Australian Government
Geoscience Australia

Geoscience Australia submission to the Senate Environment and Communications Committee "Inquiry into oil or gas production in the Great Australian Bight"

1 Introduction

Geoscience Australia provides a broad range scientific information and advice to assist governments, industry and the community with making decisions about the management of Australia's natural resources both now and into the future. Geoscience Australia has expertise in geology, geophysics, geodesy, satellite imagery, and topographic mapping.

One of Geoscience Australia's key priorities is to support investment in mineral and energy resource exploration by technically de-risking exploration opportunities through precompetitive data acquisition and regional geological studies. We have been collecting and delivering geoscience data to industry for over 70 years, leading to many mineral and energy resource discoveries.

Australia's future economic prosperity will be underpinned by maintaining a steady stream of new mineral and energy projects. In a competitive global resources market, the challenge for Australia is to continue to attract the investment to sustain the sector.

In terms of energy, Australia has a significant advantage in the production of oil and gas resources over other nations. This advantage stems from the diverse endowment, the high quality regional-scale geoscience information that lowers the technical risks for exploration, advanced exploration, drilling and processing technologies, a skilled workforce, generally favourable physical environments, relatively stable economic conditions, enabling and robust legislative and regulatory framework, and low sovereign risk. Strengthening and maintaining Australia's competitive advantage in attracting global energy investment relies on maintaining a healthy pipeline of globally-significant exploration opportunities.

Geoscience Australia plays a lead role in maintaining Australia's competitive advantage in the global energy resources sector by:

- Acquiring precompetitive data and developing new scientific concepts;
- Capturing, storing, managing and delivering offshore petroleum data and samples; and
- Undertaking regional integration studies to develop foundational understanding of energy systems.

Whilst Australia's gas resources are extensive, domestic supplies of oil are limited and production continues to decline. It is expected that the trend of decreasing oil resources will not change within the known oil basins, making the discovery of a new oil province or provinces essential to maintaining Australia's future energy security. Some of the remotest areas of Australia's maritime jurisdiction present the greatest opportunities for discovering Australia's next major oil province, including the Ceduna Sub-basin and Bight Basin in the Great Australia Bight.

2 Value of Petroleum Production to Australia

In 2014-15, the Australian energy sector accounted for about 6 per cent of gross industry value added, contributed 39 per cent of total export value, supported a large range of manufacturing industries, and provided significant employment and infrastructure (Department of Industry, Innovation and Science, 2015).

2.1 Energy Production

Australia produces energy for its own use and for export for consumption overseas. Over the 10 years to 2013–14 Australia's primary energy production increased at an average rate of 1.1 per cent per year. Total primary energy production in Australia in 2013–14 was 18,715 petajoules (PJ), around three times larger than domestic consumption.

Black and brown coal accounted for 66 per cent of Australia's primary energy production (in energy content terms) in 2013–14, followed by uranium (14 per cent) and natural gas (13 per cent). Crude oil, condensate, and naturally occurring liquefied petroleum gas (LPG) accounted for another 5 per cent. Renewables, mostly bioenergy and hydro, contributed the remaining 2 per cent. In 2013–14 Australia's primary energy production decreased by 4 per cent, underpinned by a fall in uranium oxide, crude oil and brown coal production.

2.2 Oil

Australia has limited resources of crude oil, and most known remaining oil resources are condensate and naturally occurring LPG associated with large offshore gas fields. Australia holds around 0.2 per cent of world crude oil reserves.

At the end of 2014, Australia's remaining oil resources were estimated at 29,486 PJ (5,417 Mbbl), comprising 16,463 PJ (2,800 Mbbl) of condensate, 7,066 PJ (1,202 Mbbl) of crude oil, and 5,957 PJ (1,415 Mbbl) of LPG.

Australia produces a range of liquid fuels — crude oil, condensate and naturally occurring LPG. In 2014–15, around 77 per cent of this was exported; the majority being sourced from the north-west coast of Australia.

In 2014–15 Australia's crude oil and condensate production declined by 5 per cent to 19 gigalitres, underpinned by declining production from mature fields that outweighed additional output from new projects. Naturally occurring LPG production also fell by 11 per cent to 3 gigalitres. The falls in output continues a longer term decline in Australia's production of primary petroleum.

Australia is a net importer of crude oil and other refinery feedstock but a net exporter of LPG. In 2014–15, Australia imported 24.7 gigalitres of crude oil and other refinery feedstock. The high proportion of imports as a share of total production reflects the fact that most of Australia's oil production occurs off the north-west coast of Western Australia, which is closer to Asian refineries than domestic refineries on the east coast, and is therefore more profitable to export.

With declining east coast production, domestic refineries on the east coast now mostly rely on imported feedstock. In addition to costs, crude grades produced in Australia are generally not as well suited for use by Australian refineries as those sourced from other countries.

In 2014–15, Australia exported about 15.2 gigalitres of crude oil and other refinery feedstock, up by 2 per cent from 2013–14 levels. Although the volume of exports increased, the value of crude oil and other refinery feedstock exports decreased considerably by 24 per cent in real terms to total $8.7 billion, reflecting a lower Australian dollar.

2.3 Gas

At the end of 2014, Australia's conventional gas resources were estimated at 186,200 PJ (169 trillion cubic feet, tcf). Around 92 per cent of Australia's conventional gas resources are located in the Carnarvon, Browse and Bonaparte basins off the north-west coast. There are also resources in south-west, south-east and central Australia.

Australia also has significant unconventional gas resources. Coal seam gas (CSG) resources have continued rising to an estimated 79,440 PJ (75 tcf) at the end of 2014. Large CSG resources exist in the coal basins of Queensland and New South Wales.

Australia may also have significant resources of shale and tight gas. The current estimate of shale and tight gas is 730,200 PJ (663 tcf), although the estimate has a high degree of uncertainty (Geoscience Australia, 2016).

Gas — conventional and unconventional — plays an important role in the Australian economy. Gas accounts for almost one-quarter of primary energy consumption, one-fifth of electricity generation, and is one of Australia's highest valued commodity exports. More than half of Australia's gas production is exported, and Australia is currently the world's third largest exporter of liquefied natural gas (LNG). LNG exports were worth $17 billion in 2014-15. This is projected to increase to $25 billion in 2020-21.

Australia produced 2,587 PJ (2.3 tcf) of natural gas in 2014–15. Gas production increased 6 per cent in 2014–15, supported by the start-up of the QCLNG project in Queensland. Over the past decade, Australian gas production has expanded by an average of 5 per cent a year.

Western Australia accounted for 60 per cent of Australia's total gas production in 2014–15 (1,616 PJ). The majority of this production is slated for LNG exports. Almost all gas production in Western Australia is in the Carnarvon Basin, with a small volume produced in the Perth Basin.

2.4 Energy Exports

Australia's net energy exports (exports minus imports) in 2013–14 were equivalent to 72 per cent of production. Energy exports accounted for 39 per cent of the value of Australia's total commodity exports in 2014–15 and were valued at $67 billion.

