INTRODUCTION and SUMMARY

J.G.G. Morton

Chapter 1

The Officer Basin covers an area of >300 000 km^2 in South Australia and Western Australia; this publication summarises the petroleum potential of the 100 000 km^2 in South Australia (Fig. 1.1).

An industry survey conducted by Morton (1996a) indicated that the petroleum industry in general was unable to make a judgement on the prospectivity of the Officer Basin (as well as the other Cambrian Basins in South Australia). Those representatives that could comment were generally negative in their views, quoting unfavourable economics, lack of geological knowledge, difficulties with land access and poor source quality as the main deterrents to exploration. These views are not shared by all industry members however, and exploration activity in the area is at an all time high, with two licences granted and a third under application (Fig. 1.2). This publication is written specifically for a petroleum industry audience, and aims to dispel some of the myths surrounding the Officer Basin's petroleum potential.

The Officer Basin has close geological affinities with the productive Amadeus Basin in the Northern Territory, and with basins in the former USSR and Oman, both of which host giant oil and gas fields and have proven oil reserves in the order of billions of barrels. Numerous oil shows are known in the Officer Basin from mineral and stratigraphic drillholes, although there has been little on-structure drilling for petroleum targets. Excellent reservoir quality and source are proven. Exploration economics are favourable, even at relatively low oil prices (US$18/bbl), and the area is one where Native Title considerations are not a major issue. The Officer Basin represents one of the last remaining onshore frontier exploration areas where large petroleum discoveries may still be made.

Previous exploration in the Officer Basin has been limited to a few shallow wells (mostly off-structure and drilled for mineral or stratigraphic purposes), a few regional seismic lines, and aeromagnetic and surface mapping by the Government. Petroleum licences have been issued sporadically in the area since 1954, but little modern petroleum exploration has taken place. The reasons for this have been the area's remoteness, previous access restrictions (atomic bomb testing and weapons testing), and perception that little oil will be found in Proterozoic and early Palaeozoic rocks in Australia. The State and Federal Governments have long been involved in geological investigations in the area, and have carried out most of the petroleum orientated exploration, including source rock studies, seismic acquisition, reservoir core analysis, surface mapping, aeromagnetic surveys, and stratigraphic drilling. Less than 7200 km of seismic data have been recorded and only 30 drillholes deeper than 500 m have been drilled; of these only seven had petroleum targets, and only one has subsequently been shown to have been a valid structural test. Exploration commitments for the current licences total $22 million over the next five years, and this effort should begin to validly test the potential of the area.

The natural environment in the Officer Basin is regarded as harsh desert, with low and irregular rainfall, and extremely hot conditions in the summer months. Landforms comprise undulating plains and extensive dunefields (Great Victoria Desert) with vegetation of low open woodlands, deceptively lush in spite of the harsh desert climate, low tablelands with undulating plains covered in rubble, and in the south the Nullarbor Plain, a flat featureless limestone plain. Native vegetation in these latter areas is very sparse and comprises saltbush and grasses only.

There are six parks and reserves in the region, all of which allow exploration access except for the Unnamed Conservation Park on the western State border, and the Nullarbor National Park on the southern coastal region. Most of the area is held as Aboriginal land (as a freehold title by a body corporate), the Anangu Pitjantjatjara (AP) in the north and the Maralinga Tjarutja (MT) in the south. In both of these areas, the Aboriginal people have the right to control entry to their lands and seek compensation for disturbance to their ways of life. Industry have successfully negotiated access to these lands for exploration and production. In the case of MT Lands, compensation at the exploration stage is limited to that which would apply to any other landowner in the State, as provided under the Petroleum Act. Some land access restrictions also apply to small areas around the atomic bomb test sites and in the Woomera Prohibited Area (access may be granted by the Department of Defence).

Infrastructure in the region is relatively limited, with the fully sealed Stuart Highway the main road link to Adelaide and Darwin. The Central Australia Railway links to Adelaide, and airstrips suitable for small aircraft are available at several locations. No pipelines cross the Officer Basin, although the Alice Springs–Darwin gas pipeline is 550 km to the north, and the Moomba–Port Bonython liquids pipeline ~600 km to the east. It is likely that a transcontinental pipeline will be built in the next 10–20 years to link the North West Shelf and Timor Sea gas fields with markets in the populated southeastern parts of Australia; this pipeline would most likely cross part of the Officer Basin. Surface water supplies in the area are virtually non-existent and rely on groundwater which is mostly highly saline.

