



Regional Geology of the Browse Basin

The Browse Basin is one of a series of extensional basins that collectively form the offshore province of Australia's North West Shelf, comprising also the Bonaparte, Roebuck, Offshore Canning and Northern Carnarvon basins (**Figure 1**). The basin continues to be a premier exploration target and four hydrocarbon families/petroleum systems have been identified. In 2018, two main hydrocarbon accumulations, Ichthys and Prelude, commenced production of liquefied natural gas (LNG) and condensate. Overall, proved and probable reserves (2P) for the Browse Basin are estimated at 514 MMbbl (3022 PJ) of oil and natural gas liquids and 13.96 Tcf (15 701 PJ) of gas (EnergyQuest, 2022).

Basin outline

The Browse Basin is an extensional basin that underlies the North West Shelf region (Bradshaw et al, 1988). The basin is contiguous with the Rowley Sub-basin of the Roebuck Basin to the southwest, and the Vulcan Sub-basin and Ashmore Platform of the Bonaparte Basin to the northeast (**Figure 2**).

The Browse Basin covers an area of approximately 140 000 km², comprising the Caswell, Barcoo and Seringapatam sub-basins, the Scott Plateau, and the Yampi and Leveque shelves (**Figure 2**). The main depocentre is the Caswell Sub-basin that contains a Paleozoic, Mesozoic and Cenozoic sedimentary succession in excess of 15 000 m and is the main host of commercial hydrocarbon fields.

Over 200 petroleum exploration wells have been drilled in the basin since 1970. Coverage by 2D seismic surveys is extensive. Nearly complete coverage by 3D seismic surveys exists in the Caswell Sub-basin. The entire basin is covered by potential field data, including a high-resolution aeromagnetic survey flown in 2013 (Hackney and Costelloe, 2014).

Structural elements of the Browse Basin illustrated in **Figure 2** are based on the terminology introduced by Willis (1988), Elliot (1990), O'Brien et al (1993), Hocking et al (1994), Symonds et al (1994) and Struckmeyer et al (1998). A series of shallow basement elements, the Yampi and Leveque shelves, define the southeastern boundary of the basin. The central Browse Basin is divided into the Caswell and Barcoo sub-basins. The outboard deep-water part of the basin is known as the Scott Plateau.

Yampi Shelf and Leveque Shelf

The southeastern margin of the Browse Basin is underlain by shallow basement (**Figure 3**), which is typically highly eroded with a distinct, rugose palaeotopographic relief, and is overlapped by Permian to Mesozoic sediments (Struckmeyer et al, 1998). This area is termed the Yampi Shelf in the central and northern parts of the basin, and the Leveque Shelf to the south (Hocking et al, 1994). The basinward boundary of the Leveque and Yampi shelves is defined by a 'hinge' where the dip of the basement changes from relatively flat lying to gently basinward-dipping.

Caswell and Barcoo Sub-basins

The Caswell and Barcoo sub-basins (Hocking et al, 1994) are the major depocentres of the Browse Basin (**Figure 3** and **Figure 4**). In the Caswell Sub-basin, Paleozoic to Cenozoic sediments are greater than 15 000 m thick, whereas the maximum sediment thickness in the Barcoo Sub-basin probably does not exceed 12 000 m (Struckmeyer et al, 1998). The Caswell Sub-basin is significantly wider (200 km) than the Barcoo Sub-basin (100 km), from which it is separated by a major north to north-northeast trending structural zone, the Brecknock-Scott Reef Trend (**Figure 5**). The Prudhoe Terrace is a fault-bounded terrace at intermediate depth along the southeastern flank of the Caswell and Barcoo sub-basins (Hocking et al, 1994; Struckmeyer et al, 1998).

Scott Plateau

The Scott Plateau is a deep water (approximately 2000–4000 m water depth, **Figure 5**) marginal plateau to the west and northwest of the main Browse Basin depocentres where up to 3000 m of Mesozoic to Cenozoic rocks have accumulated over Paleozoic and older basement (Stagg and Exon, 1981). Hocking et al (1994) divided this region into the Scott Plateau and Seringapatam Sub-basin, but the boundaries of these tectonic elements are poorly understood (Struckmeyer et al, 1998). Outboard of the Brecknock-Scott Reef Trend, the Seringapatam Sub-basin is interpreted as a Callovian to Aptian graben overlain by an Aptian to Holocene prograding and aggrading wedge (Hoffman and Hill, 2004).

Basin evolution and stratigraphy

The Browse Basin stratigraphic scheme presented here (**Figure 6**) is based on that from the AGSO Browse Basin Project Team (1997) and Rollet et al (2016a). Formation boundaries and unconformity-bounded sequences have been calibrated to the timescale of Ogg et al (2016). The Browse Basin fill comprises six tectonostratigraphic phases (Struckmeyer et al, 1998):

1. Mississippian to Cisuralian (middle Carboniferous–early Permian) extension (Extension 1)
2. Cisuralian to Late Triassic thermal subsidence (Thermal Subsidence 1)
3. Late Triassic to Early Jurassic inversion (Inversion 1)
4. Early to Middle Jurassic extension (Extension 2)
5. Late Jurassic to Cenozoic thermal subsidence (Thermal Subsidence 2)
6. Middle Miocene to Holocene inversion (Inversion 2)

The basin was initiated as a series of intracratonic half-graben during the Mississippian to Cisuralian (Symonds et al, 1994). Upper crustal faulting resulted in characteristic half-graben geometry with large-scale normal faults compartmentalising the basin into distinct sub-basins. Structures resulting from this late Paleozoic extensional event controlled the location of subsequent reactivation events and the distribution and nature of the sedimentary fill (Struckmeyer et al, 1998; Lawrence et al, 2014).

A few wells located on the Yampi Shelf and eastern Caswell Sub-basin have penetrated the Permo-Carboniferous succession. The Carboniferous succession is dominated by fluvial-deltaic sediments, while the Permian sediments (mainly limestones and shales) were deposited in a marine environment. The oldest Triassic rocks penetrated in the Browse Basin are marine claystones, siltstones and volcanoclastic sediments that were deposited during a regional Early Triassic marine transgression. The overlying Triassic succession includes fluvial and marginal- to shallow-marine sandstone, limestone and shale.

The Permo-Triassic thermal subsidence phase was terminated by compressional reactivation in the Late Triassic to Early Jurassic, resulting in partial inversion of Paleozoic half-graben and the formation of large scale anticlinal and synclinal features within their hanging walls. This event is marked by a regional unconformity that is correlated with the Fitzroy Movement in the Canning and Bonaparte basins (Etheridge and O'Brien, 1994). The Brecknock-Scott Reef Trend developed at this time (Struckmeyer et al, 1998).

The Early to Middle Jurassic extensional phase resulted in widespread small-scale faulting and the collapse of the Triassic anticlines. Extensional faulting was concentrated in the northeastern part of the Caswell Sub-basin and along the adjacent outer margin of the Prudhoe Terrace. The Heywood Graben, located along the inboard northeastern Caswell Sub-basin (**Figure 2** and **Figure 5**), formed during this period (Struckmeyer et al, 1998). The Lower–Middle Jurassic syn-rift sediments (Plover Formation) comprise sandstone, mudstone and coal that accumulated in deltaic and coastal plain settings, and contain both reservoir and source rocks. Widespread erosion and peneplanation in the Callovian coincided with continental breakup and the initiation of sea-floor spreading in the Argo Abyssal Plain.

From the Late Jurassic to the Cenozoic, accommodation was controlled by the interplay of thermal subsidence, minor tectonic reactivation events, and eustasy. Upper Jurassic interbedded sandstones and shales (Vulcan Formation) onlap and drape the pre-Middle Jurassic structures, providing a thin, regional seal, and potential source rocks across the basin.

Geoscience Australia's regional study of the Cretaceous interval in the Browse Basin provides detailed interpretation of the sequence development (Abbott et al, 2015; Rollet et al, 2015, 2016a, 2016b). The Cretaceous basin fill is represented by a series of six, predominantly marine, supersequences (K10-K60, **Figure 6** and **Figure 7**) that prograded into the basin and onlapped the basin margin. The K10 comprises the upper Vulcan Formation mudstone and sandstone, and Brewster Member sandstone. The K20, K30 and K40 supersequences prograded successively further into the basin, filling the Caswell and Barcoo depocentres. These sequences are dominated by mudstone (Echuca Shoals Formation and Jamieson Formation), as the rate of relative sea level rise trapped sandstone facies (e.g. Heywood Formation) along the inboard basin margin. The Asterias Member (Echuca Shoals Formation, K30 supersequence) is attributed to a submarine fan depositional environment. A major flooding event, associated with the Cretaceous eustatic peak, resulted in a landward shift in deposition. Progradation resumed with deposition of K50 mudstone and marl (Woolaston and Brown Gannet formations). The basal K60 sequence boundary is marked by incision of several submarine canyon systems into older sediments. Progradation continued with deposition of the K60 supersequence, which comprises the mudstone-prone Fenelon and Wangarlu formations, and the sandstone-prone Puffin Formation. Submarine fans are a characteristic feature of the K60 supersequence (Lech et al, 2015). Rollet et al (2016c) used the Cretaceous sequence stratigraphic framework to formulate stratigraphic plays, revise the extent of potential and effective source rocks, and refine the understanding of petroleum systems in the basin.

Basin-wide inversion commenced in the middle to late Miocene as a result of the convergence of the Australia-India and Eurasia plates (Shuster et al, 1998).

Exploration history

The Browse Basin is one of the richest hydrocarbon-bearing basins in Australia. The Caswell Sub-basin and the Leveque and Yampi shelves lie in shallow to intermediate water depths and are mature in exploration terms, hosting significant gas accumulations and discoveries of gas and, to a lesser extent, oil. This contrasts with the Barcoo Sub-basin and deep water Scott Plateau and Seringapatam Sub-basin, which are underexplored (**Figure 2**). Over 200 wells have been drilled in the basin and over 180 000 km of 2D seismic and 46 000 km² of 3D seismic data have been acquired, most of which are open file.

Exploration commenced in the Browse Basin in 1967, when the North West Shelf Joint Venture acquired 1600 km of regional seismic data (Department of Mines and Petroleum, 2014). The first well drilled in the Browse Basin was Leveque 1 (1970), a stratigraphic test of the sedimentary succession on the Leveque Shelf (**Figure 2** and **Figure 5**) which recorded a gas show in the Cretaceous interval (**Figure 9**). This was followed by the discovery of gas at Scott Reef 1 in 1971. This well intersected a thick sequence of gas-bearing reservoirs within Lower–Middle Jurassic Plover Formation sandstones and Upper Triassic sandy dolostones of the Nome Formation on the southern culmination of a faulted anticline (Willis, 1988). Two appraisal wells, Scott Reef 2A in 1977 and North Scott Reef 1 in 1982, were drilled to further delineate the extent of the accumulation (Bint, 1988). No net hydrocarbon pay was assigned to the Scott Reef 2A well, but porosity evaluation in North Scott Reef 1 inferred reservoir facies with a net thickness of 122.9–134.2 m in Jurassic sediments. In 1979, Brecknock 1 tested a broad anticlinal feature 40 km southwest of Scott Reef. The well penetrated 68.3 m of net gas sandstone in Lower to Middle Jurassic sediments (Bint, 1988).

Discoveries during the early 1980s include Brewster 1A ST1 (1980), Caswell 2 ST2 (1983) and Echuca Shoals 1 (1983). Between 1984 and 1994, exploration was focused largely on the northern Caswell Sub-basin (**Figure 8**) with the drilling of Asterias 1 ST1 (1987), Gryphaea 1 (1987), Discorbis 1 (1989, **Figure 4**) and Kalypteia 1 ST1 (1989). Along the Leveque and Yampi shelves (**Figure 2**) Trochus 1 ST1 (1991), Arquebus 1 ST1 (1991, **Figure 4**), Sheherazade 1 (1993), Copernicus 1 ST1 (1993) and Yampi 2 (1994, **Figure 3**) were drilled. Many of the wells reported minor hydrocarbon shows from either Upper Jurassic or Lower Cretaceous reservoirs (Maung et al, 1994).

Evidence of the oil potential of the basin was demonstrated by the Gwydion 1 (1995) and Cornea 1 (1997) oil and gas discoveries, both located on the Yampi Shelf (**Figure 2**). These discoveries challenged the previous perception that the basin was gas-prone (Stein et al, 1998). Gwydion 1 intersected three gas-bearing zones and one oil and gas-bearing zone in Lower Cretaceous (Barremian to Albian) shallow marine sandstones draped over a prominent basement high (Spry and Ward, 1997). The Cornea 1, 1B and 2 wells encountered a 25 m gas column overlying an 18 m oil column in a Lower Cretaceous (Albian) reservoir (Ingram et al, 2000), and were followed by nearby oil and gas discoveries at Cornea South 1 and 2 ST1 and Focus 1, oil in Sparkle 1, and gas at Stirrup 1 and Macula 1 throughout 1997–1998 (**Figure 9**). In 1998, Psepotus 1 and Caspar 1A discovered small gas accumulations within Lower Cretaceous sandstones on the Leveque Shelf and Yampi Shelf, respectively (**Figure 9**). In the Caswell Sub-basin, Adele 1 (1998) discovered gas in the lower Jamieson Formation (**Figure 10**).

Drilling in 2000 resulted in the discovery of several major gas accumulations, as well as the extension of previously recognised gas provinces. These included Brecknock South 1, located on the Brecknock-Scott Reef Trend, 19 km south of Brecknock 1, and Argus 1 to the north of this trend. Further drilling on the Brewster structure, including the Titanichthys 1, Gorgonichthys 1 and Dinichthys 1 wells, better defined the extent of gas within the Plover (Ichthys) and Montara formations, as well as the Brewster Member of the Vulcan Formation (Ban and Pitt, 2006). Crux 1, drilled in the Heywood Graben in the northeastern Caswell Sub-basin, encountered a 280 m gross gas column in the Upper Triassic Nome Formation (**Figure 10**), with secondary reservoirs being found within the Plover and Montara formations (Kaoru et al, 2004).

In 2001–02, exploration targeting Lower Cretaceous lowstand fans and ponded turbidite for oil within the Caswell Sub-basin was unsuccessful (Carbine 1 and Firetail 1), apart from an interpreted possible gas pay zone in Marabou 1 ST1 (Benson et al, 2004).

In 2003, BHP Billiton Petroleum drilled the Maginnis 1, 1A, 1A ST1 and 1A ST2 wells to test the potential of the outer deep-water Caswell Sub-basin and eastern Seringapatam Sub-basin (**Figure 2**). Instead of the predicted Plover Formation reservoir, a thick volcanic section was intersected and no hydrocarbon shows were encountered (BHP Billiton Petroleum Pty Ltd, 2003). A second deep-water well, Warrabkook 1, was drilled by BHP Billiton Petroleum Pty Ltd in 2007 in the western Barcoo Sub-basin (**Figure 2**) and encountered a 450 m layered succession of interbedded tuffs and lava flows.

Further appraisal drilling in the Ichthys gas accumulation was undertaken in 2003-04 (Ichthys 1, 1A, Ichthys 2, 2A, 2A ST1, 2A ST2 and Ichthys Deep 1) by INPEX. Gas is primarily reservoired within the upper Vulcan Formation (Brewster Member) and Plover Formation. Gas was also encountered within Callovian sandstones (reported as the Ichthys Formation, but included within the Montara Formation on **Figure 6** and **Figure 10**), and in basal Oxfordian sandstones of the lower Vulcan Formation (Ban and Pitt, 2006).