Coal was the largest energy export earner, with a value of around $37.9 billion in 2014–15, followed by LNG ($16.9 billion) and crude oil and other petroleum products ($11.5 billion). Export earnings from energy commodities decreased by 6 per cent in 2014–15, mainly as a result of a fall in coal prices.

2.5 Energy Imports

Australia's petroleum imports were valued at $34.2 billion in 2014–15. Crude oil was valued at $14.9 billion, while refined petroleum products were valued at $19.3 billion. Australia is a net importer of oil products, with refined product imports accounting for half of consumption in 2013–14. Australia also imports natural gas from the Joint Petroleum Development Area (JPDA) in the Timor Sea, for liquefaction and export as LNG. In 2013-14, Australia imported 260 PJ of gas from the JPDA.

3 Petroleum Prospectivity of Frontier Basins

In 2014, Geoscience Australia published a petroleum geology inventory of Australia's offshore frontier basins[1] (Totterdell et al., 2014). The study considered the geology and petroleum potential of 35 offshore frontier basins, sub-basins and provinces on Australia's northern, northwestern, southwestern, southern, southeastern and remote eastern margins.

The prospectivity of each basin or area was determined through an assessment of its geological history and whether the geological factors necessary for the existence of a petroleum system were known, or considered likely, to be present. Those geological factors include the presence of hydrocarbon source rocks (rocks containing high levels of organic carbon), reservoir and seal rocks, geological structures or stratigraphic features that can trap migrating hydrocarbons, and a favourable timing of hydrocarbon generation relative to timing of structuring.

The prospectivity assessments presented in Totterdell et al., (2014) have been summarised (Figure 1), with Australia's offshore frontier basins classified in terms of both their perceived prospectivity, and the confidence of this rating based on the amount (and quality) of data available. The Ceduna Sub-basin of the Bight Basin was ranked as the most prospective for hydrocarbons of all the areas considered. This assessment was based on the quality of the source rocks, the size of the basin, and the presence – both known and interpreted – of all the necessary elements for active petroleum systems.

Not only is the Ceduna Sub-basin one of the largest under-explored basins in Australia, it is considered by many in the petroleum industry to be one of the largest in the world. This is reflected in the interest taken in the area by large international companies (e.g. BP, Chevron, Statoil) that have global exploration programs, and the size of their committed expenditure. No other Australian frontier basins have attracted a similar level of interest from the international petroleum industry.

The prospectivity of the Ceduna Sub-basin is based on a unique combination of geological factors. The geological development of the sub-basin was characterised by successive large delta systems that deposited sediments into the opening seaway between Australia and Antarctica between 100 and 65 million years ago (Ma). The distribution of organic-rich marine and deltaic rocks in these sedimentary systems and their structural architecture are the keys to the basin's prospectivity. Organic-rich mudstones within the basin are believed to be buried deeply enough to generate oil and gas across much of the sub-basin. While these rich source rocks have not been intersected by previous drilling, a Geoscience Australia marine survey in 2007 that dredged rocks from canyons incised into the Ceduna and Eyre terraces, found a suite of rocks about 94 million years old that are enriched in organic carbon and capable of generating oil.

It is important to understand that as the most prospective parts of the Bight Basin are yet to be drilled much is still not known. Geoscience Australia's understanding of how the petroleum systems have developed is based on the interpretation of reflection seismic data sets, data from 10 petroleum exploration wells (most drilled on the edges of the basin), and modelling. As a result, and in common with all frontier regions, there remains a degree of uncertainty about its petroleum potential. In a recent industry newsletter, Professor Peter McCabe (The University of Adelaide) said that "huge volumes of oil have most likely been generated in the Great Australian Bight but the biggest question is whether any of it is still in the basin."

[1] A frontier basin is defined as one that is considered prospective for hydrocarbons due to its geology, but where no hydrocarbon discoveries have been made.

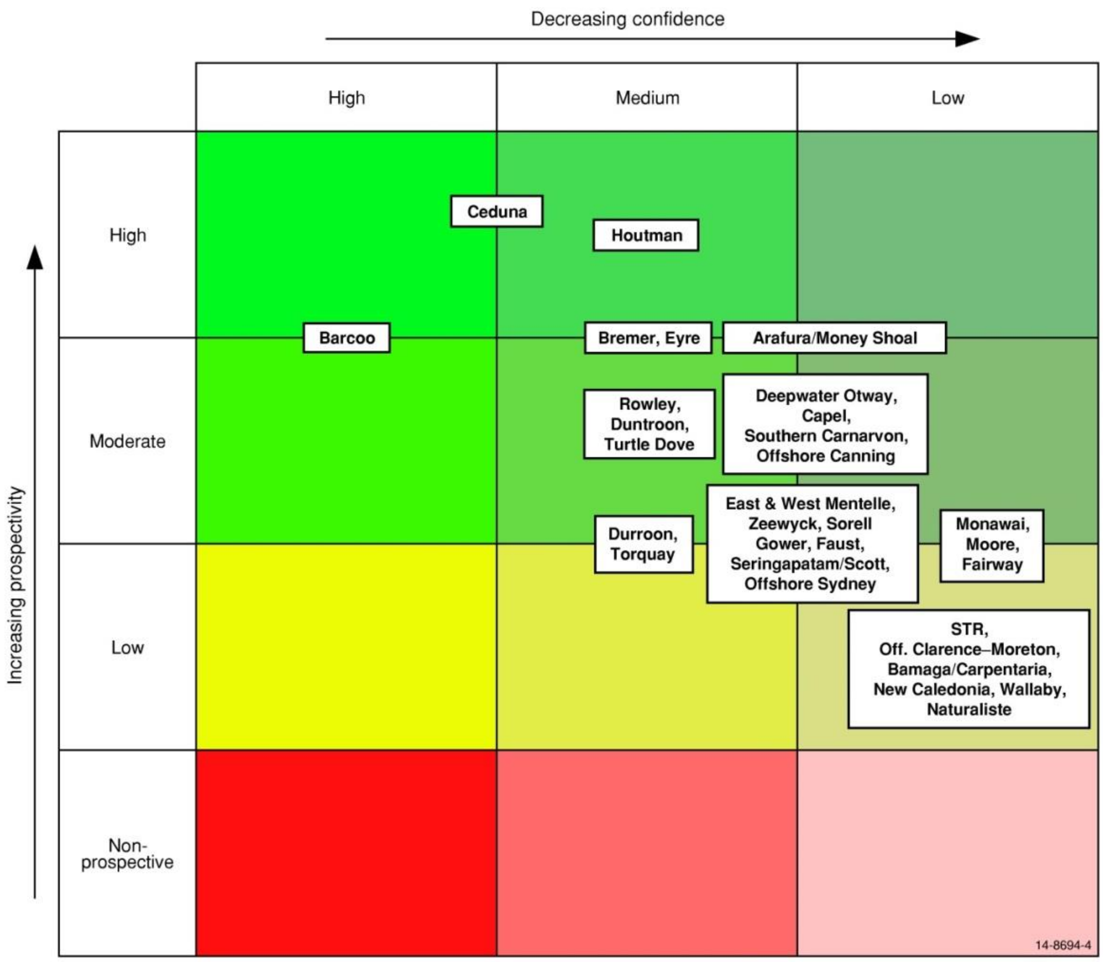

Figure 1: Prospectivity-confidence matrix for Australia's offshore frontier basins (from Totterdell et al., 2014).

