



## Regional Geology of the Gippsland Basin

The Gippsland Basin in southeastern Australia is located about 200 km east of the city of Melbourne, covering about 46 000 km<sup>2</sup>, of which two thirds are located offshore (**Figure 1**). The Gippsland Basin is recognised as one of Australia's premier hydrocarbon provinces, having continually produced oil and gas since the late 1960s. In May 2022, remaining reserves were estimated at 1.64 Tcf (1844.5 PJ) of natural gas and ethane, and 94 MMbbls (552.7 PJ) of oil and natural gas liquids (EnergyQuest, 2022). Several petroleum systems operate in the basin, with the largest oil and gas fields hosted by top-Latrobe Group (Eocene) shallow marine barrier sandstones, and additional discoveries made in intra-Latrobe Group (Upper Cretaceous–Paleocene) coastal plain and deltaic channel sandstones. Despite its mature status, parts of the basin remain underexplored and offer a variety of untested plays.

### Basin outline

The offshore Gippsland Basin is bounded to the north by Paleozoic basement of the Eastern Uplands and to the southwest by the Bassian Rise, a Paleozoic basement feature that separates it from the Bass Basin further south. The onshore portion is represented by uplifted fault blocks containing Lower Cretaceous sediments. The Gippsland Basin developed initially during the Early Cretaceous rifting between Antarctica and Australia and consisted of a primary depocentre – the Central Deep – which is flanked by structurally higher platforms and terraces to the north and south. The basin architecture is defined by a series of major fault systems, namely the Rosedale and Lake Wellington fault systems on the northern margin and the Darriman and Foster fault systems on the southern margin (**Figure 2**). The Rosedale and Darriman fault systems separate the Northern and Southern platforms from the Central Deep respectively. More than 400 exploration wells have been drilled in the basin and approximately 90 000 line km of 2D seismic data and more than forty 3D seismic surveys have been acquired. Consequently, exploration within the Gippsland Basin is mature in comparison to many other Australian basins, but it remains relatively underexplored in the centre of the Central Deep, the southern flank and the deep-water area around the Bass Canyon.

The Central Deep hosts most of the major oil and gas fields and is characterised by rapidly increasing water depths in the east (Hill et al, 1998). The eastern limit of the basin is defined by the East Gippsland Rise, a prominent north-northeast-striking 'basement' high (Moore and Wong, 2001). The western onshore limit of the basin is traditionally placed at the Mornington High, but is actually represented by outcrops of Lower Cretaceous Strzelecki Group sediments (Hocking, 1988)

The Gippsland Basin region contains a number of significant regional population centres and is serviced by an extensive road system. Petroleum infrastructure is well developed, with a network of pipelines transporting hydrocarbons produced offshore to onshore petroleum processing facilities at Longford and Orbost (**Figure 3**). From there, pipelines deliver the gas across southeastern Australia, to Sydney in New South Wales, to Adelaide in South Australia and to Tasmania. Although recent industry activity in the basin has been dominated by field developments and field extensions, exploration for both oil and gas is expected to continue due to the basin's probable untapped potential and the increasing demand for natural gas across southeastern Australia.

### Basin evolution and stratigraphy

The Gippsland Basin forms the easternmost part of an Early Cretaceous rift system between Antarctica and Australia. Initial basin architecture consisted of a rift valley complex composed of multiple, overlapping or isolated, approximately east-trending half graben. Continued rifting into the Late Cretaceous generated a broader extensional geometry that consisted of a depocentre (the Central Deep) flanked by fault-bounded platforms and terraces to the north and south. The Rosedale and Lake Wellington fault systems marked the

northern margins of the Central Deep and Northern Terrace respectively, with the Darriman and Foster fault systems defining the southern margin of the Central Deep, and the northern boundary of the Southern Platform, respectively. The Pisces Sub-basin (**Figure 2**) has been re-interpreted as belonging to a series of northeast-trending en-echelon half graben that developed along the southern basin flank (Blevin et al, 2013). The extensional faults were reactivated prior to breakup in the Tasman Sea off the Gippsland Basin (Blevin et al, 2013). To the east, the Central Deep is characterised by rapidly increasing water depths; these exceed 3000 m in the Bass Canyon (Hill et al, 1998). The eastern boundary of the basin is poorly defined and has been related to the Cape Everard Fault System, a prominent north-northeast striking basement high (Moore and Wong, 2001). The western onshore limit of the basin is traditionally placed at the Mornington High.

Initial rifting in the Early Cretaceous resulted in total crustal extension of approximately 30% (Power et al, 2001), producing a complex system of graben and half graben into which the volcanoclastic Strzelecki Group was deposited. Between 100 Ma and 95 Ma (Cenomanian), a phase of uplift and compression (Duddy and Green, 1992) produced a new basin configuration and provided accommodation space for large volumes of basement-derived sediments. Renewed crustal extension during the Late Cretaceous—perhaps associated with both Turonian extension between Australia and Antarctica evident in the Otway Basin to the west, and opening of the Tasman Sea to the east—established the Central Deep as the main depocentre. Initial deposition (Emperor Subgroup) into the evolving rift valley was dominated by large volumes of material eroded from the uplifted basin margins. A series of large, deep lakes developed, resulting in the deposition of the lacustrine Kipper Shale (Marshall and Partridge, 1986; Marshall, 1989; Lowry and Longley, 1991). The Kersop Arkose (**Figure 4** and **Figure 5**) represents the earliest erosion of uplifted granites at the southern basin margin, and the alluvial/fluvial Curlip Formation (Partridge, 1999; Bernecker and Partridge, 2001) overlies and interfingers with the Kipper Shale.

The Longtom Unconformity, spanning the entire Coniacian separates the freshwater lacustrine-dominated Emperor Subgroup from fluvial and marine sediments of the Golden Beach Subgroup (**Figure 4**, **Figure 5**, **Figure 6**) with the first marine incursion recorded by the upper Santonian sediments of the Anemone Formation (**Figure 7**, **Figure 8**) in the eastern part of the basin (Partridge, 1999; Bernecker and Partridge, 2001). Many of the earlier generated faults were reactivated during this tectonic phase, and it is likely that the change in depositional environment was related to the onset of the Tasman Sea rifting.

Rift-related extensional tectonism continued until the early Eocene and produced pervasive northwest-striking normal faults, especially in the Central Deep. A succession of fluvial, deltaic and marine sediments was deposited across the basin, forming the Halibut Subgroup. This subgroup comprises upper coastal plain fluvial sediments of the Barracouta Formation and lower coastal plain, coal-rich sediments of the Volador and Kingfish formations. The marine Kate Shale separates the Cretaceous Volador Formation from the Paleocene Kingfish Formation, and has the potential to be a significant intra-Latrobe Group seal. The Mackerel Formation overlies the Kate Shale in the eastern part of the basin (**Figure 8**) and consists of near-shore marine sandstones with intercalated marine shales. The formation marks the increasing marine influence on sedimentation toward the continental slope.

By the middle Eocene, sea-floor spreading had ceased in the Tasman Sea and there was a period of basin sag, during which the offshore basin deepened but little faulting occurred. The lower coastal plain, coal-rich Burong Formation was deposited during this phase, followed by the transgressive shallow to open marine Gurnard Formation (**Figure 9**), which is a condensed section characterised by fine- to medium-grained glauconitic siliciclastic sediments.

In the late Eocene, compressional tectonism initiated the formation of a series of northeast- to east-northeast-trending anticlines (Smith, 1988). Compression and structural growth peaked in the middle Miocene and resulted in partial basin inversion. All the major fold structures at the top of the Latrobe Group, which became the hosts for the large oil and gas accumulations, such as Barracouta, Tuna, Kingfish, Snapper and Halibut, are related to this tectonic episode. Tectonism continued to affect the basin during the late Pliocene to Pleistocene, as documented by localised uplift. Uplift affected the Pliocene section on the Barracouta, Snapper and Marlin anticlines, as well as around the township of Lakes Entrance. Ongoing tectonic activity continues in the basin as relatively minor earthquakes occur along and around major basin bounding faults to the present day.

Post-rift sedimentary processes dominated the Gippsland Basin from the early Oligocene, with the deposition of the basal unit of the Seaspray Group, the Lakes Entrance Formation (**Figure 6**, **Figure 7**). These onlapping, marly sediments provide the principal regional seal across the basin. Subsequently, the deposition of the thick Gippsland Limestone, also part of the Seaspray Group, provided the critical loading for the source rocks of the

deeper Latrobe and Strzelecki groups, with the majority of hydrocarbon generation (or certainly the preserved component) occurring in the Neogene.

Late source rock loading, as a result of the deposition of relatively thick Cenozoic sequences, means that traps developed as late as during the Neogene can be charged with economic quantities of hydrocarbons.

## Exploration history

The history of oil production in the Gippsland Basin dates back to 1924, when the Lake Bunga 1 well, which was drilled near the town of Lakes Entrance, encountered a 13 m oil column in glauconitic conglomerates overlying the Latrobe Unconformity at a depth of 370 m. Over 60 wells were drilled in the ensuing years, and by 1941, this area had produced more than 8000 bbl (1272 KL) of heavy oil (15–20°API). The most productive well was the Lakes Entrance Oil Shaft, which produced 4935 bbl (784.5 KL; Boutakoff, 1964; Beddoes, 1973).

