87SI-03 (Figure 21) and 87SI-01 (Figure 22).
Figure 21. WSW–ENE trending seismic line 3 over the Simpson Prospect (Line 87SI-03, Simpson Survey 1987).
Figure 22. NNW–SSE trending seismic line 1 over the Simpson Prospect continued (Line 87SI-01, Simpson Survey 1987)
CONCLUSIONS

- The Pedirka area contains prospective oil-mature Permian, Triassic and Jurassic successions in several major depocentres.
- There are only 7 wells and 2500 line km of modern seismic data in an area of 70,000 km².
- A proven Jurassic petroleum system occurs in Poolowanna-1, where there were significant recoveries of oil.
- Permian depocentres (Madigan and Eringa troughs) are untested as potential source ‘kitchens’. There are numerous adjacent, robust structural leads.
- Residual and palaeo-oil columns, recognised in Colson-1, indicate a previously unrecognised active Permian petroleum system.
- There is only one valid structural test (not crestal) at Permian levels. There are numerous undrilled 4-way dip closures.
- The newly recognised Purni/Tirrawarra petroleum system correlates with a prolific similar system in the Cooper Basin.
- Basal Jurassic (Poolowanna Formation) sedimentary cycles onlap Palaeozoic highs and provide attractive stratigraphic plays.
- The Triassic petroleum system which produced gas-to-surface in Poolowanna-1 is subject to an overview of its hydrocarbon potential.

REFERENCES

Prospective area greater than 40 000km²

Limited drilling programs have occurred

Best control north of Lander Trough
INTRODUCTION

The Wiso Basin (Figure 1) is a huge structural downwarp (160,000 km²), lying east of the Davenport Province and north of the Arunta Region. The southernmost depocentres, within the fault-controlled Lander Trough, could be prospective for hydrocarbons. Geophysical data suggest 3000–4500 m of Cambrian to Ordovician sediment within the trough (Figure 2), but little is known of source-rock potential or maturity. Some structuring has been recognised within this area (Figure 3).

Elsewhere, the basin is largely covered by a sheet-like Palaeozoic succession, generally less than 300 m thick. Very little drilling has occurred in the Wiso Basin and the best well control lies immediately north of the Lander Trough.

- The area prospective for hydrocarbons within the Lander Trough is approximately 40,000 km². It is virtually unexplored, except for a modern grid of aeromagnetics, available free-of-charge from NTGS.
- The trough is analogous to the Toko Syncline of the Georgina Basin. It is uncertain whether or not Neoproterozoic rocks are present, but a thick Palaeozoic section could accommodate major source rock successions.
- Basement depth in two major en echelon depocentres within the Lander Trough is estimated at 4500 m and 3000 m. Close analogies with the contiguous Georgina Basin (now largely under application) portend a rare opportunity for greenfield basin exploration.

![Figure 1. Location of the Wiso Basin.](image-url)
Figure 2. Wiso Basin (Lander Trough). Depth–to–basement (m), based on aeromagnetic data.

Figure 3. Schematic south–north cross-section through the Lander Trough (southern Wiso Basin) showing likely stratigraphic relationships and structuring.

- The stratigraphy in these two offset depocentres is unknown, but has potential to include the following petroleum systems:
  a. Ordovician petroleum systems equivalent to the prolific Horn Valley Siltstone of the Amadeus Basin.
  b. Middle Cambrian petroleum systems equivalent to the Arthur Creek/Thorntonia petroleum system of the Georgina Basin.

- Oil, migrating up-dip to more northerly shelf areas of the basin, may have been entrapped in structural plays. Stratigraphic traps are also possible, in the vicinity of palaeo-shorelines.

- Key petroleum systems in the Georgina Basin relate to the Middle Cambrian lower Arthur Creek Formation and the underlying early Middle Cambrian Thorntonia Limestone. An important unconformity separates these two units. This unconformity has regional significance and is present in the Wiso Basin (Figure 4). The NTGS interpret the Montejinni
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**Figure 4.** Stratigraphy of the Wiso Basin.

Limestone/Hooker Creek Formation/Lothari Hill Sandstone package to be equivalent to the Thorntonia Limestone (P Kruse, pers comm.). The sequence is up to 400 m thick and contains foetid black carbonates in part. This sequence is conformably overlain by the Point Wakefield Beds, which is a sequence of shallow marine siltstone/fine-grained sandstone, the thickest intersected section being 41 m in BMR Barrow Creek (Kennewell et al 1977, Questa 1989). This unit probably thickens into the Lander Trough where basinal facies (? petroleum source rocks) may have formed. Future petroleum exploration hinges on the identification of this petroleum system and also that of the Montejinni Limestone.

**CONCLUSION**

The Lander Trough area of the Wiso Basin is completely unexplored. The stratigraphy of the main possible “oil source kitchen” is unknown. The interpreted depth of burial and thermal regime supports oil generation, prior to the Alice Springs Orogeny, given the development of significant source rocks.

**REFERENCES**