3.1 Geological Basis for Prospectivity

From 1998-2000, as part of the Australian Government's Frontiers in Petroleum Initiative, Geoscience Australia undertook a study of the Bight Basin, which encompasses the Ceduna Sub-basin. The Australian Geological Survey Organisation (predecessor to Geoscience Australia) designed a research program to address scientific questions regarding the geological evolution of the basin and its likely hydrocarbon prospectivity, and to support the release of new exploration acreage in the area. The study included acquisition of two grids of regional 2D seismic reflection data.

3.1.1 Ceduna Sub-basin Geological Summary

The Bight Basin is one of a series of Mesozoic to Cenozoic basins that developed along Australia's southern margin during the breakup of eastern Gondwana. The basin is located on Australia's southern continental margin and extends from south of Cape Leeuwin in the west, to south of Kangaroo Island in the east (Figure 2).

The main depocentre of the Bight Basin is the Ceduna Sub-basin, which is located offshore of South Australia (Figure 3). The Ceduna Sub-basin covers an area in excess of 125,000 km^2 and contains at least 15,000 m of rift and post-rift Middle Jurassic–Upper Cretaceous sediments. The accumulation of sediments in the Ceduna Sub-basin is the cause of the prominent bathymetric feature—the Ceduna Terrace—seen on Figure 2.

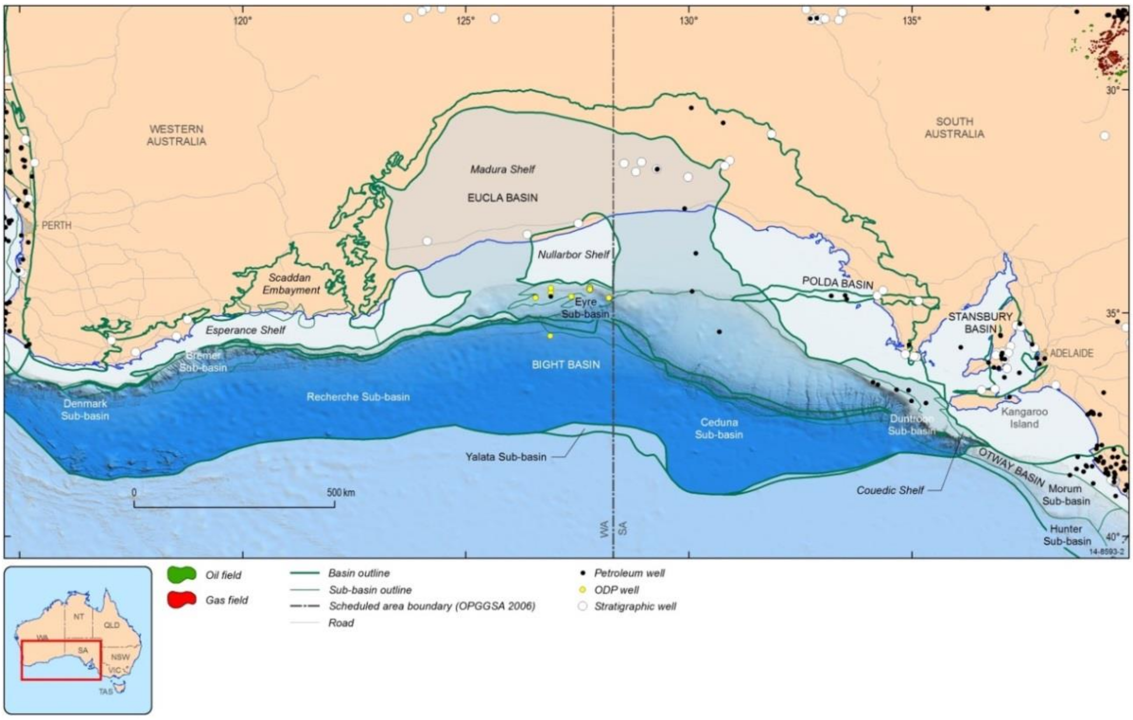

Figure 2: Map showing location of the Bight Basin.

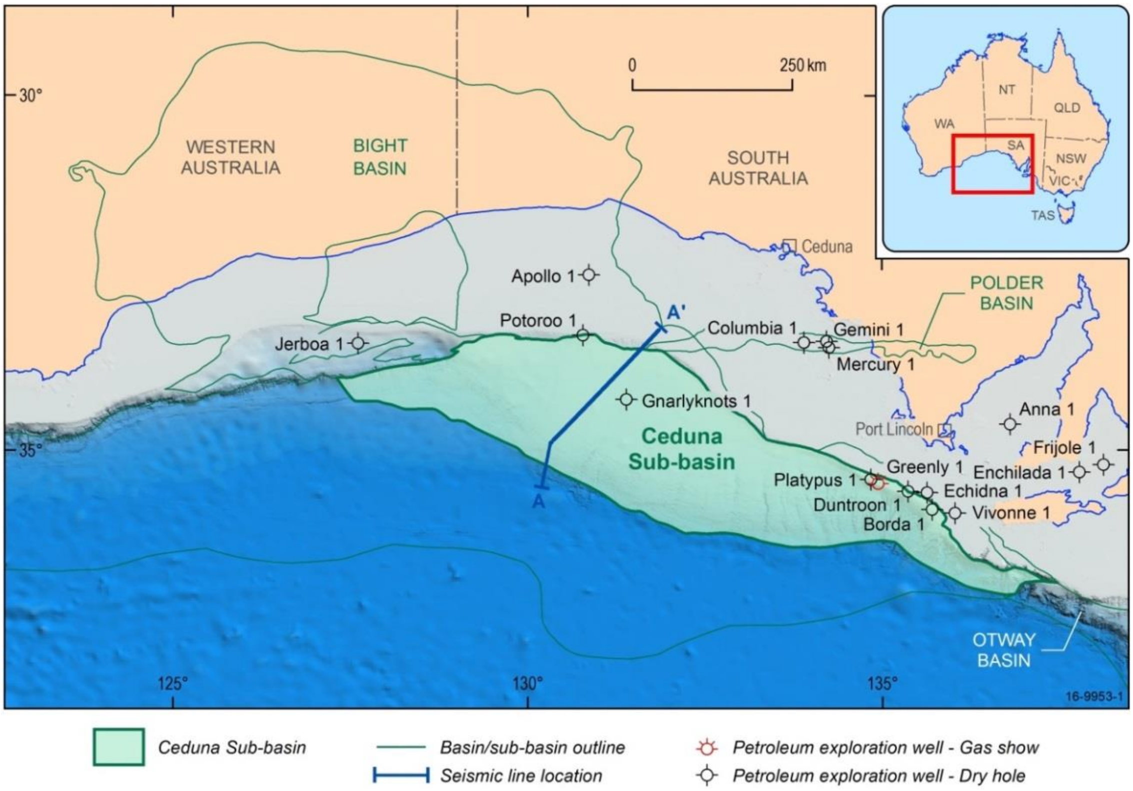

Figure 3: Ceduna Sub-basin.

