

RECORD 2025/3

# SUMMARIES OF MAJOR NEOPROTEROZOIC AND PHANEROZOIC BASINS PROSPECTIVE FOR ENERGY- RELATED COMMODITIES, WESTERN AUSTRALIA

AJ MORY AND PW HAINES







Department of **Energy, Mines,  
Industry Regulation and Safety**

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PERTH 2025



**Geological Survey of  
Western Australia**

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**Cover image** Lower Permian Poole Sandstone overlying the Grant Group in mid-distance at the centre of the Saint George Ranges Anticline, Fitzroy Trough, northern Canning Basin. View looking southeast at from Mount Tuckfield at the west end of Carolyn Valley, Saint George Ranges, 90 km southwest of Fitzroy Crossing

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# Summaries of major Neoproterozoic and Phanerozoic basins prospective for energy-related commodities, Western Australia

compiled by AJ Mory and PW Haines

## Abstract

Western Australia's onshore Neoproterozoic and Phanerozoic basins cover just over 40% of the State's 2 500 000 km<sup>2</sup> onshore extent. The State's jurisdiction extends offshore by 3 nautical miles, but the only areas where this is significant are in the Northern Carnarvon Basin between Cape Range and the Barrow – Montebello Islands and a small area within the Browse Basin surrounding Scott Reef. The energy potential of these basins includes petroleum, geothermal energy, natural H<sub>2</sub>, He, CO<sub>2</sub> sequestration and temporary underground storage of hydrocarbon gas and manufactured H<sub>2</sub>. Of these only the conventional petroleum prospectivity is well understood although, in the case of temporary underground storage, two depleted gas fields have been redeployed to enable flexibility in supplying gas to the south-west of the State.

**KEYWORDS:** Phanerozoic, Neoproterozoic, sedimentary basins, Western Australia, State jurisdiction, prospectivity, hydrocarbons, geothermal energy, natural H<sub>2</sub>, He, CO<sub>2</sub> sequestration, underground storage

## Introduction

Whereas the offshore basins have had high levels of petroleum and gas exploration and production, there have been considerably fewer investigations of geothermal energy, with onshore exploration markedly less than offshore. Nearly all basins (Fig. 1), both onshore and offshore, have significant potential for storage or geosequestration, but geothermal energy is generally considered viable only onshore. These summaries exclude coal and uranium for which reviews can be found in Mory (2017, 2023).

Five basins within Western Australia's jurisdiction, which extends into adjacent coastal waters, contain petroleum fields: the Northern Carnarvon, Browse, Bonaparte, Perth, and Canning Basins (in order of decreasing production plus reserves; see <[www.energy.gov.au/government-priorities/energy-data/australian-petroleum-statistics](http://www.energy.gov.au/government-priorities/energy-data/australian-petroleum-statistics)>). Offshore fields along the North West Shelf dominate production in the region and are mostly in Commonwealth waters, apart from the Northern Carnarvon Basin between Cape Range and the Barrow – Montebello Islands and a small portion of the Browse Basin near Scott Reef which are administered by the State (Fig. 1). Nevertheless, the Perth and Canning Basins have been significant onshore commercial discoveries, both recently and dating back to the 1960s.

The most prospective plays for conventional oil and gas exploration onshore and within coastal waters are in the:

- Mesozoic of the offshore Northern Carnarvon and Browse Basins
- Permian–Jurassic of the northern Perth Basin
- Carboniferous, Permian and Jurassic of the Bonaparte Basin
- Ordovician–Permian of the western Canning Basin.

Only minor hydrocarbon accumulations are known from remote parts of onshore Neoproterozoic and Paleozoic basins. These basins include the Neoproterozoic – lower Cambrian Amadeus, Murraba and Officer Basins (which are part of the Centralian Superbasin) and the chiefly Paleozoic

Southern Carnarvon Basin. The hydrocarbon potential of other Neoproterozoic basins and the Cambrian Ord Basin is low due to excessive burial, the lack of deformation, the uncertain presence of organic material, or the relatively thin sections preserved in the case of the Louisa and Wolfe Basins. Similarly, onshore portions of the Mesozoic Bight Basin and the Cenozoic Eucla Basin have low prospectivity as their thin sedimentary successions had minimal burial and deformation.

The shale gas and shale oil potential in the northern Perth Basin and the Canning Basin has been evaluated using dedicated wells and pilot testing of hydraulic fracture stimulation. However, as of September 2017, there is a ban on hydraulic fracturing in the South West, Peel and Perth Metropolitan areas. That ban has been extended to include the Dampier Peninsula, national parks, towns, and areas within 2 km of gazetted public drinking water source areas. Following the 2017–18 State inquiry into the safety of hydraulic fracturing in Western Australia, this procedure is now allowed only within permits that pre-date 26 November 2018.

Some Western Australian basins are also prospective for He and natural H<sub>2</sub>, although there has been no active exploration specifically targeting these commodities in the State. Historically, analyses for these gases were rarely undertaken, but some gas samples from the northwest Canning Basin have elevated levels of He and H<sub>2</sub>, and H<sub>2</sub> in the Perth Basin.

Exploration for geothermal energy is in its early stages, mostly based on desktop studies. Of the seven geothermal exploration permits awarded in 2023, four are in the Perth Basin, two in the Southern Carnarvon Basin and one in the Canning Basin, but two of these (in the latter two basins) are now pending surrender.

## Note

The compilations of fields and significant shows in exploration wells provided for each basin includes many that

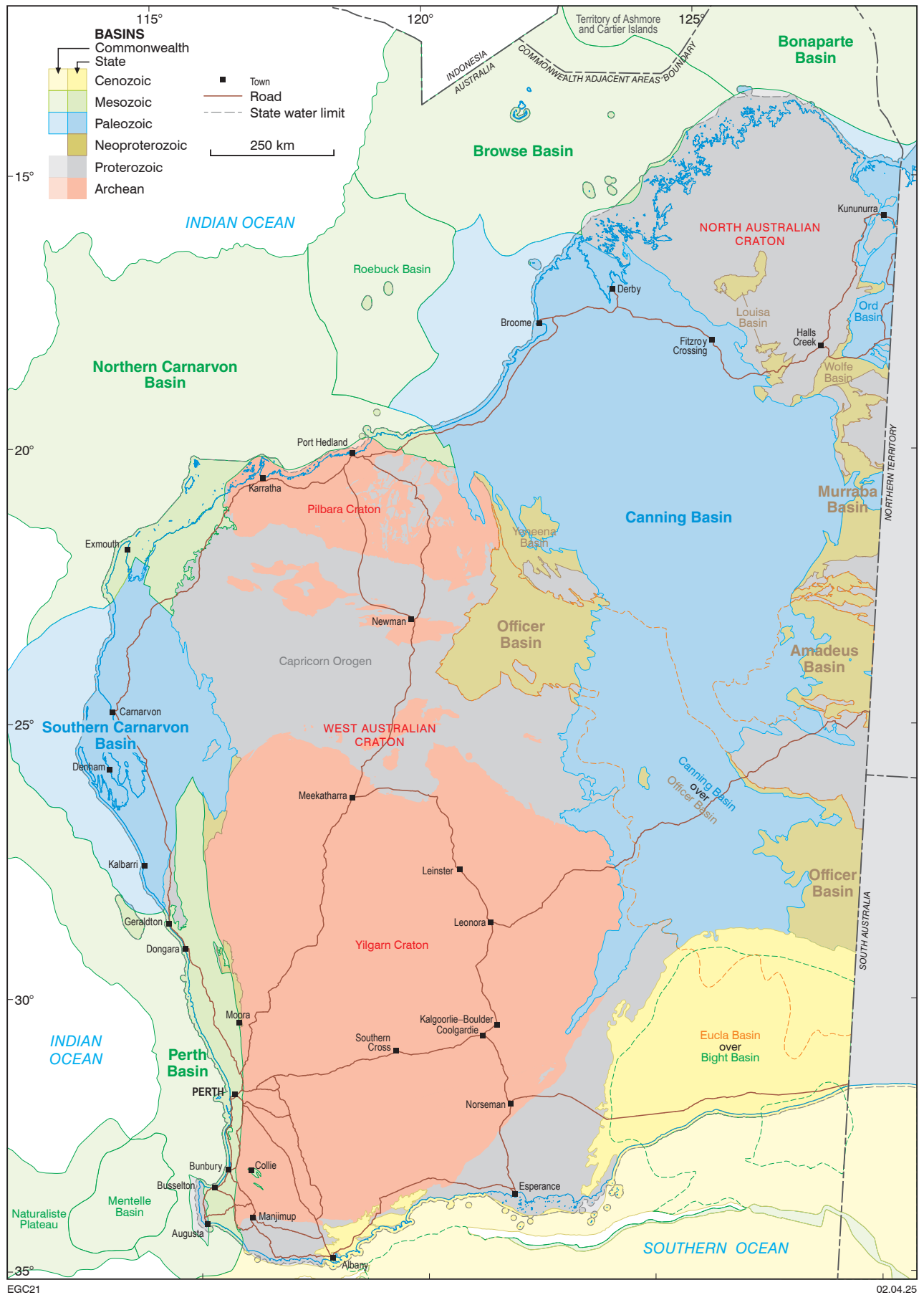


Figure 1. Simplified map of Western Australian basins considered prospective for energy-related commodities



are classified as shut-in, suspended or undeveloped while they await further assessment as to their commerciality. Discoveries classified in this way may be subeconomic – for older such wells the likelihood of development diminishes as newer discoveries are made or as further data are acquired. In addition, once-productive fields that are now shut-in may effectively be depleted. Well counts for each basin exclude sidetracks, deepenings and redrills. Estimates of seismic coverage exclude lines for which there are no navigation reports available. In general, seismic data pre-dating the mid-1960s are too poor to interpret.

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## Amadeus Basin

The Amadeus Basin (Figs 2, 3) covers about 180 000 km<sup>2</sup> in central Australia. Most of the basin lies within the Northern Territory with about 46 000 km<sup>2</sup> extending into Western Australia, including areas beneath the easternmost Canning Basin and outlying structural sub-basins in the north. Only the eastern part of the basin, with existing petroleum industry infrastructure, is well studied.

## Geological setting

The intracratonic basin overlies Paleo- to Mesoproterozoic metamorphic and igneous basement domains of the Warumpi and Aileron Provinces (north) and Musgrave Province (south), and locally contains up to 14 km of Neoproterozoic and Paleozoic sedimentary rocks. It is overlain to the west by upper Paleozoic (Permo-Carboniferous) rocks of the Canning Basin. The present basin margins are mainly of tectonic origin, the Amadeus Basin being one of several remnants of the Centralian Superbasin, a much larger intracratonic depositional system that was progressively fragmented by major convergent tectonic events including the latest Neoproterozoic to earliest Paleozoic Petermann Orogeny, and the mid- to late Paleozoic Alice Springs Orogeny.

## Exploration history

Petroleum exploration in the Amadeus Basin has been almost entirely restricted to the better studied and more accessible Northern Territory portion. The first exploration well was drilled in 1963, with the discovery of the large Mereenie oil and gas field in 1964 and Palm Valley gasfield in 1965. Both fields have been producing since the mid-1980s, with gas transported via pipelines to Alice Springs, and Darwin, and to east coast gas markets. Oil from the Mereenie field was historically transported by pipeline to Alice Springs but is now trucked directly to South Australia. Early exploration focused on prominent surface anticlines, with later exploration targeting seismically defined objectives. Other discoveries include the Dingo gasfield (1981) and Surprise oilfield (2010), and significant shows in other wells. Production from the Dingo gasfield commenced in December 2015, with the gas piped to the Owen Springs Power Station at Alice Springs.

This represents the first commercialisation of Precambrian hydrocarbons in Australia. The Surprise oilfield was in production during 2014–15 but has been shut-in due to low oil prices.

No exploration wells have been drilled in the Western Australian portion of the basin. Early work there included outcrop studies and some shallow stratigraphic drillholes, although the latter were not reported to the Department. Two lines of the 1972 Hickey Hills seismic survey show Amadeus Basin strata beneath thin cover of the Canning Basin; however, the quality of this data is very poor. More recently, Central Petroleum Ltd conducted an airborne gravity survey over SPA 7/04-5 AO, which covers most of the Western Australian part of the basin.

## Prospectivity

Studies of the Northern Territory portion of the Amadeus Basin have identified at least four petroleum systems. The youngest, Larapintine 1 of Ordovician age, is associated with the large producing Palm Valley gasfield and Mereenie oil and gas field, and the smaller shut-in Surprise oilfield. Whereas this system generated significant shows elsewhere across the northern half of the basin, it is not considered prospective in Western Australia because Ordovician strata are thin, preserved only locally, and the Horn Valley Siltstone source appears to be absent. Ongoing exploration in the Northern Territory targets older petroleum systems all related to Neoproterozoic sources such as those associated with the Dingo gasfield and other significant oil and gas shows.

Three Neoproterozoic petroleum systems possibly operate in the Amadeus Basin:

- The oldest system involves gas-prone source rocks in the lower Gillen Formation of the Bitter Springs Group. Sandstone of the underlying Heavitree Formation is the most likely reservoir, whereas a widespread salt unit in the upper Gillen Formation provides a seal. The 'Gillen petroleum system' is noted for its high content of basement-sourced helium, which comprises 6.2% of the gas in Magee 1 and 9% in Jacko Bore 1 (formerly Mt Kitty 1); gas in the latter also included 11% hydrogen.
- The second system involves potential oil-prone source rocks in the upper Bitter Springs Group, and gas-prone intervals in the Wallara and Aralka Formations, plus correlatives within the 'Inindia beds' in the south.
- The third system incorporates source rocks of the shaly Pertatataka Formation with the uppermost Neoproterozoic to Cambrian Arumbera Sandstone as a reservoir.

In the absence of drillhole information, the source and reservoir potential, and maturity of the succession within the Western Australian part of the basin remains speculative. However, the stratigraphy and facies of the western part of the basin have much more in common with the well-studied succession east of the State border than previously thought, thereby raising the possibility that some, or all, of the Neoproterozoic petroleum systems and plays tested in the Northern Territory may be present in Western Australia.

## Suggested reading

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Figure 2. Amadeus Basin tectonic subdivisions, pipelines, fields and selected wells

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Haines, PW and Allen, HJ 2020, World's oldest regional salt seal in the Amadeus and Officer Basins: implications for subsalt helium and hydrocarbons, in GSWA 2020 Extended abstracts: advancing the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2020/2, p. 10–13.

## Bonaparte Basin

The Bonaparte Basin, the most northern sedimentary basin in Western Australia, straddles the Northern Territory – Western Australia border and contains a Paleozoic to Cenozoic sedimentary succession up to 17 km thick (Figs 4, 5). The entirely Paleozoic southern onshore part covers about 20 000 km<sup>2</sup> whereas offshore the overlying Mesozoic succession thickens to the north where the basin covers over 250 000 km<sup>2</sup>, almost entirely under Commonwealth or Northern Territory jurisdiction.