Significant levels of exploration did not begin in the offshore Gippsland Basin until the mid-1960s, following the acquisition of seismic surveys that allowed the imaging of the Central Deep and the mapping of several large, anticlinal closures. The first successful well, East Gippsland Shelf 1—later known as Barracouta 1—was drilled by Esso in 1964/65 and discovered a 102.5 m gas condensate column at a depth of 1060 mKB. After the subsequent discovery of a large gas condensate accumulation at Marlin in 1966, the Gippsland Basin was perceived essentially as a gas-prone province. However, when Kingfish 1 was drilled in 1967, it discovered the largest Australian oil field known to date (1.2 Bbbl [191 GL] recoverable) and the Gippsland Basin gained international recognition as both a giant oil and gas province.

By the end of 1969, eleven fields had been discovered and the first five (Barracouta, Marlin, Snapper, Kingfish and Halibut; **Figure 1**) were in production. After the initial exploration phase, which had a high success rate, the subsequent discoveries made by the Esso/BHP Petroleum joint venture were more limited through the early 1970s; Cobia 1 (1972), Sunfish 1 (1974) and Hapuku 1 (1975) discovered significant volumes of hydrocarbons, but only Cobia came into production. In 1978, following the boost to exploration resulting from the introduction of Import Parity Pricing (i.e. the removal of artificial government pricing caps on locally produced crude oil), the giant Fortescue oil field was discovered, followed by the Seahorse and West Halibut discoveries.

Stimulated by the OPEC world oil price rise in 1979 and the relinquishment of a significant portion of the original exploration permit by Esso/BHP in October that year, new explorers, including Aquitaine, Shell and Phillips, commenced exploration in 1980. Shell, which had previously discovered the Sole dry gas field in 1973, mapped the Basker-Manta structures and drilled two successful wells, Basker 1 and Manta 1. Discoveries that were then deemed non-commercial were made at West Seahorse, Baleen and Sperm Whale by Hudebay Oil in 1981. West Tuna 1, drilled in 1984, was the last of the large to giant oil discoveries made by the Esso/BHP Petroleum joint venture. This play was atypical, as the oil was trapped by fault sealing mechanisms rather than having accumulated in a large anticlinal closure. In 1986, the Esso/BHP Petroleum joint venture discovered the Kipper gas field—estimated at 500 Bcf (14.2 Bm<sup>3</sup>) recoverable—a significant find that intersected a 213 m gas column in fluvial sandstones of the Golden Beach Subgroup. Lasmo made a minor, but significant, gas discovery near the northern basin margin at Patricia 1 (adjacent to Baleen) in 1987, with sales gas reserves of the order of 70 Bcf (2 Bm<sup>3</sup>). This field was developed by OMV and later taken over by Santos Limited. Another drilling campaign in 1989/1990, led to the discovery of the Blackback oil and gas field on the shelf edge, in water depths greater than 400 m. In 1989/90, Petrofina drilled the Archer/Anemone discovery in the southern part of the basin. Although the field proved non-commercial, the well encountered substantial quantities of oil and gas and further confirmed the prospectivity of the older part of the Latrobe Group (Golden Beach Subgroup).

Additional exploration wells were drilled in the 1990s, though no new discoveries were made. The principal operator, the Esso/BHP Petroleum joint venture, concentrated their efforts on development and work-over drilling in order to optimise production from the existing fields. Following the privatisation of State Government-owned gas utility companies between 1995 and 1999, a restructured gas market emerged that made it more attractive for explorers to search for gas in the basin. This, together with a sustained recovery in the oil price, sparked a significant resurgence in exploration activity. In 2010, Esso Australia Pty Ltd made an oil and gas discovery on the northern margin of the Central Deep; South East Remora 1 intersected significant oil and gas columns in the upper Latrobe Group and Golden Beach Subgroup, in traps associated with the Rosedale Fault System.

In the early 2000s, a number of new companies were granted exploration licences in the basin and have committed to extensive work programs. Apache Energy entered the basin in 2004 after gaining interest in permits VIC/P54, VIC/P58 and VIC/P59. The company drilled a number of wells in 2008–2009 and acquired new 3D seismic data in VIC/P59 in 2007, but relinquished this permit in early 2012. Nexus Energy Limited (Nexus) has also been active in the Gippsland Basin recently, exploring within VIC/P54 and drilling Longtom 3 which was put into production in 2009. Nexus was acquired by Seven Group Holdings in 2015 and production was suspended. The company's energy arm, SGH Energy, plans to recommence production by 2019 (Australian Financial Review, 2017) following an upgrade of the Orbost gas plant, which was previously operated by Santos and Cooper Energy.

Cooper Energy have recently expanded their acreage holding in the Gippsland Basin and currently operate production licence VIC/L32 (Sole gas field) and retention leases, VIC/RL16 (Patricia/Baleen), VIC/RL 13, 14, 15 (Basker/Manta, Gummy, Chimaera). In 2018, the company was awarded with exploration permit VIC/P72 (Northern Terrace) and in 2019 with VIC/P75 (Central Deep).

Larus Energy Ltd entered the Gippsland Basin in 2011, and operated three exploration permits on the southern margin (VIC/P63 and VIC/P64, and T/46P in Tasmanian waters) until March 2014. Other significant players in the Gippsland Basin are Bass Strait Oil Company Ltd, who operated VIC/P41 until early 2017 on the northern basin margin. The company identified several large volume prospects analogous to the Kipper and Basker/Manta/Gummy fields that lie along strike to the west of this permit. The small independent company 3D Oil was working to develop the West Seahorse oil field within VIC/P57 before it sold its interest to Carnarvon Hibiscus Pty Ltd in 2014, who have since deferred the final investment decision (FID) on developing the field due to the low and volatile oil price environment (Hibiscus Petroleum Berhad, 2016). The company also evaluated the Sea Lion prospect to the northwest of West Seahorse with Sea Lion 1 spudded in October 2015. The well was plugged and abandoned with no zones of commercial hydrocarbons encountered (Hibiscus Petroleum Berhad, 2015).

Exploration permit VIC/P70 was awarded to Liberty Petroleum Corporation (Liberty) in November 2014. The permit is located southwest of the giant Kingfish oil field and covers the Archer/Anemone and Angler gas discoveries. Liberty evaluated the resource potential of these accumulations and, in addition, focussed on the mapping of the Dory prospect which was originally drilled by Apache, who deemed the gas discovery uneconomic. The work program included the drilling of two wells in the primary term. In June 2017, Liberty successfully farmed out their interest to Esso Deepwater Gippsland Pty Ltd who, in 2018, drilled two wells designed to firm up the Dory prospect, a structure believed to contain up to 2 Tcf (2249.4 PJ) of gas. Both wells, Baldfish 1 and Hairtail 1, were unsuccessful. In November 2019, the company drilled Sculpin 1 to a total depth of 3850 m (MD) on the southwestern flank of the Bass Canyon. The well drilled in 2278 m of water, which to date is the deepest water location where a well has been drilled in offshore Australia. The well intersected stacked deep-water distributary channel sandstones, with excellent reservoir potential, but did not encounter any hydrocarbons (Spencer, 2022).

Awarded in 2016 to Llanberis Energy Pty Ltd (Llanberis), exploration permit VIC/P71 is located along the southern margin of the Gippsland Basin. Llanberis have not committed to any wells in the primary term, but plan to acquire 550 km<sup>2</sup> of new 3D seismic data to assess a number of stratigraphic traps which have the potential to hold billions of barrels of oil or trillions of cubic feet of natural gas (Llanberis Energy Pty Ltd, 2018).

In 2021 exploration permits VIC/P77 and VIC/P78 were awarded to Liberty Petroleum Corporation (Liberty Petroleum). Liberty Petroleum have not committed to any wells in the primary term of the work program, but will licence Gippsland MC3D seismic data, including 400 km<sup>2</sup> AVO and seismic inversion, and undertake geological, geophysical and petroleum prospectivity studies (NOPTA, 2021). Most recently, exploration permit VIC/P80 was awarded to Cooper Energy (MGP) Pty Ltd in April 2022.

On a regional scale, several 3D seismic surveys have been acquired over time, with the result that much of the basin is now covered by 3D seismic data. Esso/BHP Billiton completed two major 3D seismic surveys, including the 4060 km<sup>2</sup> Northern Fields survey, between October 2001 and July 2002. This was followed by the 1000 km<sup>2</sup> Tuskfish survey, which extended over the Blackback-Terakihi area and southwards into the former permit VIC/P59. In 2001, Encana acquired the Midas 2D seismic/gravity/magnetic survey, which covers approximately 830 line km across the head of the Bass Canyon, covering some of VIC/P70. A further 150 km of 2D seismic was acquired by Eagle Bay Resources NL across the former permit VIC/P65.

Sizable 3D surveys have also been acquired by Apache Energy and Bass Strait Oil Company Ltd in recent years. Drillsearch also conducted the Furneaux 2D seismic survey in early 2010, covering their permits in the southwestern part of the Gippsland Basin with a total of 1116.7 line km acquired in Victorian waters. This survey was followed by the 8000 line km 2D Gippsland Basin Southern Flanks Marine Survey (GDPI10), co-funded by the State and Commonwealth Governments, acquired over the Southern Terrace and Platform using the same seismic vessel, the M/V Aquila Explorer (SeaBird Exploration). The seismic stratigraphic interpretation report of this survey (Blevin et al, 2013) evaluates the seal potential of the basin's southern margin.

