

Geological Carbon Storage Potential of the Onshore Gippsland Basin, Victoria, Australia

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L.M. GOLDIE DIVKO, M.J. CAMPI, P.R. TINGATE, G.W. O'BRIEN & M.L. HARRISON

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Cover Image:

This image is a three-dimensional diagrammatic representation of the base and top surface of the regional top seal. The view is from the sub-surface offshore Gippsland Basin looking towards the Baragwanath Anticline in the onshore section of the basin and the Strzelecki Ranges in the distance.

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Executive Summary

In this report, the regional geological carbon storage (GCS) potential of the onshore Gippsland Basin is discussed, particularly in relation to the Victorian Government's newly offered GCS areas, GCS09-1 and GCS09-2. The sealing potential (containment), reservoir characteristics (injectivity and capacity) and the potential impacts of CO₂ injection have been considered at a high level and six GCS play fairways or play concepts have been defined. The play fairways involve two stratigraphically deeper storage concepts, namely localised sands within the Tyers River Subgroup and the upper (Albian-Aptian) Strzelecki Group; and storage plays within the younger Golden Beach, Halibut, Cobia and top Latrobe Group (Oligocene) sequences. Saline aquifer trapping appears to be the most likely storage option in all six plays.

The stratigraphically deepest plays, involving the lower (Tyers River Subgroup) and upper Strzelecki Group, are located within both exploration tender areas and comprise apparently localised sands within a stratigraphy dominated by lithic, volcanoclastic sandstones and mudstones. The critical technical uncertainty in both Strzelecki Group plays is low reservoir permeability. In the Latrobe Valley (GCS09-1), siliciclastic play options are limited to the Strzelecki Group, in particular the Tyers River Subgroup. The identification of suitable storage sites in these deeper plays will rely upon the development of a robust depositional model and an understanding of the distribution of primary porosity within the reservoirs. In particular, the details of where and how both porosity and permeability have been either preserved or lost due to diagenesis and compaction (due to burial-uplift cycles) will be critical. The likely potential resource conflicts associated with the geological storage of CO₂ within the Strzelecki Group are as yet undiscovered petroleum and geothermal resources.

The stratigraphically shallower top Latrobe Group and intraformational Latrobe Group plays occur exclusively within GCS09-2 and are located in the Seaspray and Lake Wellington depressions, relatively close to the coast. A qualitative assessment of seal potential, integrating both the characterisation of the regional Lakes Entrance Formation top seal and empirical evidence of seal failure indicates that the top seal over the central eastern Lake Wellington Depression and the southern to central nearshore areas in the Seaspray Depression are very suitable for the containment of supercritical CO₂. However, the Lakes

Entrance Formation appears to have poor retention capacity for CO₂ across the Baragwanath Anticline, in the Alberton Depression and over the Lakes Entrance Platform, due to the seal being thin to absent or of poor quality. The presence of possible gas chimneys and soil gas anomalies along the Darriman, Rosedale and Lake Wellington fault systems highlights the need to better understand the leakage and seepage processes in the area, especially in relation to reactivated faults in areas of thin seals.

Data on Latrobe Group reservoir quality in the Lake Wellington and Seaspray depressions are sparse; porosities are mostly greater than 20%, although permeabilities are highly variable. The Cobia, Halibut, Golden Beach and Emperor subgroups are all present in the Seaspray Depression, which potentially increases the geological carbon storage play options, particularly if intraformational seals are delineated in future studies. The identification of Latrobe Group faults and fault seal integrity is a key component in reducing the uncertainties associated with potential sites, particularly in the intraformational Latrobe Group. The likely potential resource conflicts associated with the geological storage of CO₂ in the Latrobe Group within the onshore Gippsland Basin are deep, potable groundwater resources and petroleum, geothermal and coal resources.