## Geological setting

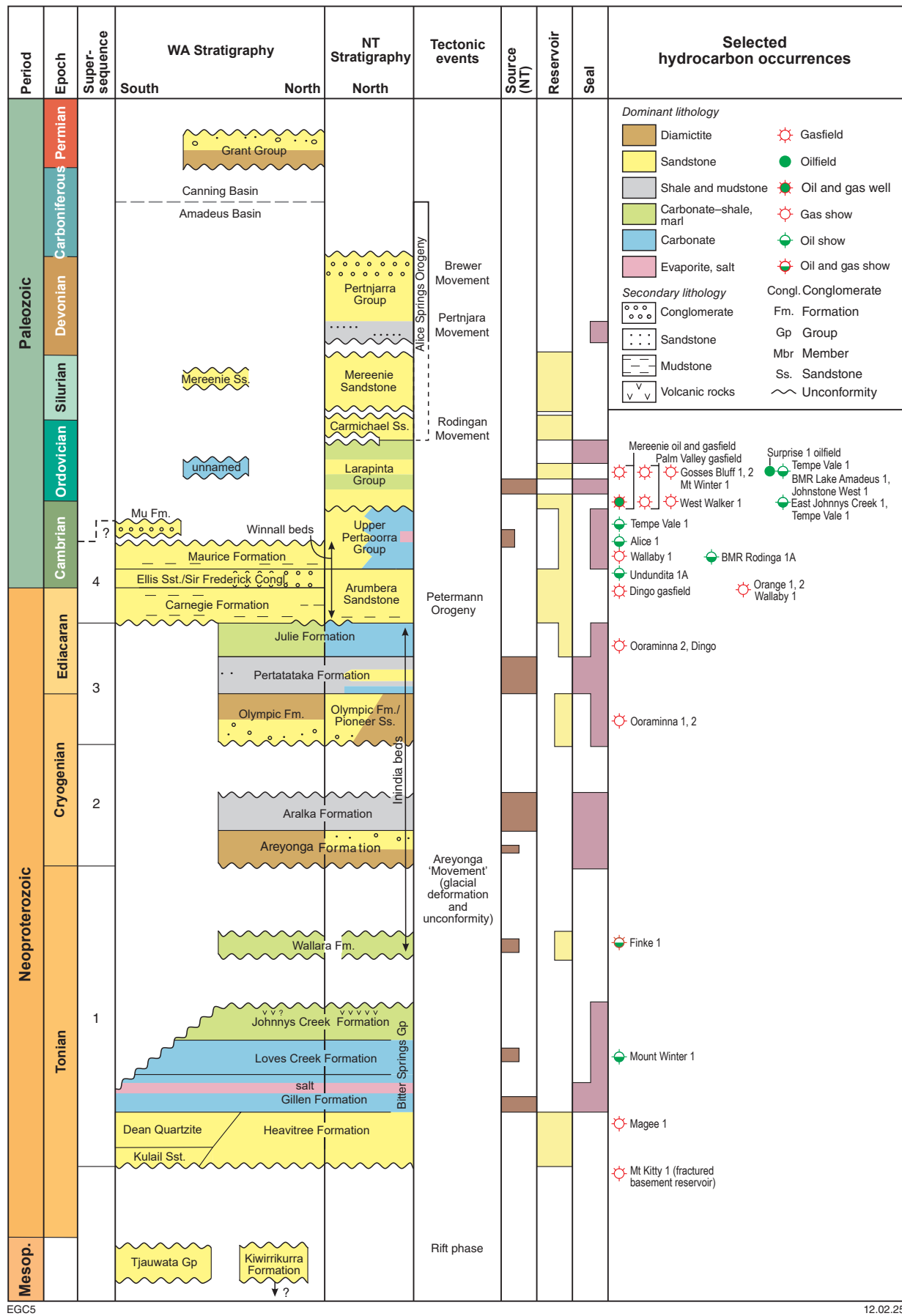
The southern onshore part of the basin onlaps onto, or is faulted against, Proterozoic terranes. The dominant structural element of the southernmost and central offshore

part of the basin is the elongate north-northwesterly trending Petrel Sub-basin that developed as a v-shaped rift during the Devonian to early Carboniferous. Overall, the succession becomes younger to the north, with only Cambrian – lower Permian strata present onshore.

The three main periods of deposition evident onshore are: Cambrian–Ordovician, which is only known onshore; Late Devonian to early Carboniferous, which represents the remnants of a rift system controlled by numerous north-northwesterly oriented normal faults; and late Carboniferous to Permian, when siliciclastic sediments encroached onto the earlier rift blocks and onlapped Proterozoic rocks, forming the flanking shelves. Offshore, salt diapirs disrupt Devonian and younger strata but the age of the evaporitic succession from which they originate is uncertain and seemingly absent onshore.

The northern offshore part of the basin is dominated by northeast-trending fault blocks associated with younger rifting events of which the Late Jurassic breakup event is the most significant. Although no wells reach below the upper Permian, seismic data reveal an even older section and rare salt structures similar to those at the southern end of the Petrel Sub-basin. The north-northwest structural trends in this sub-basin pre-date mid-Permian – Mesozoic rifting along the margin of the Australian Craton, that was close to perpendicular to the structural trends within the northern sub-basins of the basin (the Ashmore and Sahul Platforms, Vulcan Sub-basin, Londonderry High, and Malita Graben). That rifting thereby exerted little structural influence across the Petrel Sub-basin and onshore parts of the basin.

In the Cenozoic, thick shelfal carbonates prograded across the entire western margin of Australia, including the Bonaparte Basin. The mid-Miocene collision with



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Figure 3. Stratigraphy and petroleum systems of the Amadeus Basin



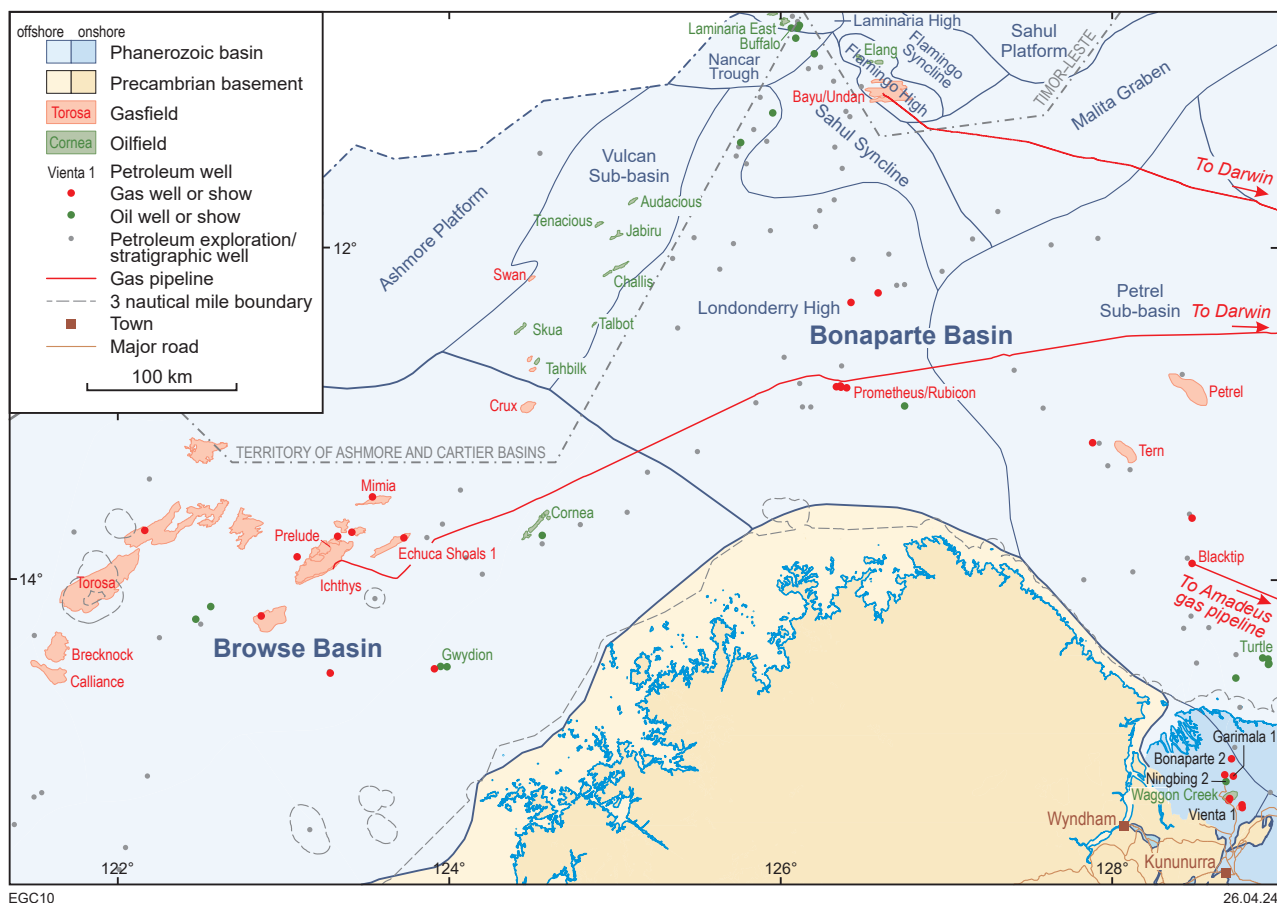


Figure 4. Bonaparte Basin tectonic sub divisions, pipelines, fields and selected wells

the Indonesian Plate to the north rejuvenated faults and produced small anticlines.

## Exploration history

Petroleum exploration of the Bonaparte Basin commenced with onshore reconnaissance of outcrops in the late 1940s. Since the drilling of the first well in the basin, Bonaparte 1 in 1963 in the onshore Western Australian portion of the basin, there have been over 350 offshore wells compared to 15 onshore, of which nine were in Western Australia. In the waters under Commonwealth jurisdiction south of the area ceded to Timor-Leste and the Territory of the Ashmore and Cartier Islands there has been more than 200 000 line km of 2D and 19 000 km<sup>2</sup> of 3D seismic data. By comparison, about 1600 line km of onshore 2D seismic data is available for the Western Australian portion of the basin.

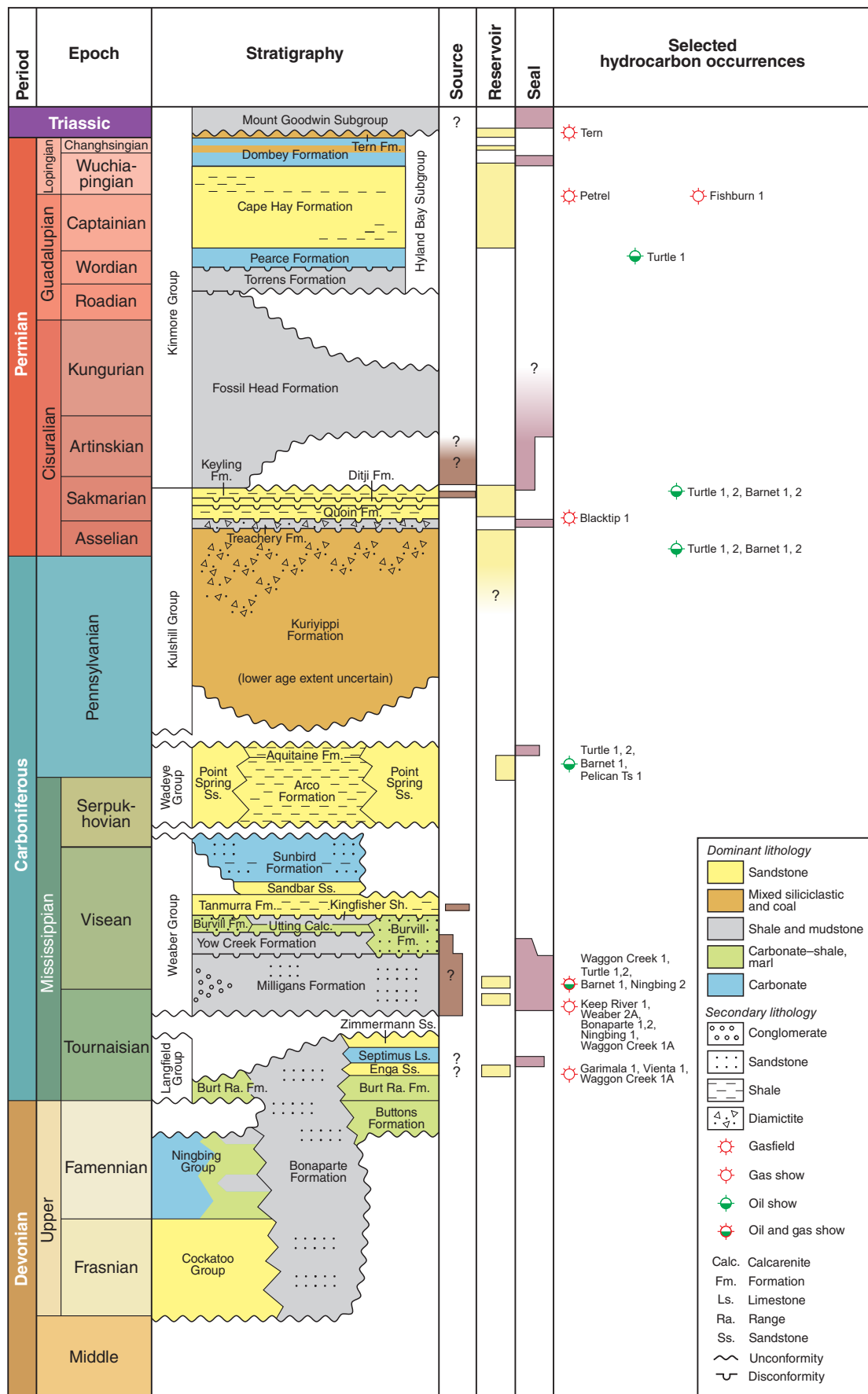
## Prospectivity

Sub-economic onshore gas accumulations (Table 1) indicate the possibility for economic hydrocarbons, but there are no developed fields. In addition, two wells had oil shows, as did many shallow mineral exploration drillholes along the edge of the basin. By comparison, the offshore Bonaparte Basin is highly prospective with over 40 oil and gas fields discovered to date, mostly in the north and northwest of the basin. The southeastern offshore part of the basin has

also yielded several fields such as Blacktip, Petrel and Tern (Fig. 4). The Devonian–Carboniferous sedimentary succession is considered to have generated hydrocarbons from dark shale of the lower Carboniferous Milligans Formation and the Upper Devonian Bonaparte Formation (Fig. 5). Potential shale plays and tight gas plays in the onshore Bonaparte Basin include shale gas from the lower Milligans Formation and tight gas sandstone and limestone reservoirs in the Langfield Group, but such plays remain untested; to date only sandstone reservoirs in Milligans Formation have successfully flowed gas.

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Figure 5. Devonian–Permian stratigraphy and petroleum systems of the southern Bonaparte Basin

**Table 1.** Southern Bonaparte Basin hydrocarbon shows

Year	Discovery	Hydrocarbon type	Reservoir	Age of reservoir
1963–64	Bonaparte 1 and 2	gas show	Milligans Formation	early Carboniferous
1982	Ningbing 1	oil and gas show	Ningbing Group and Bonaparte Formation	Late Devonian
1988	Garimala 1	gas show	Milligans Formation and Bonaparte Formation	early Carboniferous
1995	Waggon Creek 1A	gas and oil show	Milligans Formation	early Carboniferous
1998	Vienta 1	gas show	Milligans Formation and Ningbing Group	Late Devonian to early Carboniferous

## Browse Basin

The Browse Basin covers approximately 223 000 km<sup>2</sup> and lies entirely offshore, north of Broome. It contains an upper Paleozoic to Cenozoic sedimentary section up to 15 km thick. About 1600 km<sup>2</sup> surrounding Scott and Seringapatam Reefs is under State jurisdiction and includes part of the Torosa gasfield and the Zephyros 1 gas discovery.

## Geological setting

The basin borders Phanerozoic basins to the south (Roebuck and Canning) and northeast (Bonaparte), and onlaps onto the Paleoproterozoic Kimberley Basin to the southeast (Fig. 6). The oldest known successions in the basin are upper Carboniferous to lower Permian near the southeastern basin margin, which represent erosional remnants whereas the only other sections older than late Permian known in the basin are within salt diapirs.

The sedimentary succession of the Browse Basin spans a regional late Middle Jurassic unconformity (Fig. 7). The strata below are deeply buried and extensively block faulted. Overlying the breakup unconformity are up to 4000 m of relatively undisturbed Upper Jurassic to Cenozoic marine facies with small faults and anticlines that developed during the late Cenozoic collision of the Australasian and Eurasian plates.

## Exploration history

Exploration commenced in the Browse Basin in 1967 when the first seismic data was acquired. Within the area surrounding Scott Reef there has been about 3100 line km of 2D seismic data recorded, and about half of the area is covered by six partially overlapping 3D surveys. The third well drilled in the basin, Scott Reef 1 (completed in 1971), discovered one of Australia's largest gasfields (renamed Torosa) within the Lower to Middle Jurassic Plover Formation. Since then, over 140 wells have been drilled across the basin yielding over 25 hydrocarbon discoveries including the Ichthys (in 2003) and Prelude (in 2006) gasfields. Discoveries since 2011 include the Bassett West 1, Boreas 1, Crown 1, Lasseter 1, Pharos 1, Poseidon North 1, Proteus 1 and Zephyros 1.

Although the combined gas reserves of the fields in the basin total over 900 Gm<sup>3</sup> (33.4 Tcf), only two have been developed, mainly due to their isolated location in deep waters. Production from Ichthys (operated by Inpex), which

commenced in 2018, is sent to Darwin via the 890 km-long Ichthys Gas Export Pipeline. Prelude (operated by Shell) commenced production in 2018 via a floating liquefied natural gas (FLNG) facility. Development of Woodside's Brecknock, Calliance and Torosa fields has been delayed.

## Prospectivity

A surge in exploration between 2007 and 2014 yielded a highly encouraging hydrocarbon discovery rate. Reservoirs generally lie at depths between 4000 and 5000 m, or between 3000 and 3500 m towards the basin's margin where stratigraphic plays may be effective. Several structures and potential stratigraphic plays remain undrilled in the basin.