More recent geophysical and geotechnical surveys have included Hibiscus Petroleum's West Seahorse and Sea Lion surveys, consisting of bathymetry, sub-bottom profiling and sediment sampling in VIC/L31 and VIC/P57, carried out during March and July 2015. In April 2015, Geoscience Australia carried out the Gippsland Basin Infill 2D Marine Seismic Survey, GA0352, which collected approximately 900 line km of 2D reflection seismic data, acquired by the MV Duke during (Gunning et al, 2016). During this survey, Geoscience Australia also acquired Multibeam Echo Sounder (MBES) bathymetry, single-beam echo sounder and sub-bottom profiler (chirp) data along all seismic survey lines (Spinoccia, 2015).

The most recent effort to better image the structural architecture and sedimentary sequence development across the offshore Gippsland Basin is the Gippsland ReGeneration 3D reprocessing and acquisition project. The project involves both new acquisition and reprocessing and stitching of all available 3D seismic data sets by CGG. Initial results were presented at the 2019 APPEA conference highlighting the improved visualisation of fault extents, structural closures, mappable sequence boundaries and unconformities (Baillie et al, 2019). The Gippsland ReGeneration 3D volume includes 10 190 km<sup>2</sup> of high-quality reprocessed data and the state-of-the-art 8751 km<sup>2</sup> Gippsland MC 3D Marine Seismic Survey, acquired in 2020 (CGG, 2022).

Despite its long history of extensive exploration, many parts of the offshore Gippsland Basin are still relatively poorly understood and explored, and offer great potential for additional hydrocarbon discoveries.

## Production and development

Overall production of crude oil and condensate from the Gippsland Basin has been declining for over three decades, associated with an increased water cut, while gas production has remained steady. Since 2009, however, hydrocarbon production has remained relatively strong due to infill drilling in the developed fields and work-overs undertaken to renew down-hole equipment and to open new zones. Total petroleum production from the basin was 68.16 MMboe (400.8 PJ) in the 12 months to March 2022 (EnergyQuest, 2022).

The \$5.5 billion Kipper-Tuna-Turram project is the largest domestic gas development in eastern Australia and production will help maintain the production levels from the basin, which has been producing for over 40 years. Gas from the Kipper field, which holds about 620 Bcf (697.3 PJ) and from the Turram field, holding about 1 Tcf (28.3 Gm<sup>3</sup>), is piped to the existing West Tuna platform. Construction of the plant began in 2013 with production of natural gas from the Tuna field via two new pipelines in June 2013. In May 2017, the gas conditioning plant was completed and gas production commenced (ExxonMobil, 2017). In the 12 months to March 2022 production from the Gippsland JV and Kipper-Tuna-Turram combined was 288.1 PJ (256 Bcf) of gas and 1.84 MMbbls (10.8 PJ) of oil (EnergyQuest, 2022).

In the eastern portion of the Northern Terrace, the Sole Gas project includes two sub-sea production wells connected via a 67 km umbilical to the onshore Orbest Gas Processing Plant (OGPP; Cooper Energy, 2021). The Sole field holds an estimated 238 PJ of gas (2P reserves), with production commencing in 2020 following major upgrades to the OGPP to allow processing of hydrogen sulphide-rich gas (Cooper Energy, 2021). The project is designed to produce 68 TJ/day (25 PJ/annum), with gas sale agreements of 54 TJ/day (average) supply, including supply of 20 to 25 TJ/day to the Eastern Gas Pipeline. In the 12 months to March 2022 gas production from the Sole field totalled 14.2 PJ (13 Bcf), with production in Q1 2022 averaging 43 TJ/d and a record of 60TJ/d reported for 3 May (EnergyQuest, 2022).

To end of 2020, a total of 22 636 PJ (3849.6 MMbbl) of oil had been produced from the basin with remaining oil reserves (2P) of 53 PJ (9.1 MMbbl) and contingent resources (2C) of 512 PJ (87.1 MMbbl). In addition, 1647 PJ (280.1 MMbbl) of condensate had been produced, while remaining 2P reserves are 298 PJ (50.6 MMbbl) and 2C resources of 231 PJ (39.4 MMbbl). Regarding natural gas, a total of 12 066 PJ (10.73 Tcf) was produced, while 2P reserves and 2C resources are 2365 PJ (2.10 Tcf) and 2995 PJ (2.66 Tcf), respectively (Geoscience Australia, 2022).

A map showing the current main operators, active exploration permits, retention leases and production licences is provided by **Figure 10**.

## Regional petroleum systems

Despite its relatively small areal extent, the Gippsland Basin hosts numerous economic hydrocarbon accumulations, including a number of oil and gas fields that are considered 'giants' by global standards. All currently producing fields are located on the western and northern parts of the present shelf; only five discoveries (Archer/Anemone, Angler, Blackback, Dory and Gudgeon) have been made in the eastern, deeper water area (**Figure 1**).

It has been a matter of speculation as to why there is a concentration of gas accumulations in the north, whereas oil fields are more common in the southeast. The reasons for this may be due in part to the initial focus on top-Latrobe Group plays, which has resulted in numerous discoveries in sediments from the *N. asperus* and *P. asperopolus* biozones. The Latrobe Group is thickest in the Central Deep, where prospective reservoirs are located below 3,500 mSS (approximately 2.5 s TWT) and it is thus not surprising that less is known about the prospectivity of older sediments.

Another explanation for the distribution of oil and gas in the Gippsland Basin is the nature of the Latrobe Group source systems themselves. The upper coastal plain Latrobe Group depocentres, located between Barracouta and Kingfish, may have produced a mostly gas-prone hydrocarbon inventory, whereas the lower coastal depocentres east of Kingfish would probably be more oil-prone, as originally suggested by Moore et al (1992).

The strong spatial compartmentalisation of the hydrocarbon inventory is discussed in detail by O'Brien et al (2008). Analyses of palaeo-charge histories, source rock characteristics and basin modelling indicate that the majority of large fields in the Central Deep received an early oil charge and had significant palaeo-oil columns in the Neogene. These were subsequently displaced by a later gas charge triggered by increased maturation and gas expulsion from a gas-prone upper coastal plain source kitchen south of Barracouta (O'Brien et al, 2008; Liu et al, 2010).

The most recent attempt at explaining the apparent separation of oil and gas fields in the basin was put forward by Hoffman and Preston (2014). Their study, examining hydrocarbon geochemistry, charge and migration histories, draws attention to hydrocarbon modification processes, such as water washing and biodegradation, that operated after the initial hydrocarbon charge and produced different reservoir fill patterns across the basin.

Oils of the Gippsland Basin are derived from the Jurassic to Cenozoic Austral Supersystem sequences (Bradshaw, 1993), and are likely to be predominantly derived from coals and carbonaceous shales of the Latrobe Group (Summons et al, 2002; Edwards et al, 2016). Within this supersystem, the Austral 3 Petroleum System is suggested to have sourced the majority of hydrocarbons (including all producing fields, **Figure 11**) reservoirised within the Latrobe Group (O'Brien et al, 2008). The oils in the Gippsland Basin are grouped into two main oil families (Summons et al, 2002; Volk et al, 2010, 2011); both believed to originate largely from the Latrobe Group. Marine source rocks within the Anemone Formation (Latrobe Group) may also contribute additional hydrocarbons (Gorter, 2001; Ahmed et al, 2013; Edwards et al, 2016), adding more complexity to this petroleum system.

In addition, hydrocarbons sourced from the Strzelecki Group and attributed to the Austral 2 Petroleum System are also being invoked to explain the origin of some accumulations along the northern margin, such as the dry gases in the Patricia-Baleen and Sole fields and the gases in the onshore part of the basin at Gangell, Seaspray and Wombat (O'Brien et al, 2008). The molecular and carbon isotopic signatures of oil and gas from the onshore Wombat Field (**Figure 11**) are most similar to hydrocarbons sourced from the Aptian–Albian Eumeralla Formation in the Otway Basin, temporal equivalent to the Strzelecki Group, also implicating a Strzelecki source in the Gippsland Basin (Edwards et al, 2016).

If this interpretation is correct, this gas probably migrated to the top-Latrobe level in the Neogene, following loading by the prograding carbonate shelf. It may be that these 'Strzelecki-sourced' gases are present around the basin margins (and not in the Central Deep) because they are able to migrate up to the top-Latrobe level through the Latrobe Group shales, which are thin or absent, something that would be impossible through the very thick Latrobe shales within the Central Deep. If the Strzelecki Group is confirmed as a working source, then traps that are remote from the mature Central Deep Latrobe Group source, such as those located in the

Seaspray depression and on the Northern Terrace or Northern Platform, or in Latrobe migration shadows, can still be charged with relatively dry gas, providing that the local, mature Strzelecki Group source generated hydrocarbons in the Neogene.