Extensive drilling continued in the central Caswell Sub-basin from 2007 to 2010 (Shell - 14 wells, INPEX - 3 wells, and Santos - 2 wells), with gas discoveries at Prelude 1A, Fortissimo 1, Mimia 1, Concerto 1 ST1, Concerto 2 ST1 and Burnside 1 ST1 (Le Poidevin et al, 2015).

Evaluation of the gas accumulations along the Brecknock-Scott Reef Trend also continued in 2005-09, with Woodside drilling the extension/appraisal wells Torosa 1, 2, 3, 4, 5 and 6, Brecknock 2, 3 and 4, and Calliance 1, 2 and 3, as well as the Snarf 1 exploration well on the edge of the Caswell Sub-basin close to the Seringapatam Sub-basin (**Figure 8**).

Nexus Energy Ltd continued the appraisal of the Crux gas accumulation in 2006-08 with the drilling of the Crux 2 ST1, 3 and 4 wells, which encountered gas-bearing sands in the Montara, Plover and Nome formations (Nexus Energy Ltd, 2007a, 2011). The Libra 1, Octans 1 and Hippolyte 1 exploration wells tested the potential of the greater Crux area. Libra 1 and Octans 1 intersected gas-bearing sands in an accumulation interpreted to be separate from the Crux accumulation (Nexus Energy Ltd, 2011), and Hippolyte 1 intersected a 55 m gas column in the Jurassic Montara Formation (Shell Development [Australia] Pty Ltd, 2011).

Fossetmaker 1 was drilled 7 km east-northeast of Echuca Shoals 1 (**Figure 8**) and intersected an approximately 10 m gas zone, but pressure communication with Echuca Shoals 1 was unable to be determined due to tight reservoir characteristics (Nexus Energy Ltd, 2007b). In 2009, Hawkestone Oil Pty Ltd drilled Braveheart 1 ST1 to test a Barremian submarine fan play which yielded indications of residual hydrocarbons (Exoil Ltd, 2010; Rollet et al, 2016a). Woodside Energy Ltd drilled Omar 1 in 2011 to test Lower Jurassic Plover Formation and Triassic Nome Formation targets within a faulted anticlinal trend in the eastern Barcoo Sub-basin (Woodside, 2012b). All sandstone intervals were water bearing and the well was plugged and abandoned. Eupheme 1 was spudded in December 2012 in the far southwest of the Caswell Sub-basin (**Figure 8**) to test the stratigraphic section below the 'Main' Jurassic unconformity (Murphy Australia WA-423-P Oil Pty Ltd, 2013). The well failed to encounter significant hydrocarbons, and was plugged and abandoned.

In 2009-14, joint venture partners ConocoPhillips (Browse Basin) Pty Ltd and Karoon Gas Australia Ltd completed a multi-well drilling program to the northeast of the Torosa accumulation in the central Caswell Sub-basin. The program was principally designed to test Plover Formation and Montara Formation targets in tilted fault blocks associated with a northeast trending structural high referred to as the Greater Poseidon Trend. Poseidon 1 intersected three gas-bearing sandstone packages of 10 m, 67 m and 140 m gross thickness in the Plover Formation (ConocoPhillips, 2011b). Poseidon 2 intersected the same three Plover Formation sandstone packages, as well as a new gas reservoir in the overlying Montara Formation (Karoon Gas Australia Ltd, 2010a). Kronos 1 discovered gas in the Plover Formation, which flowed at an equipment-constrained 26 MMscf/d (0.7 MMm³/d; Karoon Gas Australia Ltd, 2010b). Pressure data confirmed the Kronos area is a separate gas accumulation, with a gas-water contact potentially over 200 m deeper than that at Poseidon 1 (Karoon Gas Australia Ltd, 2010b). Kontiki 1 intersected gas saturation in poor reservoir quality sands (ConocoPhillips, 2010).

A second phase of the ConocoPhillips (Browse Basin) Pty Ltd and Karoon Gas Australia Ltd joint venture commenced in 2012 with Boreas 1 which flowed gas from the primary Plover Formation reservoir (Karoon Gas Australia Ltd, 2012). Zephyros 1 penetrated gas-bearing Plover Formation sandstones that were interpreted to have high mobility values (Karoon Gas Australia Ltd, 2013a). Wireline logging in Proteus 1 indicated multiple gas-charged reservoirs within the Jurassic, with an 87 m gross reservoir with high net pay (Karoon Gas Australia Ltd, 2013b). Proteus 1 ST2 successfully flowed gas and condensate through Jurassic rocks of the Plover and Montara formations. Production wells adjacent to Proteus 1 are predicted to flow at commercial rates in excess of 100 MMcf/d (2.831 MMm³/d; Karoon Gas Australia Ltd, 2013c). Poseidon North 1 encountered Jurassic gas-bearing sands across a 20 m gross, 12 m net reservoir interval (Karoon Gas Australia Ltd, 2014a). Pharos 1 (2014) targeted an extension of the discovery of gas-bearing Montara Formation reservoirs at Proteus 1 and intersected movable hydrocarbons in the gas-charged Montara Formation across a 53 m gross interval with 34 m interpreted net pay (Karoon Gas Australia Ltd, 2014b). Grace 1, located to the north of the Greater Poseidon Trend, intersected Jurassic volcanics, and no significant hydrocarbons were encountered (Karoon Gas Australia Ltd, 2014c).

Santos Ltd and joint venture partners tested a number of faulted structural high prospects in the central Caswell Sub-basin between 2012 and 2014. The main target was Jurassic reservoirs within Triassic-Jurassic horsts. Crown 1 intersected 61 m of net gas pay in the Jurassic Montara and Plover reservoirs (Santos Ltd et al, 2013). Bassett West 1 (**Figure 4**), operated by joint venture partner Total E&P Australia, intersected 7.5 m of gas pay in Jurassic sandstones. Jurassic gas in the Plover Formation was the target of Dufresne 1 (Total E&P Australia, 2014) but the well did not intersect economic hydrocarbons. Lasseter 1 was a gas-condensate discovery, with 78 m confirmed net gas/condensate pay in the Jurassic lower Vulcan and Plover formations (Santos Ltd, 2014).

Hunt Oil spudded Schooner 1 in 2014 to the west of the Burnside gas field (Hunt Oil Australia Permit 425 Holding Company Pty Ltd, 2014). The main target was a stratigraphic pinchout of the Brewster Member associated with a roll-over anticline. Secondary targets were other Vulcan Formation sandstones and the Plover Formation. The well encountered gas shows in the Echuca Shoals and Plover formations before reaching Jurassic altered volcanics (Hunt and Schlumberger Geoservices, 2014). Pryderi 1 was spudded by CalEnergy Resources on the Yampi Shelf near Gwydion 1 in October 2014 to test an interpreted extension of the Barremian *M. australis* sandstone play (Energy-pedia, 2014; CalEnergy Resources, 2015). The well was dry with some residual oil shows. A hydrocarbon discovery was made in 2015 by Shell drilling Auriga West 1 in (OE Digital, 2015) in the northern Caswell Sub-basin near the Crux gas field. In 2019 Shell drilled the well Bratwurst 1, also in the vicinity of the Crux gas field. The well targeted Plover Formation reservoirs at approximately 4300 to 4500 m depth and was announced a significant gas and condensate discovery (Shell Australia, 2019a, 2019b).

IPB Petroleum are progressing plans to drill the Idris prospect with Quay Resources farming in for a 50% share of WA424-P in 2020, and drilling is expected in 2022 (Energy News Bulletin, 2020). The prospect consists of a stratigraphic trap up-dip of the Gwydion 1 discovery, with the oil leg sampled at Gwydion interpreted to lie below the structural spill point. IPB Petroleum estimate a significant accumulation with a prospective resource of 69 MMbbls of recoverable oil (IPB Petroleum, 2018).

Regionally significant 2D seismic surveys acquired in recent years are NWS Australia 2D Geostreamer (PGS, 2017a) and WestraliaSPAN (ION, 2017). These are deep regional surveys that extend across the North West Shelf and each includes several lines within the Browse Basin.

Much of the 3D seismic survey acquisition in the Browse Basin in recent years has focussed on undrilled or sparsely drilled areas with little or no 3D coverage. Lord 3D, Admiral 3D, Curt 3D and Rafter 3D (all commissioned by Woodside Energy Limited) occur within, or extend into, the Barcoo Sub-basin. Sandman 3D and Kraken 3D (both commissioned by Karoon Gas Australia) are located in the Seringapatam Sub-basin.

Other recent 3D surveys were acquired in the Caswell Sub-basin to improve resolution in areas with existing 3D coverage. Rosebud 3D (Shell Development Australia) is located over the Torosa gas field. Caswell 3D is centred north of the Ichthys gas field (PGS, 2017b). Schild 3D Phase 1 and Schild 3D Phase 2, are located west of the Ichthys gas field and in the Echuca Shoals area, respectively (CGG, 2017; Grahame, 2018). Cygnus 3D regional multi-client survey has been acquired to enhance Triassic structure and Jurassic reservoirs over an area that includes the Crux gas field (Spectrum, 2016). The survey was completed in four phases between late 2015 and early 2020 resulting in a contiguous dataset covering more than 7200 km² across the southern half of the Vulcan Sub-basin and eastern most Browse Basin (NOPIMS, 2022). Acquired in late 2019 and early 2020, Factory 3D (Shell Australia) covers an area of 3745 km² across the north-eastern Caswell Sub-basin (NOPIMS, 2022). Most recently the seismic survey is the Mimosa 2D MSS was completed in early 2022, 11 306 line km were acquired across the INPEX held WA-532-P, WA-533-P and WA-50-L in the Browse and Offshore Canning basins (NOPIMS, 2022).

Geoscience Australia has conducted marine surveys of the Leveque Shelf (Picard et al, 2014) and Caswell Sub-basin (Nicholson et al, 2015; Howard et al, 2016). The surveys collected data in support a CO₂ storage assessment study that was part of the National CO₂ Infrastructure Plan. In addition to acquiring shallow geological, water column, and seabed habitat data, the surveys aimed to identify and sample features indicative of active or extinct natural fluid seepage.

Production and development

The Browse Basin is a producing hydrocarbon province delivering gas and condensate from the large Ichthys and Prelude gas accumulations since October 2018.

Ichthys LNG Project

This project (Production Licences WA-50-L and WA-51-L) is operated by INPEX Browse Ltd (INPEX, 66.2%) with joint venture partners Total (26%), CPC Corporation (2.6%), Tokyo Gas (1.6%), Osaka Gas (1.2%), Kansai Electric Power Australia (1.2%), JERA (0.7%), and Toho Gas (0.4%). INPEX announced the final investment decision (FID) in 2012 for an offshore central processing facility (CPF) and a floating production, storage and offloading (FPSO) facility, connected by an 890 km gas pipeline to a liquefaction plant and export terminal in Darwin (INPEX, 2020). The natural gas is processed in Darwin, while condensate is produced via a FPSO that is permanently moored near the gas field. The project commenced production in 2018 and it is expected that the field will have a 40 year life span. In the 12 months to March 2022 8.19 Mt of LNG, 29.11 MMbbls of condensate and 1.639 Mt of LPG were produced (EnergyQuest, 2022). As of February 2021, the Ichthys gas field held an estimated 11.9 Tcf (13 384 PJ) of natural gas and approximately 451 MMbbl (2652 PJ) of condensate (EnergyQuest, 2021).

Prelude FLNG

The Prelude accumulation is situated in the north-eastern area of the Ichthys accumulation. Shell Development Australia Pty Ltd (Shell, 67.5%) is the operator of Production Licence WA-44-L in which the Prelude and Concerto gas accumulations occur, with partners INPEX (17.5%), KOGAS Prelude Pty Ltd (10%) and CPC (5%). Shell announced the FID for a Floating LNG (FLNG) project in 2011 for production from the Prelude and Concerto gas accumulations. The Prelude FLNG facility arrived at its location in July 2017 and the hook-up and commissioning phase of the project was completed in 2018. The first volume of condensate was produced in December 2018 and the first LNG cargo was shipped in June 2019 (Shell Australia Ltd, 2019). In the 12 months to March 2022 production totalled 1.728 Mt of LNG, 7.127 MMbbls of condensate and 202 000 tonnes of LPG (EnergyQuest, 2022).

Browse FLNG

The Browse FLNG project aims to commercialise the Torosa, Brecknock and Calliance gas accumulations and is operated by Woodside Petroleum Limited (Woodside, 30.6 %) with joint venture partners Shell Australia (27.0%), BP Developments Australia Pty Ltd (17.3%), Japan Australia LNG (MIMI Browse) Pty Ltd (14.4%), and PetroChina International Investment (Australia) Pty Ltd (10.7%). Following initial work assessing the possibility of production via a FLNG, the Browse Joint Venture participants and the North West Shelf (NWS) Joint Venture are progressing commercial discussions and joint technical studies on the feasibility of NWS infrastructure processing the Browse resources. The proposed offshore development concept involves two gas FPSO facilities delivering 10 Mtpa of LNG, 1.4Mtpa of domestic gas and 50 Mbbl/d of condensate via a 900 km pipeline to existing production facilities at the North Rankin complex (Woodside, 2019). Woodside as operator of the NWS was targeting FID on toll processing of gas in 2019-2020, with start-up in 2026 (EnergyQuest, 2019), but due to financial constraints has delayed the decision on development of the projects 13.9 Tcf of gas and 390 MMbbl of condensate until at least 2023 (EnergyQuest, 2021).

A map showing the current main operators, active exploration permits, retention leases and production licences is provided by **Figure 11**. The same map showing current permits and licences as well as oil & gas fields and pipelines is shown in **Figure 12**.