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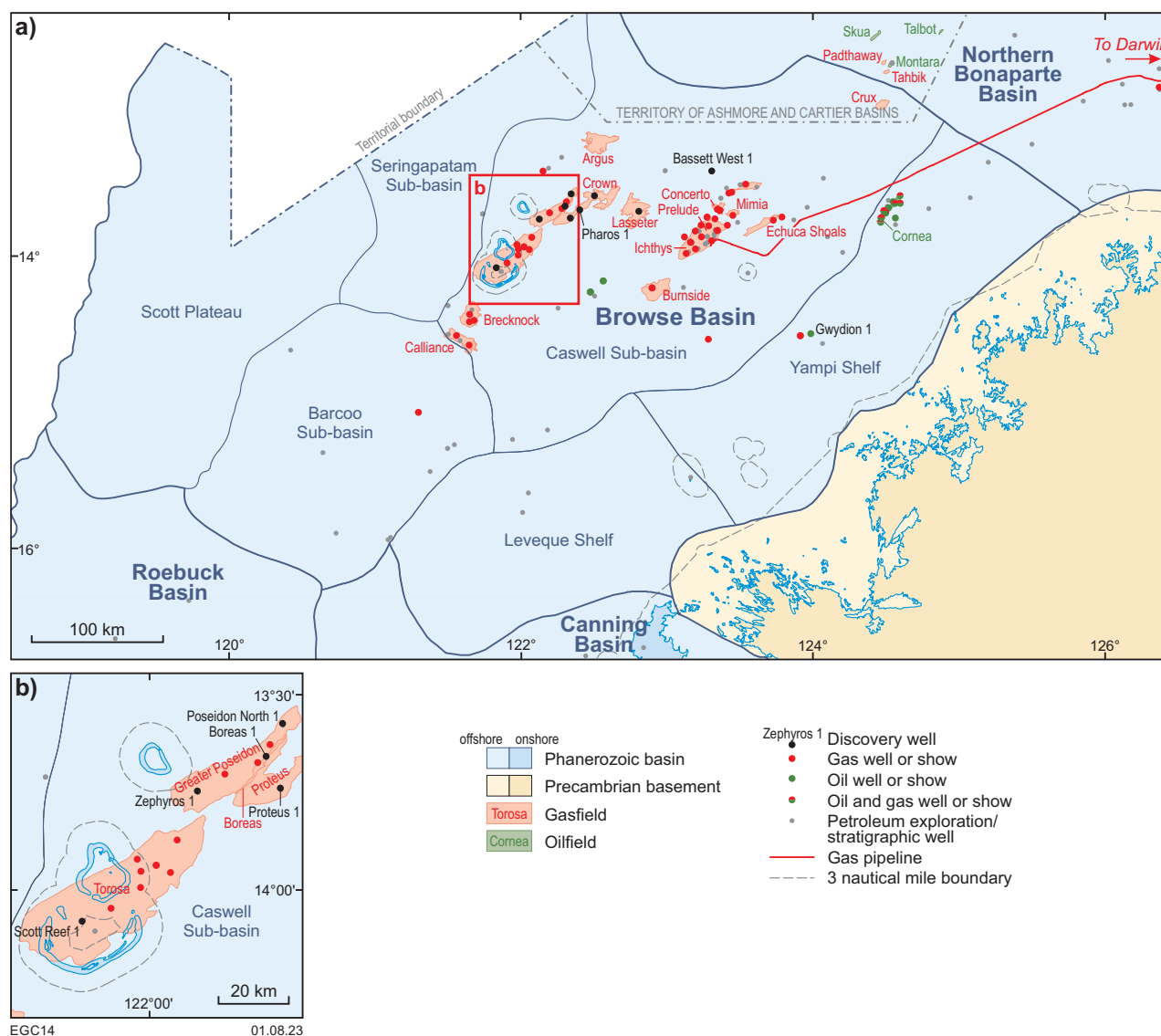


Figure 6. Browse Basin tectonic sub-divisions, pipelines, fields and selected wells

## Canning Basin

The Phanerozoic Canning Basin is the State's largest onshore basin covering over 795 000 km<sup>2</sup> of which about 55 000 km<sup>2</sup> lies offshore (Fig. 8). The bulk of the onshore succession, which is up to 15 km thick, is Paleozoic (Fig. 9). Much of the basin remains underexplored even though petroleum exploration has spanned more than a century.

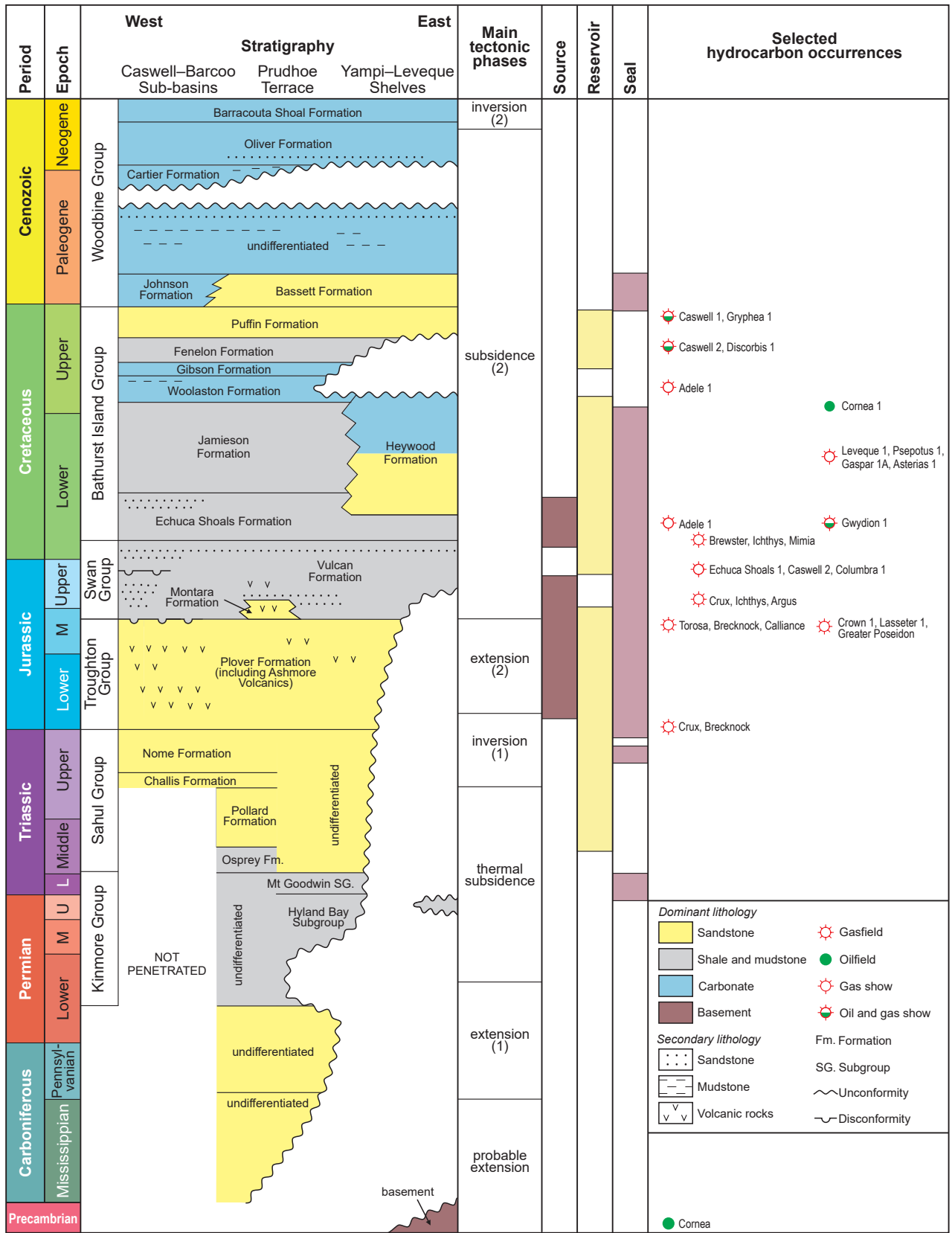
### Geological setting

The Canning Basin developed as an intracratonic sag between the West and North Australian Cratons during the early Paleozoic. The bulk of the sedimentary succession is Ordovician to Middle Triassic, mostly composed of continental to marine carbonate and clastic sedimentary facies, including widespread Upper Ordovician to Silurian evaporitic deposits (Fig. 9). Upper Cambrian sections may be present in depocentres but remain unconfirmed by drilling.

Overlying Jurassic to Cenozoic sedimentary deposits are thin, especially inland from the coast, but thicken markedly offshore towards the Roebuck Basin.

The main phases of significant tectonism producing much of the present structural configuration in the basin developed during:

- possible Cambrian to Silurian extension and rapid subsidence
- Early Devonian compression and erosion (Prices Creek Movement)
- Middle Devonian to early Carboniferous extension and subsidence
- mid-Carboniferous compression (Meda Transpression)
- late Carboniferous to Early Triassic subsidence
- mid-Triassic to mid-Jurassic uplift and erosion (Fitzroy Transpression).



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Figure 7. Stratigraphy and petroleum systems of the Browse Basin

Apart from faulting, those events did not greatly deform strata within the basin making them difficult to differentiate at a local scale. Younger strata are relatively thin, flat lying and only weakly indurated as subsequent structural events, such as the late phases of the breakup of Gondwana, barely affected the basin.

The basin contains a series of mostly west-northwest striking sub-basins (Fig. 8). These tectonic divisions apply chiefly to the succession pre-dating the Meda Transpression; overlying strata show considerably less deformation. The main divisions are:

- Fitzroy Trough – Gregory Sub-basin, a northern Devonian–Triassic depocentre containing a Phanerozoic succession estimated at up to 15 km thick. Strata older than the Devonian may be present but have not been penetrated by drilling;
- Kidson–Willara Sub-basins, a southern Ordovician–Devonian depocentre, which is up to 5 km thick overlain by a thin lower Permian and Mesozoic succession;
- Broome–Crossland Platforms, a central basement high containing an extensive Ordovician–Devonian succession over which thin lower Permian sections are preserved; and
- areas flanking the margins of the basin, onto which pre-Permian strata either abut, thin or pinch out, are designated as structural ‘shelves’. A series of minor grabens and platforms contiguous with the Anketell Shelf fringe the southwestern margin of the basin and grade westwards into a similar shelf along the northern edge of the West Australian Craton; however, identification of these features relies on limited data.

## Exploration history

Petroleum exploration began in the Canning Basin in the early 1920s when the Freney Kimberley Oil Company drilled four shallow wells following reports of oil shows in a water bore on the Lennard Shelf. Minor exploration continued until the 1950s when West Australian Petroleum Pty Ltd (WAPET) carried out regional seismic surveys and drilled 17 wells. Over the 1960s to 1980s exploration intensified, and included regional gravity, magnetic and seismic surveys, and outcrop mapping by the Bureau of Mineral Resources (BMR, now Geoscience Australia). Of the 322 onshore and six offshore (in Commonwealth waters) wells drilled in the basin, 80 were stratigraphic, 222 were new field wildcats and 32 were development or extension wells. Onshore there have been over 360 seismic surveys (totalling almost 92 000 km of 2D lines and six small 3D surveys that cover about 1300 km<sup>2</sup>), with the most concentrated coverage along the southern margin of the Lennard Shelf, southern Fitzroy Trough and adjacent areas. Offshore there have been 70 seismic surveys encompassing just over 100 000 line-km of which some extend into the adjacent Roebuck Basin.

Until the mid-1980s, exploration focused largely on the northern and central parts of the basin, with the primary exploration targets being Devonian, Carboniferous and Permian reservoirs. Whereas many wells encountered shows (particularly oil), few yielded commercial hydrocarbons (Table 2). The basin’s first commercial discovery was in 1981 at Blina on the Lennard Shelf, followed soon after by the Sundown, Lloyd, Boundary, West Terrace and West Kora oilfields, and the Point Torment gas discovery in 1992.

Significant oil and gas shows in sub salt Ordovician plays found during the 1980s and 1990s, such as Looma 1, Pictor 1 and Cudalgarra 1, have yet to lead to production.

A renewed phase of exploration began in 2006 that focused mainly on the Broome Platform, Jurgurra Terrace and Fitzroy Trough, and included the basin’s first 3D seismic survey in 2009. During this phase, renewed drilling led to the recognition of the Laurel Formation basin-centred gas system (BCGS) in 2010 and discovery of the Ungani oilfield in 2011, reservoirised in lower Carboniferous dolomites, both by Buru Energy. More recently, Buru Energy announced the 2021 discovery of the Rafael gas and condensate accumulation in the same reservoir.

## Prospectivity

Ordovician, Devonian and lower Carboniferous petroleum systems are considered the best prospects for liquid hydrocarbons with the latter (mostly the Laurel Formation) having sourced, for example, Devonian carbonate reservoirs of the Blina oilfield and Permo–Carboniferous siliciclastic reservoirs of the Boundary, Lloyd, Sundown, West Kora and West Terrace fields (Table 2). In the Fitzroy Trough lower Carboniferous siliciclastic facies of the Laurel BCGS are also prospective for tight gas. Large parts of the Canning Basin remain poorly explored with relatively few wells drilled in much of the basin. In addition, only a small percentage of wells in the basin were valid structural tests.

Play types are geographically and stratigraphically variable. For example, fracture systems associated with transfer zones connect the Lennard Shelf to the Fitzroy Trough and control migration and permeability within carbonate and siliciclastic reservoirs. In contrast, lower Carboniferous siliciclastics within the Fitzroy Trough provide both source and reservoir for the Laurel BCGS play. The Fitzroy Trough and the sub-basins on its margins have long been considered the most prospective parts of the basin due to their thick sedimentary successions, reefal carbonate buildups and structural development. Shows in these areas confirm petroleum generation and migration. The basin also contains many untested plays such as unconformity, stratigraphic, downthrown rollover, inversion fold and subsalt traps, as well as reservoirs draped over rotated fault blocks.

In the southern Canning Basin there is potential for oil and gas generation from Ordovician carbonaceous shale in the Goldwyer and upper Nambeet Formations. Potential conventional reservoirs include the Ordovician lower Nambeet and Nita Formations, Devonian carbonate and the Tandalgoo Formation, and the Permian Grant Group. In areas that lack major block faulting, salt diapirism may have generated traps. Ordovician subsalt discoveries in the Broome Platform and the Kidson Sub-basin demonstrate that mature, migrated oil from source rocks are present in the south of the basin. The recent drilling of stratigraphic well Barnicarndy 1 on the southwestern margin of the basin discovered a new Ordovician sandstone reservoir (Barnicarndy Formation) overlying thick Nambeet Formation but shales of the latter unit have minimal source potential at this location.