## Petroleum Systems Elements

Sources	<ul style="list-style-type: none"> <li>• Upper Cretaceous fluvial-deltaic Volador Formation (Halibut Subgroup)</li> <li>• Upper Cretaceous (<i>T. lilliei</i> zone) fluvial-deltaic Chimaera Formation (Golden Beach Subgroup)</li> <li>• Upper Cretaceous lacustrine Kipper Shale (Emperor Subgroup)</li> <li>• Lower Cretaceous non-marine Strzelecki Group</li> </ul>
Reservoirs	<ul style="list-style-type: none"> <li>• Eocene greensands of the Gurnard Formation (Cobia Subgroup)</li> <li>• Eocene marine barrier sandstones of the Burong Formation (Cobia Subgroup)</li> <li>• Maastrichtian–Paleocene fluvial-deltaic Kingfish Formation (Halibut Subgroup)</li> <li>• Campanian–Maastrichtian fluvial-deltaic Volador Formation (Halibut Subgroup)</li> <li>• Santonian–Campanian fluvial-deltaic Chimaera Formation (Golden Beach Subgroup)</li> <li>• Turonian fluvial and lacustrine Admiral Formation (Emperor Subgroup)</li> </ul>
Seals	<p><i>Regional seals</i></p> <ul style="list-style-type: none"> <li>• Oligocene–Miocene marine carbonate Lakes Entrance and Swordfish formations (Seaspray Group)</li> </ul> <p><i>Intraformational seals</i></p> <ul style="list-style-type: none"> <li>• Campanian volcanics</li> <li>• Santonian–Campanian Anemone Formation (Golden Beach Subgroup)</li> <li>• Turonian–Coniacian lacustrine Kipper Shale (Emperor Subgroup)</li> </ul>
Traps	<ul style="list-style-type: none"> <li>• Combined structural/stratigraphic traps</li> <li>• Stratigraphic pinch out plays</li> <li>• A variety of fault related traps, including tilted fault blocks</li> </ul>

## Source Rocks

Only a few wells have penetrated the oil- or gas-mature section of the lower Halibut and Golden Beach subgroups (**Figure 12**, **Figure 13**) and hence the distributions of the main source rock units and source rock kitchens are not fully understood. It is generally considered that the source rocks for the majority of the oil and gas in the basin are represented by organic-rich, non-marine, coastal plain mudstones and coals (Burns et al, 1984, 1987; Moore et al, 1992). Source rocks of dominantly terrestrial plant origin (Type II/III kerogen) are widely distributed throughout the Latrobe Group and generally exhibit good TOC values (>2.0%), high Rock-Eval pyrolysis potential yields ( $S_1+S_2 > 10$  mgHC/g rock) and moderate to high hydrogen indices (>250 mgHC/gTOC), suggesting that they have the potential to generate both oil and gas. The richest Latrobe Group source rocks (mainly humic to mixed organic matter types) occur within lower coastal plain and coal swamp facies. Pyrolysis experiments and kinetic modelling of primary cracking of kerogen have been recently carried out to investigate hydrocarbon generation characteristics and source rock facies variability within the Upper Cretaceous to Paleogene Latrobe Group in the Gippsland Basin (Abbassi et al, 2016). These analyses indicate that the interbedded shales of the Latrobe Group have the potential to generate black oils at early stages of kerogen cracking, and either light oils or wet gases at higher levels of thermal stress. Coals of the Latrobe Group have been shown to generate high wax paraffinic–naphthenic–aromatic oils.

Well correlations show that much of the *T. lilliei* biozone (within the Golden Beach Subgroup) is represented by low energy, lagoonal/paludal sediments in the east-southeast. This facies extends beneath the giant Kingfish oil field and across the basin to the north. In the Central Deep, sediments within the *T. lilliei* biozone accumulated in a marine environment as interbedded sandstones and marine shales (Rahmanian et al, 1990; Moore et al, 1992; Chiupka et al, 1997). Data from Hermes 1, located in the southern part of the basin, proves the existence of a thick, rich source rock unit at this level. The *T. lilliei* section within this well is over 950 m thick, with TOC values that generally exceed 10% (Petrofina Exploration Australia S.A., 1993). The Chimaera Formation (*T. lilliei*

biozone) in the deepest section at Volador 1 and Hermes 1 (**Figure 12, Figure 13**) was found to geochemically correlate (**Figure 14, Figure 15, Figure 16, Figure 17, Figure 18**), to the Angler 1 condensate (Edwards et al, 2016).

A study of condensate recovered from the Archer/Anemone discovery in the southeastern part of the basin, suggests that source rock potential may also exist within marine sediments (Gorter, 2001; Partridge, 2003). The most likely source rocks are the marine shales of the Anemone Formation (**Figure 13**) in the Golden Beach Subgroup. Partridge (2012) analysed seven cuttings samples from the type section of the Anemone Formation at Anemone 1/1A and confirmed the presence of common to abundant marine microplankton. A more recent geochemical study confirms an oil-source correlation between the Anemone 1A oil and the marginal marine Anemone Formation (*N. senectus* biozone) at Anemone 1/1A and Archer 1 (Ahmed et al, 2013; Edwards et al, 2016), suggesting that marine source rocks were developed in the eastern, deeper part of the basin.

The Strzelecki Group sediments within the onshore and offshore Gippsland Basin have been suggested as having the potential to generate significant quantities of dry gas (O'Brien et al, 2008). Fair to good quality Strzelecki Group source rocks have been intersected in a number of wells, including Wellington Park 1 and Dutson Downs 1 onshore, and Wirrah 1, 2 and 3 offshore. Overall, the Strzelecki Group appears to have a broadly similar source rock quality to its temporal equivalent, the proven gas-generating, Albian–Aptian Eumeralla Formation in the Otway Basin.

## Reservoirs and seals

Most of the major hydrocarbon accumulations in the Gippsland Basin are reservoirised in high quality sandstones of the Cobia and Halibut subgroups, where marine near-shore barrier and shoreface sandstones are traditionally regarded as the best reservoirs in the basin. The most productive reservoirs were drilled either at or near the top of the Latrobe Group and are commonly referred to as the 'top-Latrobe coarse clastics reservoirs'. This can be confusing, given that similar coarse sandstones are developed throughout the stratigraphic column. All these sandstones are diachronous and developed in response to periodic marine regressive cycles associated with low depositional rates. This provided an ideal environment for high levels of reworking and winnowing of the deltaic and coastal plain sediments. Geographically, this reservoir facies is best developed in the Barracouta, Snapper, Marlin, Bream and Kingfish fields. Reservoir distribution in intra-Latrobe sequences can be complex and frequently involves multiple stacked sandstone/shale alternations characteristic of fluvio-deltaic environments. Submarine channelling, the presence of numerous, thin, condensed sequences and the overall lower net-to-gross ratio contribute to lower reservoir quality. Nevertheless, there are many examples of good quality reservoirs in deltaic sandstones, as well as in fluvial and submarine channels. Latrobe Group reservoir porosities average 15–25% across the basin, with the best primary porosities preserved in fluvial and deltaic sandstones that are texturally mature and moderately well sorted.

In contrast to the Latrobe Group, the identification of permeable reservoirs within the Strzelecki Group has proven difficult, though primary porosity can be high. Unless an improved model for the prediction of permeability within the Strzelecki Group sandstones can be developed, such targets are inherently high-risk.

An effective regional seal for the top-Latrobe Group reservoirs is provided by calcareous shales and marls of the lower Oligocene–lower Miocene Lakes Entrance Formation at the base of the Seaspray Group (Bernecker and Partridge, 2001; Partridge et al, 2015). In the eastern part of the basin, the lowermost Seaspray Group is represented by a condensed section of calcareous shales, termed the 'Early Oligocene Wedge' (EOW) by Partridge (1999). The Oligocene–Miocene marine carbonates that comprise the EOW and the upper Oligocene to Miocene Swordfish Formation (Seaspray Group) are now recognised as lateral equivalents of the Lakes Entrance Formation (Blevin and Cathro, 2008; Goldie Divko et al, 2010; Blevin et al, 2013).

The thickness of this seal varies considerably and ranges from approximately 100 m to over 300 m in deeper water parts of the basin (O'Brien et al, 2008). In addition, many potential intraformational sealing units are present within the Latrobe Group. These include floodplain sediments deposited in upper and lower coastal plain environments, as well as lagoonal to offshore marine shales. These seals are commonly thin and mostly occur within stacked sandstone/mudstone successions; the low shale volume in such settings makes the prediction of cross-fault seal problematic. Excellent seals, such as the Turonian lacustrine Kipper Shale, are developed adjacent to the basin-bounding faults. Other effective seals are provided by several distinct volcanic horizons of Campanian to Paleocene age (e.g. as in the Kipper Field). The Kipper Shale exceeds 500 m in



thickness, whereas the volcanics are often less than 50 m thick, although they are known to exceed 100 m in the Kipper field.

## Timing of generation

From limited published data, it is concluded that the main period of hydrocarbon generation and expulsion commenced in the Miocene as a result of increased sedimentary loading of the Cenozoic carbonate sequences (Smith et al, 2000). Some interpretations suggest that hydrocarbon generation and migration is currently at a maximum (Duddy et al, 1997). In the major depocentres of the basin, restricted areas underwent an early phase of generation and migration at or around the middle Eocene. It is important to realise that at that time, no regional Lakes Entrance seal was in place and any traps would have involved older intra-Latrobe Group sealing units and earlier formed traps.

Clark and Thomas (1988) proposed that peak generation and primary migration in the Gippsland Basin occurs at depths of 4–5 km for oil and 5–6 km for gas (O'Brien et al, 2008). Peak hydrocarbon generation within the Latrobe Group source rocks is considered to take place with  $R_o$  at 0.92–1.0% (Clark and Thomas, 1988), which agrees well with the findings of Burns et al (1987), whose maturity data (using the Methylphenanthrene Index of Radke and Welte, 1983) indicated that most Gippsland Basin oils were generated with  $R_o$  at 0.9–1.16%. The hydrocarbons reservoired in the western Gippsland Basin and on the Northern Terrace have undergone some biodegradation and water washing (Burns et al, 1987; O'Brien et al, 2013; Hoffman and Preston, 2014) as a result of the invasion of the fresh-water wedge in the late Cenozoic (Kuttan et al, 1986).