Regional petroleum systems

Geochemical analyses of oils, oil stains, fluid inclusion oils, condensates, gases and source rocks from the Browse Basin have been undertaken by AGSO and Geotech (2000), Boreham et al (1997, 2001), Blevin et al (1998a, 1998b), Edwards et al (2000, 2004, 2006, 2014, 2016), Edwards and Zumberge (2005), Grosjean et al (2015, 2016), Palu et al (2017a, 2017b) and Volk et al (2005). Stable carbon isotopic data of gases and oils have been used to determine the different sources of hydrocarbons (**Figure 13**) in this basin (Edwards et al, 2014, 2016; Grosjean et al, 2015, 2016). These isotopic datasets, together with molecular analyses, provide evidence that four Mesozoic hydrocarbon families/petroleum systems are present in the Browse Basin (**Figure 13**; Kennard et al, 2004; Edwards et al, 2014, 2016; Grosjean et al, 2015, 2016; Le Poidevin et al, 2015; Rollet et al, 2016a; Palu et al, 2017a, 2017b):

- A basin wide dry gas-prone system where the gas is mostly reservoirised within the Plover Formation and sourced from mixed terrestrial and marine organic matter deposited in a fluvial-deltaic environment. The gas accumulations in Jurassic reservoirs on the Scott Reef Trend (Brecknock and Torosa), and potentially those further along its northerly extent (Crown/Proteus and Poseidon), as far as Argus, belong to this petroleum system and have condensate to gas ratios that range from 39 cm³/m³ to 196 cm³/m³ (Edwards et al, 2016). The Plover-reservoirised gases within the central Caswell Sub-basin at the Ichthys and Concerto accumulations are also attributed to this petroleum system (Rollet et al, 2016a). The most likely source for these gases is the Lower–Middle Jurassic Plover Formation (Edwards et al, 2014, 2016; Grosjean et al, 2015), although an alternative, and less preferred scenario, is a Permo-Triassic source which has been modelled by Belopolsky et al (2006). In addition, Plover-sourced gas is also found to have migrated onto the basin's easterly margins based on geochemical evidence obtained from the dry gases recovered from shallow Cretaceous reservoirs on the Yampi Shelf (Grosjean et al, 2016). It is likely that gas in Psepotus 1 and gas shows in Leveque 1 also represent Plover-sourced gases but no data are available to confirm this.
- A central sub-basin wet gas-prone system reservoirised in the Brewster Member of the upper Vulcan Formation and including the Ichthys and Prelude/Concerto accumulations (condensate to gas ratio of 337 cm³/m³). The Burnside gas accumulation, southwest of Ichthys, represents an extension of this system (Grosjean et al, 2015), as could the interpreted condensate-rich gas at Echuca Shoals (Rollet et al, 2016a). These accumulations are most likely sourced from within the marine Jurassic Vulcan Formation (Grosjean et al, 2015; Edwards et al, 2016).
- An oil- and gas-prone petroleum system sourced from mixed marine and terrestrial organic matter within the Lower Cretaceous sediments of the Echuca Shoals Formation (Blevin et al, 1998a). This petroleum system is believed to have sourced the oil within the Caswell structure in the Caswell Sub-basin and the greater Cornea and Gwydion structures on the Yampi Shelf. It has also sourced the gas

within the Kalypteia, Rondo and Adele structures in the Caswell Sub-basin (Edwards et al, 2016). A thermogenic hydrocarbon signal found in a shallow core sediment along the southern flank of the Ashmore Platform was found to be geochemically similar to Echuca Shoals sourced oils and may represent an extension of this petroleum system to the northwest (Stalvies et al, 2017).

- The Crux gas condensate discovery in the far northeastern portion of the basin (Heywood Graben) is interpreted to be sourced from predominantly terrestrial organic matter within Jurassic source rocks (Edwards et al, 2004, 2014, 2016; Grosjean et al, 2015) and represents a fourth hydrocarbon family in the basin. The satellite Libra and Octans gas accumulations, and the nearby Hippolyte gas accumulation, may also belong to this petroleum system.

Petroleum Systems Elements

Sources	<ul style="list-style-type: none"> • Aptian–Cenomanian marine Jamieson Formation • Valanginian–Aptian marine Echuca Shoals Formation • Callovian–Valanginian marine Montara and Vulcan formations • Lower–Middle Jurassic fluvial-deltaic Plover Formation
Reservoirs	<ul style="list-style-type: none"> • Upper Cretaceous shallow marine and submarine fans of the Puffin and Fenelon formations • Albian lower to upper shoreface marine sandstones of the Heywood Formation • Aptian marine <i>D. davidii</i> sands (informal) of the lower Jamieson Formation • Barremian shallow marine <i>M. australis</i> sands (informal) and submarine fans of the Asterias Member (both Echuca Shoals Formation) • Upper Jurassic–Lower Cretaceous marine sandstones of the upper Vulcan Formation (including the Berriasian Brewster Member) • Middle–Upper Jurassic marine Montara and lower Vulcan formations • Lower–Middle Jurassic fluvial-deltaic sandstones of the Plover Formation • Upper Triassic deltaic marine sandstones of the Nome Formation
Seals	<p><i>Regional Seals</i></p> <ul style="list-style-type: none"> • Lower Cretaceous marine Echuca Shoals and Jamieson formations • Upper Jurassic–Lower Cretaceous marine Vulcan Formation <p><i>Intra-formational Seals</i></p> <ul style="list-style-type: none"> • Upper Cretaceous marine Puffin Formation • Lower–Middle Jurassic fluvial-deltaic Plover Formation
Traps	<ul style="list-style-type: none"> • Triassic, Jurassic and earliest Cretaceous horsts, tilted fault blocks, and roll-over anticlines associated with Triassic–Jurassic extension • Compactional or fault propagation ‘drapes’ over extensional structural highs • Oxfordian shoreface/barrier bar sandstones of the Montara Formation • Cretaceous submarine canyon fill and basin floor fans • Upper Triassic Challis and Nome Formations, fluvial-deltaic sandstones of the Middle Jurassic Plover Formation, Oxfordian shoreface/barrier bar sandstones of the Montara Formation, Tithonian submarine fans of the upper Vulcan Formation and submarine fans of the Upper Cretaceous Puffin Formation

Source Rocks

A comprehensive assessment of the source rock potential of the Browse Basin was undertaken by Boreham et al (1997) and Blevin et al (1998a, 1998b) and revisited recently by Palu et al (2017a, 2017b) and Rollet et al (2016c, 2017, 2018). These studies recognised organic-rich rocks with fair to moderate oil potential at numerous stratigraphic levels within the Permian to Lower Cretaceous succession (**Figure 14**). Although many possible source units within this succession have liquid potential with Hydrogen Index (HI) values of >200 mg HC/gTOC, most of them contain less than 2% TOC. At these low-to-moderate TOC levels, any generated oil may not be expelled and could be subsequently cracked to gas at higher maturities.

Thin coals and pro-delta shales with high source potential occur sporadically within the thick succession of Lower–Middle Jurassic Plover Formation sediments that extend throughout the Caswell Sub-basin and reach a maximum penetrated thickness within the Barcoo Sub-basin (920 m in Barcoo 1; **Figure 14**). This section is dominated by fluvial-deltaic sediments, including pro-delta shales and coastal plain shaly coals that have significant source potential (Blevin et al, 1998b). Hydrocarbons generated from this succession are likely to be dominated by gas rather than oil. However, localised source rocks in the Heywood Graben, on the southern Scott Reef Trend and inboard Barcoo Sub-basin associated with particular biozones have some oil potential (Rollet et al, 2018).

The Upper Jurassic Vulcan Formation is generally thin throughout the Browse Basin, with major sediment thickening occurring towards the Heywood Graben in the northeast (**Figure 14**), where restricted marine source facies are likely to be best developed (Rollet et al, 2018). Localised thickening of Upper Jurassic sediments also occurs on the Leveque Shelf and Prudhoe Terrace, but here the section is dominated by deltaic facies with poorer quality terrigenous organic matter.

Thick marine claystones within the Lower Cretaceous Echuca Shoals and Jamieson formations occur within both the Caswell and Barcoo sub-basins and contain mixed marine and terrestrial organic matter with moderate source potential. Rollet et al (2016c) have used a sequence stratigraphic framework to refine the mapped distribution of potential and effective Cretaceous source rock pods.

Reservoirs and seals

Caswell Sub-basin

Exploration activity has focused on the Caswell Sub-basin, where the Upper Jurassic–Lower Cretaceous upper Vulcan and Lower Cretaceous Echuca Shoals and Jamieson formations form the regional seal. The thick (500–600 m) Callovian–Cenomanian claystone seal exceeds the throw of the faults within the underlying reservoirs, ensuring an adequate lateral seal across much of the basin. Sections within the lower Vulcan Formation also form adequate seals for Plover Formation reservoirs. Potential intraformational seals occur within the Plover Formation (Blevin et al, 1998b), while marls and mudstones provide potential seals for Campanian–Maastrichtian turbidites and submarine fan sandstones in the Puffin Formation (Benson et al, 2004). The influence of basement controlled drainage patterns on the Kimberley Block hinterland has had a profound effect on the distribution of reservoirs and seals (Tucker, 2009).

The Lower–Middle Jurassic Plover Formation and the Berriasian Brewster Member of the upper Vulcan Formation are the most laterally extensive reservoirs across the Caswell Sub-basin. Oil and gas shows also occur in locally developed sandstones of the Middle–Upper Jurassic Montara Formation, and in submarine fans and turbidites of Barremian, Campanian and Maastrichtian age (Le Poidevin et al, 2015; Rollet et al, 2016a).

The Ichthys, Prelude, Concerto and Mimia gas accumulations are collectively reservoirised within the Plover, Montara and upper Vulcan (Brewster Member) formations. The Plover Formation at these locations comprises a fluvial-deltaic sandstone and mudstone succession with marine affinities towards the top. The main reservoir is characterised by cross-bedded channel sandstone. The top of the Plover Formation is associated with the regional Callovian unconformity; however, at Ichthys, the unconformity is poorly expressed with the estuarine to paralic sandstones of the Plover Formation passing into lagoonal and barrier island clastics of the 'Ichthys Formation', and then into the shoreface and shelfal sandstones of the basal Montara Formation and lower Vulcan Formation (Ban and Pitt, 2006; Le Poidevin et al, 2015). The Montara Formation is a thinner, secondary reservoir of localised extent, consisting of prograding fan-delta systems. The Brewster Member is a thick sequence of clean, relatively high net/gross sands (Arsalan et al, 2017) that often exhibits poor to moderate reservoir properties.

The Crux structure within the Heywood Graben in the northeastern Caswell Sub-basin hosts gas within the Upper Triassic Nome Formation, Lower–Middle Jurassic Plover Formation and Middle–Upper Jurassic Montara Formation (Le Poidevin et al, 2015). The Nome Formation was deposited in a high-energy fluvial environment and comprises quartz-rich, medium- to very coarse-grained sandstone with interbedded siltstone, mudstone and minor coal. Unlike those of the Nome Formation, the Plover Formation sandstones are fine- to very fine-grained and are interbedded with occasional medium to coarse grained sandstones, siltstones, claystones and minor coals.

Brecknock-Scott Reef Trend

The upper Plover Formation is the main reservoir at the Brecknock and Calliance accumulations, while the lower Plover Formation acts as the main reservoir at Torosa. The older sandstones were deposited in a fluvial-dominated upper delta plain with the younger sandstones reflecting deposition in a more tidally influenced lower delta plain environment. Tuffaceous volcanics are also present at some locations within the lower Plover Formation (Tovaglieri et al, 2013)

Yampi Shelf

The Cornea oil and gas accumulation on the Yampi Shelf is reservoirised within the Cretaceous Heywood Formation, in which fine- to very fine-grained sandstones of Albian age were deposited in a shoreface environment. The primary seal is a marine Albian claystone; however, it shows elevated gas readings at some locations and only provides a partial seal. Gwydion 1 discovered three gas-bearing zones and one oil- and gas-bearing zone in shallow marine sandstones of the Echuca Shoals Formation to upper Heywood Formation in a small closure draped over a prominent basement high. A follow-up well, Caspar 1A, discovered gas and residual oil in a small structure on the migration path to the Gwydion accumulation (Le Poidevin et al, 2015; Rollet et al, 2016a).

Timing of generation

Hydrocarbon expulsion modelling (Kennard et al, 2004; Palu et al, 2017a, 2017b) indicates multiple effective source units for gas expulsion in the basin, whereas effective oil charge is largely restricted to the Heywood Graben in the northeast, the central and southern Caswell Sub-basin, and possibly the rift section beneath the deep-water Scott Plateau and Seringapatam Sub-basin (**Figure 15** and **Figure 16**).

Modelling suggests significant quantities of gas were expelled from the Plover Formation throughout the Browse Basin, including the southern, outer and northeastern Caswell Sub-basin, Seringapatam Sub-basin and parts of the Barcoo Sub-basin. This gas expulsion occurred during the Late Cretaceous until the present (Palu et al, 2017a, 2017b). Further to the northeast, oil was expelled from Jurassic sediments in the Plover Formation in the Heywood Graben during the Paleogene and Neogene and the lower Vulcan Formation during the Neogene (Kennard et al, 2004). Fluid inclusion analysis indicates that these Jurassic sediments are the likely source of the thick palaeo-oil columns interpreted in Heywood 1 and Crux 1 (Eadington and Middleton, 2000; Brincat et al, 2004). Lesser quantities of oil are modelled to have been expelled from the Vulcan Formation in the central and southern Caswell Sub-basin. An investigation of the fluid inclusions in the gas reservoirs of the Browse Basin has shown that the hydrocarbon charge consisted of an early oil charge, filling only the crests of the structures before being either displaced or absorbed by gas (CSIRO Petroleum, 2002). Only relatively minor gas expulsion, but no oil, is predicted to have occurred in the Barcoo Sub-basin where source rocks are generally leaner (Kennard et al, 2004; Palu et al, 2017a, 2017b). If the Jurassic units of the Seringapatam Sub-basin contain good quality source rocks, then significant quantities of oil and gas could have been expelled during the Paleogene (Kennard et al, 2004).

Hydrocarbon generation and expulsion studies of Lower Cretaceous (Echuca Shoals and Jamieson formations) source rocks using Small Angle Neutron Scattering (SANS), confirm the existence of potential source rocks that are sufficiently thermally mature to generate both oil and gas, but which show either little or no evidence of expulsion or effective regional charge (Radlinski et al, 2004). Similarly, fluid inclusion analysis provides no evidence of an effective regional oil charge of Cretaceous reservoirs in the Caswell Sub-basin (CSIRO Petroleum, 2002; Brincat et al, 2004). In a recent petroleum systems study, Rollet et al (2016c) applied a seismic sequence stratigraphic approach to map potential and effective source rocks within the Lower Cretaceous succession (K10–K40 supersequences, **Figure 15**). Source rock intervals are condensed section deposits associated with seismic clinoform bottomsets. The number and distribution of source intervals may be greater than recognised in previous studies. Burial history and hydrocarbon expulsion models indicate that the K10–K30 source intervals contribute to several effective petroleum systems within the basin. Modelling results suggest that these Lower Cretaceous source rocks have the potential to generate some gas and minor liquids across the central Caswell Sub-basin, with minor expulsion occurring in the late Eocene (Palu et al, 2017a, 2017b).

Effective oil charge from parts of the Echuca Shoals Formation is confirmed by geochemical analysis of the Cornea, Gwydion and Caswell accumulations (Boreham et al, 1997; Blevin et al, 1998a; Edwards and Zumbege, 2005). The transport of this oil on the Yampi Shelf may have been facilitated by the Plover gas migration (Grosjean et al, 2015; 2016; Edwards et al, 2016). The Echuca Shoals Formation is also the source of the gas within the Kalyptea, Rondo and Adele structures in the Caswell Sub-basin (Grosjean et al, 2015; 2016; Edwards et al, 2016).

Play types

The main targets in the Caswell Sub-basin have been structural traps comprising Permo-Triassic and Jurassic-earliest Cretaceous horsts, tilted fault blocks and rollover anticlines associated with inversion-related structural highs (**Figure 7** and **Figure 17**). Stratigraphic traps have also been the main objectives within Campanian, Aptian–Albian and Barremian submarine fans:

- K10 thick sandstone-prone clinoform topset and localised basal sandstones associated with third-order clinoform topset (e.g. Yampi 1) sealed by K20–K30 supersequences (Echuca Shoals Formation) and that may receive charge from the matured source rocks within the J10–K10 supersequences (Plover and Vulcan formations),
- K20 second-order clinoform topset dominated by mudstone punctuated by 5–10 m thick intervals of fine to very fine sandstone sealed by the regional K30 claystone, K30 basal clinoform topset of shallow marine shelfal deposits and submarine fans sealed by 80–400 m claystone of the upper K30 supersequence forming the regional seal across the region,

- K40 basal third-order clinoform topset of fine-grained and glauconitic sandstone sealed by basin-floor and slope mudstone of the upper K40 supersequence,
- K60.0–K64.0 fourth-order clinoform topset forming a prograding wedge of mixed sandstone, siltstone, claystone, small early-middle Campanian submarine fans and larger late Campanian submarine fans. Reservoir and seal pairs of varying quality within the clinoform topsets may be subject to compartmentalisation. Good quality reservoir and seal pairs are restricted to the lower-middle and upper Campanian submarine fans overlain by good intraformational and top seals. Oil was intersected in this play at Caswell 2 ST1 in a thin, very well sorted, very fine-grained, glauconitic sandstone.
- The K20–K60 plays may receive charge from the matured source rocks within the K20–K30 supersequences (Echuca Shoals Formation).