The total storage capacity of the onshore Gippsland Basin is unknown, although it is clearly one to two orders of magnitude less than that of the offshore part of the basin. The geoscience data which are currently available across the onshore basin are inadequate to undertake quantitative modelling or estimation of storage potential, with current estimates (0-65 Mt) based upon a combination of the total sealed pore volume and inferred saturation efficiencies within saline aquifers. A program of new data collection is required; these data would in turn allow for more accurate estimates of storage capacity and also the assessment of potential impacts on other earth resources.

The present study, whilst regional in nature, provides a pre-competitive geological framework for the assessment of blocks GCS09-1 and GCS09-2 and also forms the basis for the subsequent exploration and site characterisation evaluation phases.

1 Introduction

The Gippsland Basin, one of Australia's most prolific hydrocarbon producing basins, is located about 200 km east of Melbourne, Victoria, in south-eastern Australia. The basin has both onshore and offshore elements. Giant oil and gas fields are located in the offshore part of the basin. In the Latrobe Valley onshore, extensive deposits of brown coal are present and these are used to supply the majority of the State's electricity. This low-cost electricity has historically been a key component underpinning Victoria's manufacturing and industrial success. In addition, the potential exists to significantly expand the utilization of brown coal and to develop new value-added industries, such as coal-to-liquids.

Current annual carbon dioxide emissions from electricity generation in the Latrobe Valley comprise over 60 Mt, and it is likely that its use over the next 10 to 20 years will be contingent on reducing the coal industry's greenhouse footprint. Geological carbon storage (GCS) is a key enabling technology, which could allow for the ongoing use of Victoria's massive brown coal resources. Many of the oil fields within the basin are now near the end of their production lives and hence the opportunity exists to develop areas previously used for petroleum production for GCS. However, such a process would effectively turn the basin's pore space into a multiple use zone, at least in the short to medium term. Management of potential conflicts between incumbent and future hydrocarbon producers and explorers within the basin and the needs of CO₂ emitters, and the wider society, to reduce emissions to meet mandated targets, will provide significant challenges into the future.

Given the strategic nature of geological carbon storage for the long term use of coal in Victoria, a state government initiative, VicGCS, was funded for four years (from mid-2008) to investigate the geological carbon storage potential of the Gippsland Basin. The aims of the initiative are to better understand the issues associated with geological storage of CO₂: containment, injectivity-capacity and impacts on resources and the environment.

The purpose of this report is to provide precompetitive geoscientific information to support the Victoria's first GCS exploration tender in the onshore Gippsland Basin. Two exploration tender areas (GCS09-1 and GCS09-2) are available (Figure 2.1). The GCS09-1 exploration tender area is centered over the Latrobe Valley in central South Gippsland. The GCS09-2 (Figure 2.1) exploration tender area covers the onshore Lake Wellington, Seaspray and Alberton depressions and the area immediately to the west in the Gippsland Basin.

This report synthesises results from previous work and integrates new data to investigate the key issues associated with geological storage across the exploration tender areas. The storage potential of the permits is evaluated under three broad technical themes: containment (seal characteristics), injectivity-capacity (reservoir characteristics and distribution) and impacts (on discovered and undiscovered resources and the environment).

The westernmost permit, GCS09-1, is dominated by two storage plays, both of which occur within low-permeability sands in the Early Cretaceous Strzelecki Group. The primary focus of new work presented in this report has been on the easternmost permit, GCS09-2, within which four Latrobe Group (Late Cretaceous to early Tertiary) storage plays have been defined. These plays all involve a combination of Latrobe Group storage formations and the regional Lakes Entrance Formation top seal, plus or minus intraformational Latrobe Group seals; the exploration plays which have been successfully exploited in the search for hydrocarbons offshore. Within GCS09-2, potential storage sites occur at levels below the regional top seal, the Oligocene Lakes Entrance Formation. However, these carbon storage plays have as yet largely unproven top seal and fault seal integrity. Hence, a large part of this report is focused on delineating the characteristics of the ultimate source of containment, the regional top seal.