The Ordovician Goldwyer Formation and the Carboniferous Laurel Formation have potential for shale gas and oil with the latter estimated by the US Energy Information Administration in 2013 to contain 11.9 Tm<sup>3</sup> (420 Tcf) gas in place with a risked recoverable resource of 0.53 Tm<sup>3</sup> (18.9 Tcf). Whereas estimates of the former by US Energy



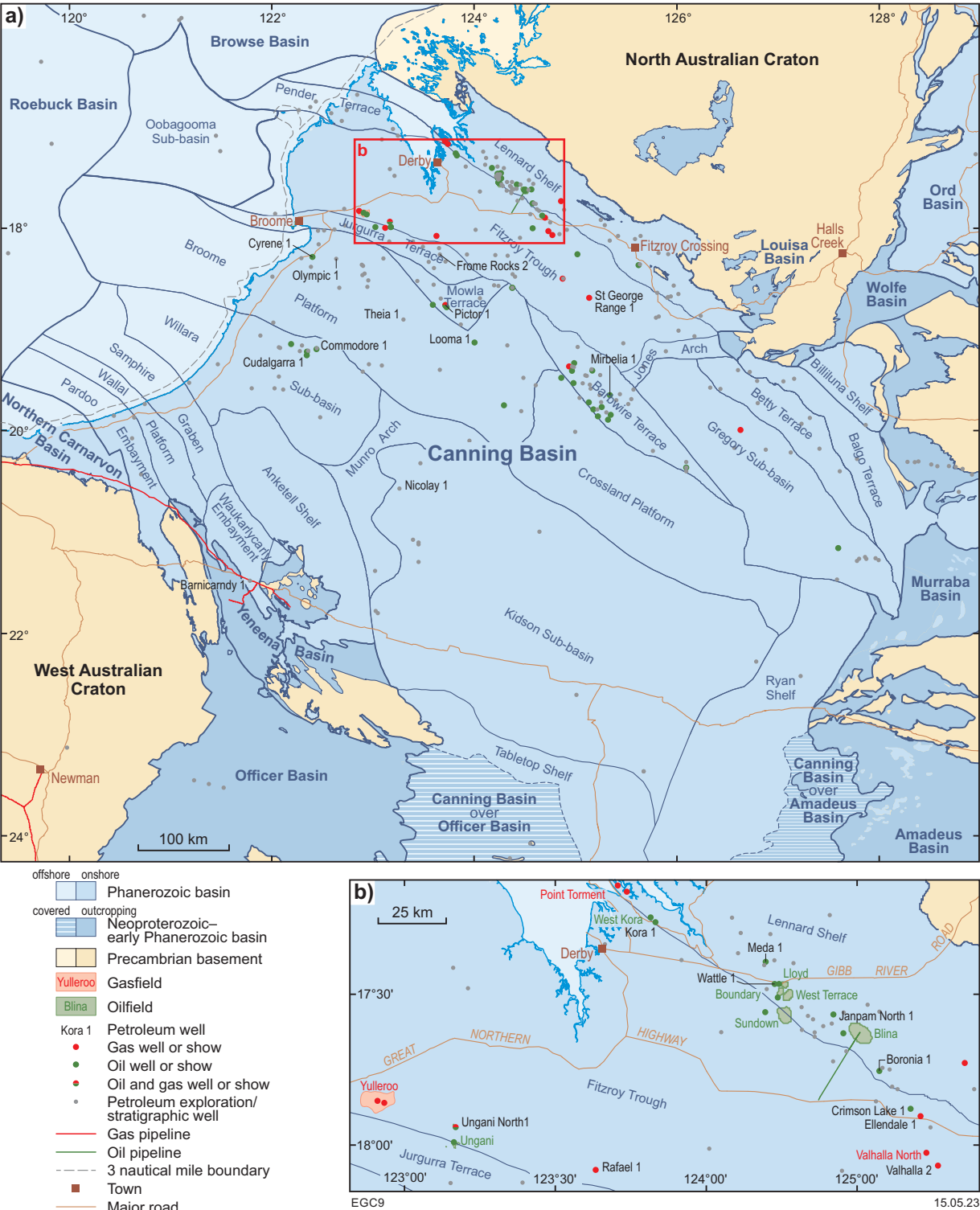


Figure 8. Canning Basin tectonic subdivisions, pipelines, fields and selected wells

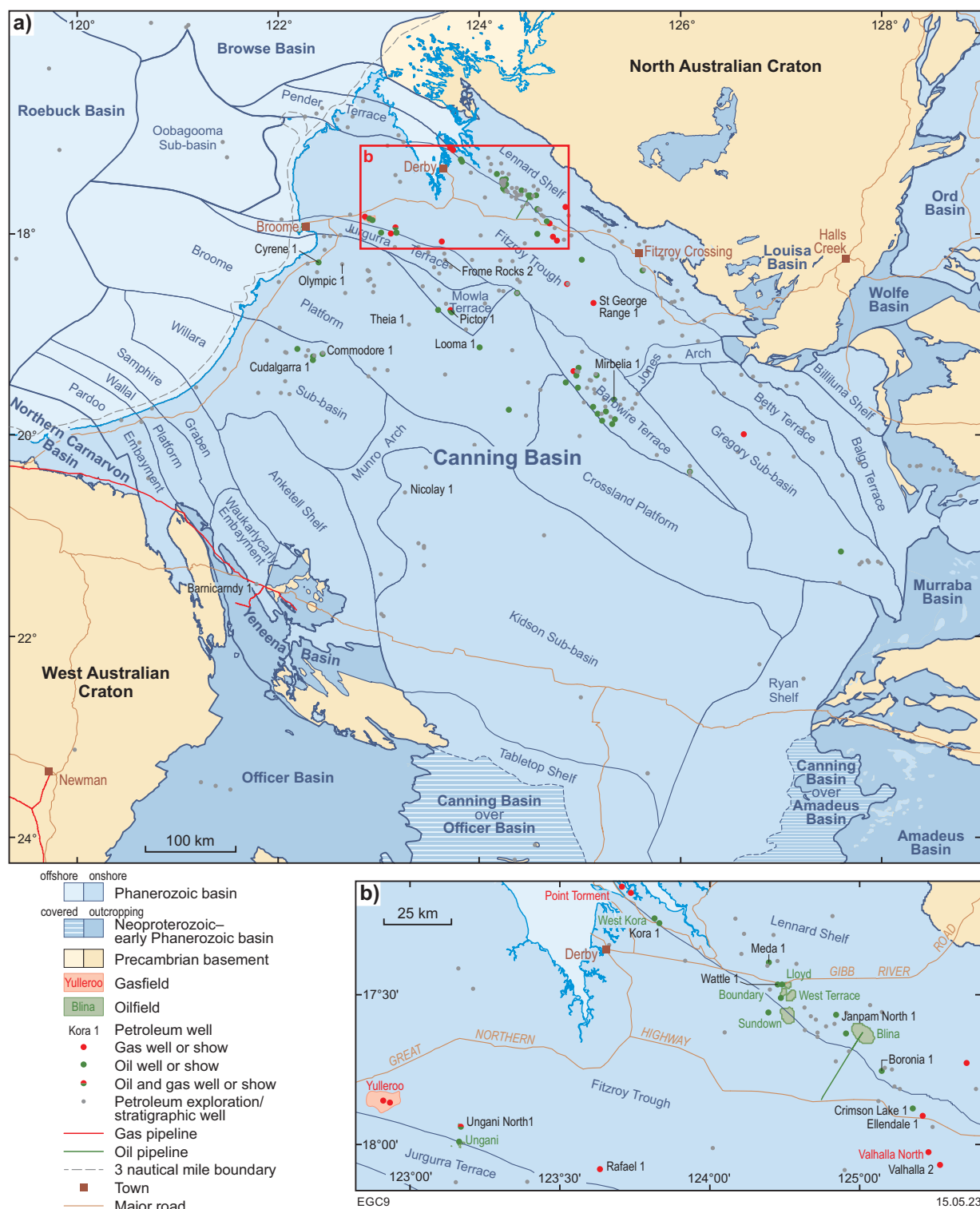


Figure 9. Stratigraphy and petroleum systems of the Canning Basin

Table 2. Canning Basin petroleum fields and shows

<i>Year</i>	<i>Field/discovery</i>	<i>Hydrocarbon type</i>	<i>Reservoir</i>	<i>Age of reservoir</i>	<i>Status</i>
1958	Meda 1	oil show	Laurel Nullara	early Carboniferous Late Devonian	p and a
1965	St George Range 1	gas show	Laurel	early Carboniferous	p and a
1967	Yulleroo	gas	Laurel	early Carboniferous	undeveloped
1979	Ellendale 1	gas show	Laurel	early Carboniferous	p and a
1981	Blina	oilfield	Nullara Yellow Drum	Late Devonian early Carboniferous	shut-in
1982	Sundown	oilfield	Grant	Permian–Carboniferous	shut-in
1982	Kora 1	oil show	Reeves	mid-Carboniferous	p and a
1982	Boronia 1	oil show	Pillara	Late Devonian	p and a
1984	West Kora	oilfield	Reeves	mid-Carboniferous	depleted
1984	Pictor 1	oil and gas show	Nita	Ordovician	p and a
1985	Mirbelia 1	oil show	Mellinjerie	Devonian	p and a
1985	West Terrace	oilfield	Grant	Permian–Carboniferous	depleted
1987	Lloyd	oilfield	Anderson	early Carboniferous	shut-in
1987	Janpam North 1	oil show	Nullara	Late Devonian	p and a
1988	Crimson Lake 1	oil show	Grant	Permian–Carboniferous	p and a
1990	Boundary	oilfield	Grant	Permian–Carboniferous	shut-in
1992	Point Torment 1	gas	Anderson	early Carboniferous	suspended
1994	Wattle 1	oil show	Yellow Drum	early Carboniferous	p and a
1996	Looma 1	oil show oil and gas show	Acacia Nita, Nambeet	Ordovician	p and a
2011	Ungani	oilfield	Laurel	early Carboniferous	producing
2011	Valhalla 2	gas show	Laurel	early Carboniferous	suspended
2012	Valhalla North 1	gas	Laurel	early Carboniferous	suspended
2012	Ungani North1	oil and gas show	Laurel	early Carboniferous	suspended
2021	Rafael 1	gas and condensate discovery	'Ungani dolomite', Laurel	early Carboniferous	suspended

**NOTES:** Abbreviation: p and a = plugged and abandoned

Information Administration are considerable, they also make many assumptions that are not realistic. Recent tests of the Ordovician include Theia 1, Nicolay 1, Olympic 1, Cyrene 1 and Commodore 1. Of these, Theia 1 confirmed the presence of high TOC shales with oil potential in an over-pressured zone of the lower Goldwyer Formation on the Broome Platform.

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## Murraba Basin

The Murraba Basin is exposed, or lies beneath shallow cover, over about 26 000 km<sup>2</sup> in central–north Australia, straddling the border with the Northern Territory, of which about 20 000 km<sup>2</sup> is within Western Australia (Fig. 10). The basin is part of the Centralian Superbasin and may extend farther west, at depth, beneath the northeast Canning Basin.

## Geological setting

The Murraba Basin was introduced in 2005 for the Neoproterozoic sedimentary succession previously included in the upper part of the Birrindudu Basin — that name is now restricted to strata of late Paleoproterozoic to early Mesoproterozoic age. Previously, the Neoproterozoic section was correlated with the basal succession (Supersequence 1) of the Neoproterozoic Centralian Superbasin. For this

reason, and because outcrop is largely limited to sandstone, the basin was assumed to have no significant petroleum prospectivity but a recent reconnaissance outcrop study of the southern Murraba Basin has significantly revised the basin's age through comparison to adjacent parts of the Superbasin.

The Murraba Basin has a broadly similar stratigraphy and depositional history to the Neoproterozoic to lower Cambrian sedimentary succession within the Amadeus Basin (Fig. 11), although meagre exposures mean some parts remain poorly understood given the lack of deep drilling. The basin unconformably overlies Paleoproterozoic basement rocks of the Aileron Province in the south, the Granites–Tanami Orogen and Tanami Basin in central areas, and the Birrindudu Basin in the north (Fig. 10). Contacts with coeval basins — the Amadeus Basin in the south and Wolfe Basin in the north — are not exposed but are inferred to be faulted. The Paleozoic–Mesozoic Canning Basin is in fault contact to the west and locally overlies the Murraba Basin. Strata in the basin are gently folded and faulted apart from local tight folds near major fault zones.

The basal succession of sandstone and conglomerate, which includes up to 400 m of Munyu Sandstone in the south, is interpreted as a direct correlative of the Heavitree Formation of the Amadeus Basin. The Lewis Range Sandstone in the north may be an equivalent, but could be younger. The overlying unnamed interval, inferred from limited outcrop of carbonate and extensive regolith containing carbonate clasts, is of significant, but uncertain, thickness. This interval is considered to be the equivalent of the upper Tonian Bitter Springs Group, and possibly the Wallara Formation, in the Amadeus Basin, which contains several potential source horizons and a widespread lower salt seal. The thick siliciclastic Hidden Basin beds in the southwest is no older than lower Tonian based on detrital zircon dating, but correlations to other units of this age are unclear.

Two Cryogenian glacial successions, locally separated by thick black shale with hydrocarbon source potential, are present elsewhere in the Centralian Superbasin (Areyonga, Aralka and Olympic Formations of the Amadeus Basin). The only evidence for these glacial–interglacial successions is possible basement-derived glacial erratics within the regolith overlying the carbonate-bearing interval.

The upper part of the basin, the redefined Redcliff Pound Group, comprises a broadly shallowing-upward succession of sandstone, siltstone, minor conglomerate and carbonate of shallow marine, deltaic and terrestrial (fluvial, eolian) origin, of inferred Ediacaran — early Cambrian age. Siliciclastic input in the upper part of this interval indicates uplift and erosion to the west likely related to early phases of the Petermann and partly coeval Paterson Orogenies. The main locus of these events is to the south and west, respectively, within the Amadeus, Officer and Yeneena Basins.

Much of the deformation in the Murraba Basin pre-dates Paleozoic deposition in the Canning Basin, probably in the early Cambrian during the final phase of the Petermann and Paterson Orogenies. However, structural events as young as Triassic clearly affected Permian strata along the eastern margin of the Canning Basin, and may also have affected the Murraba Basin, particularly along its western margin.



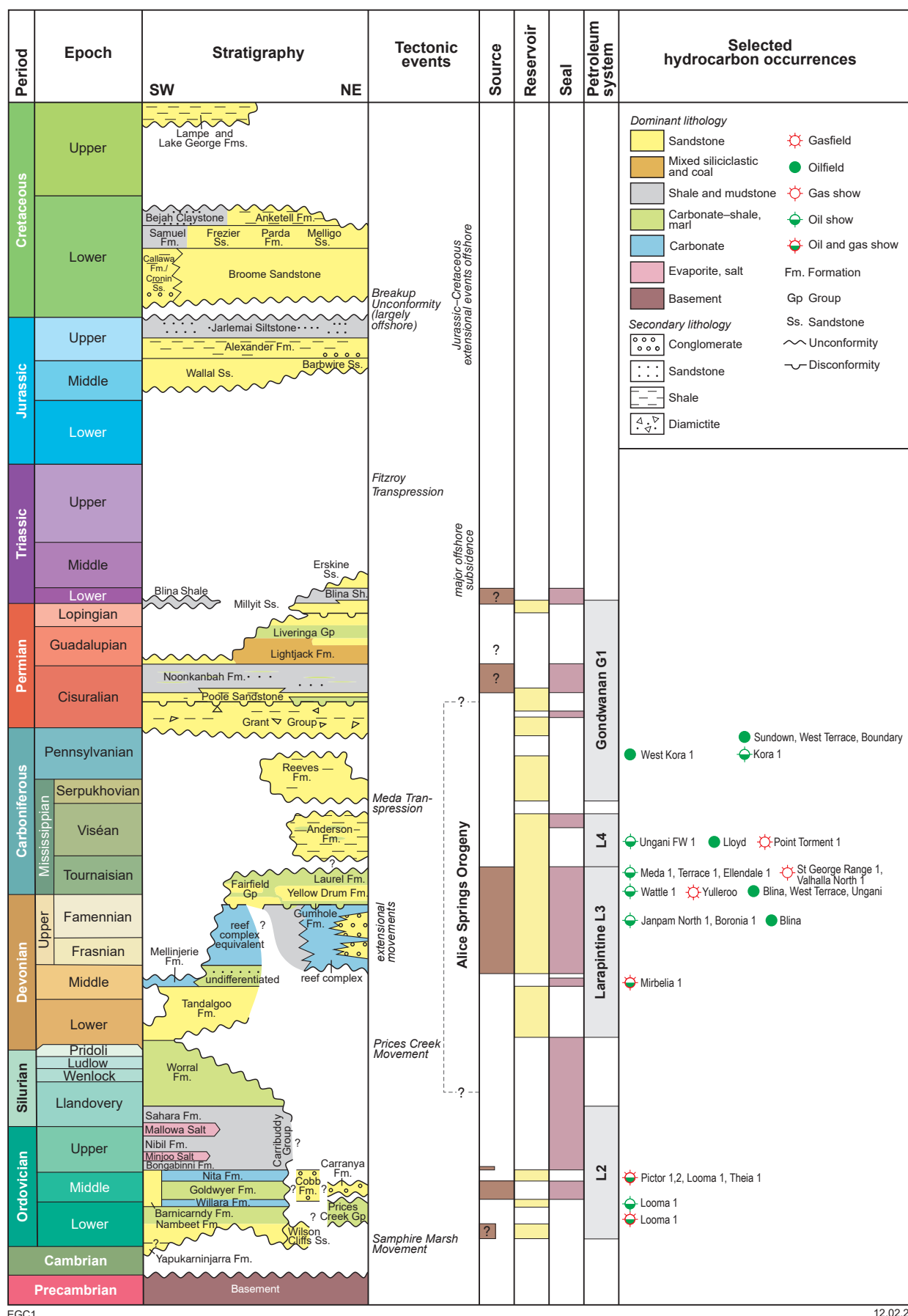
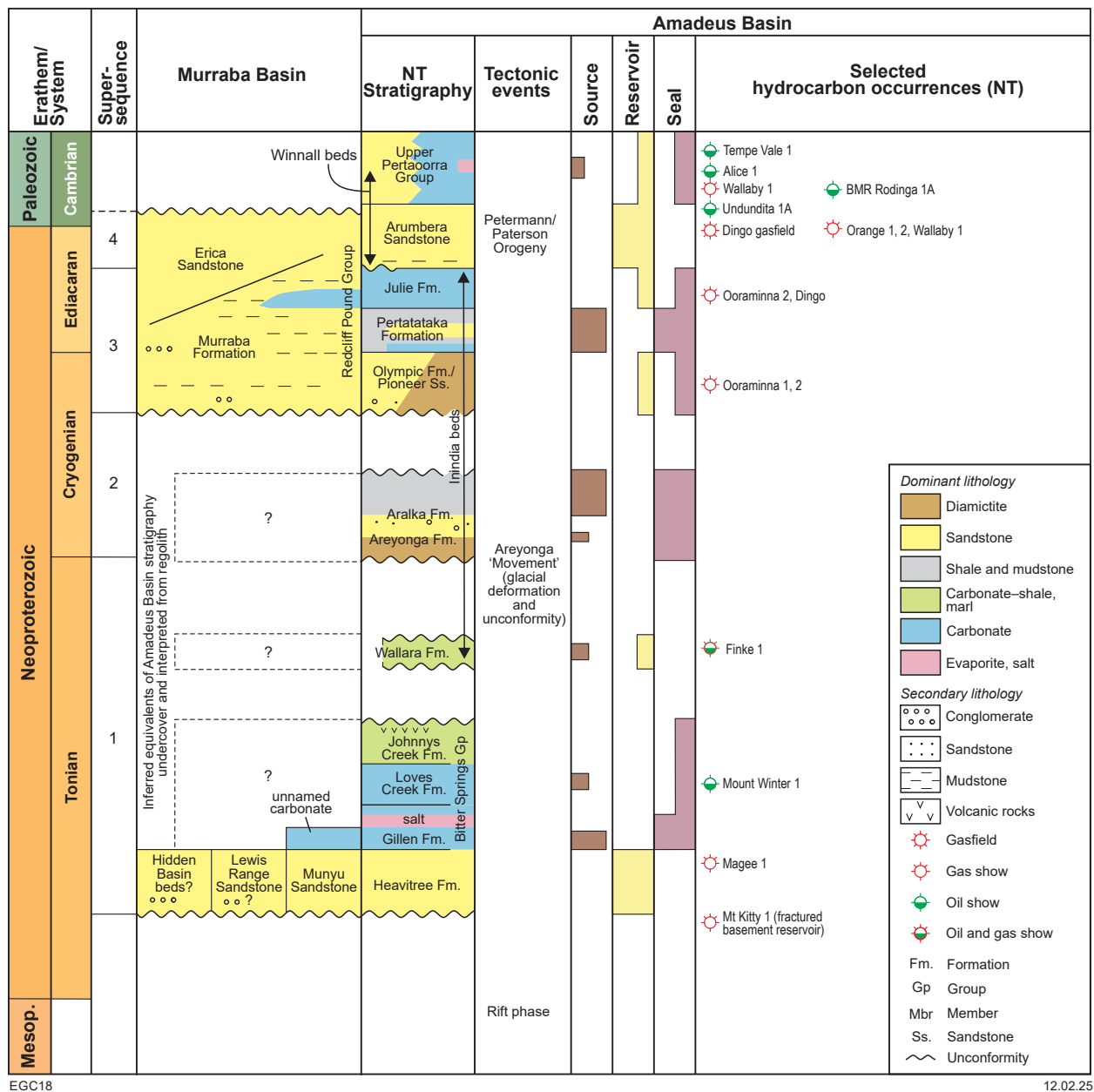