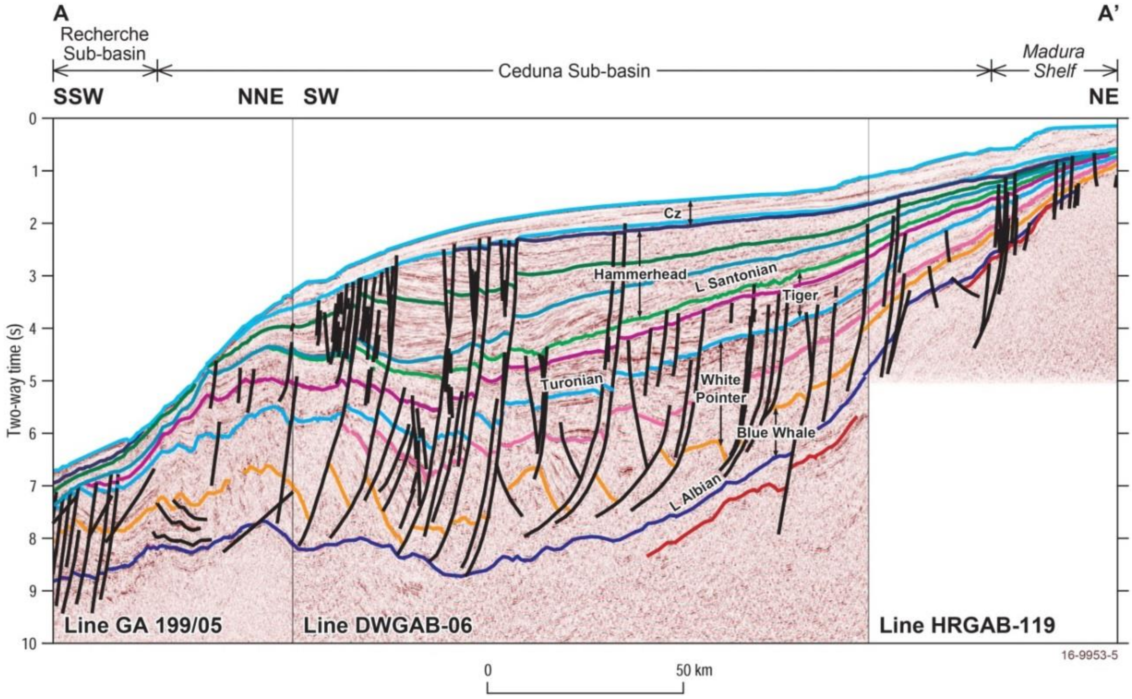

Figure 4: Seismic cross-section across the Ceduna Sub-basin. Location of seismic line shown in Figure 3.

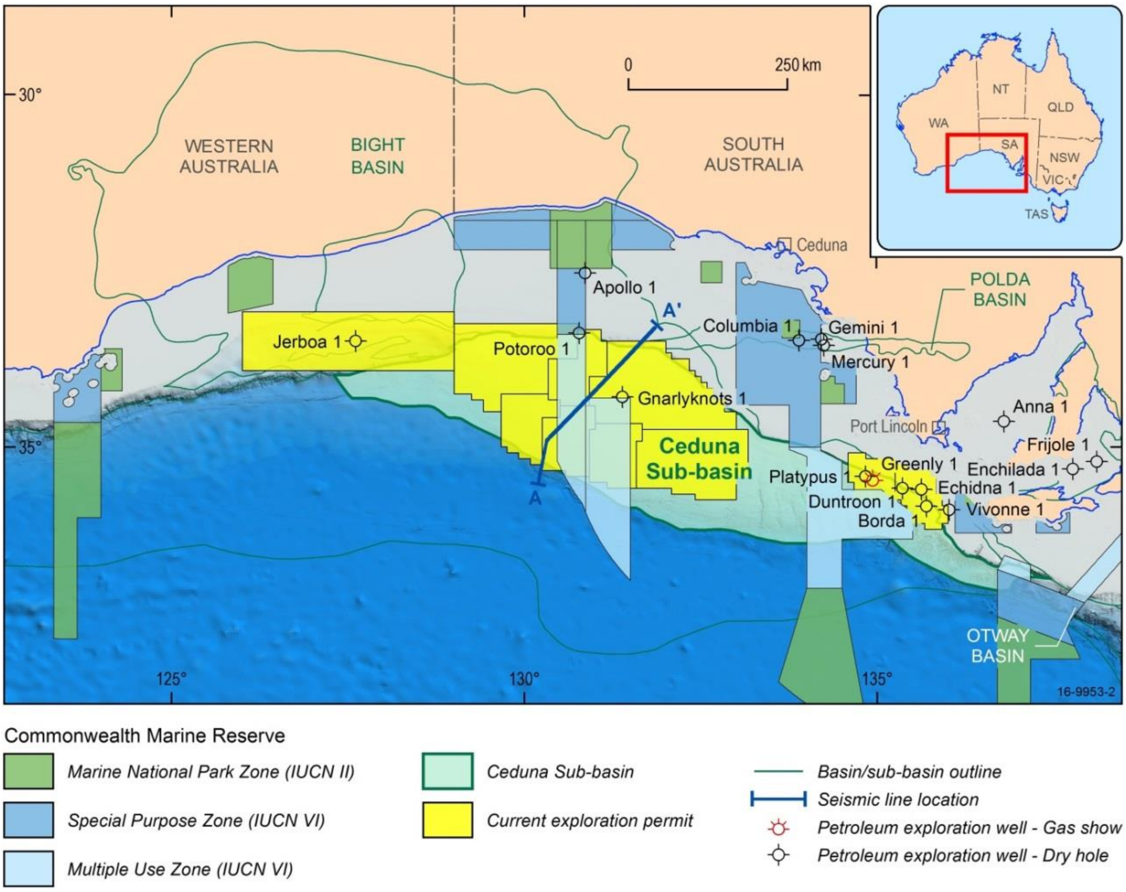

Figure 5: Eastern Bight Basin permits.

These sediments accumulated in the basin as it evolved from an intracontinental rift between the still connected Australian and Antarctic continents (about 165 Ma), to a passive margin basin following sea-floor spreading between the continents (about 84 Ma) and Australia's subsequent drift northward. Figure 4 is a seismic cross-section from the northern Ceduna Sub-basin that crosses BP and Chevron operated permits (EPP 39 and 45 respectively – see Figure 5) and shows the typical geology of the basin. The coloured horizons differentiate the different stratigraphic sequences.