The geometry, capacity and mineralogy of the regional top seal in the onshore Gippsland Basin has been examined and integrated with seal failure data to provide an assessment of regional containment potential at this level. New Mercury Injection Capillary Pressure (MICP) and Automated Mineral Analysis (AMA) data sets have been incorporated with existing analyses and leakage and seepage data to produce a refined interpretation of CO₂ containment potential.

The reservoir characteristics of potential CO₂ storage plays in the Strzelecki and Latrobe groups across the onshore Gippsland Basin have been investigated via the analysis of new samples, and the collation of open-file porosity and permeability data. Current estimations of storage capacity are discussed, as are the potential impacts of CO₂ storage in the plays described.

To facilitate integration between the onshore GCS programs and with future studies offshore, data from within State waters adjacent permit GCS09-2 (three nautical mile limit) are also included in the scope of this study. The potential impacts of CO₂ injection into the six defined play types are also considered.

2 GCS Exploration Tender Areas

Invitation is sought for applications for Greenhouse Gas Sequestration Exploration Permits in Victoria. Two exploration tender areas (GCS09-1 and GCS09-2) are available (see Figure 2.1). Applications are due on the 5th March 2010.

The GCS09-1 exploration tender area, covering 2966 sq km, is centered over the Latrobe Valley in central South Gippsland. The GCS09-2 exploration tender area covers the onshore Lake Wellington, Seaspray and Alberton depressions and the area immediately to the west in the Gippsland Basin and is 5005 sq km in extent.

2.1 Data Availability

Well data such as well completion reports, wireline logs (in hardcopy) and open file reports are available for both petroleum wells and water bores across both exploration tender areas (see well and bore locations in Figure 2.1).

Seismic coverage varies across the two exploration tender areas (Figure 2.2). Seismic data are available in the form of field data, UKOOA data, SEG Y data and scanned images of hardcopy seismic sections. Details of the available seismic surveys are summarized in Appendix 1.

In the GCS09-1 exploration tender area, seismic coverage is sparse. The area is covered by surveys GKG05, GBA01A, GBA99A, GSG92A, GSG91A, GSR82A (just touching the block), and BMR1959. With the exception of surveys GSG92A and BMR1959, the remainder have processed data in digital format. Field data are available for all surveys with the exception of GSG92A and BMR1959. All surveys have navigation data.

In the GCS09-2 exploration tender area, there is fair seismic coverage, especially near the coastal belt. Approximately 35% of the lines comprise digital processed data. Approximately 50% of the surveys are 1970 and pre-1970 vintage; the remainder is post 1970. All surveys have navigation data. Field data are available for all surveys with the exception of surveys GA64, GWS60A, GB81A and GSG92A. Surveys GWS65A, GWS65B, GWS61A, GAW62A are comprised of analogue field data only.

2.2 Previous and Current Work

Work commenced on the CO₂ storage potential of the Gippsland Basin during the GEODISC program (Bradshaw & Rigg, 2001; Rigg *et al.*, 2001, Bradshaw *et al.*, 2002). More detailed investigations were carried out by the CO2CRC (Hooper *et al.*, 2005) as part of their Latrobe Valley CO₂ storage assessment utilising the GEODISC ESCCI

methodology. The overwhelming majority of the identified geological storage potential was in the offshore Gippsland Basin, although two plays were considered in the onshore basin: one intraformational Golden Beach Subgroup and another intraformational Strzelecki Group. An upper Latrobe Group play was not presented as it was considered to be inadequately sealed by the Lakes Entrance Formation across the onshore (Hooper *et al.*, 2005).

Gibson-Poole *et al.* (2006) reviewed CO₂ geological storage opportunities as part of a state-wide assessment and Bunch *et al.* (2009) has conducted a site-screening study of the onshore Gippsland Basin. Three siliciclastic reservoir-seal pairs were identified with potential for storage:

- Tyers River Subgroup reservoir – intraformational Strzelecki Group seal,
- Golden Beach Subgroup reservoir– intraformational Golden Beach/basal Halibut Subgroup seal, and
- Intraformational-Latrobe Group (Late Cretaceous to Eocene) reservoir and seal.