## Play types

During its long exploration history, a large variety of play types have been successfully tested in the Gippsland Basin. The giant oil and gas fields discovered early in the history are all related to large anticlinal closures in the Central Deep at top-Latrobe Group level, where coarse-grained coastal plain and shallow marine barrier sands provide excellent reservoirs. Further top-Latrobe discoveries have been made in increasingly deeper water, including erosional channel plays in the eastern part of the basin such as Blackback, Marlin and Turrum. In these, channel cut and fill sediments are preserved as complex successions of intraformational reservoir and seal facies.

Other top-Latrobe play types are known to exist on the flanks of the basin. On the Northern and Southern terraces, the Latrobe Group rapidly decreases in thickness and pinches out near the bounding faults of the Northern and Southern platforms. Stratigraphic pinch-out plays have been tested on both the Northern and Southern terraces. Here the top-Latrobe Group is represented in the west by the coal-bearing lower-middle coastal plain sediments of the Burong Formation and in the east by the marine sandy glauconitic mudstones of the Gurnard Formation. The Gurnard Formation is characterised by facies changes and acts as a seal as well as a reservoir unit on the northern margin where it hosts the Patricia-Baleen gas accumulation (Bernecker et al, 2002). Structural play types are also developed on the basin terraces. The Leatherjacket oil and gas discovery is an example of an inverted normal fault-closure that comprises top- and intra-Latrobe Group reservoir objectives.

Structural plays are dominant within the Halibut and Golden Beach subgroups. They commonly involve down-thrown fault traps that comprise intra-Latrobe fluvial reservoirs and intraformational seals. The Basker/Manta/Gummy oil and gas field in the northeastern Central Deep is an example of such a play type. The Golden Beach Subgroup play is restricted to the Central Deep where the main fairway is represented by the Chimaera Formation comprising fluvial and coastal plain sediments sealed by either Campanian volcanics, upthrown shales of the Emperor Subgroup or intraformational mudstones. The play is proven on low-side fault closures at the Kipper gas field (Bernecker et al, 2002).

Mapping of the Pisces Sub-basin shows there is a significant thickness of sediment present in the easternmost half graben, which may be prospective for hydrocarbon generation if source facies are present (Blevin et al, 2013). A new play was successfully tested by the Longtom 2 and 3 wells, which targeted fluvial units within the Emperor Subgroup. This subgroup is dominated by the Kipper Shale, which can be up over 1000 m thick (Bernecker and Partridge, 2001), but it also includes underlying and overlying coarse-grained fluvial sediments. The stratigraphic position of the Emperor Subgroup has meant that it has been penetrated by drilling only on

the Northern and Southern terraces. However, the Longtom gas discovery confirms the viability of this new play type along the flanks of the Central Deep.

Exploration plays in the Strzelecki Group have been identified in the onshore Seaspray Depression. The North Seaspray and Wombat gas discoveries, assessed as tight gas plays, are most likely sourced from Lower Cretaceous coaly floodplain deposits and hosted by fluvial sandstones with moderate to good porosity but low permeability. As such, this configuration resembles the gas discoveries in the coeval Otway Group in the onshore Otway Basin. It has been suggested that the gas in the Patricia-Baleen and Sole fields on the offshore Northern Terrace may be sourced from the Strzelecki Group (O'Brien et al, 2007, 2008). If this is the case, then the shallower areas outside the Central Deep may offer additional exploration opportunities.

## Critical Risks

With hydrocarbon production in the Gippsland Basin spanning nearly 50 years, exploration activity has clearly been rewarded with great commercial success. However, since the early 2000s, exploration has slowed significantly, adding only small volumes of gas to the existing inventories. It can be argued that the top-Latrobe Group play, hosting the giant fields such as Barracouta, has been tested across the entire basin and is unlikely to yield any new major discoveries. An exception could be the channel facies play in the eastern Central Deep and along the northwestern flank of the Bass Canyon as exemplified by the recently re-mapped Dory structure south of Blackback.

The intra-Latrobe Group, including the Golden Beach Subgroup and Kipper Shale, may hold the key for future exploration success. Little is known about the location and extent of the palaeo-shoreline during deposition of the Golden Beach Subgroup, which would provide a better understanding of reservoir and sealing facies in the eastern deeper water part of the basin. Targets within the deeper intra-Latrobe would require the drilling of wells that exceed 4500 mTD, as documented by the small oil and gas accumulations at Archer/Anemone and Angler. It is also uncertain how many of the fine-grained marine sediment intervals of the Golden Beach Subgroup are potential source rocks due to the small number of intersections with geochemical analyses.

Further outboard, in areas surrounding the Bass Canyon, the regional seal of the Lakes Entrance Formation and associated calcareous sediments of the Seaspray Group, thin rapidly in an eastward direction. It remains a matter of speculation whether reservoir and source rock facies are adequately developed in the Emperor Subgroup and some sections of the Strzelecki Group, for commercial accumulations to be found.

## 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 webpage for the [Gippsland 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 environment information

The following section contains information about the existing marine parks, their special habitat zones and physiographic features within the Gippsland Basin (**Figure 19**). 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, generally three nautical miles from the shore, and extend to the outer boundary of Australia's Exclusive Economic Zone, 200 nautical miles 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 Gippsland Basin region.

#### *Australian Marine Parks: South-east Marine Parks Network*

The South-east Marine Parks Network comprises 14 Commonwealth marine reserves, together representing examples of the ecosystems of the South-east Marine Region. The network is located within the South-east Marine Region, which incorporates Commonwealth waters extending from near the far south coast of New South Wales, around Tasmania and as far west as Kangaroo Island in South Australia. It includes the Commonwealth waters of Bass Strait and those surrounding Macquarie Island in the Southern Ocean. The Commonwealth marine area starts at the outer edge of state waters, 3 nautical miles (5.5 kilometres) from the shore (territorial sea baseline), and extends to the outer boundary of Australia's exclusive economic zone, 200 nautical miles from the territorial sea baseline. State and territory jurisdictions extend from the shoreline to 3 nautical miles offshore.

The South-east Marine Region is recognised as a major marine biogeographic region. When compared to most of the world's marine environments, the marine environments of temperate Australia display an enormous diversity of plant and animal species and are believed to have the most diverse marine floral assemblage in the world. High diversity in terms of the number of species is a feature common to many plant and animal communities in the Region. In addition to high diversity, the Region has large numbers of endemic species, that is, species found nowhere else in the world.

Significant variation in water depth and sea-floor features found throughout the South-east Marine Region are contributing factors to the high level of species diversity in the Region. Sections of the continental shelf, including Bass Strait, have a mosaic of rocky reefs and soft sediments. The shelf habitats support a diverse range of species from a broad range of taxonomic groups. The shelf break, which includes the edges of the continental shelf and the upper slope, serves to intensify currents, eddies and upwellings, creating a rich and productive area for biodiversity, including species that are fished commercially and recreationally.

Sea-floor canyons along the continental margin have been identified as important ecological features in the Region. Canyons can have steep or rugged topography that provide habitat for sessile invertebrates, such as corals, which in turn attract other organisms and higher order species. Depending on their size and shape, canyons can intensify local currents and the concentration of nutrients to enhance productivity and biodiversity.

Two of the marine parks within the South-east Marine Parks Network overly or are adjacent to the Gippsland Basin—Beagle Marine Park and East Gippsland Marine Park.

Management plans for the South-east Marine Parks Network are in place, and can be viewed at: <https://parksaustralia.gov.au/marine/pub/plans/se-network-management-plan2013-23.pdf>

#### *Beagle Marine Park*

The [Beagle Marine Park](#) lies entirely within Bass Strait, with its northwestern edge abutting Victorian waters southeast of Wilson's Promontory. It is a shallow-water marine park surrounding Hogan and Kent island groups,

and the Kent Group Marine Reserve. Beagle Marine Park covers 2928 km<sup>2</sup>, protects rocky reefs and diverse sponge gardens, and is an important foraging area for seabirds that breed on the surrounding islands.

#### **Statement of significance**

- The Beagle Marine Park contains the following sea-floor features: basin, plateau, shelf and sill.
- The park contains ecosystems, habitats and communities associated with the Southeast Shelf Transition.
- Important migration path for the Southern Right Whale.
- Important foraging area for Australian Fur Seal, Killer Whale, White Shark, Shy Albatross, Australasian Gannet, Short-tailed Shearwater, Pacific and Silver gulls, Crested Tern, Common Diving Petrel, Fairy Prion, Black-faced Cormorant, and Little Penguin.
- The park contains cultural and heritage sites including:
  - Wreck of the steamship SS Cambridge
  - Wreck of the ketch Eliza Davies

The park is zoned Multiple Use Zone IUCN Category VI. Mining operations, including exploration, are allowed.

#### ***East Gippsland Marine Park***

The [East Gippsland Marine Park](#) is located off the northeast corner of Victoria, on the continental slope and escarpment. It covers 4137 km<sup>2</sup> with water depths from 600 metres to over 4000 metres.

#### **Statement of significance**

- The East Gippsland Marine Park contains the following sea-floor features: abyssal plain, deep ocean floor, canyon, escarpment, knoll, abyssal hill and slope.
- Features with particularly high biodiversity and productivity include Bass Cascade and the upwelling zone east of Eden.
- The marine park protects examples of important ecosystems, habitats and communities associated with the Southeast Shelf Transition
- The park is an important foraging area for Wandering, Black-browed, Yellow-Nosed and Shy albatrosses, Great-winged Petrel, Wedge-tailed Shearwater and Cape Petrel.
- Important migration area for Humpback Whale.