The earliest sediments were deposited in lakes and by rivers in a series of rift valleys. As the Earth's crust continued to stretch and subside with the opening of the proto-Southern Ocean, sedimentation became more widespread and eventually marine conditions began to dominate. By about 100 Ma, a narrow seaway, closed off at its eastern end, existed between Australia and Antarctica. Thick marine shales (the Blue Whale Supersequence shown near the base of the cross-section in Figure 4) accumulated in this seaway. From about 98-65 Ma, massive delta systems fed sediments into the basin (White Pointer, Tiger and Hammerhead supersequences). While the rivers that formed these deltas no longer exist, the presence of large delta systems in the Great Australian Bight during the Cretaceous is indicated by the sedimentology of rocks intersected in wells such as Potoroo 1 and Gnarlyknots 1A, and the architecture of the sedimentary packages revealed by seismic data. A regional crustal uplift at the end of the Cretaceous resulted in the basin being cut-off from sediment input. Deposition from that time on was dominated by cool-water carbonate sedimentation; these carbonate rocks are seen in the cliffs at the head of the Great Australian Bight.

3.1.2 Petroleum Systems of the Ceduna Sub-basin

Only ten petroleum exploration wells have been drilled in the eastern Bight Basin[2], five of those in the Ceduna Sub-basin (Figure 3). With the exception of Gnarlyknots 1A, all wells have been drilled in relatively shallow water near the basin margin and the deeper part of the sub-basin remains largely untested. Only one well, Gnarlyknots 1A, has targeted the most prospective part of the Ceduna Sub-basin. Oil shows and gas indications in Greenly 1 in the eastern Ceduna Sub-basin and evidence of a breached accumulation in Jerboa 1 (in the Eyre Sub-basin) provide support for the presence of active petroleum systems in the basin. Indirect evidence for the presence of hydrocarbons is provided by numerous indicators on seismic and remote sensing data, and the occurrence of asphaltites derived from a marine source in stranded coastal bitumens. Although Gnarlyknots 1A was unsuccessful (see below), a number of secondary indications of hydrocarbon charge have been described from analyses of well samples.

The key to the petroleum prospectivity of the Ceduna Sub-basin is the distribution of Upper Cretaceous marine and deltaic sediments. Potential source rocks are interpreted to be present throughout this succession, including oil-prone marine shales (Blue Whale and Tiger supersequences respectively), deltaic and shallow marine shale and coal (White Pointer Supersequence), and pro-delta shales (Hammerhead Supersequence; Figure 4). Recent dredging of upper Cenomanian–Turonian (94 Ma) organic-rich marine rocks by Geoscience Australia has confirmed the presence of high quality potential source rocks. Excellent reservoir rocks and potential intraformational seals are present in the Upper Cretaceous deltaic successions, and regional seals could be provided by Upper Cretaceous marine shales. In addition, potential source rocks are likely to be present within Jurassic–Early Cretaceous (165–140 Ma) rift and post-rift successions along the northern and eastern margins of the sub-basin. Key potential source rocks here are lacustrine shales and fluvio-lacustrine coals and carbonaceous shales.

[2] By comparison, the Gulf of Mexico, which is of comparable areal extent contains over 100,000 wells.

Regional petroleum systems modelling has shown that potential Jurassic to Cretaceous source intervals in the Ceduna Sub-basin have reached maturities adequate to generate and expel liquid and gaseous hydrocarbons, and are likely to have generated and expelled hydrocarbons since the Campanian (since 84 Ma) in the central part of the sub-basin. Sediment loading of the Upper Cretaceous succession and, in particular, the Hammerhead supersequence, was the critical event in the maturation of successively younger source rocks. Three dimensional (3D) petroleum systems modelling indicates that the sub-basin has experienced several phases of hydrocarbon generation, expulsion and accumulation. Early generated and accumulated oil and gas from potential source rocks of the Blue Whale and White Pointer supersequences are likely to have spilled from earlier structures, but may have accumulated through remigration into structures along the basin margin. Late (25 Ma and younger) generated and accumulated oil and gas from the Blue Whale and White Pointer supersequences is potentially preserved in structures in the inboard and outboard parts of the basin. Generation and expulsion from lower Turonian organic-rich rocks started in the Late Cretaceous and is continuing to the present day.

Geochemical analysis of rocks dredged by Geoscience Australia from a canyon on the western edge of the Ceduna Sub-basin showed that some of the rocks (those about 94 Ma), have excellent hydrocarbon source rock potential (mentioned above). These rocks also share some of the characteristics of rocks found elsewhere in the world that were deposited during a period of major climatic, environmental and oceanic change called “Oceanic Anoxic Event 2”. This event represents one of the largest carbon cycle perturbations in Earth history, with widespread organic-matter burial in oxygen depleted environments (preserved as black shales). A site in the western Ceduna Sub-basin will be drilled (570 m) by the International Ocean Discovery Program vessel JOIDES *Resolution* in late 2017 to obtain a continuous core through this section; the material will be made available to international scientific researchers.

3.2 Oil and Gas Exploration in the Bight Basin

Petroleum exploration in the Bight Basin has occurred in three major cycles—the late 1960s to early 1970s, the early 1990s, and 2000–present. In nearly 50 years of exploration in the offshore Bight Basin no hydrocarbon discoveries have been made from the 10 petroleum exploration wells drilled. However, with the exception of Gnarlyknots 1A, all wells were drilled (in relatively shallow water) near the basin margin (Figure 6) and the deeper and thicker part of the sub-basin remains largely untested. Approximately 100,000 line-km of 2D seismic data, and 33,000 km of 3D seismic data have been acquired in the basin, most in the Ceduna Sub-basin. Figure 6 shows the location of open file seismic data in the basin and Figure 7 shows the location of confidential non-exclusive 3D seismic surveys.

Early oil and gas explorers in the basin (late 1960s–early 1990s) included Shell Development (Australia), Outback Oil, BP, Esso Exploration and Production, and Hematite Petroleum (now BHP Petroleum).

The most recent phase of exploration began in 2000 when a joint venture (JV) comprising Woodside Energy, Anadarko Australia and PanCanadian Petroleum were awarded permits in the Ceduna Sub-basin, with an indicative investment of $90 million over 6 years, including the commitment to drill one well. The JV collected 2D and 3D seismic data and drilled the Gnarlyknots 1A well, prior to relinquishing the permits in 2007.

In 2003, the Gnarlyknots 1A well was drilled by the Woodside Energy led joint venture, however, due to harsh ocean conditions, the well was plugged and abandoned at 4736 m before reaching the prime objective; the cost of the well was ~$53 million and PanCanadian and Anadarko subsequently left.

The lack of success for this well, the first well to target the thicker, more prospective succession in the outboard Ceduna Sub-basin, had a large negative impact on perceptions of prospectivity in the basin and raised doubts about the presence of hydrocarbon source rocks in the basin.

Following the failure of the Gnarlyknots 1A well, Geoscience Australia undertook a precompetitive study in 2007 at a total cost of $6.7 million to address some of the key uncertainties and negative perceptions. The resulting collection and identification of world-class marine, oil-prone potential source rocks in the Bight Basin stimulated renewed exploration following another round of acreage release in 2009.