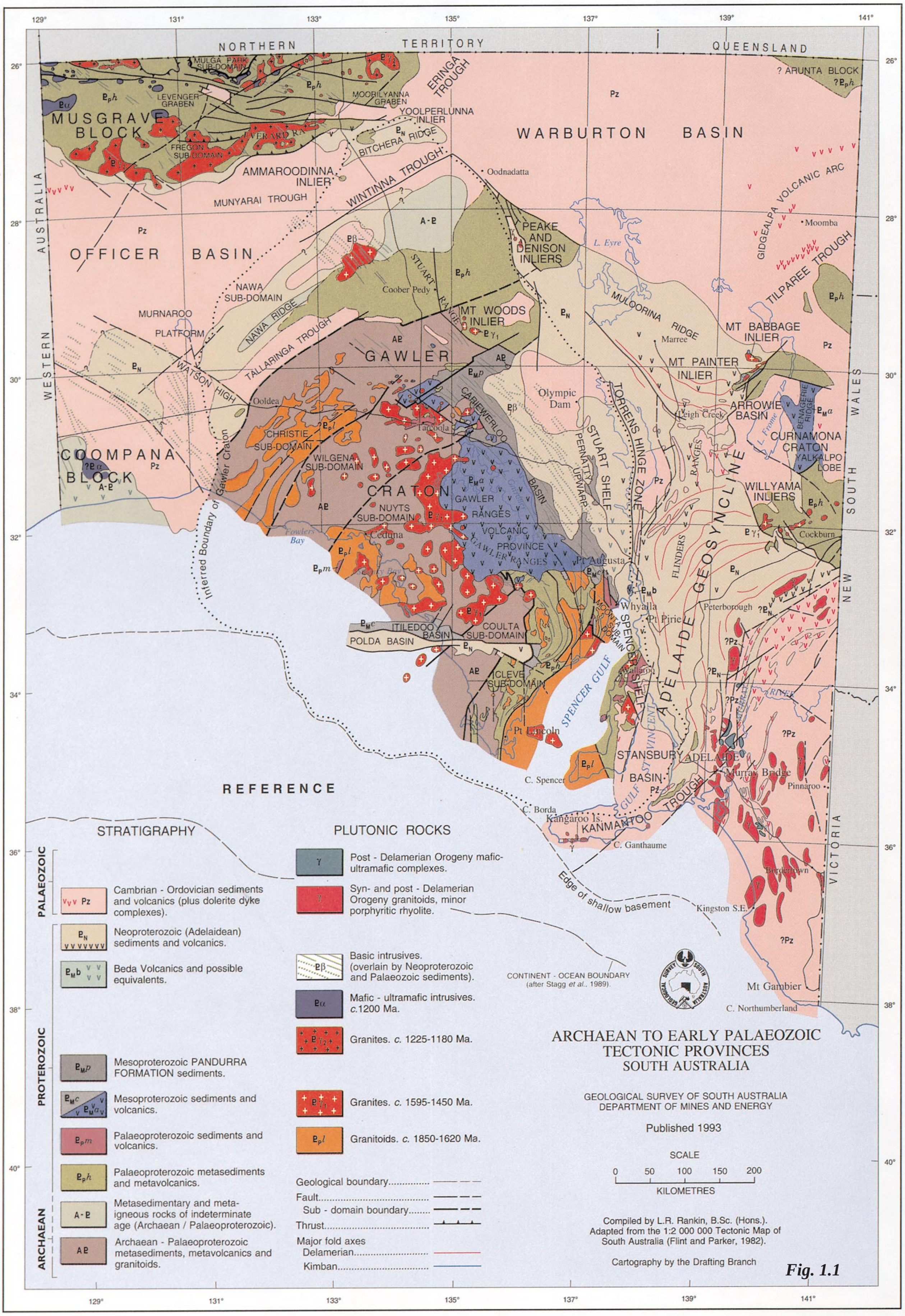
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
NEW SOUTH WALES
VICTORIA
MUSGRAVE BLOCK
MULGA PARK SUB-DOMAIN
LEVENGER GRABEN
FREGON SUB-DOMAIN
EVERARD
MOORILYANNA GRABEN
ERINGA TROUGH
YOOLPERLUNNA INLIER
BITCHERA RIDGE
AMMAROODINNA INLIER
WINTINNA TROUGH
MUNYARAI TROUGH
WARBURTON BASIN
? ARUNTA BLOCK
GIDGEALPA VOLCANIC ARC
TILPAREE TROUGH
Moomba
Oodnadatta
OFFICER BASIN
PEAKE AND DENISON INLIERS
L. Eyre
NAWA SUB-DOMAIN
NAWA RIDGE
Coober Pedy
STUART RANGE
MT WOODS INLIER
MULGARINA RIDGE
Marree
MT BABBAGE INLIER
MURNAROO PLATFORM
TALLARINGA TROUGH
WATSON HIGH
GAWLER
MT PAINTER INLIER
Olympic Dam
Ooldea
CARIEWERLOO BASIN
Tarcoola
TORRENS HINGE ZONE
STUART SHELF
PERNATTY UPWARP
Leigh Creek
ARROWIE BASIN
BENAGERIE RIDGE
CURNAMONA CRATON
YALKALPO LOBE
WILLYAMA INLIERS
COOMPANA BLOCK
CHRISTIE SUB-DOMAIN
WILGENA SUB-DOMAIN
CRATON
NUYTS SUB-DOMAIN
GAWLER RANGES VOLCANIC PROVINCE
FLINDERS RANGES
ADELAIDE GEOSYNCLINE
Inferred Boundary of Gawler Craton
Ceduna
Fowlers Bay
Pt Augusta
Cockburn
Whyalla
Pt Pirie
Peterborough
ITILEDOO BASIN
POLDA BASIN
COULTA SUB-DOMAIN
MOONTA SUB-DOMAIN
SPENCER SHELF
CLEVE SUB-DOMAIN
SPENCER GULF
Pt Lincoln
C. Spencer
STANSBURY BASIN
ADELAIDE
Murray Bridge
Pinnaroo
GULF ST VINCENT
KANMANTOO TROUGH
C. Borda
Kangaroo Is.
C. Gantheaume
Bordertown
Kingston S.E.
Edge of shallow basement
CONTINENT - OCEAN BOUNDARY (after Stagg et al., 1989).