Critical risks

Proven petroleum systems and migration pathways have been established in the region of the combined Release Areas. Success relies on the identification of additional traps with access to charge from effective source rocks. Reservoir quality is a potential risk, particularly because of the occurrence of volcanics within the Jurassic Plover Formation. Reservoir quality is also a risk within the Triassic in addition to top and lateral seals, where interbedded siltstones and carbonates were deposited in a shallow marine environment. Trap integrity is a risk due to fault reactivation in the late Miocene-Pliocene. A long vertical migration pathway is required for hydrocarbons sourced from the Echuca Shoals Formation through to the K60 reservoirs (Puffin Formation). The viability of fault migration to Puffin reservoirs remains unresolved. Drilling risks associated with the Cenozoic succession are well known in the Caswell Sub-basin. These include severe mud loss in the Basset and Oliver formation carbonate rocks, and drill-hole instability associated with loose sand in the Grebe Formation (i.e. Woodbine Group).

Geoscience Australia products and data

A range of Geoscience Australia's publications, data and products cited throughout the text are available via the links provided in the [references](#). Themes include basin geology, stratigraphy, organic geochemistry, petroleum systems and prospectivity. The project webpages for the [Browse Basin Petroleum Systems Study](#) and [Browse Basin CO₂ Storage Project](#) provide useful summaries and links to related publications and data.

Data discovery tools

- The [National Offshore Petroleum Information Management System \(NOPIMS\)](#) provides access to wells and survey data acquired primarily in Commonwealth waters and submitted under legislation, currently the Offshore Petroleum and Greenhouse Gas Storage Act 2006. This data can be downloaded or packaged on request. NOPIMS has been upgraded to provide access to over 50 years of data submission of well and survey information. It represents more than 1 million records and includes an [interactive mapping tool](#) for data discovery.
- [Geoscience Australia's Data Discovery Portal](#) provides full access to Geoscience Australia data and other publically available data sources as well as a suite of analytical and multi-criteria assessment tools. This includes the [Acreage Release](#) and [Energy](#) personas that allow access to a wide range of geological and geospatial data. Themes include source rock geochemistry, petroleum wells, stratigraphic information, province and basin geology, geophysical survey data coverage and other fundamental geospatial and administrative datasets.
- The [National Petroleum Wells Database](#) application provides access to Geoscience Australia's Oracle petroleum wells databases. Data themes include header data, biostratigraphy, organic geochemistry, reservoir and facies, stratigraphy, velocity and directional surveys. Data is included for offshore and onshore regions, however scientific data entry is generally limited to offshore wells and is dependent on Geoscience Australia's project activities.

Marine and environment information

The following section contains information about the existing marine parks, their special habitat zones and physiographic features within the Browse Basin (**Figure 18**). The information is provided in support of business decisions with respect to planned exploration and development activities.

Marine Parks

Australian Marine Parks (Commonwealth reserves proclaimed under the EPBC Act in 2007 and 2013) are located in Commonwealth waters that start at the outer edge of state and territory waters, 3 nautical miles (nm) (5.6 km) from the shore, and extend to the outer boundary of Australia's Exclusive Economic Zone, 200 nm (370.4 km) from the shore. Marine parks have also been established by the state and territory governments in their respective waters. The marine parks operate under management plans that provide a balance between protection of the marine environment, cultural heritage, and sustainable use of the area. Links to these management plans are provided for each marine park or marine park network in the Browse Basin region.

Australian Marine Parks: North-west Marine Parks Network

The North-west Marine Parks Network comprises thirteen marine parks within the North-west Marine Region, which extends from the Western Australian-Northern Territory border to Kalbarri, south of Shark Bay. The marine environment of the area is characterised by shallow-water tropical marine ecosystems, a large area of continental shelf (including the narrowest part of continental shelf on Australia's coastal margin), and continental slope, with two areas of abyssal plain to depths of 600 m. The region has high species diversity and globally significant populations of internationally significant threatened species. A small number of species are found nowhere else but most of the region's species are tropical and found in other parts of the Indian Ocean and the western Pacific Ocean.

Four of the marine parks within the North-west Marine Parks Network overly or are adjacent to the Browse Basin–Kimberley Marine Park, Argo-Rowley Terrace Marine Park, Ashmore Reef Marine Park, and Cartier Island Marine Park.

Management plans for the North-west Marine Parks Network are in place, and can be viewed at:

<https://parksaustralia.gov.au/marine/pub/plans/north-west-management-plan-2018.pdf>

Kimberley Marine Park

The [Kimberley Marine Park](#) is located approximately 100 km north of Broome, extending from the Western Australian state water boundary north from the Lacepede Islands to the Holothuria Banks offshore from Cape Bougainville. The marine park is adjacent to the Western Australian Lalang-garram / Camden Sound and North Kimberley marine parks. The Kimberley Marine Park covers an area of 74 469 km² and water depths from less than 15 m to 800 m.

Statement of significance

The Kimberley Marine Park is significant because it includes habitats, species and ecological communities associated with the Northwest Shelf Province, Northwest Shelf Transition and Timor Province. It includes two Key Ecological Features: the ancient coastline at the 125 m depth contour (an area of enhanced productivity and migratory pathway for cetaceans and pelagic marine species); and continental slope demersal fish communities (valued for high levels of endemism and diversity and the second richest area for demersal fish species in Australia).

The marine park provides connectivity between deeper offshore waters, and the inshore waters of the adjacent Western Australia North Kimberley Marine Park and Lalang-garram / Camden Sound Marine Park.

The Kimberley Marine Park is assigned IUCN category VI and includes three zones assigned under the North-west Marine Parks Network Management Plan (2018): National Park Zone (II), Habitat Protection Zone (IV), and Multiple Use Zone (VI).

Argo-Rowley Terrace Marine Park

The [Argo-Rowley Terrace Marine Park](#) is located approximately 270 km north-west of Broome, Western Australia, and extends to the limit of Australia's exclusive economic zone. The marine park is adjacent to the Mermaid Reef Marine Park and the Western Australian Rowley Shoals Marine Park. The marine park covers an area of 146 003 km² and water depths between 220 m and 6000 m.

Statement of significance

The Argo-Rowley Marine Park is significant because it contains habitats, species and ecological communities associated with the Northwest Transition and Timor Province bioregions. It includes two Key Ecological Features: canyons linking the Argo Abyssal Plain with the Scott Plateau (valued for high productivity and aggregations of marine life); and Mermaid Reef and Commonwealth waters surrounding Rowley Shoals (valued for enhanced productivity, aggregations of marine life and high species richness).

The Argo-Rowley Marine Park is the largest in the North-west Network, surrounding the existing Mermaid Reef Marine Park and reefs of the Western Australian Rowley Shoals Marine Park. It includes the deeper waters of the region and a range of seafloor features such as canyons on the slope between the Argo Abyssal Plain, Rowley Terrace and Scott Plateau. These are believed to be up to 50 million years old and are associated with small, periodic upwellings that result in localised higher levels of biological productivity.

The marine park is assigned IUCN category VI and includes three zones assigned under the North-west Marine Parks Network Management Plan (2018): National Park Zone (II), Multiple Use Zone (VI), and Special Purpose Zone (Trawl) (VI).

Ashmore Reef Marine Park

The [Ashmore Reef Marine Park](#) is located approximately 630 km north of Broome and 110 km south of the Indonesian island of Roti. It is located in Australia's External Territory of Ashmore and Cartier Islands and is within an area subject to a Memorandum of Understanding (MoU) between Indonesia and Australia, known as the 'MoU Box'. The marine park covers an area of 583 km² and water depths from less than 15 m to 500 m. It contains three vegetated sand cays that are permanently above water: West, Middle and East islands.

Statement of significance

The Ashmore Reef Marine Park is significant because it includes habitats, species and ecological communities associated with the Timor Province bioregion. It includes two Key Ecological Features: Ashmore Reef and Cartier Island and surrounding Commonwealth waters (valued for high productivity and breeding aggregations of birds and other marine life); and continental slope demersal fish communities (valued for high levels of endemism).

Ashmore Reef is the largest of three emergent oceanic reefs in the region and the only one with vegetated islands. The marine park is an area of enhanced biological productivity and a biodiversity hotspot, supporting a range of pelagic and benthic marine species and an important biological stepping stone facilitating the transport of biological material to the reef systems along the Western Australian coast via the south-flowing Leeuwin Current which originates in the region.

The Ashmore Reef Ramsar site is located within the boundary of the marine park. The site was listed under the Ramsar Convention in 2002 and is a wetland of international importance under the EPBC Act. An [Ecological Character Description](#) that sets out the Ramsar listing criteria met by the site, the key threats and knowledge gaps, is available from the [Department of Climate Change, Energy, the Environment and Water](#).

The Ashmore Reef Marine Park is assigned IUCN category Ia and includes two zones assigned under the North-west Marine Parks Network Management Plan (2018): Sanctuary Zone (Ia) and Recreational Use Zone (IV). Note that mining operations including exploration are not allowed in designated Sanctuary Zones (Ia).

Cartier Island Marine Park

The [Cartier Island Marine Park](#) is located approximately 45 km south-east of Ashmore Reef Marine Park and 610 km north of Broome, Western Australia. Both marine parks are located in Australia's External Territory of Ashmore and Cartier Islands and are within an area subject to a Memorandum of Understanding (MoU) between Indonesia and Australia, known as the 'MoU Box'. The marine park covers an area of 172 km² and water depths from less than 15 m to 500 m.

Statement of significance

The Cartier Island Marine Park is significant because it includes habitats, species and ecological communities associated with the Timor Province. It includes two key ecological features: Ashmore Reef and Cartier Island and surrounding Commonwealth waters (valued for high productivity and breeding aggregations of birds and other marine life); and continental slope demersal fish communities (valued for high levels of endemism).

Like the islands of Ashmore Reef, Cartier Island is a biodiversity hotspot and an important biological stepping stone, facilitating the transport of biological material to the reef systems along the Western Australian coast via the south-flowing Leeuwin Current which originates in the region.

The Cartier Island Marine Park is assigned IUCN category Ia (Strict Nature Reserve) and includes one zone assigned under the North-west Marine Parks Network Management Plan (2018): Sanctuary Zone (Ia).

Western Australian Marine Parks

Western Australia contains 20 marine parks, nature reserves, and management areas. These marine protected areas were created to protect natural features and aesthetic values of the marine environment whilst also allowing recreational and commercial uses that do not compromise conservation values. Two of these marine parks overly or intersect the Browse Basin: North Kimberley Marine Park and Lalang-garram / Camden Sound Marine Park.

North Kimberley Marine Park

The North Kimberley Marine Park is located in the Indian Ocean and the Timor Sea in the waters of Western Australia's Kimberley region. The marine park extends north-east from York Sound, around Cape Londonderry and the Joseph Bonaparte Gulf to the Western Australia/Northern Territory boundary, and from the mainland high water mark to the limit of State coastal waters. The park covers approximately 1 845 000 hectares with its south-western boundary located about 270 km north-east of Derby.

The zoning scheme for the North Kimberley Marine Park comprises:

- eight sanctuary zones
- nine special purpose zones (recreation and conservation)
- two special purpose zones (cultural heritage)
- general use in the remainder of the park

Special purpose zones (recreational and conservation) acknowledge the recreational and cultural value of the area and allow for compatible commercial activities whilst providing enhanced protection and conservations for ecological values. Special purpose zones (cultural heritage) provide for recognition and protection of sites of high cultural significance to the traditional owners. Sanctuary zones protect areas of critical habitat to maintain healthy functioning of the complex ecosystems that make up the marine park.

The North Kimberley Marine Park is jointly managed by Western Australian Parks and Wildlife Service and the Wunambal Gaambara, Balanggarra, Ngarinyin, and Miriuwung Gajerrong traditional owners for each of their respective saltwater management areas. Wunambal Gaambara country extends from south of Prince Frederick Harbour to Napier Broome Bay in the north of the Kimberley. Balanggarra sea country stretches from Napier Broome Bay to Cambridge Gulf and Wyndham. Miriuwung Gajerrong country extends from Cambridge Gulf into the Northern Territory. For further details, refer to the [North Kimberley Marine Park Management Plan](#).

Lalang-garram / Camden Sound Marine Park

The Lalang-garram / Camden Sound Marine Park is located about 150 km north of Derby (300 km north of Broome) and covers an area of approximately 705 000 hectares. The northern boundary of the marine park meets the mainland coast at Brunswick Bay just south of Cape Wellington at approximately 15°10'51.6"S, 124°50'06"E, then extends south-westerly to 15°12'00"S, 124°48'45"E, then extends west along latitude 15°12'00"S to the limit of WA coastal waters. The southern boundary meets the mainland coast north-east of Montgomery Reef at approximately 15°52'36"S, 124°25'00"E, then extends south along longitude 124°25'00"E to latitude 16°03'00"S, then west along that latitude south of Montgomery Reef to longitude 123°45'00"E, then north along that longitude to latitude 15°55'00"S, then west along that latitude to the limit of Western Australian coastal waters.

The zoning scheme for the Lalang-garram / Camden Sound Marine Park comprises:

- 'no-take' sanctuary zones
- one special purpose zone (whale conservation)
- one special purpose zone (wilderness conservation)
- one special purpose zone (pearling)
- general use zones

Sanctuary zones are 'look but don't take' areas that provide the highest level of protection for vulnerable or specially protected species, and protect representative habitats and communities from human disturbance. Special purpose zones are managed for a particular priority purpose, and uses incompatible with that purpose are not permitted in these zones. General use zones are all areas in the park that are not included in a sanctuary or special purpose zone. Conservation of natural values is still the priority, but activities including petroleum exploration and production are permitted where they do not compromise the ecological values of the marine park.

The Lalang-garram / Camden Sound Marine Park lies within the traditional country of three Aboriginal native title groups. The Dambimangari people's determination overlies the majority of the marine park. A section of the Wunambal Gaambera people's Uunguu determination includes a small portion of St George Basin, while a small section of the Mayala people's claim (native title not determined at the time of writing) overlies the southwest corner of the marine park. The marine park will be jointly managed with Traditional Owners, through a joint management body (or bodies), where joint management agreements have been discussed and finalised with Traditional Owners.

For further details, refer to the [Lalang-garram / Camden Sound Marine Park Management Plan](#).