The results were announced in January 2011; four permits (EPPs 37–40) were awarded to BP Exploration (Alpha), with an indicative guaranteed work program of $605 million, including four wells, and a secondary work program in excess of $800 million in three subsequent years. Subsequently (in 2013), Statoil took a 30% interest in these permits.[3]

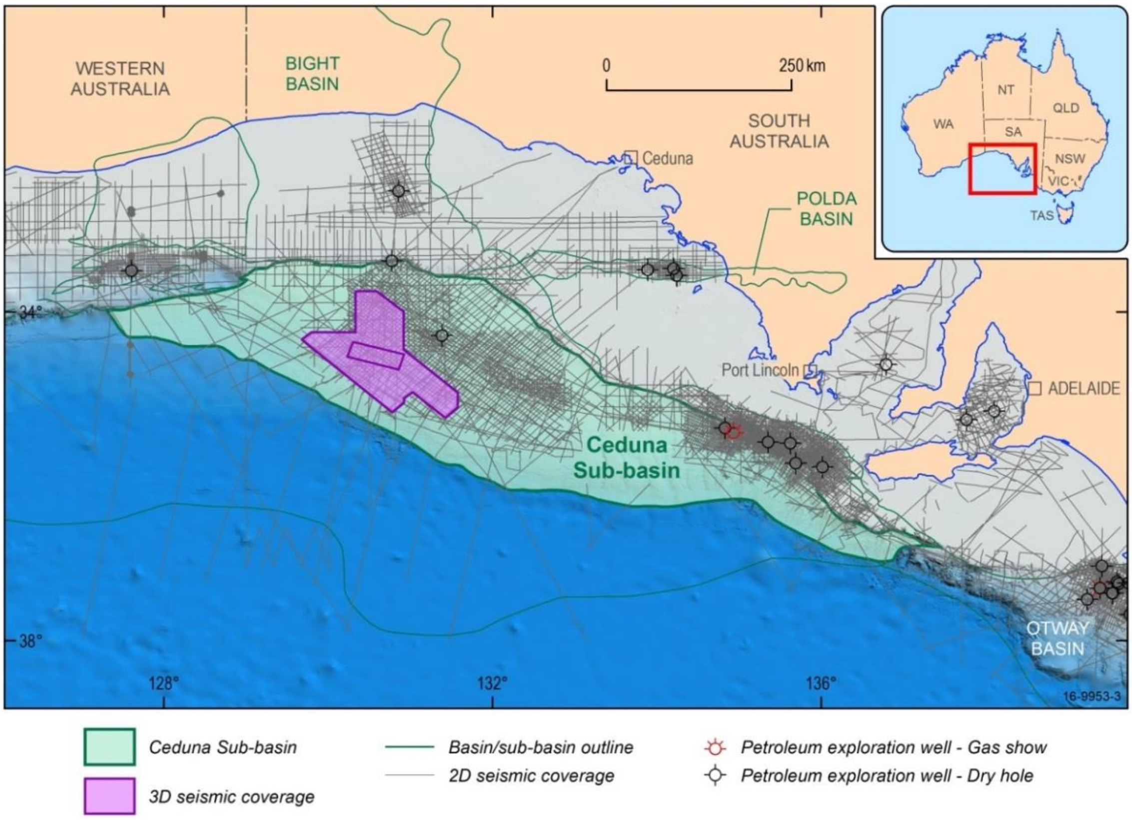

Figure 6: Open file seismic data, eastern Bight Basin.

[3] On 11 October 2016, BP announced it would not progress its exploration drilling programme in the Great Australian Bight, citing that the project would not be able to compete for capital investment with other upstream opportunities in its global portfolio (http://www.bp.com/content/dam/bp-country/en_au/media/media-releases/bp-decides-not-proceed-with-great-australian-bight-exploration.pdf).

Further acreage was released in 2012 and results announced in October 2013; two permits (EPPs 44, 45) were awarded to Chevron Australia New Ventures Pty Ltd., with an indicative guaranteed work program of $486 million, including four wells, and a secondary work program of $10 million in three subsequent years. One permit (EPP 43) was awarded to Murphy Australia Oil Pty Ltd and Santos Offshore Pty Ltd, with an indicative guaranteed work program of $50 million, and a secondary work program of $53 million in three subsequent years. The guaranteed work programs of geological and geophysical studies for the three permits is valued at $536 million over the first three years, bringing the total guaranteed minimum exploration investment across all permits in the Bight Basin to $1.2 billion.

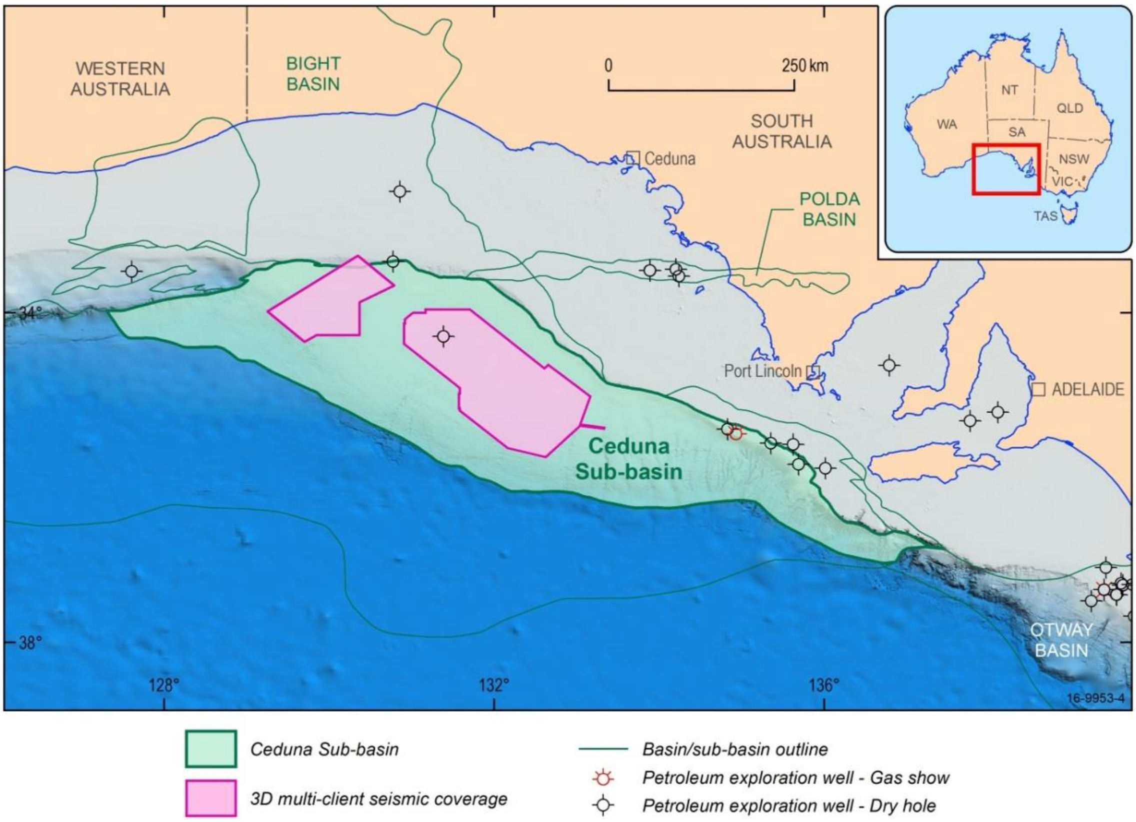

Figure 7: Confidential seismic data, eastern Bight Basin.