Mt Gambier
C. Northumberland
REFERENCE
STRATIGRAPHY
PALAEOZOIC
Cambrian - Ordovician sediments and volcanics (plus dolerite dyke complexes).
PROTEROZOIC
Neoproterozoic (Adelaidean) sediments and volcanics.
Beda Volcanics and possible equivalents.
Mesoproterozoic PANDURRA FORMATION sediments.
Mesoproterozoic sediments and volcanics.
Palaeoproterozoic sediments and volcanics.
Palaeoproterozoic metasediments and metavolcanics.
Metasedimentary and meta-igneous rocks of indeterminate age (Archaean / Palaeoproterozoic).
ARCHAEAN
Archaean - Palaeoproterozoic metasediments, metavolcanics and granitoids.
PLUTONIC ROCKS
Post - Delamerian Orogeny mafic-ultramafic complexes.
Syn- and post - Delamerian Orogeny granitoids, minor porphyritic rhyolite.
Basic intrusives. (overlain by Neoproterozoic and Palaeozoic sediments).
Mafic - ultramafic intrusives. c.1200 Ma.
Granites. c. 1225-1180 Ma.
Granites. c. 1595-1450 Ma.
Granitoids. c. 1850-1620 Ma.
Geological boundary
Fault
Sub - domain boundary
Thrust
Major fold axes
Delamerian
Kimban
ARCHAEAN TO EARLY PALAEOZOIC TECTONIC PROVINCES SOUTH AUSTRALIA
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA DEPARTMENT OF MINES AND ENERGY
Published 1993
SCALE
0 50 100 150 200
KILOMETRES
Compiled by L.R. Rankin, B.Sc. (Hons.). Adapted from the 1:2 000 000 Tectonic Map of South Australia (Flint and Parker, 1982).
Cartography by the Drafting Branch