Biologically important areas

The Browse Basin overlaps or is close to the following biologically important areas:

- The Brown Booby, Greater Frigatebird, Lesser Crested Tern, Lesser Frigatebird, Little Tern, Red-footed Booby, and Roseate Tern breeding, foraging, and resting areas overlap and/or lie near the Kimberley, Pilbara, and Gascoyne coasts and islands, and Ashmore Reef.
- Humpback whale breeding, calving, and nursing areas are located to the south of the Basin. Pygmy blue whales also occur in the region.
- Dugong foraging occurs along the Kimberley coast, on the Dampier Peninsula.
- Inshore dolphins including the Australian Snubfin, Indo-Pacific Humpback, and Indo-Pacific Spotted Bottlenose dolphins breed, calve, and forage around the sounds and harbours inland of the Browse Basin.
- Green and Flatback turtles nest on islands and mainland coasts in the vicinity of the Browse Basin.
- Whale Sharks forage in the region from the 200 m isobath to the shore.

The [National Conservation Values Atlas](#) and the [Atlas of Living Australia](#) provide further information and visualisations concerning animals and plants recorded in the Browse Basin region.

Heritage

Australia protects its shipwrecks and associated underwater heritage through the [Underwater Cultural Heritage Act 2018](#).

There are no [historic shipwreck protected zones](#) in the Browse Basin region. There are several shipwrecks within the Browse Basin that are not associated with a defined protected zone. These can be identified using the [Australian National Shipwreck Database](#) map search tool.

Fisheries

The following [Commonwealth fisheries](#) are within the Browse Basin area:

- The Southern Bluefin Tuna Fishery covers the entire sea area around Australia, out to 200 nm from the coast. The fishing season runs for 12 months, starting on 1 December.

- The Western Tuna and Billfish Fishery covers the sea area west from the tip of Cape York in Queensland, around Western Australia, to the border between Victoria and South Australia. Fishing occurs in both the Australian Fishing Zone (generally between 3 and 200 nm from the coast) and adjacent high seas. The fishing season runs for 12 months, starting on 1 February.
- The North West Slope Trawl Fishery is located in deep water from the coast of the Prince Regent National Park to Exmouth between the 200 m depth contour to the outer limit of the Australian Fishing Zone. The fishing season runs for 12 months, starting on 1 July.

The Browse Basin is located within the Western Australia North Coast Bioregion. The Western Australian Government manages 12 [commercial fisheries](#) within the bioregion. [Recreational](#) fishing also occurs within the Western Australian North Coast Bioregion.

Climate of the region

The northwest shelf region experiences a dry (arid tropical) climate with two distinct seasons: the northwest monsoon (October-March) and the northeast to southeast monsoon (April-September), with a rapid transitional period between each season. At the closest onshore weather station (Derby Aero), approximately 90% of the annual mean rainfall (690 mm) occurs in the period between December and March and is associated with storm activity. Winds during the summer monsoon are typically westerly to northwesterly and humid. During the winter monsoon, winds are typically drier southeasterlies which originate over the Australian mainland. The annual mean maximum and minimum temperatures recorded at Derby were 38.2°C and 14.7°C respectively, for the period from 1972 to 2019 (BOM, 2019a).

Offshore, water temperatures in reef lagoons are typically 28-30°C, while during strong La Niña events, sea surface temperatures may reach 34°C. The region is subject to cyclone activity, and the cyclone season officially runs from November to May, with approximately five tropical cyclones occurring per year on average. Highest cyclone activity in the region typically occurs during March and April. Between 1996/97 and 2006/07, 17 tropical cyclones passed within 200 km of Browse Island (BOM, 2019b).

Oceanic regime

Oceanic circulation in the Browse Basin is strongly influenced by the southward flowing Indonesian Throughflow, and by the Leeuwin Current along the northwestern shelf edge (Condie and Andrewartha, 2008). The surface water above the Caswell and Barcoo Sub-basins, together with Scott Plateau and the Seringapatam Sub-basin, form part of the zone over which the Indonesian Throughflow passes. The warm, low salinity, south-westerly currents of the Indonesian Throughflow joins the westward directed South Equatorial Current (Kuhnt et al, 2004; Adamo et al, 2009). This surface current transports warm equatorial water south-eastward towards the Wharton Basin, in the northeast quarter of the Indian Ocean. At the shelf break on the Yampi and Leveque shelves, the seasonal (autumn) Holloway Current transports warm water, heated on the northwest shelf, southwards (Adamo et al, 2009). The Holloway Current begins to flow at the termination of the northwest monsoon season. An anticlockwise surface gyre exists between the Indonesian Throughflow and the Holloway Current (Adamo et al, 2009).

The northwest shelf experiences small ocean-swell waves (<1.5 m significant wave height), but is affected by tropical cyclones during the monsoon season (November–March; Porter-Smith et al, 2001). While the mean annual wave power is low (~0-2 W/m²), cyclone-generated currents can erode and transport sediment over large spatial extents (Porter-Smith et al, 2001).

The northwest shelf and the Browse Basin region is macrotidal, and inshore is ebb-tide dominated. The Kimberley Coast experiences some of the largest tides in the Southern Hemisphere. Tidal ranges generally exceed four metres on the Leveque Shelf; tidal ranges of up to 10 m occur at Broome, and up to 12.5 m in King Sound. Tides at Broome are semi-diurnal (two high tides, and two low tides per day). On the outer shelf, the ebb and flood tidal currents run orthogonal to the coast (James et al, 2004) whereas on the inner shelf, flood tidal currents run parallel to the coast. Tidal currents are strongest around the shelf break (James et al, 2004). Tidal currents also play a significant role in nearshore and coastal sediment transport. For example, in King Sound, tides frequently mobilise significant areas of medium-grained sand (250–500 µm diameter) (Porter-Smith et al, 2001).

The Browse Basin and Kimberley coastal region are characterised by large internal waves, internal tides and strong seasonality in the near-surface ocean circulation (McKinnon et al, 2015). Internal waves occur around the shelf break (Holloway, 1987), with resulting internal tides present across the continental slope from approximately 100 m to 1000 m depths (Holloway, 2001). Internal waves with 60 m amplitudes have been observed forming around Scott Reef, located in water depths of ~500 m on the continental slope of the northwest shelf (Wolanski and Deleersnijder, 1998).

Important oceanographic drivers of biological productivity in the northwest region include:

- Weakening of the Indonesian Throughflow and Leeuwin Current during the northwest monsoon (December to March) leading to increased upwelling and productivity.
- Seasonal reversal in wind direction, resulting in opposite flow direction to that of the Leeuwin Current during summer, and hence upwelling.
- Cyclones that result in physical disturbance, nutrient input via run-off, and changes in plankton distributions (DEWHA, 2008; McKinnon et al, 2015).

Seabed environments: regional overview

The Browse Basin extends from shallow shelf waters adjacent to the Kimberley coast of Australia, to near-abyssal depths on the western margin of Scott Plateau. At the basin scale, the Yampi and Leveque Shelves form terraced and plateaued seabed on the eastern margin of the main Browse Basin depocentres of the Caswell and Barcoo sub-basins (Harris et al, 2003). The width of the shelf is greatest across the Yampi Shelf-Prudhoe Terrace to Scott Reef transect, where it is approximately 250 km.

The edge of the Yampi Shelf and the transition to the Caswell Sub-basin occurs in water depths of 100–130 m on the Prudhoe Terrace, with most of the Caswell Sub-basin lying in water depths of 200–500 m. The western margin of the Caswell Sub-basin marks a transition from shelf to slope settings. Where there are shelf-edge reefs, the transition to deeper water is sharp. However, the transition to deep water across inter-reefal areas from shelf to slope, is significantly more gradual. The majority of the Scott Plateau is in water depths of 2000–3000 m, while its western slope occurs in water depths of 3000–5000 m. The plateaued Seringapatam Sub-basin mostly lies in water depths of 1700–2300 m. Several submarine canyons are present along the Caswell to Seringapatam Sub-basin transition, and on the western slope of the Scott Plateau where it abuts the Argo Abyssal Plain.

Islands and reefs

The Kimberley-Browse coastal and offshore region is a poorly studied area of high conservation value, consisting of emergent oceanic reefs, submerged oceanic shoals, fringing coastal coral reefs, mangroves, tidal mudflats and a turbulent water column (McKinnon et al, 2015). The principal islands and reefs in the Browse region include Browse Island, Echuca Shoal, Heywood Shoal, Scott Reef, Adele Island, Seringapatam Reef and Lynher Reef. Additional shoals include Vulcan Shoal, Goeree Shoal and Eugene McDermott Shoal. Compared with the generally high tidal energy environment of the northwest shelf, reefs provide shallow water environments with comparatively low energy regimes. At North Scott Reef and elsewhere, coral reef has developed since the early Holocene sea level rise, over previously exposed reefal lithologies deposited during the last interglacial (Collins, 2011, 2014). Shallow-water reefs such as Scott Reef are prone to damage during tropical cyclones (e.g. Cyclone Fay of 2004).

Surficial sediment on the northwest shelf is predominantly carbonate. The northwest shelf (<300 m depth) is an oceanic carbonate ramp, similar in scale to the Great Bahama Bank (James et al, 2004; Belde et al, 2014), and hosts a large number of coral reefs. These include isolated oceanic reefs (Ashmore, Seringapatam and Scott reefs, Rowley Shoals), and the island-associated shelf reefs of the Kimberley coast and Dampier archipelago, Pilbara reefs (Barrow and Montebello Islands), and Ningaloo Reef (Collins, 2011; Collins and Testa, 2010; Wilson, 2013). The seabed is mostly composed of unconsolidated sediment on the continental shelf. This consists of medium- and coarse-grained carbonate-rich sands and gravels derived from relict fossiliferous carbonate material, with minor authigenic phosphate and glauconite components (Collins, 2011). Between 200 m and 500 m water depths, hard seabed and sandy carbonate sediments are dominant. In deeper water, particularly in areas distal to reefs, the seabed is dominated by fine and fine-medium grained unconsolidated sediments (Kuhnt et al, 2006). There are also areas of seabed in these deeper settings with a hard rock substrate. In the western Caswell Sub-basin, large-scale sediment bedforms indicate strong southeast–northwest oriented bottom-flow currents. These are potentially related to internal tides (Belde et al, 2014).

Shelf

Along the Yampi and Leveque shelves, sediments are of mixed age, with little modern material being deposited. Sediment here is sourced either from the post-mortem deposition of skeletal carbonate, or from the coast via cross-shelf transport. However, at the coast any transport of modern terrigenous sediment is generally in a shore-parallel direction.

The continental shelves of the Yampi Shelf, Prudhoe Terrace and Leveque Shelf, located in a high-energy, shallow water, tropical setting, have a much thinner sediment cover than the centrally located Caswell Sub-basin (Stephenson and Cadman, 1994). Hardgrounds are present at several points along this sediment-starved margin (Rollet et al, 2006). Vibracores up to 2.5 m long recovered on the Leveque Shelf, bottom out on hard substrates (Picard et al, 2014). These cores were recovered from an area with elongate, shore-normal banks and ridges, carbonate terraces, channels, and large bedforms up to eight metres high and dominated by coarse sediment.

Ecology

A diverse range of benthic marine habitats have been identified within the Browse Basin, including habitats found in shallow water (seagrass beds, coral reefs and atolls, shoals and banks), moderate-depth water (methane seeps, shelf and slope), and deep water (canyons and marginal plateaus). The majority of the Browse Basin, however, comprises shelf and marginal plateau habitats. Many shallow habitats are comparatively well studied (e.g. Scott Reef and Seringapatam Reef), but in contrast, little is known about the biology and physical environments of deeper habitats (e.g. Scott Plateau and canyons). Field studies within the region have identified highly diverse marine assemblages, with many species endemic to this region. Shelf habitats are dominated by crustaceans and polychaetes, with mixed patches of sponges and octocorals (Picard et al, 2014; Howard et al, 2016). Biogeographical comparisons of biodiversity across the broader Northwest-Indonesian region suggest that the Browse Basin may lie midway along a biodiversity gradient from extremely high diversity in the north to much lower diversity in the south (Berry, 1986; Veron and Marsh, 1988). However, due to low sampling density, it is unclear how general these biodiversity patterns may be among habitats or taxa.

Biodiversity in the Browse Basin may be higher than surrounding basins, as suggested by bioregionalisation and seascape maps. The Browse Basin is composed of two Provincial Bioregions, which by definition are centres of demersal fish endemism (Heap et al., 2005). In comparison, transition areas located to the northeast and southwest of Browse Basin are regions of overlap between Provincial Bioregions. Thus, the Browse Basin likely has a higher level of endemism than surrounding regions.

Rich assemblages of invertebrates (particularly corals and sponges) and fish (especially sharks) have been recorded from a variety of benthic habitats within the Browse Basin. The offshore coral reef assemblages, such as those recorded from Scott and Seringapatam reefs, are unique to the northwest region, and represent some of the few offshore coral atolls in Western Australia (Veron and Marsh, 1988; Skewes et al, 1999; Wells and Allen, 2005). Diverse coral communities have also been found in deeper waters surrounding Scott Reef (up to 60 m depth; Berry, 1986), suggesting that these unique coral habitats may extend beyond the normal shallow water zones. A variety of reefs, shoals and banks have also been identified in the Browse Basin and are known to support often large aggregations of pelagic and benthic fishes, making these areas both ecologically and commercially important (CSIRO, 1980; Stehouwer, 1981). Hydrothermal vents and methane seeps have also been reported from several locations on the Yampi Shelf (O'Brien and Glenn, 2005; CSIRO, 2005; Rollet et al., 2006). Although seeps and vents are known to provide a unique environment for chemosynthetic organisms, these have not been recorded around the vents and seeps examined within the Browse Basin (CSIRO, 2005). Rather, these vent and seep habitats seem to provide a novel hard substrate that supports a range of filter-feeding organisms—such as sponges and corals—that are commonly found on other hard substrates (e.g. shoals and reefs) within the region.

Recent geological history

The modern geomorphic characteristics of the Browse Basin are inherited from pre-existing structures. During the Quaternary these were further developed, particularly through reef growth and differential sedimentation during sea-level oscillations of up to 130 m. Modern reefs have generally developed on palaeo-reefal structures. Since the onset of the middle Pleistocene, peak glacial sea levels—up to 130 m below the present—would have exposed the Yampi and Leveque shelves and Prudhoe Terrace (Lisiecki and Raymo, 2005; Head et al, 2008; Gibbard et al, 2010). Associated glacial palaeo-coastlines are situated in the vicinity of Browse Island, in the Caswell Sub-basin. Areas including the Cornea region (northern Yampi Shelf) would have been intermittently sub-aerially exposed since the middle Pleistocene. A prominent terrace-edge scarp at a depth of 125 m on the Leveque shelf is considered to have been formed during glacial sea level lowstands, the most recent being the global Last Glacial Maximum (23 000–19 000 years before present) (Collins, 2011; James et al, 2004). It has been suggested that subsidence has been occurring on the northwest shelf since at least the last interglacial, at about 125 000 years before present (Collins and Testa, 2010).

Seabed seepage

In the Browse Basin, hydrocarbon seeps have been observed around Cornea on the northern Yampi Shelf (Jones et al, 2005; Rollet et al, 2006; Logan et al, 2010). Pockmarks have also been noted in the Oobagooma Sub-basin and Broome Platform of the offshore Canning Basin, southwest of the Leveque Shelf (Jones et al, 2007, 2009). Pockmark formation at these latter locations has been attributed to the expulsion of seawater at the seabed, driven by tidal pumping through the shallow sub-surface. Recently, small pockmarks have been observed at the seabed in the northeast of the Caswell Sub-basin (Howard et al, 2016). Pockmarks similar to those observed by Jones et al (2007) are present on the Leveque Shelf (Picard et al, 2014). Active expulsion of gas bubbles imaged by side scan sonar and single beam echo-sounder systems, and suggesting seep activity has been observed along the southern flank of the Ashmore Platform (Stalvies et al, 2017).