Since award of the permits, exploration activities by the permit holders have resulted in the acquisition of ~32,000 km^2 of 3D seismic data, which has completely altered the knowledge base for the basin, from disparate 2D data of varying vintages to an almost blanket coverage of modern high quality 3D data.

4 Marine Environmental Assets

4.1 Marine Protected Area Zoning

Between 2001 and 2004 Geoscience Australia acquired and collated a wide range of seabed data to characterise the environmental assets of Australia's four Marine Bioregions – the Great Australian Bight is part of the South-west Marine (Bio-)Region. These and other geoscience data collected up until 2011 were available as scientific input to inform the development of the network of Commonwealth Marine Reserves, declared in 2012. Since then, additional marine data has been publically released by Geoscience Australia and used by Government to guide the management of reserves and the broader marine estate. More recently, the outputs of Geoscience Australia marine process models (e.g. the dispersal of larvae within submarine canyons) and advice identifying significant gaps in Australia's marine geoscience data, have informed the review of the zoning of the Commonwealth Marine Reserves undertaken in 2015-2016. These data are likely to inform the development of management plans for the South-west, North-west, North, Coral Sea and Temperate East marine regions that are due to be released in 2017.

Due to the great extent and depth of Australia's marine estate, there is a dearth of biological data for many regions including large areas of the Great Australian Bight. Seabed geoscience data (e.g. depth, shape and composition of the seabed) and satellite observations of the sea surface provide some of the few spatially extensive sets of available marine environmental information. They are used to classify seabed environments, predict spatial patterns of biodiversity and are essential for modelling key ecosystem processes, such as upwelling around submarine canyons and connectivity between regions.

4.2 Great Australian Bight – Environmental Summary

The following provides summary information collated and published by Geoscience Australia on the marine environment of the Great Australian Bight. Material in this section describes the geomorphological and oceanographic features that support the unique biological features of the Great Australian Bight region.

4.2.1 Geomorphology and Sediments

4.2.1.1 Coast

The coast of the Great Australian Bight is part of the world's longest south-facing continental margin. It experiences small tidal heights but is exposed to the strong wind and wave regimes generated in the Southern Ocean, and is therefore referred to as a wave-dominated coast. Intense low-pressure systems that traverse the Southern Ocean occasionally hit the coast.

The Great Australian Bight coast is dominated by the Cenozoic marine limestone cliffs of the Nullarbor Plain, in places forming sheer faces up to 120 m high. Beaches to the east and west of the cliffline are composed of carbonate or mixed carbonate/quartz sand. Along the low-lying sections of coast there are also vast sand flats and large dune fields (e.g. Kaniaal and Warren beaches, Western Australia), with a few small estuaries on the eastern margin. A defining feature of much of this southern coast is the negligible discharge of terrigenous sediment by rivers compared with the volume of bioclastic carbonate sediment produced on the Continental Shelf (<200 m water depth).

4.2.1.2 Continental Shelf and Slope

The Great Australian Bight is the most extensive physiographic feature on the southern margin of the Australian continent. Spanning 1,500 km of coastline between Cape Pasley in the west and Cape Catastrophe in the east, the seabed within the Bight comprises a broad continental shelf and continental slope that descends to 4,500 m water depth (Fig. 1; Hughes et al., 2009). The continental shelf is widest within the central Great Australian Bight, extending approximately 200 km and tapering to about 70 km at each end with the shelf edge at 150 m to 200 m water depth. Rocky reefs are concentrated in the shallower nearshore areas and around islands in the eastern Great Australian Bight. Across the shelf, the seabed is flat to gently sloping on a gradient of less than 0.01 degrees. The boundary with the upper slope ranges from a convex slope of 200 m relief in the northwest to a steep escarpment in the southeast that reaches a maximum height of 1000 m.

Seaward of the shelf, the continental slope comprises an upper and lower slope, with the upper slope forming the Ceduna Terrace where prospective petroleum areas are located. Water depths across the Ceduna Terrace range from 500 m to 2,000 m on a gradient of 0.6 degrees, and beyond this the lower slope steepens to almost 4 degrees to the foot of the slope. High resolution mapping across the western part of the Ceduna Terrace in 1999 (Hill et al., 2001) shows a dissected seabed characterised by troughs, gullies and erosion scarps that are tens to hundreds of metres in height. These features are evidence for mass wasting of the seabed over geological timescales (Hughes et al, 2009).

Seabed sediments on the shelf and upper slope comprise carbonate sands and gravels derived from extensive colonies of bryozoans and sponges that thrive under the influence of seasonal up-welling of nutrient-rich waters onto the shelf (James et al., 2001, 2004). This zone of sediment production has been termed a “sediment factory” and is recognised as integral to the progradation (seaward advance) of the upper slope during the Cenozoic (65 Ma to present; James et al., 2004). In deeper waters of the outer Ceduna Terrace and lower slope, seabed sediments are dominantly muds, comprising calcareous ooze.

Submarine canyons have incised deeply into the continental slope within the Great Australian Bight. Of the 74 canyons mapped between the western end of the Bight (123.5^{o} E) and offshore from the Coorong (139^{o} E), most are located in the southeast of the Bight and in deep water of the continental slope, including 45 canyons that form the Murray Canyon group (Huang et al., 2014). Only two canyons are shelf-incising canyons (Du Couedic Canyon and Sprigg Canyon), reaching to water depths less than 300 m. These shallower canyons are known to provide habitat for rich communities of biota. For example, Du Couedic canyon supports approximately 140 species of seabed flora, mostly sponges (Currie and Sorokin, 2014). Canyons also influence local productivity of the Great Australian Bight by acting as pathways for localised upwelling of nutrient-rich waters, such as that which occurs in the vicinity of the shelf-incising canyons south of Kangaroo Island (presumably Du Couedic and Sprigg canyons) where a subsurface pool of cold and nutrient-rich water occurs along the coast in summer (Kampf, 2010).