Again, top Latrobe Group plays were discounted due to an interpreted lack of suitable seal in the overlying Seaspray Group.

Deep, un-mineable coal seams have been recognised elsewhere as potential storage locations for CO₂ (e.g. Kaldi & Gibson-Poole, 2008). However, while there are Cretaceous and Cenozoic coal seams present in the onshore Gippsland Basin, current information indicates that there is limited capacity for storage of significant volumes of CO₂ (Bunch *et al.*, 2009) and both injectivity characteristics and containment potential are uncertain. Further information on CO₂ storage potential in Gippsland Basin coal can be found in Gibson-Poole *et al.* (2006).

Under the VicGCS initiative, work to date has focussed on increasing understanding of the Gippsland Basin at a regional scale (O'Brien *et al.*, 2008), and mapping top seal potential within the basin (Goldie Divko *et al.*, 2009); given the concerns regarding top seal quality, especially within the onshore portion of the basin (Hooper *et al.*, 2005). VicGCS has also presented information on fluid migration within the basin utilising information from petroleum systems data (O'Brien *et al.*, 2008).



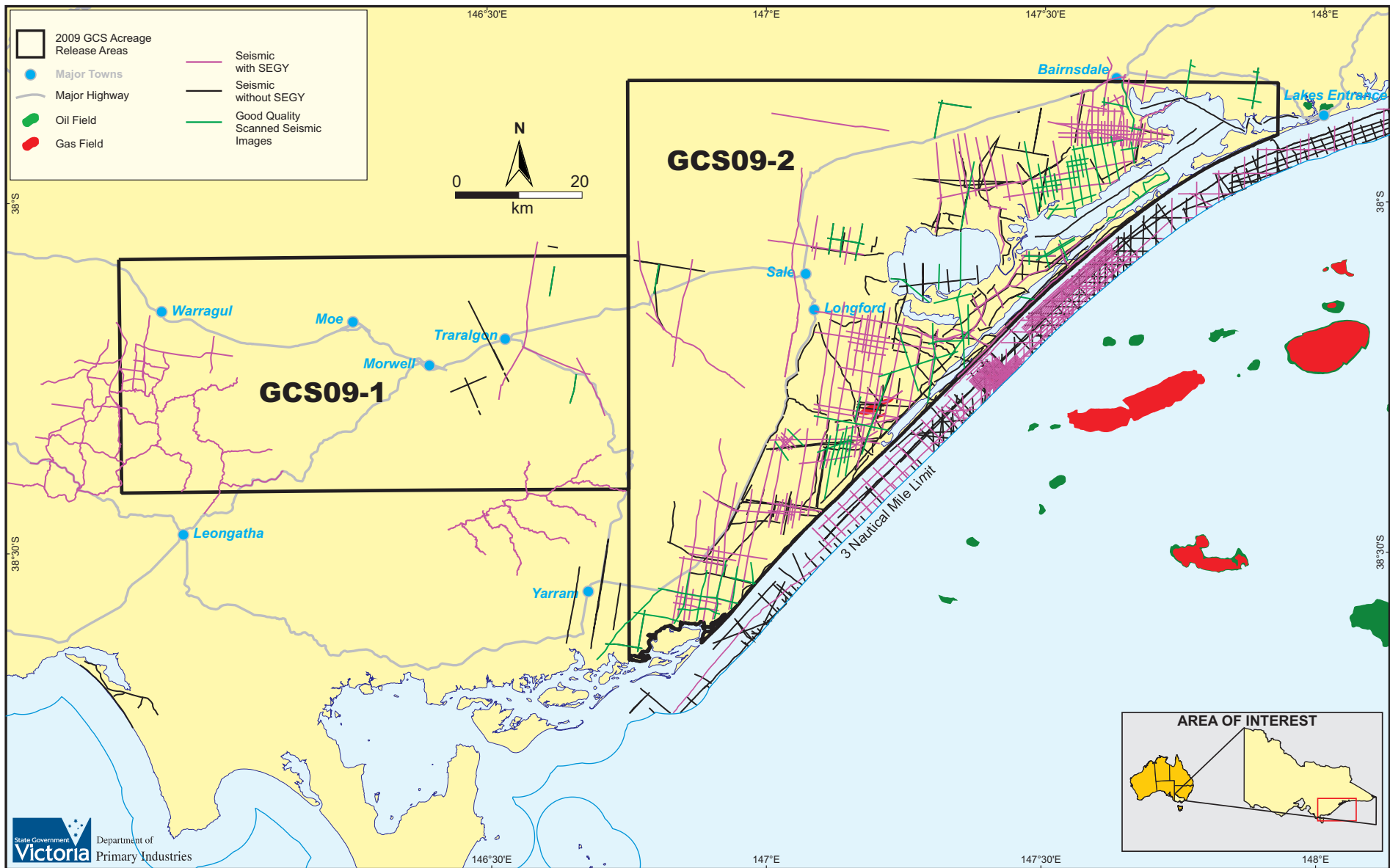


Figure 2.2 Open file seismic coverage over GCS exploration tender areas

3 Regional Geology

The Gippsland Basin, one of Australia's most prolific hydrocarbon provinces, is situated in south-eastern Australia and is located about 200 km east of the city of Melbourne, Victoria.

The basin, which has both onshore and offshore elements, is a world-class hydrocarbon province and contains several giant oil and gas fields. The vast majority of the discoveries are reservoired within the siliciclastics of the Late Cretaceous to Paleogene Latrobe Group and almost all of the currently producing fields are located offshore in shallow water (at depths of less than approximately 100 m). Onshore, the undeveloped Wombat, North Seaspray and Gangell gas fields are reservoired in the older Strzelecki Group within the Seaspray Depression.