Fig. 1.1

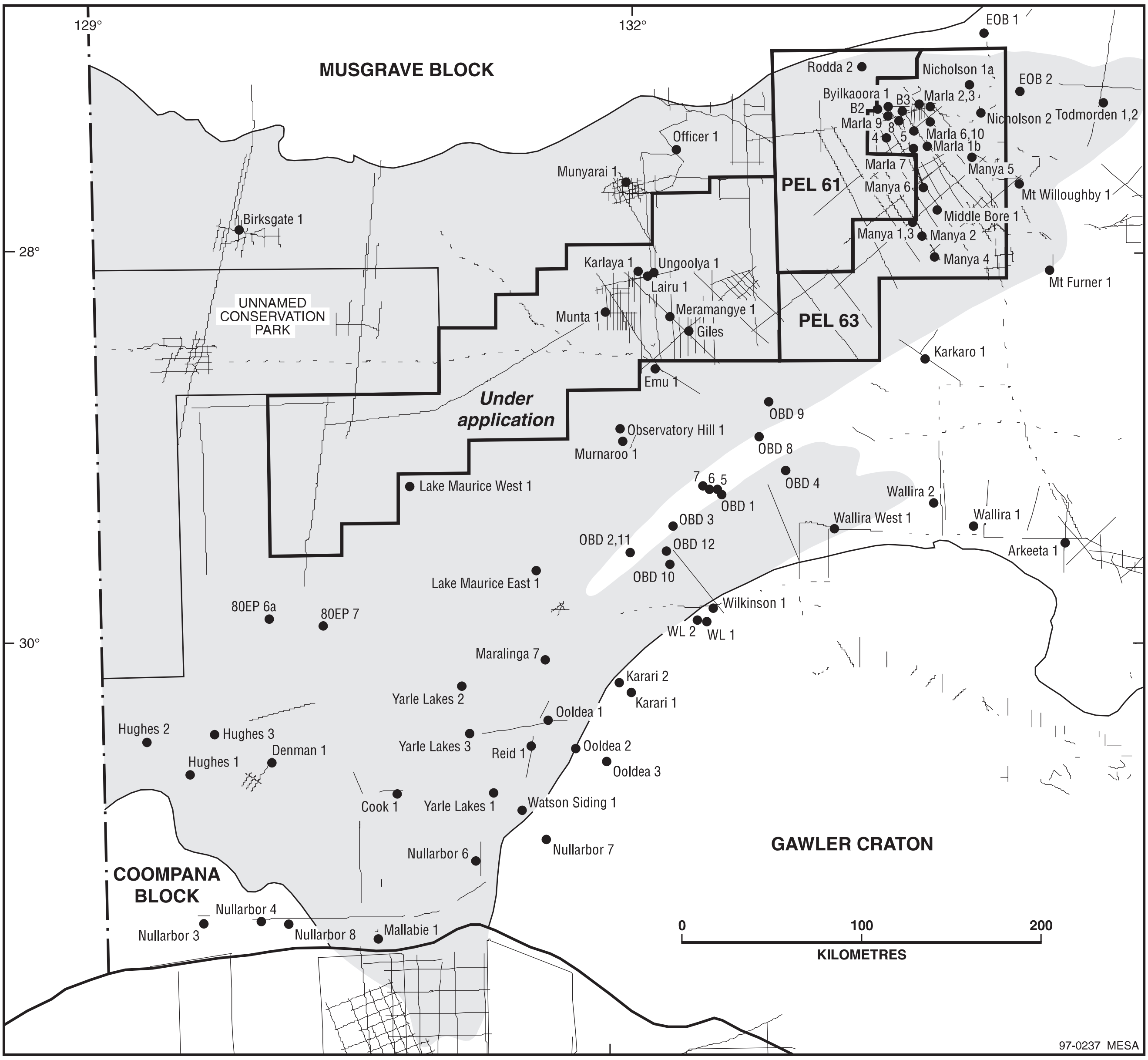

Fig. 1.2 *Well locations and seismic coverage, Officer Basin.*

The basin in South Australia is bounded to the north by the Musgrave Block, to the southwest and southeast by the Coompana Block and Gawler Craton respectively, but is poorly defined to the northeast where it merges with the Warburton and Amadeus Basins and is covered by Arckaringa and Eromanga Basin sediments. Sediments are thickest in the Munyarai Trough, and are abruptly truncated by thrust faults against the southern margin of the Musgrave Block. Thrusting is most clearly seen in the Marla Overthrust Zone. Other significant depocentres are the Tallaringa Trough, Birksgate Sub-basin and Manya Trough. The southern part of the basin, designated the Nullarbor Platform, is poorly known due to Tertiary cover of the Eucla Basin, but is most likely to be Neoproterozoic sediments only.