Figure 10. The Western Australian component of the Murraba Basin and adjacent terrains



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Figure 11. Stratigraphy of the Murraba Basin compared to Neoproterozoic–Cambrian stratigraphy, tectonic events, and hydrocarbon systems of the Amadeus Basin

## Exploration history

There has been no petroleum or geothermal exploration within the Murraba Basin although the Bureau of Mineral Resources (now Geoscience Australia) drilled a series of shallow stratigraphic holes across the northern part of the basin in 1974. There is no seismic data across the basin but a few Canning Basin lines just cross the faulted edge of the basin. Aeromagnetic and radiometric data (flown with 200 m to 400 m line spacing) are available across all of the WA part of the basin. A recent gravity survey covering the southern part of the basin and adjacent Canning Basin provides data at 2.5 km spacing, with lower resolution data available in the north.

## Prospectivity

Poor outcrop, the paucity of seismic data and the lack of deep drilling render the basin's prospectivity speculative. The similarity of the succession to the Neoproterozoic of the Amadeus Basin suggests equivalents to some of the petroleum systems in that basin may be present. With an estimated basin thickness greater than 2000 m in depocentres, maturation of source beds low in the succession (as in the Amadeus Basin) is feasible. The level of structural complexity and tectonic history is similar to the Amadeus Basin, suggesting a comparable variety of potential structural traps. In addition, indications of a halotectonic style for some surface structures suggest the presence of

deep salt. If sufficiently thick, an equivalent to the subsalt, high-helium 'Gillen petroleum system' in the Amadeus Basin may be present. Ediacaran–Cambrian hydrocarbon systems, analogous to the Dingo gasfield of the Amadeus Basin, are unlikely due to insufficient burial and lack of an apparent seal in the upper part of the succession, except perhaps where the Murraba Basin is deeply buried below the Canning Basin.

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## Northern Carnarvon Basin

Most of the basin lies offshore, extending north from the Pilbara region to the continental–oceanic crust boundary, and covers about 500 000 km<sup>2</sup> (Fig. 12). The Northern Carnarvon is transitional to, and overlies, the predominantly onshore Southern Carnarvon Basin. Several islands (e.g. Barrow Island, Airlie Island, Varanus Island and Thevenard Island) host oil and gas production facilities and bases in the basin and extend the State's jurisdiction offshore by up to 98 km from the coast.

Barrow Island, which contains the Barrow Island oilfield, is the site of the Gorgon LNG and domestic gas plant. All other operational plants are onshore. In 2017, the depleted Tubridgi gasfield 25 km west of Onslow became a gas storage facility. A project to sequester CO<sub>2</sub> from the Gorgon gasfield beneath Barrow Island became operational in August 2019. About 7 Mt had been injected by November 2022 with 120 Mt planned over the estimated 40-year life of the project.

## Geological setting

The Northern Carnarvon Basin is dominated by a southwest-trending set of major depocentres – the Exmouth, Barrow, Dampier and Beagle Sub-basins – in which the Mesozoic sedimentary succession is up to 15 km thick. In these sub-basins, Paleozoic sedimentary rocks (Fig. 13) are commonly at considerable depths. Shoreward of these depocentres are the Peedamullah Shelf and Lambert Shelf, whereas a mid-basin arch consisting of the Rankin Platform and the Alpha Arch flank them seaward. The Kangaroo Trough, Dixon Sub-basin, and Exmouth Plateau lie farther offshore (Fig. 12).

The breakup of Gondwana controlled the evolution of the Northern Carnarvon Basin. Prior to breakup, several sedimentary sequences were deposited in an elongate basin between Precambrian basement of the Pilbara region and continental blocks to the northwest.

However, strata older than Triassic have been intersected in relatively few wells confined to the eastern margin of the basin so the early evolution of the basin is poorly known. At the end of the Paleozoic, rapidly subsiding, northeast-trending troughs developed in the Northern Carnarvon Basin to form its present-day framework, followed by faulting and breakup in the Jurassic when thick siliciclastic sequences accumulated in offshore marine to continental settings. Final continental separation in the early Neocomian was farther offshore than the aborted rifts along the axis of the Barrow and Dampier Sub-basins, resulting in a trailing edge, passive margin basin. In the Late Cretaceous, global oceanic circulation patterns changed allowing deposition to shift from siliciclastic to carbonate-dominated, resulting in the progradation of a thick carbonate deposits across the entire offshore basin.

## Exploration history

In 1953, the first exploration well in the basin, Rough Range 1, discovered oil next to the eastern edge of the Exmouth Sub-basin. Follow-up discoveries of oil at Barrow Island (1964), and of gas in North Tryal Rocks 1 (1971), established the Northern Carnarvon Basin as a major hydrocarbon province. To date there are 174 fields, and over 3000 wells in the basin. In addition, there are 890 wells on Barrow Island, mostly for development of the eponymous field, which is likely to be shut-in by mid-2025. Sixty-four fields lie within the State's coastal waters or onshore, of which (in 2024) 28 are depleted, four are still producing, 14 are shut-in or suspended, and 18 are undeveloped. Given the age of the last discovery under State jurisdiction (Wonnich Deep in 2007), most of the shut-in or suspended fields probably are effectively depleted. Tubridgi, the only onshore gasfield in the basin (on the Peedamullah Shelf), was discovered in 1981 and is now used for gas storage following its depletion in 2005.

Offshore there is a grid of regional and detailed seismic surveys, mainly north of Exmouth Gulf, with a significant proportion also having 3D coverage. Exploration has remained sparse over most of the onshore part of the basin, except for the Rough Range – Cape Range area.

## Prospectivity

The Northern Carnarvon Basin, and in particular the Barrow and Dampier Sub-basins, is regarded as the premier hydrocarbon basin of Australia, and is one of Australia's more intensely explored areas. Numerous oil and gas fields in the Northern Carnarvon Basin demonstrate the petroleum potential of the region, particularly offshore (Table 3). Oil production is primarily from reservoirs within the Barrow Group and sandy intervals (Windalia Sand, Mardie Greensand and Birdrong Sandstone) of the lower Winning Group (Table 3), all which post-date breakup. The Lower Cretaceous Barrow Group has excellent reservoir characteristics, and Middle Miocene faulted anticlines provide many structural traps. The Upper Jurassic Dingo Claystone is the main source for accumulations hosted in post-breakup reservoirs. The sub-basin margins and depocentres along the sub-basin axes, may hold the key to future discoveries.

Within the Dampier Sub-basin, production of gas, condensate, and associated minor oil, is primarily from

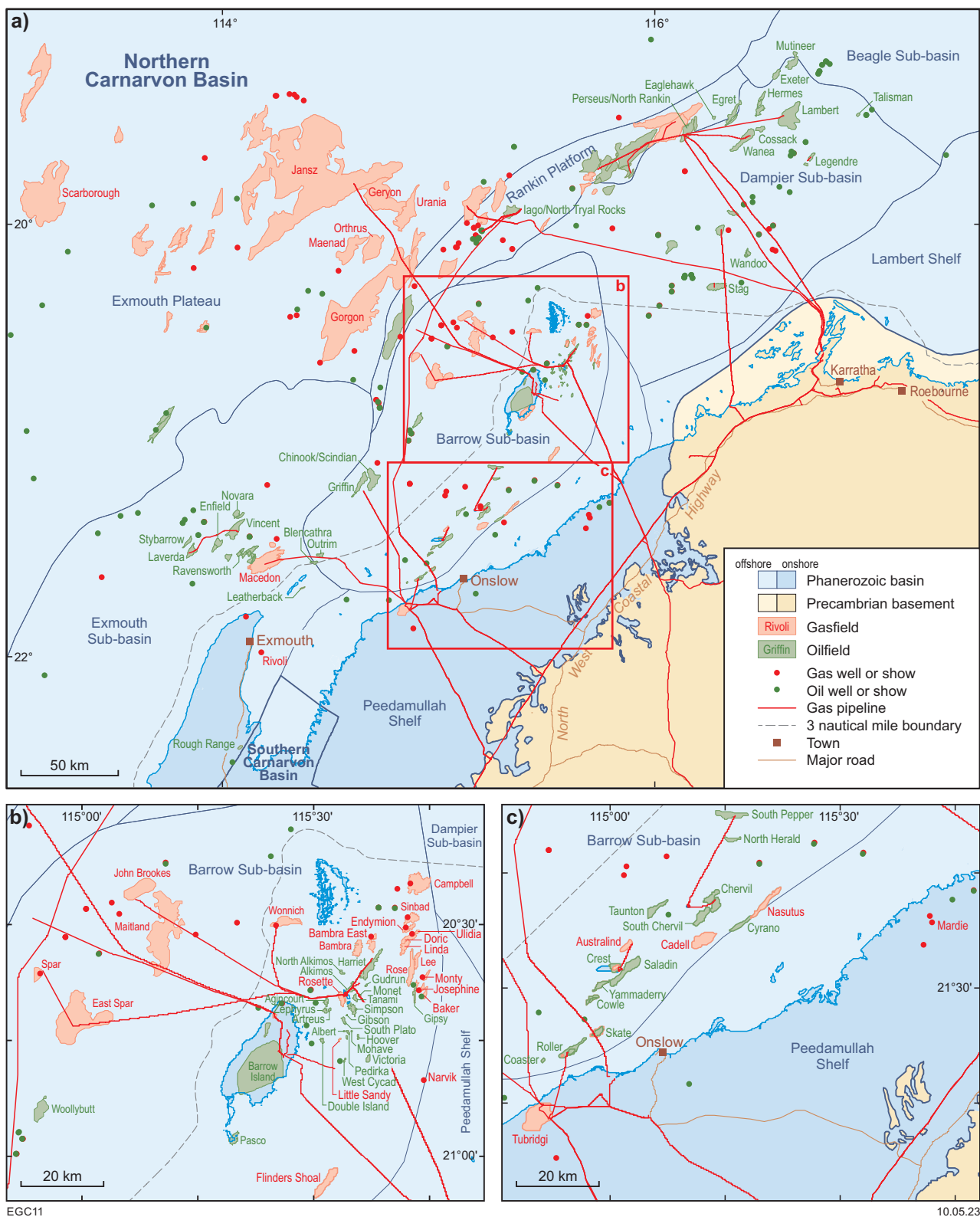
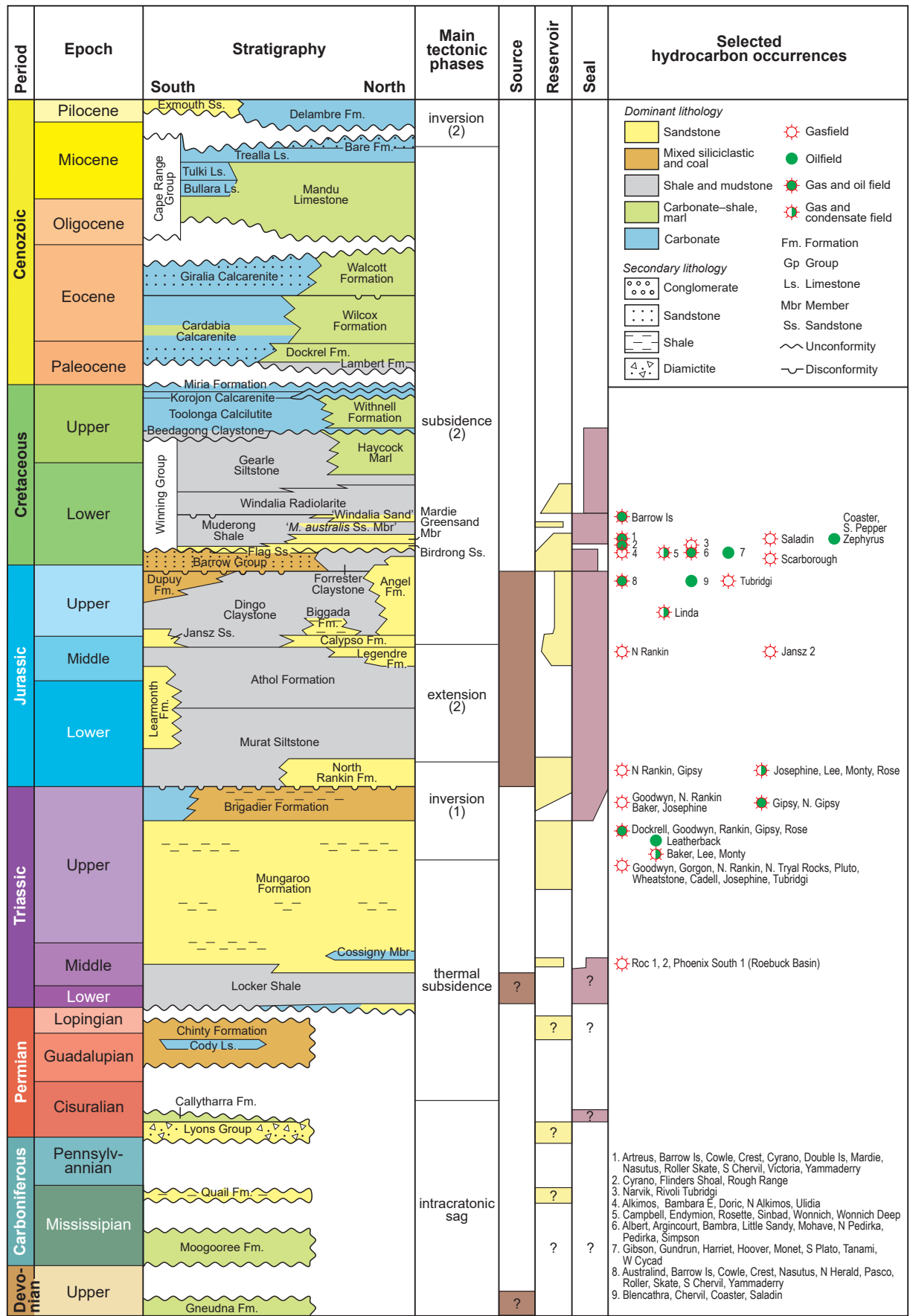