The reserve is zoned Multiple Use Zone IUCN Category VI. Mining operations, including exploration are allowed.

#### ***Victoria Marine Protected Areas***

##### ***Ninety Mile Beach Marine National Park***

The [Ninety Mile Beach Marine National Park](#) (2750 ha) extends from Ninety Mile Beach, southwest of Seaspray to the limit of Victorian coastal waters. The park protects an internationally significant sandy environment, recognised for its exceptionally high diversity of marine invertebrates. Low calcarenite reefs, scattered throughout the park, support a unique invertebrate biota, including colourful sponge gardens. The long sandy beach provides extensive habitat for shorebirds, including international migratory waders and the threatened Hooded Plover.

The park is zoned a National Park IUCN Category II. Category II areas are managed primarily for ecosystem protection and recreation. All forms of extraction are prohibited in the park (Parks Victoria, 2006b).

### *Beware Reef Marine Sanctuary*

The [Beware Reef Marine Sanctuary](#) (220 ha) is an offshore sanctuary approximately 400 km east of Melbourne and 30 km south-east of Orbost. It lies offshore 5 km south-east of Cape Conran, and covers Beware Reef and its surrounds. The sanctuary contains a partially exposed granite reef environment, which provides habitat for a rich diversity of marine biota. Intertidal and subtidal reef, subtidal soft sediment and pelagic communities are represented in the sanctuary. The exposed rocky platform of the reef is a haul-out site for Australian Fur Seals and New Zealand Fur Seals. The sanctuary also houses threatened fauna—including several birds species and marine mammals—and a seascape of high cultural significance to Indigenous people, as well as three historic shipwrecks.

The sanctuary is zoned IUCN Category II. All forms of extraction are prohibited in the park (Parks Victoria, 2006a).

### *Point Hicks Marine National Park*

The [Point Hicks Marine National Park](#) (4000 ha) is approximately 450 km east of Melbourne and 25 km south of Cann River. The park extends from the east of Clinton Rocks to the eastern end of Stable Bay and includes Whaleback Rock, and from the high water mark seaward three nautical miles to the edge of Victorian waters. The vertical boundary of the park extends to 200 m below the seabed. The park contains a diversity of habitats including subtidal and intertidal reefs, subtidal soft sediment, and sandy beaches, hosting a very high diversity of fauna, including intertidal and subtidal invertebrates. Of note is the co-occurrence of eastern temperate, southern cosmopolitan, and temperate species, as a result of mixing of warm eastern and cool southern waters. The park contains threatened fauna including whales and several bird species, as well as other marine mammals—including dolphins and Australian and New Zealand fur seals, and transient reptiles including turtles and sea snakes.

The park is a seascape of high cultural significance to Indigenous people, as well as containing a diverse and rich maritime and post-European-settlement history, including shipwrecks and evidence of shipping history.

The park is zoned a National Park IUCN Category II. All forms of extraction are prohibited in the park (Parks Victoria, 2006c).

### *Wilsons Promontory Marine National Park*

The [Wilsons Promontory Marine National Park](#) (15,604 ha) is located approximately 220 km southeast of Melbourne, and extends from the mean high water mark from the southern end of Norman Bay to Cape Wellington, and offshore to within 300 m of the Glennie Group of islands. The Wilsons Promontory Marine National Park forms part of a system of 13 Marine National Parks and 11 Marine Sanctuaries in Victorian waters, and adjoins the Wilsons Promontory Marine Park and the Wilsons Promontory Marine Reserve. The area is the largest marine protected area in Victoria and contains a diverse range of habitats that host high biodiversity and a number of endemic marine flora and fauna, including threatened marine mammals and shorebirds. Over 300 different species have been recorded in Wilsons Promontory Marine National Park. Threatened bird species including the Hooded Plover, White-bellied Sea Eagle and Caspian Tern feed within the waters of the marine park. The park supports a large breeding population of Australian Fur Seals. Other marine mammals include the Southern Right Whale, Humpback Whale, Andrew's Beaked Whale, Pilot Whale, Sperm Whale, Goose-beaked Whale, Common and Bottlenose Dolphins. Leatherback turtles have also been recorded.

The park encompasses transitional waters of the Southeast Shelf Transition zone within the Flinders Bioregion (Interim Marine and Coastal Regionalisation for Australia, IMCRA V4), and represents the boundary of eastern and western distributions for at least 65 species (Plummer et al, 2003). The Flinders Bioregion experiences highly variable wave exposure and supports high fish and plant species richness.

The park is a seascape of high cultural significance to a number of Indigenous Traditional Owner groups, including the Gunaikurnai and Boon Wurrung people. The area forms part of a past land link to Tasmania occupied and used by Indigenous people. A rich post-European maritime and shipping history is evidenced by [historic shipwrecks](#) and other maritime infrastructure. In recognition of the area's outstanding values and heritage importance, the Wilsons's Promontory Marine Park, Marine Reserve, and sections of the Marine National Park are listed on the [Register of the National Estate](#).

The park is zoned a National Park IUCN Category II. All forms of extraction are prohibited in the park (Parks Victoria, 2006c). Management plans for the area are in place, and can be viewed at [Wilsons Promontory Marine National Park and Marine Park Management Plan 2006](#)

#### *Corner Inlet Marine National Park and Corner Inlet Marine and Coastal Park*

The [Corner Inlet Marine National Park](#) (1550 ha) and [Corner Inlet Marine and Coastal Park](#) (28,585 ha) are located 180 km southern of Melbourne, adjacent to Wilsons Promontory National Park. The Corner Inlet Marine National Park forms part of a system of 13 Marine National Parks and 11 Marine Sanctuaries in Victorian waters. The park protects a network of mangrove, saltmarsh, mud banks and subtidal reef environments, including a representative area of the only extensive *Posidonia australis* seagrass meadows in Victoria. This seagrass community is recognised as an important nursery habitat and supports the most diverse fauna of all marine habitats in the Corner Inlet and Nooramunga area. Corner Inlet Marine National Park supports nine ecological communities including macroalgae, saltmarsh and mangrove communities, and intertidal rocky reef habitats.

The park forms part of the Corner Inlet Ramsar Site, which supports 20% of Victoria's total wader population and is part of the East-Asian Australasian Flyway for migratory wader birds. Six nationally threatened fauna species have been recorded in the park, as well as 13 migratory bird species listed under the Japan–Australia Migratory Bird Agreement (JAMBA) and the China–Australia Migratory Bird Agreement (CAMBA) (Plummer et al. 2003).

Corner Inlet Marine National Park forms part of the Victorian Embayments Bioregion (IMCRA V4), characterised by sheltered waters with extensive areas of subtidal and intertidal sediments. The characteristic flora and fauna composition of the park results in part from the transition of distributions from warm-water species from the NSW coast and cool-water species found throughout Victoria.

The park is a seascape of high cultural significance to a number of Indigenous Traditional Owner groups, including the Gunaikurnai and Boon Wurrung people.

The Corner Inlet Marine National Park is zoned IUCN Category II. The Corner Inlet Marine and Coastal Park is zoned IUCN category VI. Management plans for the area are in place, and can be viewed at [Corner Inlet Marine National Park Management Plan 2005](#).

#### *Shallow Inlet Marine and Coastal Park and Nooramunga Marine and Coastal Park*

The [Shallow Inlet Marine and Coastal Park](#) (1974 ha) and [Nooramunga Marine and Coastal Park](#) (15000 ha) together form part of the ecologically important Corner Inlet Ramsar site (67,000 ha). The parks contain a range of habitats including mangrove, saltmarsh, and intertidal areas that host diverse marine communities. The parks are recognised as high conservation value areas for wading birds.

Both the Shallow Inlet Marine and Coastal Park and the Nooramunga Marine and Coastal Park are assigned IUCN zoning Category VI.

#### *French Island Marine National Park*

The [French Island Marine National Park](#) (2980 ha) is approximately 75 km southeast of Melbourne in Western Port, and forms the northern seaward boundary of French Island National Park. The park contains a range of significant habitats including mangrove and saltmarsh areas of State geomorphological significance, and forms part of the Western Port Ramsar site. Seagrass beds provide important nursery and feeding habitat for King George Whiting, Bream, Mullet, and Australian Fur Seals. The park supports important waterfowl and migratory bird habitats listed under Japan-Australia Migratory Birds Agreement (JAMBA) and the China-Australia Migratory Birds Agreement (CAMBA).

The park is within the Sea Country of the Bunurong Traditional Owners and is of high cultural significance.

The park is assigned the IUCN zoning Category II (National Park).



### *Bunurong Marine National Park*

The [Bunurong Marine National Park](#) (2050 ha) is located approximately 140 km southeast of Melbourne, and is bounded to the west and east by the Bunurong Marine Park (1203 ha). Together, the Bunurong Marine National Park and Bunurong Marine Park extend along approximately 17 km of coastline. The park features extensive intertidal rock platforms and rocky reefs extending several kilometres offshore. The park contains a range of habitats that support abundant and diverse marine flora and fauna communities, including 201 algal species, 87 fish species, and 258 subtidal invertebrates. The park represents an important habitat for a number of threatened species including the Hooded Plover and the rare echinoderm *Pentocnus bursatus*.

The park lies within the Central Victoria Marine Bioregion (IMCRA V4), characterised by steep to very steep offshore gradients, sandy beaches and cliffs, with sea temperatures representative of Bass Strait waters.