The structural history of the Officer Basin, from mid-Neoproterozoic to Late Devonian (~820–360 Ma), comprises four stages. Stage 1 (~780–760 Ma) was the development of a Centralian Superbasin which linked the Officer Basin with the other main central Australian Proterozoic to early Palaeozoic basins, and which were also in close proximity to basins with similar geology in North America, Siberia and the Persian Gulf prior to the breakup of the Rodinian Supercontinent. Evaporitic units began to move soon after deposition and were responsible for some of the present structural architecture of the basin. At the end of this stage, ~100–500 m of erosion may have occurred due to glaciogenic processes associated with deposition of the overlying Sturtian tillite. Stage 2 (~560–550 Ma) marked the onset of compressional basin development, deposition of further Neoproterozoic sediments, and culminated in the Petermann Ranges Orogeny with extensive thrust faulting and up to 3000 m of erosion. Stage 3 (~536–507 Ma) comprised Cambrian deposition in elongate troughs (possibly mildly extensional) halted by up to 2000 m of uplift associated with the Delamerian Orogeny. Some reactivation of earlier thrust faulting also occurred at this time. Stage 4 (~500–360 Ma) comprised Ordovician to Devonian deposition as a thick wedge, thickening to the north against the Musgrave Block, and terminated by the Alice Springs Orogeny.

The lithostratigraphy of the basin is still relatively poorly known, due mainly to poor stratigraphic control and a multitude of sedimentary units with similar environments of deposition but of differing ages. The stratigraphy is complex, with at least 26 mappable formations and many members. The formations have been grouped to reflect the structural stages described above. The Callanna Group sediments comprise fluvial and aeolian sandstone (Pindyin Sandstone), and marginal marine evaporitic units (Alinya Formation and Coominaree Dolomite). The intervening Sturtian glacial sequence (Chambers Bluff Tillite) is found only in the northern margin of the basin. Both this and the Callanna Group sequences are terminated by volcanics, also known only from the northern margin of the basin. The overlying Lake Maurice Group comprises fluvio-deltaic to aeolian sediments (Tarlina Sandstone, Meramangye Formation and Murnaroo Formation), which is overlain by the lower Ungoolya Group of more marine origin (Dey Dey Mudstone, Karlaya Limestone, Tanana Formation and Munyarai Formation). The Narana Formation (upper Ungoolya Group) is interpreted to have been deposited as a submarine canyon fill. The basal Cambrian Marla Group comprises the aeolian to marine Relief Sandstone intercalated with the marine Ouldburra Formation. The overlying Observatory Hill Formation has been well studied and records a variety of palaeoenvironments from fluvial to alkaline playa lake. The upper Marla Group comprises shallow marine to fluvial sandstones (Arcoeillinna and Trainor Hill Sandstones) separated by the shallow marine Apamurra Formation. The shallowest sediments of the Officer Basin, separated from the Marla Group by the poorly known Kulyong Formation (volcanics and sands), are the marginal marine Mount Chandler Sandstone, Indulkana Shale and Blue Hills Sandstone of the Munda Group. The youngest unit in the basin is the Devonian non-marine Mimili Formation, restricted to the central Munyarai Trough.

Previously there have been significant problems associated with a lack of biostratigraphic correlation tools for the largely non-marine and Precambrian succession in the Officer Basin. This has recently been dramatically altered by the demonstration of abundant acritarchs in the more marine parts of the sequence and establishment of five preliminary acritarch assemblages that can be used for Proterozoic well to well correlations. Other biostratigraphic tools that have been or may be used in the basin are stromatolites, marine invertebrates and trace fossils. Other techniques, such as geochronology, magneto- and chemostratigraphy, and event- and lithostratigraphy, have also proven useful for regional correlation.

The Officer Basin has undoubtedly sourced oil as evidenced from the oil shows recorded, some of which have been proven from biomarkers to have derived from Neoproterozoic sources. Potential source rocks appear to be quite organically lean on average, but this is largely due to conventional sampling techniques not being suitable for the cyanobacterial mat source prevalent in the Officer Basin, where the source lithologies occur as thin laminae in a lean matrix. In the Siberian Platform, the source for the prolific oil and gas fields is believed to average only 0.3% Total Organic Carbon (TOC) and is of similar cyanobacterial origin. The main source rock formations in the Officer Basin (Alinya Formation, Dey Dey Mudstone, Karlaya Limestone, Ouldburra Formation and Observatory Hill Formation) have average TOC between 0.2 and 0.42%, but locally may range up to 4.6%. Kerogen type is generally oil prone Type I to III, and maximum genetic potentials range from 0.91 to 7.34 kg hydrocarbon per tonne of source rock.