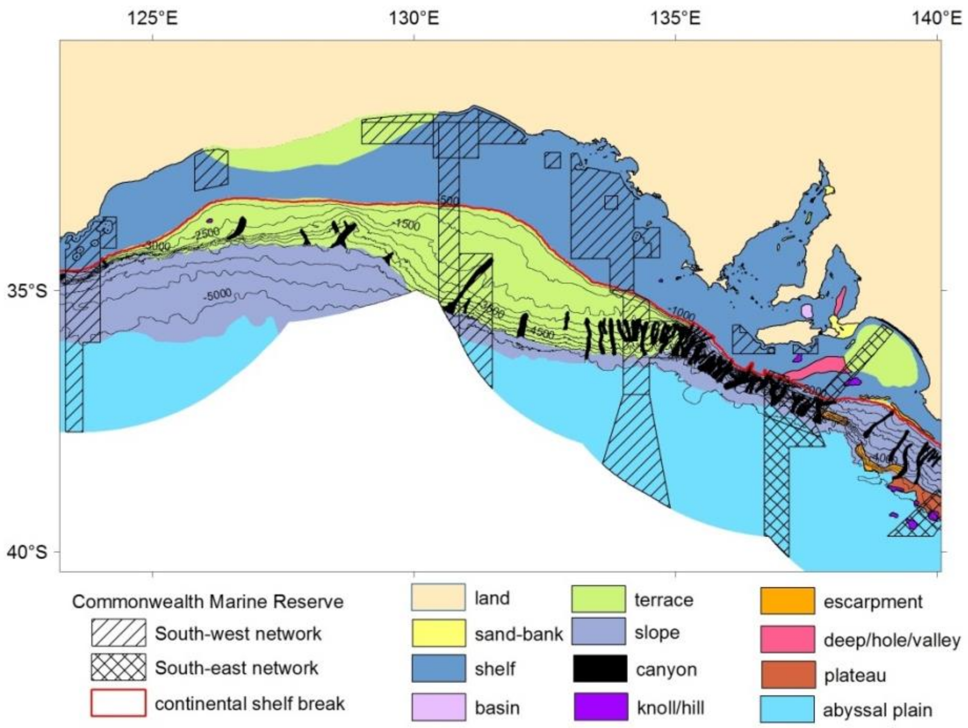

Figure 8: Seabed geomorphic features of the Great Australian Bight, with Commonwealth Marine Reserves shown.

4.2.2 Marine Ecology

4.2.2.1 Marine Mammals – Cetaceans

At least 17 species of cetacean have been recorded in the Great Australian Bight, including migratory species such as sperm, blue, minke and humpback whales and residential species such as orcas and dolphins (Edyvane, 1998). The most common whale in the Great Australian Bight is the southern right whale *(Eubalanea australis)* which is listed as 'endangered' under the *Environment Protection and Biodiversity Conservation Act 1999.* Due to the migratory nature of this species, it is difficult to estimate population sizes. There is a transient Australian population of around 1,500 individuals that migrate from their feeding grounds in the Southern Ocean to breeding grounds along the southern Australian coast, one of only two habitats in the world in which this species will reproduce (Edyvane, 1998). Once in coastal waters, most animals aggregate within a narrow zone 1 km from the coast at the head of Bight. This globally important calving habitat has been recognised as a major conservation value in the Great Australian Bight Commonwealth Marine Reserve.

4.2.2.2 Benthic Invertebrates

The Great Australian Bight supports one of the world's most diverse soft-sediment ecosystems (Ward et al., 2006) and has a high level of endemism, meaning many species occur nowhere else in the world. An estimated 85% of fish, 95% of molluscs, and 90% of echinoderms are endemic to southern Australia. Similarly, the Great Australian Bight has one of the world's highest species richness of macroalgae, with over 1,200 species (McLeay et al., 2003) and 75% of red algae species endemic to southern Australia (Womersley, 1990). In contrast, infauna (animals beneath the seafloor) do not appear to be particularly diverse in the Bight (Currie et al., 2009).

The high levels of species richness and endemism in the Great Australian Bight may be explained several ways. The Leeuwin Current allows for incursions of tropical species to the region, and over time, some of these may have established isolated populations and evolved independently of their tropical source populations. In addition, the continental shelf is quite wide in the Great Australian Bight, providing a relatively large area in which many shallow water species can exist. Submarine canyons are also more likely to contain endemic fauna than nearby areas without canyons at similar depths (Vetter and Dayton, 1998; 1999), due to geographic barriers to recruitment and evolutionary isolation. Finally, the relative isolation of the Great Australian Bight due to geographic barriers allows species to evolve in a defined region, with minimal emigration to and from other parts of Australia.

Much of the information about biodiversity in the Great Australian Bight is for the continental shelf, with little known about biodiversity along the deeper waters of the continental slope. In a survey of sponges in the former Benthic Protection Zone, only 25% of taxa were able to be identified to species level, and of these, 48% were new records for the Great Australian Bight (Sorokin et al., 2007). Other patterns from the Great Australian Bight shelf waters include:

Suspension feeders were the most common feeding group collected on the continental shelf of the Great Australian Bight Marine Park Benthic Protection Zone (GABMP BPZ), representing 86% of species found. This is unusually high and may reflect lack of terrigenous sediment input, which limits the food available to deposit feeders (Ward et al., 2006).

The outer shelf and upper slope are often dominated by abundant bryozoan and sponge communities, which occur more frequently on hard seabed substrates. Hardgrounds composed of Tertiary (66–2.5 Ma) and Pleistocene (2.5 Ma–11.7 ka) aged limestone outcrops on the seabed contain the most abundant fauna, including bryozoans, sponges and other sessile invertebrates. Rippled sandy bottoms have almost no epibenthos (Richardson et al., 2005).

On the continental shelf, species richness and biomass decline with increasing water depth and the proportion of mud in the seabed sediments, except for crabs and shrimp which increase with mud content (Ward et al., 2006).

Smaller sessile species may be more prevalent in deeper waters with higher proportions of mud, as they may be able to better use fine sediments (Sorokin et al., 2007).

5 Summary

Australia's future economic prosperity will be underpinned by maintaining a steady stream of new energy projects.

While Australia's gas resources are extensive and exports are expected to grow significantly to the end of the decade, domestic supplies of oil are limited and production continues to decline. It is expected that the trend of decreasing oil resources will not change within the known oil basins, making the discovery of a new oil province or provinces essential to maintaining Australia's future energy security.

Some of the remotest areas of Australia's maritime jurisdiction present the greatest opportunities for discovering Australia's next major energy province. A recent national appraisal by Geoscience Australia of the hydrocarbon potential of Australia's offshore frontier areas ranked the Ceduna Sub-basin of the Bight Basin as the nation's most prospective area for oil and gas. This assessment was based on the quality of the source rocks, the size of the basin, and the presence – both known and interpreted – of all the necessary elements for active petroleum systems.

A Geoscience Australia study of the prospectivity of the Bight Basin (and Ceduna Sub-basin) in 2007 worth $6.7 million confirmed the presence of world-class marine, oil-prone potential source rocks. Petroleum systems modelling has shown that these rocks are likely to have generated and expelled hydrocarbons. This stimulated renewed exploration with guaranteed work programs totalling more than $1.2 billion by several super-major petroleum companies following a round of acreage release in 2009.

Resource exploration in the Great Australian Bight must be balanced with consideration to the environmental assets. Recent environmental studies published by Geoscience Australia to inform the development of the Commonwealth Marine Reserves network, reveal a complex environment characterised by harsh oceanographic conditions and important carbonate-dominated shelf and canyon environments that support a rich and diverse marine fauna, with significant levels of endemism. In addition, parts of the Great Australian Bight, in the vicinity of the deeply incised canyons, support localised upwelling of nutrient-rich waters and enhanced productivity.

In a competitive global resources market, the challenge for Australia is to continue to attract the investment to sustain the energy sector through maintaining a healthy pipeline of globally-significant exploration opportunities. Precompetitive geological studies by Geoscience Australia play a key role in attracting energy exploration investment and help maintain Australia's competitive advantage in the global energy resources sector.

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