The park is a seascape of high cultural significance to a number of Indigenous Traditional Owner groups, including the Boon Wurrung people. A rich post-European maritime and shipping history is evidenced by [historic shipwrecks](#) and other maritime infrastructure. In recognition of the area's outstanding values and heritage importance, sections of the Marine National Park and Marine Park are listed on the [Register of the National Estate](#).

Bunurong Marine National Park is assigned the IUCN zoning Category II (National Park). Bunurong Marine Park is zoned IUCN Category VI. Management plans for the area are in place, and can be viewed at [Bunurong Marine National Park Management Plan 2006](#)

### *Churchill Island Marine National Park*

The [Churchill Island Marine National Park](#) (670 ha) is located in Western Port, extending from the eastern shore of Phillip Island to the north point of Churchill Island and along the western shore. The park is part of the Western Port Ramsar site and is assigned the IUCN zoning Category II (National Park).

### *Gippsland Lakes Coastal Park*

The [Gippsland Lakes Coastal Park](#) (17688 ha) is jointly managed by the Gunaikurnai (Traditional Owners) and the Victorian government. The park stretches 90 km along a narrow strip of coastline from Seaspray to Lakes Entrance, and takes in extensive dune systems, woodlands, and heathlands. The park is largely onshore, but includes a significant area of water, including Lake Reeve and Bunga Arm, and are an important drought refuge for many species of waterbirds. Lake Reeve is a narrow, shallow water body adjacent to the coastal dune barrier that has been listed under the Ramsar Convention as a wetland of international importance for its waterfowl habitat. The park contains a large array of significant plant and animal species, including more than 190 species of birds, 26 species of native mammals, 17 species of reptiles, and 11 species of amphibians. Crescent Island is an environmentally and culturally important breeding site for pelicans, little terns, and fairy terns. The park is one of the most important sites in Victoria for the endangered New Holland mouse. The waters of the park provide a habitat for bottlenose dolphins.

The park comprises the following management zones: Conservation Zone, Conservation & Recreation Zone, Ramsar Wetland, Recreation Development Zone, Special Management Zone, Hunting (Ducks & Quail only), Hunting (Hog Deer, Duck, & Quail).

## **Biologically important areas**

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

- The Shy, Indian Yellow-Nosed, Black-browed, Buller's, Campbell, and Wandering albatrosses breed and forage within the Gippsland Basin
- The Antipodean, Black-browed, and Campbell albatrosses, and the White-faced Storm Petrel forage in the region
- The Common Diving Petrel is present year-round, and breeds in the region from July through to December



- Southern right whale migration and resting areas are located within the basin. This activity generally occurs in coastal areas between May and November, although whales may stay year-round. Pygmy Blue Whale also forage in the region.
- Indo-Pacific and Spotted Bottlenose dolphins breed, calve, and forage to the north of the basin, in the state waters of the East Marine Region (within the 20 metre water depth contour)
- The basin overlaps the White Shark distribution area, also used as a breeding nursery and opportunistic feeding area in autumn, winter, and spring in waters to 1000 m depth.

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

## Heritage

### *Maritime Heritage*

Australia protects its shipwrecks and associated underwater heritage through the [Underwater Cultural Heritage Act 2018](#) [Historic Shipwrecks Act 1976](#).

There are two [Commonwealth historic shipwreck protected zones](#) in the Gippsland Basin region: the paddle steamer Clonmel and the screw steamer SS Glenelg. The Clonmel is located just south of Sunday Island, and was one of the first steam-powered vessels on the Australian coast. The vessel was wrecked in 1841, and is now one of the most significant archaeological sites in Victoria. The protected zone extends in all directions from the shipwreck, with a radius of 50 metres. The SS Glenelg is located to the south-east of Ninety Mile Beach Marine National Park, and is historically significant as one of the worst maritime disasters in Victorian history, with the deaths of at least 38 people and only three survivors. The wreck also has archaeological significance. The protected zone extends in all directions from the shipwreck, with a radius of 500 metres.

There are several additional shipwrecks within the Gippsland Basin that are not associated with a defined protected zone. These can be identified using the [Australian National Shipwreck Database](#) map search tool.

### *Cultural Heritage*

The Gunaikurnai Traditional Owner Land Management Agreement and Gunaikurnai Native Title Agreement recognise that the Gunaikurnai hold native title over much of Gippsland, including 200 m of sea country offshore.

## Fisheries

The following [Commonwealth fisheries](#) are within the Gippsland Basin area (state fisheries included in indent text):

- The Bass Strait Central Zone Scallop Fishery operates in the Bass Strait above Tasmania and extends from the Victoria/New South Wales border, around southern Australia to the Victoria/South Australian border. The fishery is between the Victorian and Tasmanian scallop fisheries that lie within 20 nm of their respective coasts. The default period for the fishing season is 1 April to 31 December, although the 2018 season opened on 19 July and closed 31 December.
- The [Victorian Scallop Fishery](#) extends out to 20 nautical miles from the high tide mark, excluding bays and inlets. Continued low levels of scallop abundance have resulted in a low Total Allowable Commercial Catch of 135 tonnes since 2015/2016.
- The Eastern Tuna and Billfish Fishery extends from Cape York in Queensland to the South Australian/Victoria border. Fishing occurs both in the Australian Fishing Zone (generally between 3 and 200 nautical miles from the coast) and adjacent high seas. The fishing season generally runs for 12 months, starting on 1 March. However, the 2018 season ran for 10 months from 1 March to 31 December.

- The Small Pelagic Fishery extends from the Queensland/New South Wales border, typically outside three nautical miles, around southern Australia to a line at latitude 31°S (near Lancelin, north of Perth). The Gippsland Basin intersects the western sub-area of this fishery. The fishing season runs for 12 months, starting on 1 May.
- The Southern and Eastern Scalefish and Shark Fishery stretches south from Fraser Island in southern Queensland, around Tasmania, to Cape Leeuwin in southern Western Australia. The fishery is comprised of major sectors, of which three overlap the Gippsland Basin: the Commonwealth South East Trawl Sector, the Scalefish Hook Sector, and the Shark Hook and Shark Gillnet Sector. The fishing season runs for 12 months, starting on 1 May.
- 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 Southern Squid Jig Fishery is located off New South Wales, Victoria, Tasmania, and South Australia and in a small area of oceanic water off southern Queensland. The fishing season runs for 12 months, starting on 1 January.

The Gippsland Basin also overlaps the [Victorian Wrasse \(Ocean\) Fishery](#). The commercial fishery extends along the entire length of the Victorian coastline and out to 20 nautical miles offshore, except for marine reserves.

Significant research has been undertaken in the Gippsland Basin on the potential impacts of marine seismic surveys on fisheries and the marine environment (see Bruce et al, 2018 and review by Carroll and Przeslawski 2020). The Gippsland Marine Environmental Monitoring (GMEM) project was developed in response to concerns from the fisheries industry about seismic survey activity in the Gippsland Basin, as well as a broader need to acquire baseline data to quantify potential impacts of seismic operations on marine organisms. Publications from this work can be found on [Geoscience Australia's website](#).

## Climate of the region

The region is characterised by a cool temperate climate, with precipitation delivered throughout the year and few temperature extremes. At the closest onshore weather station (Point Hicks Lighthouse), mean minimum and maximum temperatures were 8.2°C and 24°C for the period 1966–2019 (BOM, 2019). Mean annual rainfall recorded over the past 53 years at Point Hicks Lighthouse is 963.9 mm (BOM, 2019). The region is at the edge of a known climate change hotspot with a documented 0.8°C rise in sea surface temperature, which may impact the marine ecosystem (Oliver et al, 2013; Hobday and Hartog, 2016).

## Oceanic regime

The region has cool temperate waters. Sea surface temperatures (SSTs) range between 13°C in winter and 18°C in summer (Barton et al, 2012), with high levels of interannual variations in SST often linked to warm eastern incursions from the East Australian Current (Przeslawski et al, 2018). Tidal range is microtidal with 0.6 m neap tides and 0.9 m spring tides (Plummer et al, 2003; Barton et al, 2012). The area is protected by Tasmania from southwesterly swells, but is influenced by southeasterly and easterly swells. Tidal currents, high energy swells and southwesterly winter winds result in well mixed coastal waters and the northeasterly coastal movement of sand (Plummer et al, 2003; Barton et al, 2012). In general, salinity and temperature are consistent throughout the water column, indicating high levels of vertical mixing (Przeslawski et al, 2018).

## Seabed environments: regional overview

The offshore Gippsland Basin extends from the Gippsland Lakes coast, Victoria, to the mid-continental slope (Bunch et al, 2011). The principal geomorphic features of the offshore basin include an inner (0–50 m) to mid (50–100 m) shelf region, which narrows from 200 km in the south to 20 km in the north, with a broad and shallow valley (50–150 m) in the west and a broad terrace (110–210 m) in the east. Several large easterly flowing canyons (130– >4,500 m) dissect the continental slope.

Approximately 78% of the Gippsland coast is composed of highly erodible siliciclastic sediment (Sjerp and Charteris, 2008). Offshore shelf sediments, in contrast, are dominated by calcium carbonate ( $\text{CaCO}_3$ ) with mean grain sizes equivalent to medium to fine sand (Jones and Davies, 1983). Very fine sand occurs immediately offshore of Lakes Entrance, and in deeper water (~75–100 m) near the heads of the major canyons (Jones and Davies, 1983).