Maturity of the Officer Basin sediments cannot be derived using conventional vitrinite reflectance measurements due to lack of land plant material in pre-Devonian rocks. Instead, the distribution of triaromatic hydrocarbons (methylphenanthrene index — MPI) extracted from source rocks and oil shows can be used and calculated as an equivalent vitrinite reflectance (VR_{calc}). The source rocks in the Officer Basin are thermally mature, with large areas of both the Proterozoic and Cambrian source formations being within the present-day oil window (VR_{calc} = 0.65–1.0), although some areas of the Munyarai Trough, Marla Overthrust Zone and Manya Trough appear to be over mature. There are difficulties in modelling maturity for the Officer Basin wells due to inadequate temperature, maturity and kinetic data. The Ouldburra Formation in the Manya Trough is calculated to have entered the oil window between 510 and 370 Ma, and entered the dry gas window at 315 Ma, where it remains at present. On the Ammaroodinna Ridge, the Precambrian succession entered the oil window at 570 Ma (and is still within it), and the Dey Dey Mudstone and Karlaya Limestone are presently just within it. In the Marla Overthrust Zone, the Dey Dey Mudstone and Karlaya Limestone entered the oil window at ~570 Ma and the wet gas window at 550 Ma. In contrast, the Observatory Hill Formation entered the oil window at 450 Ma, where it remains.

At least eight reservoir horizons have been identified in the Officer Basin, nearly all of which are fluvial or aeolian arkosic sandstones with secondary porosity. Reservoir thicknesses are generally in the range 100–400 m, with the exception of multiple sandstone reservoirs in the Ouldburra Formation which average 4 m, but cumulatively may reach 100 m in individual wells. Carbonate reservoirs with vuggy porosity are also known from the Ouldburra. Core analysis of the sandstone reservoirs indicate excellent characteristics, with average porosities in the range 10--25% and permeabilities up to 8000 md. The sands are generally clean with low clay content. It is considered that there is low risk associated with reservoirs or seals in the Officer Basin.

There have been few valid tests of the variety of compressional structural traps that have been identified in the Officer Basin. Trap types consist of foreland and detached thrusts (including trapdoor structures), tilted fault blocks (associated with salt withdrawal) and salt walls, domes, etc. Potential also exists for subcrop unconformity traps, stratigraphic traps and palaeo-relief associated with submarine canyon cutting. Potential volumes of typical traps are very large, up to billions of barrels, and the smallest are of the order of several hundred million barrels (unrisked oil in place).

Exploration and production economics have been modelled to quantify the minimum prospect size that could be targeted by potential explorers. This model accounted for both exploration expenditure prior to discovery (dry holes, exploration seismic, etc.) and development capital and operating expenditures; a 12.5% real discount rate was used. At an oil price of ~US$25/bbl, a 5 million barrel (800 000 kL) oil in place field would be economic to produce and explore for, provided that the field was discovered within the initial five-year term of a PEL. If the oil price were US$18/bbl, the minimum economic field size would be 10 million barrels (1.59 million kilolitres) oil in place. In both these scenarios, oil would be trucked to market. If a larger field was discovered (50 million barrels (7.9 million kilolitres)), then construction of a pipeline to Port Bonython would be economic.

The undiscovered resource potential of the basin has been assessed using Monte Carlo techniques, with a 50% probability of exceeding 500 million kilolitres (3 billion barrels) of recoverable oil. The range of estimates was a 90% probability of exceeding 260 million kilolitres (1.6 billion barrels) to a 10% chance of exceeding 744 million kilolitres (4.7 billion barrels). While this assessment may appear to be unrealistically large, other Precambrian and Cambrian petroleum basins (with which the Officer Basin has significant geological similarities) in the USSR (Moscow Basin and Lena-Tunguska Province), China and Oman have potential oil reserves up to 16 billion barrels. Six main reservoir plays (Pindyin Sandstone, Tarlina Sandstone, Murnaroo Formation, Relief Sandstone, sands of the Ouldburra Formation and the Arcoeillinna Sandstone) were assessed using relatively conservative input parameters, such as a wildcat success rate of 1 in 10 wells, gross reservoir thickness of 16 to 100 m, net to gross ratios of 35–87%, and reservoir porosities of 12–18%. The potentially productive area for each play is mapped using all available data on source rock distribution, maturity, reservoir distribution and probable depths to targets.

Abbreviations used in this text are summarised in Appendix 1.1.