National seabed mapping data and information

Geoscience Australia provide acoustic datasets including bathymetry, backscatter, and sidescan sonar to assist in understanding the shape and composition of the sea floor. Geoscience Australia also maintains the Marine Sediment database ([MARS](#)), comprising information from seabed sediment samples collected during marine surveys between 1905 and 2017. Data available include percentage mud/sand/gravel, mean grain size, and sediment texture.

These data are easily discoverable and accessible through the [AusSeabed Marine Data Portal](#). [AusSeabed](#) is an innovative national seabed mapping initiative designed to coordinate data collection efforts in Australian waters, and provide open access to quality-controlled seabed data. AusSeabed is currently focussed on the enabling accessibility of bathymetry data in Australian waters, however the long-term goal is to establish a comprehensive online platform containing data and information, including tools to support data collectors and users in connecting with the broader seabed mapping community. This platform will also include derived data products including morphological and geomorphological maps of the sea floor.

Other online information resources

Please follow these links for more detailed information pertaining to the marine and environmental summaries provided in this section.

- [Bureau of Meteorology: climate statistics](#)
- [National Conservation Values Atlas](#)
- Australian Marine Parks: [North-west Marine Parks Network](#)
- [Western Australian Marine Parks and Reserves](#)
- [AusSeabed](#)
- [Commonwealth Fisheries](#)
- [Historic shipwrecks](#)
- [Protected Matters Search Tool](#)

References

ABBOTT, S., CAUST, D., ROLLET, N., LECH, M., ROMEYN, R., ROMINE, K., KHIDER, K. AND BLEVIN, J., 2015—[Seven Cretaceous low-order depositional sequences from the Browse Basin, North West Shelf, Australia: a framework for CO₂ storage studies](#). AAPG International Conference and Exhibition, 13-16 September 2015, Melbourne, Australia.

- ADAMO, N.D., FANDRY, C., BUCHAN, S. AND DOMINGUES, C., 2009—Northern sources of the Leeuwin Current and the "Holloway Current" on the North West Shelf. *Journal of the Royal Society of Western Australia*, 92, 53-66.
- AGSO AND GEOTECH, 2000—[Characterisation of Natural Gases from West Australian Basins](#). Australian Geological Survey Organisation, Canberra.
- AGSO BROWSE BASIN PROJECT TEAM, 1997—[Browse Basin high resolution study, interpretation report, North West Shelf, Australia](#). Record, 1997/38. Australian Geological Survey Organisation, Canberra.
- ARSALAN, S.I., ICHIZAWA, K. AND FURUYA, K., 2017— Visualisation of geomorphological features and interpretation of the depositional system of the Brewster Member, Ichthys Field. *The APPEA Journal*, 57, 288–300.
- BAN, S. AND PITT, G., 2006—The Ichthys giant gas-condensate field. 2006 AAPG International Conference and Exhibition, 5–8 November, Perth, Australia, Abstract.
- BELDE, J., BACK, S. AND REUNING, L., 2014—Three-dimensional seismic analysis of sediment-waves and related geomorphological features on a carbonate shelf exposed to large amplitude internal waves, Browse Basin region, Australia. *Sedimentology*, 62, 87-109.
- BELOPOLSKY, A.V., WOODFINE, R., STOVER, C., PIGGOT, N., PRICE, S. AND JONES, B., 2006—Reservoir systems of Browse Basin, Northwest Shelf of Australia, in a sequence stratigraphic framework. 2006 AAPG International Conference and Exhibition, 5–8 November, Perth, Australia, Abstract.
- BENSON, J.M., BREALEY, S.J., LUXTON, C.W., WALSH, P.F. AND TUPPER, N.P., 2004—Late Cretaceous ponded turbidite systems: a new stratigraphic play fairway in the Browse Basin. *The APPEA Journal*, 44(1), 269–285.
- BERRY, P.F., 1986—Faunal surveys of the Rowley Shoals, Scott Reef and Seringapatam Reef. Records of the Western Australian Museum, Supplement No. 25.
- BHP BILLITON PETROLEUM PTY LTD, 2003—Maginnis-1, -1A, -1A/ST1 & -1A/ST2 Well Completion Report, unpublished.
- BINT, A.N., 1988—Gas fields of the Browse Basin. In: Purcell, P.G. and R.R. (eds), *The North West Shelf, Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 1988, 413–417.
- BLEVIN, J.E., BOREHAM, C.J., SUMMONS, R.E., STRUCKMEYER, H.I.M. AND LOUTIT, T.S., 1998a—An effective Lower Cretaceous petroleum system on the North West Shelf: evidence from the Browse Basin. In: Purcell, P.G. and R.R. (eds), *The Sedimentary Basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, WA, 1998, 397–420.
- BLEVIN, J.E., STRUCKMEYER, H.I.M., CATHRO, D.L., TOTTERDELL, J.M., BOREHAM, C.J., ROMINE, K.K., LOUTIT, T.S. AND SAYERS, J., 1998b—Tectonostratigraphic framework and petroleum systems of the Browse Basin, North West Shelf. In: Purcell, P.G. and R.R. (eds), *The Sedimentary Basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, WA, 1998, 369–395.
- BOREHAM, C.J., HOPE, J.M. AND HARTUNG-KAGI, B., 2001—Understanding source, distribution and preservation of Australian natural gas: a geochemical perspective. *The APPEA Journal*, 41(1), 523–547.
- BOREHAM, C.J., ROKSANDIC, Z., HOPE, J.M., SUMMONS, R.E., MURRAY, A.P., BLEVIN, J.E. AND STRUCKMEYER, H.I.M., 1997—[Browse Basin Organic Geochemistry Study, North West Shelf, Australia. Volume 1, Interpretation Report](#). Record 1997/5. Australian Geological Survey Organisation, Canberra.
- BRADSHAW, M.T., YEATES, A.N., BEYNON, R.M., BRAKEL, A.T., LANGFORD, R.P., TOTTERDELL, J.M. AND YEUNG, M., 1988—Palaeogeographic evolution of the North West Shelf region. In: Purcell, P.G. and R.R. (eds), *The North West Shelf, Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 29–54.
- BRINCAT, M.P., LISK, M., KENNARD, J.M., BAILEY, W.R. AND EADINGTON, P.J., 2004—Evaluating the oil potential of the gas-prone Caswell Sub-basin: insights from fluid inclusion studies. In: Ellis, G.K., Baillie, P.W. and Munson, T.J. (eds), *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, 19–20 June 2003. Northern Territory Geological Survey, Special Publication 1, 437–455.

- BUREAU OF METEOROLOGY, 2019a—Climate statistics for Australian locations: Summary statistics for DERBY AERO. Bureau of Meteorology, Commonwealth of Australia. Available from http://www.bom.gov.au/climate/averages/tables/cw_003032.shtml (last accessed 1 August 2020).
- BUREAU OF METEOROLOGY, 2019b—Tropical Cyclones in the Northern Territory. Bureau of Meteorology, Commonwealth of Australia. Available from <http://www.bom.gov.au/cyclone/about/northern.shtml> (last accessed 1 August 2020).
- CALENERGY RESOURCES, 2015—Pryderi-1 Well Completion Report (Basic Data), unpublished.
- CALENERGY RESOURCES 2015—Pryderi-1 Well Completion Report (Basic Data), unpublished.
- CGG, 2017—[webpage] Schild Phase I & II. <http://www.cgg.com/en/What-We-Do/Multi-Client-Data/Seismic/Asia-Pacific/Schild> (last accessed 1 August 2020).
- COLLINS, L.B., 2011—Geological setting, marine geomorphology, sediments and Oceanic Shoals growth history of the Kimberley region. *Journal of the Royal Society of Western Australia*, 94, 89-105.
- COLLINS, L.B., 2014—Carbonate shelf sediments of the western continental margin of Australia. In: Chiocci, F.L. and Chivas, A.R. (eds.) *Continental Shelves of the World: Their evolution during the last Glacio-eustatic cycle*. Geological Society, London, 41, 255-272.
- COLLINS, L.B. AND TESTA, V., 2010—Quaternary development of resilient reefs on the subsiding Kimberley continental margin, northwest Australia. *Brazilian Journal of Oceanography*, 58, 67-77.
- CONDIE, S.A. AND ANDREWARTHA, J.R., 2008—Circulation and connectivity on the Australian North west shelf. *Continental Shelf Research*, 28, 1724-1739.
- CONOCOPHILLIPS, 2010—Kontiki-1 well completion report, volume 2: Interpretive data. Document No: KONT-1/004.
- CONOCOPHILLIPS, 2011b—Poseidon-1 well completion report, volume 2: Interpretive data. Document No: POSE-1/004.
- CSIRO, 1980—FRV Soela: Cruise Summary SO5/80. CSIRO Division of Fisheries and Oceanography, Cronulla. 10pp.
- CSIRO, 2005—RV Southern Surveyor. Voyage Summary SS 06/2005. CSIRO Division of Marine Research, Hobart. 19pp.
- CSIRO PETROLEUM, 2002—GOI Analysis Browse Basin. DAR Number 1298. unpublished report.
- DEPARTMENT OF MINES AND PETROLEUM, 2014—[Web page] Western Australia's Petroleum and Geothermal Explorer's Guide, 2014 Edition. <http://www.dmp.wa.gov.au/Documents/Petroleum/PD-RES-PUB-100D.pdf> (last accessed 1 August 2020).
- DEWHA, 2008—The North-west Marine Bioregional Plan: Bioregional Profile. Department of Environment Water Heritage and Arts: Canberra.
- EADINGTON, P.J. AND MIDDLETON, H., 2000—History of hydrocarbon charge and pore water migration in the Crux-1 Gas-Condensate Well, Browse Basin, Timor Sea. CSIRO Petroleum Confidential Report No. 00-069 to Nippon Oil Exploration Pty Ltd.
- EDWARDS, D.S., BOREHAM, C.J., ZUMBERGE, J.E., HOPE, J.M., KENNARD, J.M. AND SUMMONS, R.E., 2006—Hydrocarbon families of the Australian North West Shelf: a regional synthesis of the bulk, molecular and isotopic composition of oils and gases. 2006 AAPG International Conference and Exhibition, 5–8 November, Perth, Australia, Abstract.
- EDWARDS, D.S., GROSJEAN, E., KUSKE, T., LE POIDEVIN, S., CHEN, J., HONG, Z., BOREHAM, C., ROLLET, N. AND ZUMBERGE, J., 2014—[Redefining the petroleum systems of the Browse Basin](#). In [McKirdy, D.M. and Löhr, S. \(eds\) Life, Environments and Resources. 18th Australian Organic Geochemistry Conference, 30 November – 2 December 2014, Adelaide. Program and Abstracts.](#)

- EDWARDS, D.S., GROSJEAN, E., PALU, T., ROLLET, N., HALL, L., BOREHAM, C.J., ZUMBERGE, A., ZUMBERGE, J.E., MURRAY, A.P., PALATY, P., JINADASA, N., KHIDER, K. AND BUCKLER, T., 2016—[Geochemistry of dew point petroleum systems, Browse Basin, Australia. In: Australian Organic Geochemistry Conference, Fremantle, December 4-7.](#)
- EDWARDS, D.S., KENNARD, J.M., PRESTON, J.C., SUMMONS, R.E., BOREHAM, C.J. AND ZUMBERGE, J.E., 2000—Bonaparte Basin: geochemical characteristics of hydrocarbon families and petroleum systems, AGSO Research Newsletter, December 2000, 14–19.
- EDWARDS, D.S., PRESTON, J.C., KENNARD, J.M., BOREHAM, C.J., VAN AARSEN, B.K.J., SUMMONS, R.E. AND ZUMBERGE, J.E., 2004—Geochemical characteristics of hydrocarbons from the Vulcan Sub-basin, western Bonaparte Basin, Australia. In: Ellis, G.K., Baillie, P.W. and Munson, T.J. (eds), Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, 19–20 June 2003. Northern Territory Geological Survey, Special Publication 1, 169–201.
- EDWARDS, D.S. AND ZUMBERGE, J.E., 2005—[Oils of Western Australia II. Geoscience Australia and GeoMark Research Ltd, Canberra and Houston.](#)
- ELLIOT, R.M.L., 1990—Browse Basin. In: *Geology and Mineral Resources of Western Australia: Geological Survey of Western Australia, Memoir 3*, 535–547.
- ENERGY-PEDIA, 2014—[webpage] Australia: CalEnergy's Pryderi-1 well in the Browse Basin disappoints. <http://www.energy-pedia.com/news/australia/new-161583> (last accessed 1 August 2020).
- ENERGYQUEST, 2019—Energy Quarterly, June 2019 Report. Available at: <http://www.energyquest.com.au/reports.php?id=1> (last accessed 1 August 2020).
- ENERGYQUEST, 2021—Energy Quarterly, March 2021 Report. Available at: <http://www.energyquest.com.au/reports.php?id=1> (last accessed 1 May 2021).
- ENERGYQUEST, 2022—Energy Quarterly, June 2022 Report. Available at: <http://www.energyquest.com.au/reports.php?id=1> (last accessed July 2022).
- ENERGY NEWS BULLETIN, 2020—[webpage] Drilling in Browse oil prospect on the horizon, 30 November 2020. <https://www.energynewsbulletin.net/m-a/news/1400238/drilling-in-browse-oil-prospect-on-the-horizon> (last accessed 5 May 2021)
- ETHERIDGE, M.A. AND O'BRIEN, G.W., 1994—Structural and tectonic evolution of the Western Australian margin basin system. *PESA Journal*, 22, 45–63.
- EXOIL LTD, 2010—[webpage] Quarterly activity report to 31 December 2009. <https://www.nsx.com.au/ftp/news/021722429.pdf> (last accessed 1 August 2020).
- GIBBARD, P.L., HEAD, M.J., WALKER, M.J.C. AND THE SUBCOMMISSION ON QUATERNARY STRATIGRAPHY, 2010—[Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma.](#) *Journal of Quaternary Science*, 25, 96–102.
- GRADSTEIN, F. M., OGG, J. G., SCHMITZ, M. D. AND OGG, G. M., 2020—*Geologic Time Scale 2020*. Elsevier.
- GRAHAME, J., 2018—[Mesozoic to Cenozoic depositional environments and fluid migration within the Caswell Sub-basin: Key insights from new interpretation and modelling of the Schild phase 2 3D.](#) AEGC Conference. Extended Abstract.
- GROSJEAN, E., EDWARDS, D.S., BOREHAM, C.J., HONG, Z., CHEN, J. AND SOHN, J., 2016—[Using neo-pentane to probe the source of gases in accumulations of the Browse and Perth Basins. In: 19th Australian Organic Geochemistry Conference. Fremantle, 4-7 December 2016.](#)
- GROSJEAN, E., EDWARDS, D.S., KUSKE, T., HALL, L., ROLLET, N. AND ZUMBERGE, J., 2015—[The source of oil and gas accumulations in the Browse Basin, North West Shelf of Australia: a geochemical assessment. AAPG International Conference and Exhibition, 13–16 September 2015, Melbourne, Australia, Abstract.](#)