Figure 12. Northern Carnarvon Basin tectonic sub-divisions, pipelines, fields and selected wells





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Figure 13. Stratigraphy and petroleum systems of the Northern Carnarvon Basin

Table 3. Northern Carnarvon Basin gas and oilfields

Year	Field/discovery	Hydrocarbon type	Reservoir	Age of reservoir	Status
1955	Rough Range	oil	Birdrong Sandstone	Early Cretaceous	shut-in
1966	Barrow Island	gas, oil	Gearle Siltstone	mid-Cretaceous	producing
			Windalia Radiolarite	Early Cretaceous	
			Muderong Shale	Early Cretaceous	
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
			Flacourt Formation	Early Cretaceous	
			Dupuy Formation	Late Jurassic	
1967	Pasco	gas, oil	Barrow Group	Early Cretaceous	undeveloped
1969	Flinders Shoal	gas, oil	Birdrong Sandstone	Early Cretaceous	undeveloped
1979	Campbell	gas, condensate	Flag Sandstone	Early Cretaceous	depleted
1981	Tubridgi	gas	Birdrong Sandstone	Early Cretaceous	depleted, now
			Flacourt Formation	Early Cretaceous	used for gas
			Mungaroo Formation	Late Triassic	storage
1983	Bambra	gas, oil, condensate	Flag Sandstone	Early Cretaceous	producing
1983	Chervil	oil	Flacourt Formation	Early Cretaceous	depleted
1983	Harriet	oil	Flag Sandstone	Early Cretaceous	shut-in
1983	North Herald	gas, oil	Upper Barrow Group	Early Cretaceous	depleted
1983	South Chervil	gas, oil	Barrow Group	Early Cretaceous	undeveloped
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
1983	South Pepper	oil	Barrow Group	Early Cretaceous	depleted
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
1985	Bambra East	gas	Flag Sandstone	Early Cretaceous	suspended
1985	Saladin	gas	Mardie Greensand Member, Muderong Shale.	Early Cretaceous	depleted
		oil	Flacourt Formation	Early Cretaceous	
1987	Rosette	gas, condensate	Flag Sandstone	Early Cretaceous	depleted
1988	Yammaderry	oil, gas	Flacourt Formation	Early Cretaceous	depleted
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
1989	Rivoli	gas	Birdrong Sandstone	Early Cretaceous	undeveloped
1990	Cowle	gas, oil	Mardie Greensand Mbr, Muderong Shale	Early Cretaceous	depleted
			Flacourt Formation	Early Cretaceous	
1990	Roller	gas, oil	Flacourt Formation	Early Cretaceous	depleted
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
1990	Sinbad	gas, condensate	Flag Sandstone	Early Cretaceous	depleted
1991	Leatherback	oil	Mungaroo Formation	Late Triassic	undeveloped
1991	Skate	gas, oil	Flacourt Formation	Early Cretaceous	depleted
			Mardie Greensand Member, Muderong Shale.	Early Cretaceous	
1991	Tanami	oil	Flag Sandstone	Early Cretaceous	shut-in
1992	Ulidia	gas	Flag Sandstone	Early Cretaceous	undeveloped
1993	Australind	gas, oil	Barrow Group	Early Cretaceous	undeveloped
1994	Alkimos	oil	Flag Sandstone	Early Cretaceous	depleted
1994	Crest	gas, oil	Mardie Greensand Member, Muderong Shale.	Early Cretaceous	depleted
			Flacourt Formation	Early Cretaceous	
1995	Blencathra	oil	Barrow Group	Early Cretaceous	undeveloped
1995	Wonnich	gas, condensate	Flag Sandstone	Early Cretaceous	shut-in
1996	Agincourt	gas, oil, condensate	Flag Sandstone	Early Cretaceous	shut-in
1996	Doric	gas	Flag Sandstone	Early Cretaceous	depleted
1998	Gipsy	gas, oil	Brigadier Formation	Late Triassic	depleted
			Mungaroo Formation	Late Triassic	
			North Rankin Formation	Early Jurassic	
1998	Rose	gas, condensate	North Rankin Formation	Early Jurassic	shut-in
			Brigadier Formation	Late Triassic	
			Mungaroo Formation	Late Triassic	
1999	Cadell	gas	Mungaroo Formation	Late Triassic	undeveloped
1999	Coaster	oil	Mardie Greensand Member, Muderong Shale.	Early Cretaceous	undeveloped
			Barrow Group	Early Cretaceous	
1999	Lee	gas, condensate	North Rankin Formation	Late Jurassic	producing
			Brigadier Formation	Late Triassic	
			Mungaroo Formation	Late Triassic	
1999	Monty	gas, condensate	North Rankin Formation	Early Jurassic	undeveloped
			Brigadier Formation	Late Triassic	
			Mungaroo Formation	Late Triassic	
1999	Narvik	gas	Birdrong Sandstone	Early Cretaceous	undeveloped
1999	Nasutus	gas, oil	Mardie Greensand Member, Muderong Shale.	Early Cretaceous	undeveloped
			Upper Barrow Group	Early Cretaceous	
1999	North Gipsy	gas, oil	Brigadier Formation	Late Triassic	depleted
			North Rankin Formation	Early Jurassic	
2000	Baker	gas	Brigadier Formation	Late Triassic	undeveloped
			Mungaroo Formation		
2000	Josephine	gas	North Rankin Formation	Early Jurassic	undeveloped
			Brigadier Formation	Late Triassic	
			Mungaroo Formation	Late Triassic	
2000	Linda	gas, condensate	'Linda Sandstone Member', Dingo Claystone	Late Jurassic	producing
2000	Mardie	gas	Intra-Muderong Shale sands	Early Cretaceous	undeveloped
2000	North Alkimos	oil	Flag Sandstone	Early Cretaceous	shut-in
2000	Simpson	gas, oil	Flag Sandstone	Early Cretaceous	depleted
2001	Gudrun	oil	Flag Sandstone	Early Cretaceous	depleted
2001	South Plato	oil	Flag Sandstone	Early Cretaceous	shut-in
2002	Double Island	oil, gas	'Double Is. Ss Mbr', Muderong Shale	Early Cretaceous	shut-in
2002	Endymion	gas, condensate	Flag Sandstone	Early Cretaceous	depleted
2002	Hoover	oil	Flag Sandstone	Early Cretaceous	depleted
2002	Little Sandy	gas, oil	Flag Sandstone	Early Cretaceous	shut-in
2002	Pedirka	gas, oil	Flag Sandstone	Early Cretaceous	shut-in
2002	Victoria	oil	'Double Isand Sandstone Member', Muderong Shale	Early Cretaceous	shut-in
2003	Cyrano	gas, oil	Mardie Greensand Member, Muderong Shale.	Early Cretaceous	undeveloped
			Birdrong Sandstone	Early Cretaceous	
2003	Gibson	oil	Flag Sandstone	Early Cretaceous	depleted
2003	North Pedirka	gas, oil	Flag Sandstone	Early Cretaceous	depleted
2004	Monet	oil	Flag Sandstone	Early Cretaceous	depleted
2005	Albert	gas, oil, condensate	Flag Sandstone	Early Cretaceous	depleted
2005	Artreus	gas, oil, condensate	'Double Isand Sandstone Member', Muderong Shale	Early Cretaceous	depleted
2005	Mohave	gas, oil	Flag Sandstone	Early Cretaceous	depleted
2006	West Cycad	oil	Flag Sandstone	Early Cretaceous	shut-in
2006	Zephyrus	oil	'Double Isand Sandstone Member', Muderong Shale	Early Cretaceous	depleted
2007	Wonnich Deep	gas, condensate	Flag Sandstone	Early Cretaceous	undeveloped

pre-breakup sandstones of the Upper Jurassic to mid-Upper Triassic Angel, Brigadier and Mungaroo Formations. Truncation and fault traps control pre-breakup accumulations, which probably are sourced by the Triassic Locker Shale, Jurassic Dingo Claystone and possibly intra-Mungaroo Formation shales.

Despite the intense historic exploration, new discoveries continue to be made within the proven hydrocarbon-rich Barrow and Dampier Sub-basins, and in the less explored surrounding sub-basins. Successful exploration includes different play types and extensions of known discoveries and models. The support facilities in the basin also allow relatively small offshore fields to be developed. The nearshore is considered to be highly prospective but largely unexplored owing to the difficulty of conducting seismic and drilling operations in a shallow-water, environmentally sensitive zone. New petroleum plays in the Lower Triassic are currently the focus of exploration activities within the nearshore Northern Carnarvon Basin due to the recent Phoenix South and Roc oil and gas discoveries in the adjacent Roebuck Basin. Evaluation of CO<sub>2</sub> sequestration in depleted fields or saline aquifers, or storage of other gasses, is at an early stage.

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## Officer Basin

The Officer Basin extends 1500 km from the southeastern flank of the Pilbara Craton to the central-western part of South Australia and covers about 310 000 km<sup>2</sup> within Western Australia (Fig. 14).

## Geological setting

This Neoproterozoic to Paleozoic intracratonic basin encompassing five major west to northwest-trending elongate depocentres (Fig. 14) with a sedimentary thickness of up to 8 km. The basin is predominantly Neoproterozoic, overlying older Proterozoic to Archean sedimentary, igneous and metamorphic rocks and overlain by Permo-Carboniferous and Cretaceous strata of the Canning Basin. The basin contains a mixed carbonate, silty and sandy siliciclastic, and evaporitic succession dominated by shallow marine to coastal deposition. The sedimentary succession preserves four supersequences common to central Australian Neoproterozoic basins, although the Supersequence 2 is restricted in distribution in Western Australia (Fig. 15). At the northwest end of the Officer Basin, Supersequence 1 is inferred to transition to the contiguous Yeneena Basin, although correlations are uncertain due to structural complications and extensive cover.

The structural configuration of the basin is controlled largely by major salt deposits, which mobilised during several tectonic episodes. Five structural zones are recognised in Western Australia: the Salt-ruptured Zone, the Birksgate, Wells and Blake Sub-basins, and the southern Westwood Shelf. The Salt-ruptured Zone, with evidence of extensive salt movement from seismic data or outcropping structures, coincides with an elongate depocentre along the northeastern margin of the basin. Near the South Australian border this zone is contiguous with the western end of the Birksgate Sub-basin, a major depocentre that lies mostly within South Australia. Thinner and less deformed parts of the basin southwest of the Salt-ruptured Zone include the mainly flat-lying Westwood Shelf in the east and the more deformed Wells and Blake Sub-basins in the northwest. The basin has a complex history with several tectonic episodes – the most significant are the late Tonian Miles Orogeny, which terminated deposition in the adjoining Yeneena Basin, and the contiguous Ediacaran–Cambrian Paterson and Petermann Orogenies, when major uplift of basement in the Paterson Orogen and Musgrave region, respectively, shed large volumes of coarse siliciclastic sediments into the basin.

## Exploration history

There have been several periods of stratigraphic and exploration drilling in the Western Australian part of the basin since 1965. The most significant was in the 1980s when three of the four new field wildcat wells in the basin were drilled – the other 29 wells were stratigraphic tests mostly drilled by government agencies – and when nearly 80% of the 8600 line-km of 2D seismic data across the basin was acquired.

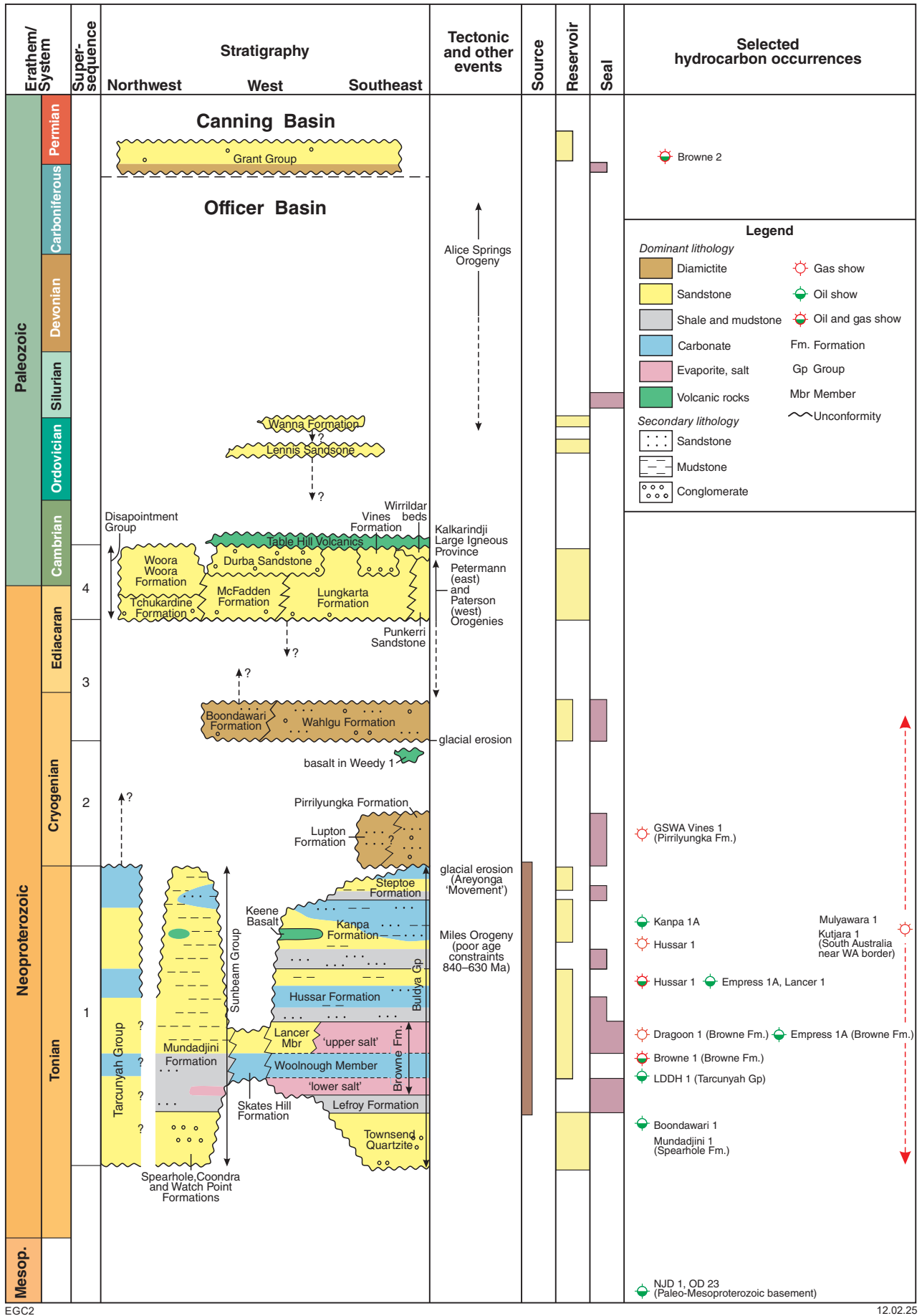
## Prospectivity

Whereas Neoproterozoic sedimentary rocks source commercial accumulations of hydrocarbons in coeval strata in the eastern Amadeus Basin within the Northern Territory – notably the Dingo gasfield discovered in 1981 – only minor



Figure 14. Officer Basin tectonic sub-divisions and selected wells





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Figure 15. Stratigraphy and petroleum systems of the Officer Basin

**Table 4. Officer Basin hydrocarbon shows**

Year	Discovery	Hydrocarbon type	Reservoir	Age of reservoir
1965	Browne 1	Gas cut mud, cut fluorescence, trace oil in core	Browne Formation	Neoproterozoic
1965	Browne 2	Gas cut mud, cut fluorescence, trace oil in core	Paterson Formation	Permian
1980	Kennecott Neal Junction N1-1*	Bitumen in core	Browne Formation	Neoproterozoic
1981	WMC NJD 1*	Bleeding oil in core Bitumen in core	Browne Formation unnamed	Neoproterozoic ?Mesoproterozoic
1982	Dragoon 1	Mud gas to 1% methane equivalent, including hydrocarbons up to C <sub>5</sub> H <sub>12</sub>	Browne Formation	Neoproterozoic
1982	Hussar 1	Mud gas readings to 1000 ppm. Possible gas blow on air lift. Trip gas up to 4.6%. 72% oil saturation from log analysis	Kanpa Formation Hussar Formation	Neoproterozoic
1982	Kanpa 1A	Dull yellow-orange and light yellow-white cut fluorescence, brown oil stains in sandstone and dolomite cuttings	Kanpa Formation	Neoproterozoic
1993	Normandy Lake Disappointment LDDH 1*	Bitumen in core	Tarcunyah Group	Neoproterozoic
1996	Jubilee GM Nabberu OD 23*	Bleeding oil and bitumen in core	Scorpion Group	Paleo – Mesoproterozoic
1997	Boondawari 1	40% oil fluorescence in core	Spearhole Formation	Neoproterozoic
1997	GSWA Empress 1A	Bitumen in core	Hussar Formation and Browne Formation	Neoproterozoic
1997	Mundadjini 1	10% oil fluorescence in core	Spearhole Formation	Neoproterozoic
1999	GSWA Vines 1	Total gas peaks 25 times background	Pirrilyungka Formation	Neoproterozoic
2003	GSWA Lancer 1	Bitumen in core	Hussar Formation	Neoproterozoic

**NOTE:** \* mineral exploration drillhole

hydrocarbon shows are recorded in the Officer Basin in Western Australia (Table 4). However, that is likely a function of the large proportion of wells drilled being stratigraphic and the thinness of possible source intervals found to date. Traps in the eastern zone of salt deformation may be breached due to continued salt movement. To the west ubiquitous low dips are not encouraging for structural plays.