Quaternary shelf sediments have aggraded to a maximum of 120–150 m (Mitchell et al, 2007). Across the inshore shelf, sediment is predominantly quartz-rich, with typically 0–30% carbonate content (Smith and Gallagher, 2003). The highest carbonate content (> 80%) is found in seabed sediments to the southwest, or northeast of the transect from Lakes Entrance to Bass Canyon. The middle to outer shelf and canyons have higher carbonate percentages (~50–80 %), which may be due to the presence of remnant materials derived from lowstand fluvial systems extent during glacial periods (Mitchell et al, 2007), which are visible in magnetic surveys (Mitchell et al, 2007).

## Ecology

The Gippsland Basin is part of the Southeast Marine Bioregion, which extends from the far south coast of New South Wales to Kangaroo Island, and intersects part of the ‘Great Southern Reef’ temperate reef network. The diverse geomorphic features combine with poleward flowing boundary currents, shelf-break induced upwelling and eddies to enhance primary productivity and result in a high level of species diversity. The coastal environments of the Southeast Bioregion therefore support a range of communities, including giant kelp forests, rocky reefs and extensive temperate seagrass meadows. The high diversity, endemism, structural complexity and productivity of the region’s giant kelp forests make the Great Southern Reef network globally unique (Bennett et al, 2016). The numerous offshore submarine canyons (e.g. Big Horseshoe Canyon, Bass Canyon, Everard Canyon, Anemone Canyon, Mudskipper Canyon) also link continental shelf and deep continental slope environments, providing important habitat for a range of organisms, particularly infaunal species (Huang et al, 2018). This area is a feeding ground and migration pathway for blue and humpback whales (Gill et al, 2011), and is important for other cetaceans, seals, sharks and seabirds (Australian Government, Department of the Environment, 2015). This region also hosts high levels of macroalgae diversity (Womersley, 1990), and possibly represents one of the most diverse marine floral assemblages in the world (Australian Government, Department of the Environment, 2015). Baseline seabed surveys undertaken in 2018 by the Institute for Marine and Antarctic Studies (University of Tasmania), Geoscience Australia and the University of Sydney confirmed the presence of a diverse temperate sponge/bryozoan dominated invertebrate assemblage on low-profile reef features that also support large aggregations of port Jackson shark (*Heterodontus portjacksoni*) (Barrett et al, 2021). These features likely represent the seabed expression of the underlying sedimentary rock of the Bass Strait region, which during the last glacial period would have formed a notable high point in the land bridge between Tasmania and Victoria (Barrett et al. 2021).

## Recent geological history

The modern Gippsland coast represents the boundary between the offshore and onshore Gippsland sub-basins. In the offshore Gippsland Basin, the Seaspray Group comprises cool water carbonates (generally 60–80%  $\text{CaCO}_3$ ), which form the cover unit for the region’s major reservoir succession (Latrobe Group). The Seaspray Group is subdivided into three subgroups, the uppermost and most recent of which is the Neogene–Quaternary Hapuku Subgroup (Wallace et al, 2002). These sedimentary strata typically consist of basal quartz-rich siltstone, overlain by carbonate rich coarse bioclastic grainstone (Holdgate et al, 2000; Gallagher et al, 2003). Onshore, the lateral equivalent of the Hapuku Subgroup is the Jemmys Point Formation, which consists of silty/shelly sandstone with interspersed mica-rich siltstone (Holdgate et al, 2000).

Holdgate et al (2003) have described the tectonic and eustatic implications of magnetic ridge and channel features in the Gippsland Basin. On the shelf, extensive ridges are visible in magnetic (Holdgate et al, 2003) and topographic (Beaman et al, 2005; Brooke et al, 2017) datasets. These underlie the modern coastal Gippsland Lakes and are aligned at a low angle, oblique to the modern Lakes Entrance barrier system. They are therefore distinct from the modern system and are interpreted as buried regressive strandlines and barriers, which formed during lower sea levels in the early Pleistocene (as well as the late Miocene, and early and late Pliocene) (Holdgate et al, 2003). The absence of magnetic palaeo-shorelines from the shelf immediately south of Lakes Entrance are suggestive of subsequent uplift and erosion (up to 0.2 Ma ago; Holdgate et al, 2003).

Ancient river channels extend from the onshore basin to the offshore edge of the continental shelf. These fluvial systems are well represented in the magnetic dataset, and formed during lowstands in the middle to late Pleistocene (Lisiecki and Raymo, 2005; Lewis et al, 2013) when they extended the modern Gippsland rivers to the (now) offshore palaeo-shorelines. Sub-bottom profiles indicate that these channels are <500 m wide and have a total depth of up to 40 m beneath the present seabed.

## National seabed mapping data and information

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

These data are discoverable and accessible through the AusSeabed [Marine Data Discovery 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 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 such as 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: [South-east Marine Parks Network](#)
- [AusSeabed](#)
- [Parks Victoria Marine protected areas](#)
- [Commonwealth Fisheries](#)
- [Victorian Fisheries Authority—Commercial Fisheries](#)
- [Historic shipwrecks](#)
- [Protected Matters Search Tool](#)

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## Figure Captions

- Figure 1** Map of the Gippsland Basin showing bathymetry, petroleum well distribution and oil and gas fields.
- Figure 2** Tectonic elements map of the Gippsland Basin showing bathymetry, petroleum well distribution and oil and gas fields.
- Figure 3** Map showing petroleum exploration and production permits, oil and gas fields and petroleum production infrastructure in the Gippsland Basin.
- Figure 4** Stratigraphic chart for the Gippsland Basin showing hydrocarbon occurrences in the Central Deep, on the Northern Terrace and on the Southern Terrace (Geologic Time Scale after Gradstein et al, 2020).
- Figure 5** Stratigraphic chart for the Southern Terrace showing well intersections of hydrocarbons (Geologic Time Scale after Gradstein et al, 2020).
- Figure 6** Stratigraphic chart for the western Central Deep showing well intersections of hydrocarbons (Geologic Time Scale after Gradstein et al, 2020).
- Figure 7** Stratigraphic chart for the eastern Central Deep showing well intersections of hydrocarbons (Geologic Time Scale after Gradstein et al, 2020).
- Figure 8** Stratigraphic chart for the Shelf Edge and Continental Slope showing well intersections of hydrocarbons (Geologic Time Scale after Gradstein et al, 2020).
- Figure 9** Stratigraphic chart for the Northern Terrace showing well intersections of hydrocarbons (Geologic Time Scale after Gradstein et al, 2020).
- Figure 10** Map showing the current main operators, active exploration permits, retention leases and production licences
- Figure 11** Map showing the distribution of oil families in the Gippsland Basin (after Edwards et al, 2016).
- Figure 12** Well correlation diagram from the western Central Deep (Dolphin 1) to the northern flank of the Bass Canyon (Great White 1) showing depositional facies relationships.
- Figure 13** Well correlation diagram from the western Central Deep (Barracouta A3) to the edge of the Bass Canyon (Billfish 1) showing depositional facies relationships.
- Figure 14** Dendrogram showing distinct source rock groups using bulk carbon isotopes and molecular (biomarker) analyses from selected wells. Orange: Chimaera Formation source rock (CFSR) extracts that have mixed land-plant and lacustrine signatures consistent with deposition in a lower coastal plain facies. Green: Volador Formation source rocks (VFSR) with strongly terrestrially influenced oxic depositional environment. Blue (comprising two sub-groups): Anemone Formation source rocks (AFSR) were deposited in sub oxic to oxic environments containing mixed marine algal and terrestrial higher plant derived organic matter (after Edwards et al, 2016).
- Figure 15** Dendrogram showing Latrobe Group oil-source correlations using bulk carbon isotopes and molecular (biomarker) analyses from selected wells. Orange: Angler 1 and Blackback 2 oils have mixed land-plant and lacustrine signatures that show similarity to lower coastal plain source rocks from the Chimaera Formation (CFSR) in the deepest sections (*T. lilliei* biozone) at Volador-1 and Hermes-1. These samples plot separately from the Central Deep oils that have a terrestrial fingerprint. Blue: Anemone 1A oil and Blackback 2 fluid inclusion oil show most similarity to Anemone Formation source rocks (AFSR) with mixed marine/terrestrial signatures. Green: the geochemical signature of the Volador Formation source rocks (VFSR) deposited in strongly oxic environments and containing terrestrial higher plant remains does not correlate with any oil (after Edwards et al, 2016).

- Figure 16** Oil-source correlations for selected wells. The  $\delta^{13}\text{C}$  isotope values of the Anemone 1 oil (blue) fall within the range of values exhibited by the marine Anemone Formation source rock extracts (after Edwards et al, 2016).
- Figure 17** Oil-source correlations for selected wells. The  $\delta^{13}\text{C}$  isotope values of the Angler 1 oil (orange) is most similar to the source rock extract of the Chimaera Formation at 3369 m in Omeo 1 ST1, but is somewhat different to other extracts of this formation in other wells (after Edwards et al, 2016).
- Figure 18** Oil-source correlations for selected wells. The  $\delta^{13}\text{C}$  isotope values of the Volador Formation source rock extracts (green) show a wide range in values and envelop those of the Chimaera and Anemone formations. The isotopic values of the oils from the Bream and Halibut fields fall in between the range displayed by the Anemone 1 and Anger 1 oils (after Edwards et al, 2016).
- Figure 19** Map showing marine reserves, marine parks, multiple use zones and ecological features in the Gippsland Basin.