- HACKNEY, R. AND COSTELLOE, M., 2014—[webpage] New geophysical data for CO₂ storage and hydrocarbon prospectivity in the Browse Basin. <http://www.ga.gov.au/news-events/news/latest-news/new-geophysical-data-for-co2-storage-and-hydrocarbon-prospectivity-in-the-browse-basin2> (last accessed 1 August 2020).
- HARRIS, P., HEAP, A., PASSLOW, V., SBAFFI, L., FELLOWS, M., PORTER-SMITH, R., BUCHANAN, C. AND DANIELL, J., 2003—[Geomorphic features of the continental margin of Australia](#). Record 2003/030. Geoscience Australia, Canberra.
- HEAD, M.J., GIBBARD, P. AND SALVADOR, A., 2008—The Quaternary: its character and definition. *Episodes*, 31, 234-238.
- HEAP, A.D., HARRIS, P.T., HINDE, A. AND WOODS, M., 2005—[Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone: Report to the National Oceans Office on the Development of a National Benthic Marine Bioregionalisation in Support of Regional Marine Planning](#). Department of Environment and Heritage, Geoscience Australia, CSIRO, Canberra.
- HOCKING, R.M., MORY, A.J. AND WILLIAMS, I.R., 1994—An atlas of Neoproterozoic and Phanerozoic basins of Western Australia. In: Purcell, P.G. and R.R. (eds), *The Sedimentary Basins of Western Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 1994, 21–43.
- HOFFMAN, N. AND HILL, K.C., 2004—Structural-stratigraphic evolution and hydrocarbon prospectivity of the deep-water Browse Basin, North West Shelf, Australia. In: Ellis, G.K., Baillie, P.W. and Munson, T.J. (eds), *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, 19–20 June 2003. Northern Territory Geological Survey, Special Publication, 1, 393–409.
- HOLLOWAY, P.E., 1987—Internal hydraulic jumps and solitons at a shelf break region on the Australian North West Shelf. *Journal of Geophysical Research*, 92, 5405-5416.
- HOLLOWAY, P.E., 2001—A regional model of the semidiurnal internal tide on the Australian North West Shelf. *Journal of Geophysical Research*, 106 (C9), 19625-19638.
- HOWARD, F.J.F., NICHOLSON, C., BERNARDEL, G., CARROLL, A.G., GROSJEAN, E., HACKNEY, R., LECH, M., MELROSE, R., NICHOL, S.L., PICARD, K., RADKE, L.C., ROLLET, N., ROMEYN, R. AND SIWABESSY, P.J.W., 2016—[A marine survey to investigate seal integrity between potential CO₂ storage reservoirs and seafloor in the Caswell Sub-basin, Browse Basin, Western Australia: GA0345/GA0346/TAN1411 – Post-survey Report](#). Record 2016/05. Geoscience Australia, Canberra.
- HUNT AND SCHLUMBERGER GEOSERVICES, 2014—Schooner-1 End Of Well Report (EOWR) Geoservices Schlumberger Mudlogging, 44pp.
- HUNT OIL AUSTRALIA PERMIT 425 HOLDING COMPANY PTY LTD, 2014—Schooner 1 Well Completion Report (Basic Data), unpublished.
- INGRAM, G.M., EATON, S. AND REGTIEN, J.M.M., 2000—Cornea case study: lessons for the future. *The APPEA Journal*, 40(1), 56–65.
- INPEX, 2020—[webpage] The Ichthys LNG Project <https://www.inpex.com.au/projects/ichthys-lng/> (last accessed 1 August 2020).
- ION, 2017—[webpage] WestraliaSPAN http://www.iongeo.com/Data_Library/Asia_Pacific/WestraliaSPAN/ (last accessed 1 August 2020).
- IPB PETROLEUM, 2018—[webpage] ASX Announcement. Idris Prospective Resources Significantly Increased, 11 May 2018 <https://www.asx.com.au/asxpdf/20180511/pdf/43tyfqvyjw3b34.pdf> (last accessed 5 May 2021).
- JAMES, N.P., BONE, Y., KYSER, T.K., DIX, G.R. AND COLLINS, L.B., 2004—The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: north-western Australia. *Sedimentology*, 51, 1179-1205.
- JONES, A.T., KENNARD, J.M., LOGAN, G.A., GROSJEAN, E. AND MARSHALL, J., 2009—Fluid expulsion features associated with sand waves on Australia's central North West Shelf. *Geo-Marine Letters*, 29, 233-248.

JONES, A.T., KENNARD, J.M., RYAN, G.J., BERNARDEL, G., EARL, K.L., ROLLET, N., GROSJEAN, E. AND LOGAN, G.A., 2007—[Geoscience Australia Marine Survey SS06/2006 Post-Survey Report: Natural hydrocarbon seepage on the Central North West Shelf. Record 2007/21. Geoscience Australia, Canberra.](#)

JONES, A.T., LOGAN, G.A., KENNARD, J.M. AND ROLLET, N., 2005—[Testing natural hydrocarbon seepage detection tools on the Yampi Shelf, Northwestern Australia. Geoscience Australia Survey S267, Post-survey report. Record 2005/15 Geoscience Australia, Canberra.](#)

KAORU, M., KURATA, Y., CHRISTIANSEN, D.J. AND SCOTT, J., 2004—The Crux gas-condensate discovery, northern Browse Basin, Australia. In: Ellis, G.K., Baillie, P.W. and Munson, T.J. (eds), Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, 19–20 June 2003. Northern Territory Geological Survey, Special Publication, 1, 67–79.

KAROON GAS AUSTRALIA LTD, 2010a—[webpage] ASX Announcement. Poseidon-2 Progress Report No. 19, 3 February 2010. https://www.karoonenergy.com.au/wp-content/uploads/2010/02/Poseidon-2_Progress_Report_No_19_03022010.pdf (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2010b—[webpage] ASX Announcement. Kronos-1 Progress Report No. 12, 19 May 2010. <http://asx.com.au/asxpdf/20100519/pdf/31qdxbh4cpmt4.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2012—[webpage] ASX Announcement. Boreas-1 flowing gas at facility constrained stabilized rate of 30.2 million standard cubic feet per day, during the clean-up flow, 17 October 2012. <http://asx.com.au/asxpdf/20121017/pdf/429fks45m4jl7j.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2013a—[webpage] ASX Announcement. Zephyros-1 Exploration Well in WA-398-P Progress Report No 9, 13 March 2013. <http://asx.com.au/asxpdf/20130313/pdf/42dmjnm8ny5444.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2013b—[webpage] ASX Announcement. Browse Basin Gas Discovery at Proteus-1 Progress Report No 12, 30 August 2013. <http://asx.com.au/asxpdf/20130830/pdf/42j1tpvl6zcassd.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2013c—[webpage] ASX Announcement. Proteus-1 ST2 successfully flows condensate bearing gas Progress Report 13, 17 September 2013. <http://asx.com.au/asxpdf/20130917/pdf/42jdvn14kk8h0.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2014a—[webpage] ASX Announcement. Grace-1 Exploration Well in WA-314-P Progress Report No 10, 31 January 2014. <https://www.asx.com.au/asxpdf/20140131/pdf/42mfzkhxhxtbc.pdf> (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2014b—[webpage] ASX Announcement. Poseidon North-1 Exploration Well, WA-315-P Progress Report No 4, 16 May 2014. https://www.karoonenergy.com.au/wp-content/uploads/2014/05/Poseidon_North-1_Progress_Report_no_4..pdf (last accessed 1 August 2020).

KAROON GAS AUSTRALIA LTD, 2014c—[webpage] ASX Announcement. Browse Basin Gas Discovery at Pharos-1 Exploration Well, WA-398-P Progress Report No 5, 17 July 2014. https://www.karoonenergy.com.au/wp-content/uploads/2014/07/Pharos-1_Progress_Report_No_5.pdf (last accessed 1 August 2020).

KELMAN, A.P., KHIDER, K., ROLLET, N., ABBOTT, S., GROSJEAN, E., AND LECH, M., 2017—Browse Basin Biozonation and Stratigraphy, Chart 32, Geoscience Australia's Basin Biozonation and Stratigraphy Chart Series. Geoscience Australia, Canberra. <http://pid.geoscience.gov.au/dataset/ga/76687>

KENNARD, J.M., DEIGHTON, I., RYAN, D., EDWARDS, D.S. AND BOREHAM, C.J., 2004—Subsidence and thermal history modelling: new insights into hydrocarbon expulsion from multiple petroleum systems in the Browse Basin. In: Ellis, G.K., Baillie, P.W. and Munson, T.J. (eds), Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, 19–20 June 2003. Northern Territory Geological Survey, Special Publication, 1, 411–435.

- KUHNT, W., BLUMEL, M., BOCH, R., DEWI, K.T., DA COSTA MONTEIRO, F., DURKOP, A., HANEUTH, T., HEIDEMANN, U., HOLBOURNE, A., JIAN, Z., VAN DER KAARS, S., KAWAMURA, H., KAWOHL, H., NURNBERG, D., OBDYKE, B., PETERSEN, A., REGENBERG, M., ROSENTHAL, Y., RUHLEMANN, C., SADEKOV, A., SALOMON, B., TIAN, J., XU, J. AND ZURAIDA, R., 2006—Cruise Report SONNE-185 "Variability of the Indonesian Throughflow and Australasian Climate History of the Last 150 000 years (VITAL)". Kiel, Germany: Ins fur Geowiss., Christian-Albrechts Univ Zu Kiel.
- KUHNT, W., HOLBOURN, A., HALL, R., ZUVELA, M. AND KASE, R., 2004—Neogene history of the Indonesian Throughflow. In: Clift, P., Kuhnt, W., Wang, P. AND Hayes, D. (eds.) *Continent-Ocean interactions Within East Asian Marginal Seas*. American Geophysical Union.
- LAWRENCE, S.H.F., THOMPSON, M., RANKIN, A.P.C., ALEXANDER, J.C., BISHOP, D.J. AND BOTERHOVEN, B., 2014—A new structural analysis of the Browse Basin, Australian North West Margin. *The APPEA Journal* 54(1), 1–10.
- LECH, M.E., ROLLET, N., CAUST, D. AND ROMINE, K.K., 2015—[Paleogeographic Evolution of Early Campanian to Maastrichtian Supersequences in the Caswell Sub-Basin – Implications for CO₂ Storage and Hydrocarbon Entrapment](#). AAPG International Conference and Exhibition, 13-16 September 2015, Melbourne, Australia.
- LE POIDEVIN, S.R., KUSKE, T.J., EDWARDS, D.S. AND TEMPLE, P.R., 2015—[Australian Petroleum Accumulations Report 7 Browse Basin: Western Australia and Territory of Ashmore and Cartier Islands Adjacent Area, 2nd edition. Record 2015/10](#). Geoscience Australia, Canberra.
- LISIECKI, L.E. AND RAYMO, M.E., 2005—A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}\text{O}$ records. *Paleoceanography*, 20, 1-17.
- LOGAN, G.A., JONES, A.T., KENNARD, J.M., RYAN, D. AND ROLLET, N., 2010—Australian offshore natural hydrocarbon seepage studies, a review. *Marine and Petroleum Geology*, 27, 26-45.
- MAUNG, T.U., CADMAN, S. AND WEST, B., 1994—A review of the petroleum potential of the Browse Basin. In: Purcell, P.G. and R.R. (eds), *The Sedimentary Basins of Western Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 1994, 333–346.
- MCKINNON, A.D., DUGGAN, S., HOLLIDAY, D. AND BRINKMAN, R., 2015—Plankton community structure and connectivity in the Kimberley-Browse region of NW Australia. *Estuarine, Coastal and Shelf Science*, 153, 156-167.
- MURPHY AUSTRALIA WA-423-P OIL PTY LTD, 2013—Eupheme 1 Final Well Completion Report, unpublished.
- NEXUS ENERGY LTD, 2007a—[webpage] ASX Announcement. Progress Report No.16. Completion of drilling operations Crux-2 ST1 appraisal well in exploration permit AC/P23, 20 April 2007. <http://asx.com.au/asxpdf/20070420/pdf/312170pr711f3k.pdf> (last accessed 1 August 2020).
- NEXUS ENERGY LTD, 2007b—[webpage] ASX Announcement. Fossetmaker-1 appraisal well intersects a tight gas column in Exploration Permit WA-377-P. 3 September 2007. <http://asx.com.au/asxpdf/20070903/pdf/314c2mk96z4rq2.pdf> (last accessed 1 August 2020).
- NEXUS ENERGY LTD, 2011—[webpage] ASX Announcement. Crux Field – Liquids Project, SEAAOC 6 October. <http://asx.com.au/asxpdf/20111006/pdf/421l8s97407m4r.pdf> (last accessed 1 August 2020).
- NICHOLSON, C., ROMEYN, R., LECH, M., ABBOTT, S.T., BERNARDEL, G., CARROLL, A., CAUST, D., GROSJEAN, E., HACKNEY, R., HOWARD, F., MELROSE, R., NICHOL, S., RADKE, L., ROLLET, N., SIWABESSY, J. AND TRAFFORD, J., 2015—[Browse Basin 2014 Marine Survey: Investigating containment for potential Late Cretaceous CO₂ storage plays](#). AAPG International Conference and Exhibition, 13-16 September 2015, Melbourne, Australia.
- O'BRIEN, G.W., ETHERIDGE, M.A., WILCOX, J.B., MORSE, M., SYMONDS, P., NORMAN, C. AND NEEDHAM, D.J., 1993—The structural architecture of the Timor Sea, north-western Australia: implications for basin development and hydrocarbon exploration. *The APEA Journal*, 33(1), 258–278.

O'BRIEN, G.W. AND GLENN, K.C., 2005—Natural hydrocarbon seepage, sub-seafloor geology and eustatic sea-level variations as key determiners of the nature and distribution of carbonate build-ups and other benthic habitats in the Timor Sea, Australia. The Beagle, Records of the Museum and Art Galleries of the Northern Territory 2005, Supplement 1, 31-42.

OE DIGITAL, 2015—[Web page] Shell finds hydrocarbons on Auriga <http://www.oedigital.com/component/k2/item/10136-shell-finds-hydrocarbons-on-auriga> (last accessed 1 August 2020).

PALU, T., HALL, L., EDWARDS, D., GROSJEAN, E., ROLLET, N., BOREHAM, C.J., BUCKLER, T., HIGGINS, K., NGUYEN, D. AND KHIDER, K., 2017a—[Source Rocks and Hydrocarbon Fluids of the Browse Basin. AAPG-SEG 2017 Conference.](#)

PALU, T., HALL, L., GROSJEAN, E., EDWARDS, D., ROLLET, N., BOREHAM, C.J., MURRAY, A.P., NGUYEN, D., KHIDER, K. AND BUCKLER, T., 2017b—[Integrated Petroleum Systems Analysis to Understand the Source of Fluids in the Browse Basin, Australia. APPEA Conference Extended Abstract.](#)

PGS, 2017a—[webpage] NWS Australia 2D GeoStreamer® <https://www.pgs.com/data-library/asia-pacific/nw-australia/nws-australia/> (last accessed 1 August 2020).

PGS, 2017b—[webpage] Caswell 3D GeoStreamer® <https://www.pgs.com/data-library/asia-pacific/nw-australia/caswell/> (last accessed 1 August 2020).