Lancer 1 intersected reservoir facies with >20% porosity, and permeability locally up to 10 darcies, as well as halite and shale beds thicker than 10 m that may be effective seals. The discovery of bitumen in the Tonian succession in several stratigraphic wells and mineral drill holes points to generation and migration of at least some liquid hydrocarbons, possibly involving lateral migration beneath the salt seal from deep sources in the basin depocentre. Geochemical modelling indicates most potential source rocks entered the oil-maturation window after the formation of structural traps in the Ediacaran–Cambrian and have remained at that level.

Play types in the Officer Basin vary geographically and stratigraphically. Subsalt mini-basin plays may be present, particularly in the Salt-ruptured Zone. Such plays are higher risk for reservoir and source, although halite beds should have sealing capacity. Suprasalt plays include folded four-way dip closures arising generated by low-amplitude, broad, open folds, and isoclinal to overturned thrust folds. Many of the larger folds are over salt diapirs, but opportunities for flanking traps or lateral truncation traps remain unexplored. Stratigraphic traps in the subsalt and suprasalt section remain untested.

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## Perth Basin

The Perth Basin extends west from the Yilgarn Craton to the edge of the continental shelf, southwest to the offshore Mentelle Basin and north-northwest along the edge of the Southern Carnarvon Basin (Fig. 16). The basin covers about 205 000 km<sup>2</sup>, of which 50 000 km<sup>2</sup> is onshore, and contain a Permian–Mesozoic succession up to 12 km thick. Offshore sub-basins contain a much thicker, mostly Mesozoic–Cenozoic, succession.

Two major onshore gas pipelines from Dongara and Dampier traverse the basin to near Bunbury and Pinjarra, respectively. The depleted Mondarra gasfield, connected to both pipelines near Dongara, provides temporary storage of up to 18 PJ. The field allows flexibility in supplying gas to the south-west of the State with an injection capacity close to 70 TJ/day whereas it is possible to withdraw up to 150 TJ/day.

Approximately 150 km south of Perth, the South West Hub (a government-funded research project during 2011–18) investigated the CO<sub>2</sub> storage potential of Triassic sandstone over the ‘Harvey Ridge’. Although there is no structural trap

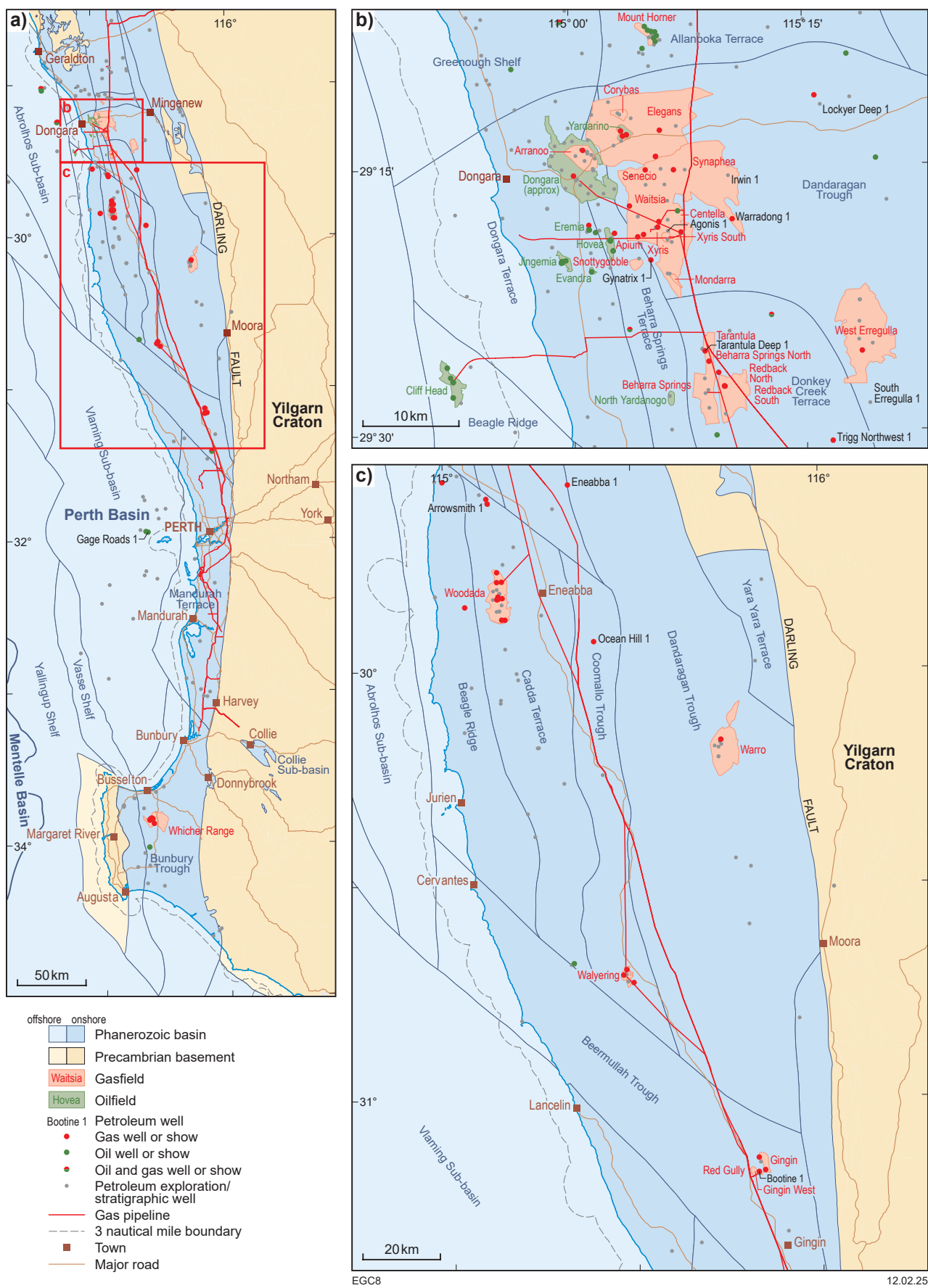


Figure 16. Perth Basin tectonic subdivisions, pipelines, fields and selected wells

or seal, and to date no trial injections of CO<sub>2</sub>, modelling based on core and log analysis indicates the 1500 m-thick, brine-saturated sandstone could accommodate at least 800 000 tonnes of CO<sub>2</sub> per annum over 30 years. In addition, depleted fields may have potential for permanent CO<sub>2</sub> sequestration, or temporary storage of gas or H<sub>2</sub>.

## Geological setting

The Perth Basin forms a north–south elongate rift along the west coast of the continent. Onshore the major structural features are the Darling Fault bordering the Yilgarn Craton to the east, with the main depocentres along the Dandaragan Trough and its southern equivalents. The contact with the Mentelle Basin to the southwest is transitional. The basin contains mainly Permian and younger continental clastic rocks (Fig. 17) deposited in a rift system that culminated with the breakup of Gondwana in the earliest Cretaceous (Berriasian–Hauterivian). Two major tectonic phases incorporate Permian extension to the southwest and northwest transtension associated with breakup. Sinistral and dextral movements, respectively, are inferred along the Darling Fault during these phases. Many new faults developed during breakup and most major faults reactivated, with some producing associated wrench-induced anticlines.

## Exploration history

The earliest exploration was shallow drilling on the margin of the basin near the State's south coast during the early 1900s but without success. Exploration within the basin began in earnest in 1949, when the BMR (now Geoscience Australia) commenced the first gravity survey in the northern onshore part of the basin. WAPET was the first private company to explore the basin with gravity and seismic surveys. Both the BMR and WAPET acquired the first seismic surveys in 1955 and drilled stratigraphic wells across the onshore northern Perth Basin in the late 1950s, leading WAPET to drill the basin's first wildcat well, Eneabba 1, in 1961.

To date there are 377 onshore and 53 offshore (in Commonwealth waters) wells in the basin, and over 320 seismic surveys acquired, of which 22 are 3D. The onshore wells, include 174 new field wildcats, 41 stratigraphic, 135 development or extension and six for coal bed methane. Known hydrocarbon accumulations include 23 commercial oil and gas-condensate fields, of which 17 are now depleted or shut-in (Table 5). Up to 2024, the basin yielded 20 Tl of gas (707.5 Tcf) and just over 5 Gl of oil (31.6 MMbbl). Gas production is likely to rise significantly given recent discoveries such as Waitsia, West and South Erregulla, and Lockyer Deep. Most wells lie in the northern onshore part of the basin, as do the commercial hydrocarbon accumulations (apart from Cliff Head) making this the second highest production region within the State's jurisdiction.

Reservoirs for the productive oil and gas fields within the northern Perth Basin are mostly within the Permian or Lower–Middle Jurassic with minor production from the Lower–Middle Triassic. Of the fields still in production:

- Senecio and Waitsia have gas in the lower Permian 'Kingia' and High Cliff Sandstones
- Cliff Head has oil in the lower Permian Irwin River Coal Measures
- Beharra Springs, Jingemia, Redback and Tarantula reservoirs are in the upper Permian Dongara Sandstone.

The Waitsia gasfield, discovered in 2014 by Senecio 3, is the largest onshore northern Perth Basin discovery to date with estimated gas reserves of 3.7 x 10<sup>9</sup> m<sup>3</sup> (1.3 Tcf) gas-in-place. Tight reservoirs in the basin have led to early depletion or shutting-in of some fields, or their remaining undeveloped. Gas in the basin is mainly dry with over 94% methane and minimal condensate. Associated oil is typically light and highly paraffinic, typically with high wax contents, pour points and saturated hydrocarbons.

## Prospectivity

The northern Perth Basin is the second highest petroleum-producing province under Western Australian jurisdiction after the inshore waters of the Northern Carnarvon Basin. Petroleum-system analysis indicates widespread mature source rocks, abundant reservoirs and favourable timing of structures for hydrocarbon entrapment. Seal is a critical factor owing to the intense faulting and high sand-to-shale ratio of the post-Lower Triassic succession. The success rate for wells in the northern part of the basin since 2001 has increased due to the application of 3D seismic surveys, most of which were conducted north of the Woodada field. In addition, viable deeper plays, as shown by the Permian Waitsia gasfield, are also present. Major play types include Permian–Triassic and Jurassic anticlines, and Permian–Triassic tilted fault blocks and stratigraphic traps.

Four petroleum systems have been identified within the basin (Fig. 17):

- Gondwanan 1 with a Permian source (e.g. Waitsia)
- Gondwanan 2 with a mostly Triassic source (e.g. Dongara, Cliff Head, Hovea and Mount Horner)
- Austral 1 with Jurassic sources (e.g. Walyering)
- Austral 2 with an Upper Jurassic – Lower Cretaceous source (e.g. the Gage Roads 1 oil show).

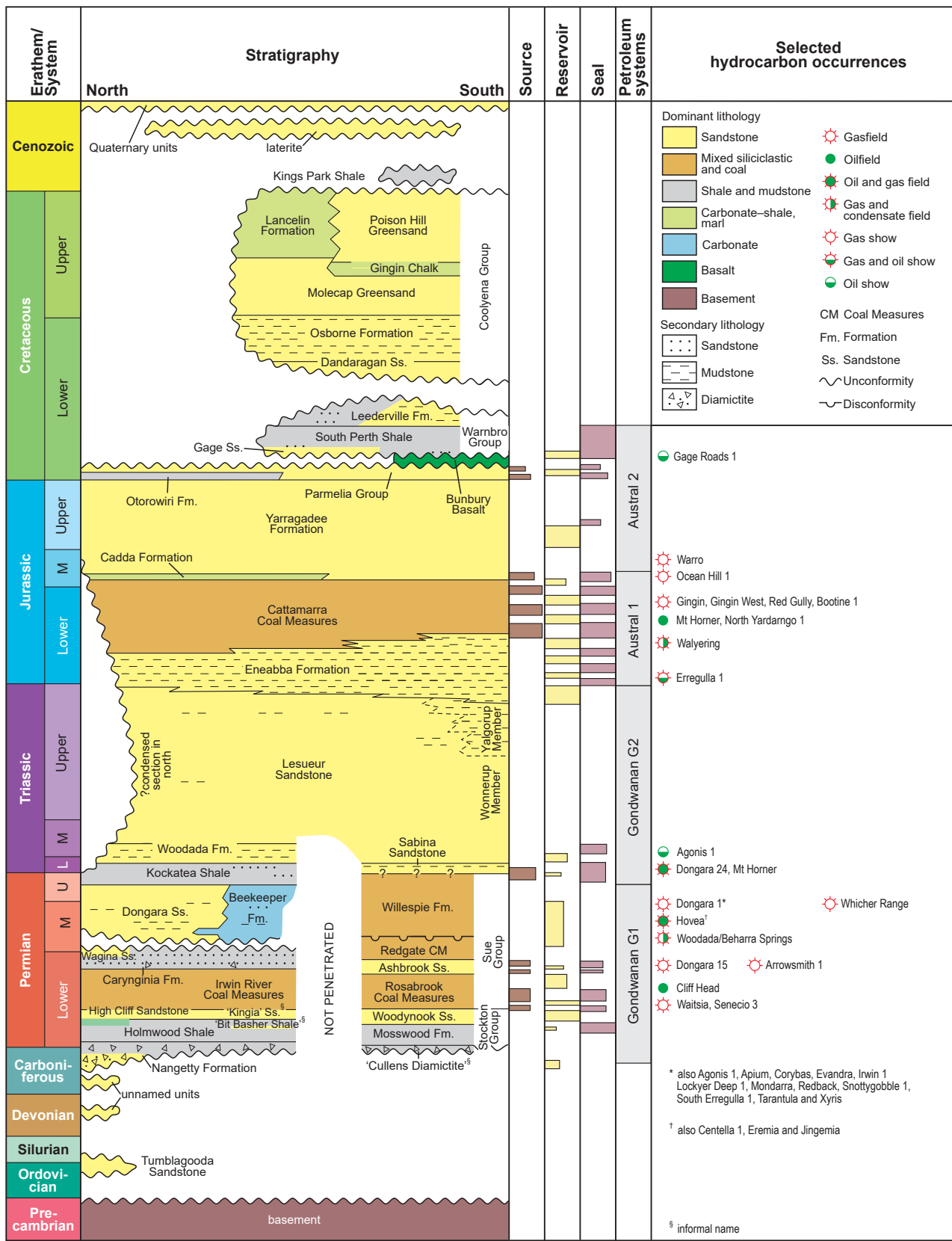
Whereas oil and gas production has decreased as fields deplete, deep gas resources have the potential to compensate for this decline, especially from fields such as Waitsia and West Erregulla with plays encompassing the High Cliff and 'Kingia' Sandstones.

Whereas the Permian to Cretaceous stratigraphic and structural evolution of the southern Perth Basin resembles that of the northern Perth Basin, the area may have poor sealing potential as there are no thick marine intervals or thick regional shales below the Cretaceous. Nevertheless, several wells in the region had hydrocarbon shows of which the most significant were gas flows on test from the Permian Sue Coal Measures in the Whicher Range wells; however, attempts to stimulate this reservoir were unsuccessful.

The northern Perth Basin has attracted interest in geothermal energy based on seismic reflection data and petroleum wells indicating suitable temperatures and reservoir properties to support power generation from depths >2500 m.

Given the number of now depleted, or nearing depletion, fields in the north of the basin, there is a high likelihood that some will be repurposed to store flammable gas or geosequester CO<sub>2</sub>. At present only Mondarra is used for temporary storage of natural gas but other fields may be required for such use if the capacity of the pipelines increases. Of the fields potentially available for H<sub>2</sub> storage,





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Figure 17. Stratigraphy and petroleum systems of the Perth Basin

Table 5. Perth Basin shows and fields

Year	Field/discovery	Hydrocarbon type	Reservoir	Age of reservoir	Status of fields
1964	Yardarino	gas	Dongara	mid- to late Permian	depleted
		oil, condensate	Carynginia/IRCM	early Permian	
1965	Mount Horner	oil	Cattamarra	Early Jurassic	depleted
			Arranoo	Early Triassic	
			Dongara	mid- to late Permian	
			IRCM	early Permian	
1965	Gingin	gas, condensate	Cattamarra	Early Jurassic	depleted
1965	Arrowsmith 1	gas show	Carynginia	early Permian	
1966	Dongara	gas	Dongara	mid- to late Permian	shut-in
		oil, condensate	Carynginia/ IRCM	early Permian	
		oil	Arranoo	Early Triassic	
1966	Erregulla 1	gas shows	Cattamarra/Eneabba	Early Jurassic	
		oil shows	Eneabba	Early Jurassic	
1968	Whicher Range	gas, oil show	Willespie	early Permian	undeveloped
1968	Mondarra	gas, condensate	Dongara	mid- to late Permian	depleted, now used for gas storage
		oil show			
1968	Gage Roads 1	oil show	Carnac	Early Cretaceous	
1971	Walyering	gas, condensate	Cattamarra	Early Jurassic	producing
1977	Warro 1	gas show	Yarragadee/Cadda	Jurassic	undeveloped
1980	Woodada	gas, condensate	Beekeeper	mid-Permian	depleted
1981	Warradong 1 <sup>‡</sup>	gas show	Dongara	mid- to late Permian	undeveloped
1981	Bootline 1	gas and oil shows	Cadda/Cattamarra	Early Jurassic	
1990	North Yordanogo 1	oil	Cattamarra	Early Jurassic	produced on test only
1990	Beharra Springs	gas, condensate	Dongara/Beekeeper	mid- to late Permian	producing
1991	Ocean Hill 1	gas show	Cadda/Cattamarra	Early Jurassic	undeveloped
2001	Hovea	gas, oil	Dongara	mid- to late Permian	shut-in
2002	Cliff Head	oil	IRCM	early Permian	producing
2002	Jingemia	oil, gas	Dongara	mid- to late Permian	shut-in
2004	Redback	gas	'Wagina'	late Permian	producing
2004	Xyris	gas	Dongara	mid- to late Permian	shut-in
2004	Apium	gas	Dongara	mid- to late Permian	shut-in
2004	Tarantula	gas	'Wagina'	late Permian	shut-in
2004	Agonis 1	gas	Dongara, 'Wagina'	mid- to late Permian	undeveloped
		oil	Woodada	Triassic	
2004	Centella 1	oil	Dongara	mid- to late Permian	undeveloped
2004	Xyris South 1	gas	Dongara	mid- to late Permian	shut-in
2005	Corybas 1	gas	IRCM	early Permian	shut-in
2005	Evandra	gas	Dongara	mid- to late Permian	shut-in
2006	Eremia <sup>*</sup>	oil, gas	Dongara	mid- to late Permian	shut-in
2006	Snottygobble 1	gas	Dongara, 'Wagina'	mid- to late Permian	suspended
2009	Gingin West	gas	Cadda/Cattamarra	Early to Middle Jurassic	shut-in
2009	Redback South 1	gas	'Wagina'	late Permian	suspended
2011	Red Gully	gas, condensate	Cadda/Cattamarra	Early to Middle Jurassic	shut-in
2014	Senecio 3 <sup>*</sup>	gas	High Cliff/'Kingia sandstone'	early Permian	producing
2015	Irwin 1	gas	Dongara	early Permian	undeveloped
2015	Waitsia	gas	High Cliff Sandstone	early Permian	producing
2019	West Erregulla	gas	'Kingia sandstone'	early Permian	undeveloped
2021	Lockyer Deep 1	gas	High Cliff/'Kingia sandstone'	early Permian	undeveloped
2022	South Erregulla 1	gas, condensate	'Wagina', 'Kingia sandstone'	early Permian	undeveloped
2023	Gynatrix 1	gas	'Kingia sandstone'	early Permian	suspended
2023	Trigg Northwest 1	gas	'Kingia sandstone'	early Permian	undeveloped
2023	Tarantula Deep 1	gas	'Kingia sandstone'	early Permian	undeveloped
2024	Erregulla Deep 1	gas	'Kingia sandstone'	early Permian	undeveloped

**NOTE:** + Determined in 2006 as a separate field to Jingemia, previously regarded as a pool within the Jingemia field

\* discovery well for the Waitsia gasfield

‡ considered to be within the Synaphea structure

smaller fields such as Xyris, Yardarino and Beharra Springs are highly rated, whereas Dongara may be unsuitable for such a purpose as it is too large or has been compromised by older, poorly completed wells.

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## Southern Carnarvon Basin

The Southern Carnarvon Basin covers approximately 190 000 km<sup>2</sup> west of the Precambrian West Australian Craton (Fig. 18). The onshore, primarily Paleozoic part of the basin has seen less exploration compared to the adjoining Permian–Mesozoic Perth and Northern Carnarvon Basins to the south and north, respectively.

## Geological setting

The elongate north-trending Southern Carnarvon Basin contains two principal structural elements: the western Gascoyne Platform, and the eastern Merlinleigh and Byro Sub-basins separated by the Proterozoic Carrandibby Inlier (Fig. 18). The Gascoyne Platform contains gently folded Ordovician to Devonian strata, unconformably overlain by a veneer of Mesozoic and younger rocks, which thicken to the west. In comparison, the Merlinleigh and Byro Sub-basins are characterised by an upper Carboniferous to Permian section, which is up to 7 km thick, underlain by a relatively thin Devonian – lower Carboniferous section. Thin Cretaceous and younger strata onlap onto the western edges of these sub-basins (Fig. 19).

Seismic data indicate that the breakup of Gondwana during the Mesozoic had the greatest impact on the structural evolution of the area and produced wrench-induced north- and northwest-trending faults, particularly along the western

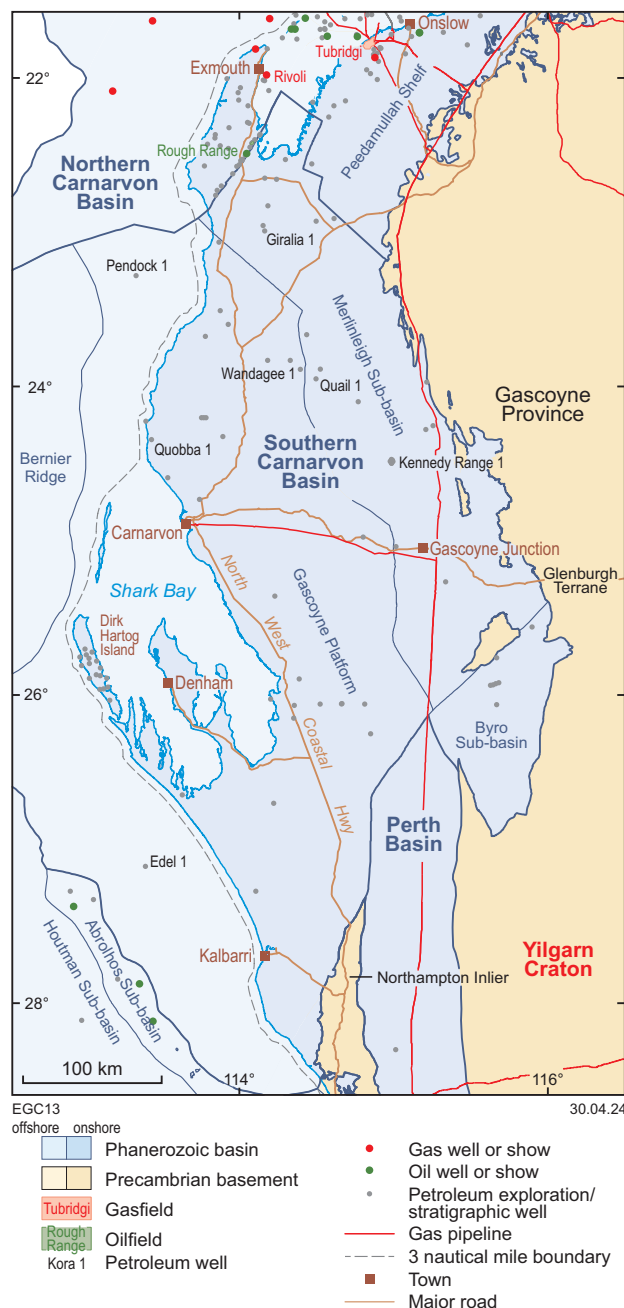
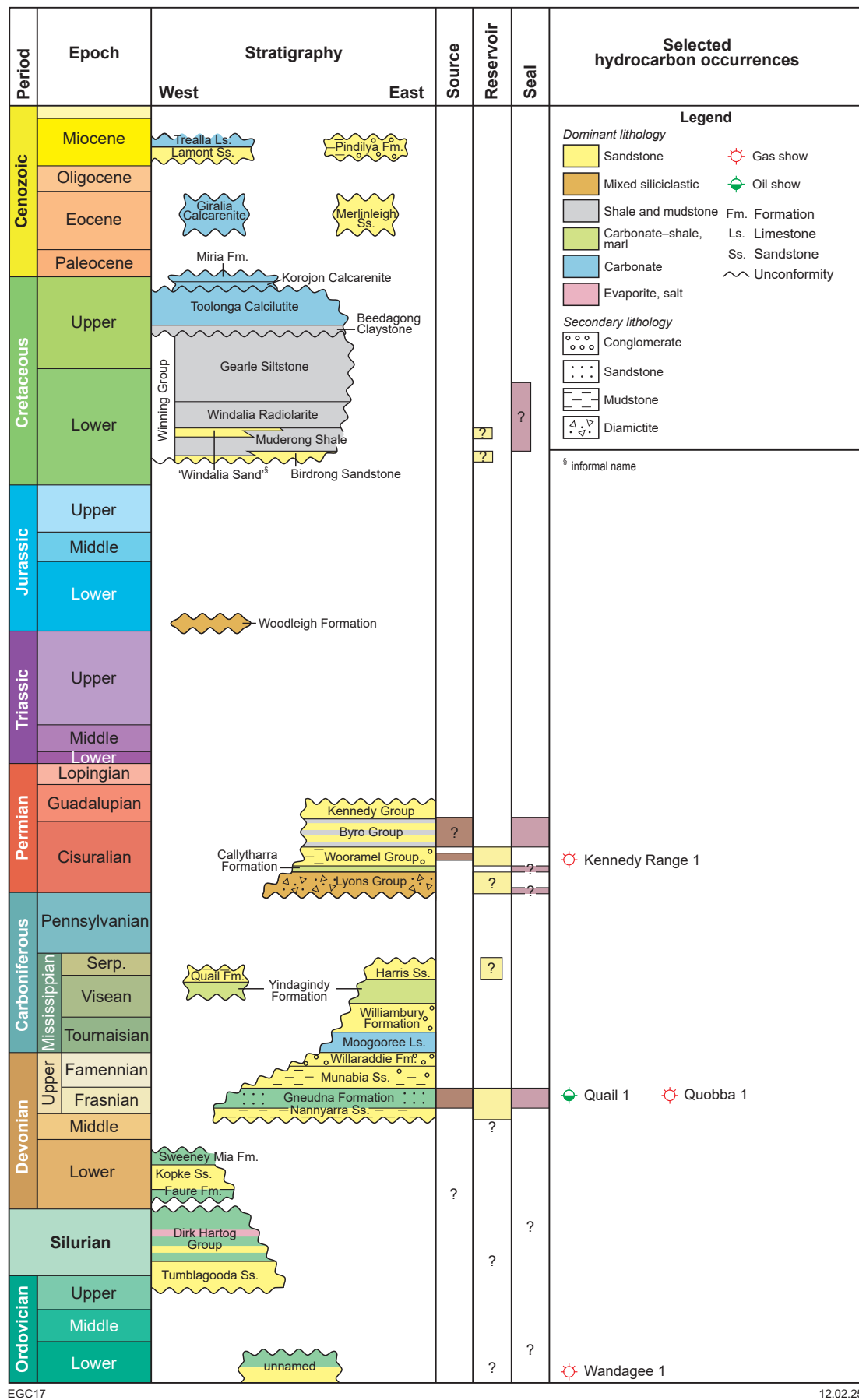


Figure 18. Southern Carnarvon Basin tectonic sub-divisions, pipelines, fields and selected wells

margin of the Merlinleigh Sub-basin, and long-wavelength folds. The collision of the Australian continent with the Indonesian Plate in the Miocene caused structural inversion and reverse movement on many faults previously dominated by normal movement as well as forming a series of broad folds, especially across the Gascoyne Platform.

## Exploration history

Petroleum exploration in the basin commenced in the 1930s, after WG Woolnough first drew attention to the prospectivity of the Wooramel River area, and following small gas shows in shallow water bores in the northern part of the region. Comprehensive exploration programs by WAPET in the 1950s and 1960s followed the company's oil discovery at Rough Range in the adjacent Exmouth Sub-basin of the Northern Carnarvon Basin — the field that was not produced until the 1990s. That exploration mostly focused on Cenozoic anticlines along faults in the Giralia – Rough



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Figure 19. Stratigraphy and petroleum systems of the Southern Carnarvon Basin

Range area, Dirk Hartog Island and Kennedy Range. As early drilling of these and other onshore coastal anticlines proved unsuccessful, by the mid- to late 1960s exploration activity had largely moved offshore to the Northern Carnarvon Basin.

Of the 88 onshore wells drilled in the Southern Carnarvon Basin, 61 were stratigraphic tests, 23 were new field wildcats and four cross the Rough Range Fault into the Merlinleigh Sub-basin. The only offshore wells are Edel 1 and Pendock 1. Of the 12 000 km of 2D seismic data acquired from 47 surveys in the onshore portion of the basin between 1951 and 2013, about two-thirds can be interpreted. The distribution of the lines is irregular with most shot in the Giralia – Rough Range area and next to the northwest Kennedy Range within the Merlinleigh Sub-basin.

## Prospectivity

There are few valid tests of hydrocarbon traps in the region, no hydrocarbon discoveries and few shows (Table 6). Lower Cretaceous sandstone facies were the main exploration objective in the northern part of the basin as they have excellent reservoir characteristics.

Seal adequacy and distance from effective source rocks are risks in the southern portion. Source rocks in lower Permian, Upper Devonian, and Silurian strata (Larapintine 2 and 3, Transitional, and Gondwanan petroleum systems, respectively) are typically thin and immature to mid-mature for hydrocarbon generation. Possible lower Permian source rocks are mostly gas prone with low productivity potential. By comparison, some thin Devonian–Silurian beds have good source characteristics. Burial of the

Cretaceous succession (Austral petroleum system) has been insufficient to generate hydrocarbons in this basin. Several structural highs adjacent to major faults along the eastern edge of the Gascoyne Platform may have provided vertical conduits for migrating hydrocarbons but remain untested.

Elevated temperatures in several artesian bores near the coast indicate potential for geothermal energy but such uses are presently limited to heating and cooling.

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Table 6. Southern Carnarvon Basin hydrocarbon shows

<i>Year</i>	<i>Discovery</i>	<i>Hydrocarbon type</i>	<i>Reservoir</i>	<i>Age of reservoir</i>
1962	Wandagee 1	Poor gas show	Tumblagooda Sandstone	Ordovician
1963	Quail 1	Trace oil	Gneudna Formation	Devonian
1966	Kennedy Range 1	Fair gas shows	Moogaloo Formation (Wooramel Group)	early Permian
1984	Quobba 1	High background C4	Gneudna Formation	Devonian
1986	Lefroy Hill 1	Minor dead oil shows	Windalia Radiolarite	Cretaceous
2001–02	Carlston 1	Poor gas show	Gneudna Formation	Devonian



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# SUMMARIES OF MAJOR NEOPROTEROZOIC AND PHANEROZOIC BASINS PROSPECTIVE FOR ENERGY-RELATED COMMODITIES, WESTERN AUSTRALIA

AJ Mory and PW Haines

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