PICARD, K., NICHOL, S.L., HASHIMOTO, R., CARROLL, A., BERNARDEL, G., JONES, L.E.A., SIWABESSY, P.J.W., RADKE, L.C., NICHOLAS, W.A., CAREY, M.C., STOWAR, M., HOWARD, F.J.F., TRAN, M. AND POTTER, A., 2014—[Seabed environments and shallow geology of the Leveque Shelf, Browse Basin, Western Australia: GA0340/SOL5754 - Post-survey report. Record 2014/10. Geoscience Australia, Canberra.](#)

PORTER-SMITH, R., HARRIS, P.T., ANDERSEN, O.B., COLEMAN, R., GREENSLADE, D., JENKINS, C.J., 2001—Classification of the Australian continental shelf based on predicted sediment threshold exceedance from tidal currents and swell waves. *Marine Geology*, 211, 1-20.

RADLINSKI, A.P., KENNARD, J.M., EDWARDS, D.S., HINDE, A.L. AND DAVENPORT, R., 2004—Hydrocarbon generation and expulsion from Early Cretaceous source rocks in the Browse Basin, North West Shelf, Australia: a Small Angle Neutron Scattering study. *The APPEA Journal*, 44(1), 151–180.

ROLLET, N., ABBOTT, S.T., LECH, M.E., CAUST, D. AND ROMEYN, R., 2015—[Cretaceous Stratigraphic Play Fairways and Risk Assessment in the Browse Basin: Implications for CO₂ Storage. AAPG International Conference and Exhibition, 13-16 September 2015, Melbourne, Australia.](#)

ROLLET, N., ABBOTT, S., LECH, M.E., ROMEYN, R., GROSJEAN, E., EDWARDS, D., TOTTERDELL, J., NICHOLSON, C., KHIDER, K., NGUYEN, D., BERNARDEL, G., TENTHOREY, E., ORLOV, C. AND WANG, L., 2016a—[A regional assessment of CO₂ storage potential in the Browse Basin: Results of a study undertaken as part of the National CO₂ Infrastructure Plan. Record 2016/17. Geoscience Australia, Canberra.](#)

ROLLET, N., ABBOTT, S., LECH, M.E., ROMEYN, R., KHIDER, K., GROSJEAN, E., EDWARDS, D., NICHOLSON, C., TOTTERDELL, J., BERNARDEL, G., TENTHOREY, E., NGUYEN, D., WANG, L. AND HACKNEY, R., 2016b—[Petroleum Prospectivity and CO₂ Storage Assessment in the Offshore Browse Basin, North West Shelf, Western Australia & Ashmore and Cartier Islands. 35th International Geological Congress, Cape Town, South Africa.](#)

ROLLET, N., EDWARDS, D., GROSJEAN, E., PALU, T., HALL, L., TOTTERDELL, J., BOREHAM, C.J. AND MURRAY, A.P., 2018—[Regional Jurassic sediment depositional architecture, Browse Basin: Implications for petroleum systems. AEGC Conference Extended Abstract.](#)

ROLLET, N., GROSJEAN, E., EDWARDS, D., PALU, T., ABBOTT, S., TOTTERDELL, J., LECH, M., KHIDER, K., HALL, L., ORLOV, C., NGUYEN, D., NICHOLSON, C., HIGGINS, K. AND MCLENNAN, S., 2016c—[New insights into the petroleum prospectivity of the Browse Basin: results of a multi-disciplinary study. APPEA Journal, 56 \(1\), 483-494.](#)

- ROLLET, N., GROSJEAN, E., EDWARDS, D., PALU, T., HALL, L., ABBOTT, S., LECH, M., TOTTERDELL, J., NGUYEN, D., KHIDER, K., BOREHAM, C.J., HIGGINS, K. GUNNING, M-E AND NICHOLSON, C., 2017—[Depositional Framework of Petroleum Systems, Browse Basin, Offshore North West Shelf, Australia. AAPG-SEG 2017 Conference.](#)
- ROLLET, N., LOGAN, G.A., KENNARD, J.M., O'BRIEN, P.E., JONES, A.T. AND SEXTON, M., 2006—Characterisation and correlation of active hydrocarbon seepage using geophysical data sets: an example from the tropical carbonate Yampi Shelf, northwest Australia. *Marine and Petroleum Geology*, 23, 145-164.
- SANTOS LTD, 2014—ASX Announcement. Significant gas-condensate discovery at Lasseter in the Browse Basin. <http://www.asx.com.au/asxpdf/20140822/pdf/42rnkhcdtjfcy.pdf> (last accessed 1 August 2020).
- SANTOS LTD, CHEVRON AND INPEX, 2013—Crown-1/1 ST1 final data report, prepared by J. Pitman (Consultant).
- SANTOS LTD, 2013a—[webpage] ASX Announcement. Gas Discovery in the Browse Basin, 7 June 2013. <http://asx.com.au/asxpdf/20130607/pdf/42gc3bnw7yfx1b.pdf> (last accessed 1 August 2020).
- SHELL AUSTRALIA LTD, 2019—[webpage], First LNG cargo shipped from Prelude FLNG. <https://www.shell.com.au/about-us/projects-and-locations/prelude-flng/prelude-e-news/first-lng-cargo-shipped-from-prelude-flng.html> (last accessed 1 August 2020).
- SHELL AUSTRALIA LTD, 2019a—Bratwurst Environment Plan Summary. <https://www.nopsema.gov.au/assets/epdocuments/A677427.pdf>
- SHELL AUSTRALIA LTD, 2019b—[webpage] Bratwurst: A significant discovery for Shell. <https://www.shell.com.au/media/2019-media-releases/shell-significant-discovery.html> (last accessed 1 August 2020).
- SHELL DEVELOPMENT (AUSTRALIA) PTY LTD, 2011—Hippolyte-1 Well Completion Report, Interpretive Data, AC/P41, Browse Basin, Australia, unpublished.
- SHUSTER, M.W., EATON, S., WAKEFIELD, L.L. AND KLOOSTERMAN, H.J., 1998—Neogene tectonics, greater Timor Sea, offshore Australia: implications for trap risk. *The APPEA Journal*, 38(1), 351–379.
- SKEWES, T.D., GORDON, S.R., MCLEOD, I.R., TARANTO, T.J., DENNIS, D.M., JACOBS, D.R., PITCHER, C.R., HAYWOOD, M., SMITH, G.P., POINER, I.R., MILTON, D., GRIFFIN, D. AND HUNTER, C., 1999—Survey and stock size estimates of the shallow reef (0-15 m deep) and shoal area (15-50 m deep) marine resources and habitat mapping within the Timor Sea MOU74 box. Volume 2: Habitat mapping and coral dieback. CSIRO Division of Fisheries Final Report, July 1999, 59pp.
- SPECTRUM, 2016—[Web page] NW Shelf multi-client seismic: unrivalled 3D seismic coverage over 2016 Acreage Release <http://www.spectrumgeo.com/wp-content/uploads/Aus-2016-Acreage-Release-Seismic-Brochure.pdf> (last accessed 18 July 2019)
- SPRY, T.B. AND WARD, I., 1997—The Gwydion discovery: a new play fairway in the Browse Basin. *The APPEA Journal*, 37(1), 87–104.
- STAGG, H.M.J. AND EXON, N.F., 1981—Geology of the Scott Plateau and Rowley Terrace off northwestern Australia. Bureau of Mineral Resources, Geology and Geophysics, Bulletin, 213, 93pp.
- STALVIES, C., TALUKDER, A., ROSS, A., GROSJEAN, E., CARR, A., WILLIAMS, A., GRESHAM, M., BINNING, M. AND JABLONSKI, D., 2017—Establishing Hydrocarbon Charge to the Ashmore Platform, Bonaparte Basin, Australia: A Natural Seeps Study. *Marine and Petroleum Geology* 82, 56-68.
- STEHOUWER, P.J., 1981—Report on a dropline fishing operation: Observations of the “Takuryo Maru No. 11” during feasibility fishing operations in the Australian fishing zone. Fishery Report No. 6, Department of Primary Production, October 1991. 28pp.
- STEIN, A., MYERS, K., LEWIS, C., CRUSE, T. AND WINSTANLEY, S., 1998—Basement control and geoscientific definition of the Cornea discovery, Browse Basin, Western Australia. In: Purcell, P.G. and R.R. (eds), 1998, *The Sedimentary Basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, WA, 1998, 421–431.

- STEPHENSON, A.E. AND CADMAN, S.J., 1994—Browse Basin, Northwest Australia: the evolution, palaeogeography and petroleum potential of a passive continental margin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 111, 337-366.
- STRUCKMEYER, H.I.M., BLEVIN, J.E., SAYERS, J., TOTTERDELL, J.M., BAXTER, K. AND CATHRO, D.L., 1998—Structural evolution of the Browse Basin, North West Shelf: new concepts from deep-seismic data. In: Purcell, P.G. and R.R. (eds), 1998, *The Sedimentary Basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, WA, 1998, 345–367.
- SYMONDS, P.A., COLLINS, C.D.N. AND BRADSHAW, J., 1994—Deep structure of the Browse Basin: implications for basin development and petroleum exploration. In: Purcell, P.G. and R.R. (eds), *The Sedimentary Basins of Western Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 1994, 315–331.
- TOTAL E&P AUSTRALIA, 2014—Dufresne 1 / Dufresne 1B Well Completion Report (Basic), unpublished.
- TOVAGLIERI, F., GEORGE, A.D., JONES, T. AND ZWINGMANN, H., 2013—Depositional and volcanic history of the Early to Middle Jurassic deltaic reservoirs in Calliance and Brecknock Fields (Plover Formation), Browse Basin, North West Shelf, Australia. *West Australian Basins Symposium*, Perth, WA, 18–21 August, 2013.
- TUCKER, S.P., 2009—Post-rift marine transgression of the southern Browse Basin margin: controls on hydrocarbon reservoir development and exploration potential. *The APPEA Journal*, 49(1), 43–63.
- VERON, J.E.N. AND MARSH, L.M., 1988—Hermatypic corals of Western Australia: Records and annotated species list. *Records of the Western Australian Museum*, Supplement No. 29.
- VOLK, H., BRINCAT, M.P., GEORGE, S.C., KENNARD, J.M., EDWARDS, D.S., BOREHAM, C.J., AHMED, M. AND LISK, M., 2005—Clues to fill histories of gas fields in the Caswell Sub-basin—evidence from the distribution and geochemistry of palaeo-oils. *The APPEA Journal*, 45(1), 679.
- WELLS, F.E. AND ALLEN, G.R., 2005—Marine biodiversity on offshore coral reefs in north-western Australia. *The Beagle, Records of the Museum and Art Galleries of the Northern Territory* 2005, Supplement 1, 43-50.
- WILLIS, I., 1988—Results of exploration, Browse Basin, North West Shelf, Western Australia. In: Purcell, P.G. and R.R. (eds), *The North West Shelf, Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, 1988, 259–272.
- WILSON, B., 2013—The biogeography of the Australian North West Shelf: environmental change and life's response, Elsevier. Burlington, M. A., 413 pp.
- WOLANSKI, E. AND DELEERSNIJDER, E., 1998—Island-generated internal waves at Scott Reef, Western Australia. *Continental Shelf Research*, 18, 1649-1666.
- WOODSIDE, 2012b—Omar 1 Well Completion Report, unpublished.
- WOODSIDE, 2019—[Web page] Proposed Browse to NWS Project Draft EIS/ERD (December 2019) https://files.woodside/docs/default-source/current-consultation-activities/australian-activities/proposed-browse-to-north-west-shelf-project---draft-eis-erd.pdf?sfvrsn=12d274a8_4 (last accessed 5 May 2021).

Figure Captions

- Figure 1** Location map showing the sedimentary basins of Australia's North West Shelf.
- Figure 2** Map of the Browse Basin showing bathymetry, petroleum well distribution and oil and gas fields.
- Figure 3** Seismic section (line BBHR07) across the Caswell Sub-basin highlighting the onlap of Mesozoic sediments on basement underlying the Yampi Shelf.
- Figure 4** Seismic section (line BBHR15) across the boundary between the Barcoo and Caswell sub-basins, highlighting the different thickness of the Mesozoic successions.
- Figure 5** Tectonic elements map of the Browse Basin showing bathymetry, petroleum well distribution, and oil and gas fields.
- Figure 6** Stratigraphic chart for the Browse Basin showing hydrocarbon occurrences. Based on the Browse Basin Biozonation and Stratigraphy Chart (Kelman et al, 2017). Geologic Time Scale after Gradstein et al (2020).
- Figure 7** Schematic cross-section (not to scale) depicting hydrocarbon play types in the Caswell Sub-basin within **a)** sequence stratigraphic context, and **b)** lithostratigraphic context.
- Figure 8** Map of the Caswell Sub-basin showing bathymetry, petroleum well distribution, oil and gas fields, and Ichthys to Darwin pipeline.
- Figure 9** Stratigraphic chart for the Leveque and Yampi shelves showing well intersections of hydrocarbons. Based on the Browse Basin Biozonation and Stratigraphy Chart (Kelman et al, 2017). Geologic Time Scale after Gradstein et al (2020).
- Figure 10** Stratigraphic chart for the Caswell and Barcoo sub-basins showing well intersections of hydrocarbons. Based on the Browse Basin Biozonation and Stratigraphy Chart (Kelman et al, 2017). Geologic Time Scale after Gradstein et al (2020).
- Figure 11** Map showing the current main operators, active exploration permits, retention leases and production licences.
- Figure 12** Map showing petroleum exploration permits, oil and gas fields and petroleum production facilities in the Browse Basin.
- Figure 13** **a)** Hierarchical cluster analysis for oil and condensate families in the Browse Basin (Edwards et al., 2016) and **b)** carbon isotopic data for individual hydrocarbons in natural gases and oils from the Browse Basin (Grosjean et al., 2015, 2016). These data highlight the source differences between the Cretaceous-sourced (K20-K30 supersequences) fluids, from Adele 1 (gas) and Kalyptea 1 ST1 (gas and oils), which are depleted in ^{13}C (green), with those of Jurassic-sourced fluids (J10-J20 supersequences) from the Scott Reef Trend, which are enriched in ^{13}C (orange), and fluids with intermediate composition from the Ichthys and Burnside accumulations that are interpreted to be sourced and sealed by the K10 supersequence (pink). Fluid from Crux 1 in the Heywood Graben is isotopically enriched in ^{13}C (blue). The supersequence labelled after the well name in the key is the reservoir.
- Figure 14** Petroleum systems modelling results for the K20-K30 supersequences (Echuca Shoals Formation), J30-K10 supersequences (Vulcan Formation) and J10-J20 supersequences (Plover Formation). Columns definitions are; **a)** net source rock thickness (m); **b)** transformation ratio (TR; mass fraction); and **c)** maturity (%Ro).
- Figure 15** Petroleum systems modelling results for; **a)** K20-K30 supersequences (Echuca Shoals Formation); **b)** J30-K10 supersequences (Vulcan Formation); and **c)** J10-J20 supersequences (Plover Formation). Row definitions; 1) gas expelled (bcf/km²); and 2) oil expelled (mmbbl/km²).

- Figure 16** Hydrocarbon expulsion maps (oil + gas mmboe/km²) for; **a)** K20-K30 supersequences (Echuca Shoals Formation); **b)** J30-K10 supersequences (Vulcan Formation); and **c)** J10-J20 supersequences (Plover Formation). The extent of the modelled expelled hydrocarbons and known hydrocarbon accumulations is used to define the potential extent of the associated petroleum systems.
- Figure 17** Schematic cross-section through the Caswell Sub-basin, showing mappable sequences and key petroleum wells.
- Figure 18** Map showing marine reserves, marine parks, multiple use zones and ecological features in the Browse Basin.