The details of the basin's tectonic architecture and its stratigraphy are provided in the following sections.

3.1 Tectonic Architecture

The Gippsland Basin is an east-west trending feature that formed as a consequence of the break-up of Gondwana (Rahmanian *et al.* 1990, Willcox *et al.*, 1992; Willcox *et al.*, 2001; Norvick & Smith, 2001; Norvick *et al.*, 2001) in the Mesozoic. The basin's evolution is recorded by three major depositional sequences ranging from Early Cretaceous to Recent in age and the overall tectonic control on the sedimentary systems of the basin is imprinted by a series of basin-wide angular unconformities.

As part of the Early Cretaceous rift system that developed during the initial separation of Australia and Antarctica, the early architecture of the Gippsland Basin featured a rift valley complex composed of multiple north east – south west trending half-grabens into which the Strzelecki Group was deposited. A period of regional uplift occurred around 95Ma, which resulted in the development of the Otway

Unconformity. A second phase of rifting occurred from the Late Cretaceous to Eocene, associated principally with Tasman Sea spreading, and this produced a classic extensional basin geometry comprising a depocentre (the Central Deep) flanked by platforms and terraces to the north and south. The Darriman and Foster fault systems on the southern basin margin, and the Rosedale and Lake Wellington fault systems on the northern margin define these areas (Figure 3.1). The onshore basin architecture is comprised of the Alberton, Seaspray and Lake Wellington (including the Latrobe Valley) depressions, which are the onshore extensions of the Central Deep, Northern Terrace and Southern Terrace respectively, and the Lakes Entrance Platform to the north of the Lake Wellington Fault System. In the west of the basin, a compressional event uplifted the Strzelecki Group to form the Narracan and Balook blocks, which now form the Strzelecki Ranges.

The second phase of rifting provided the accommodation space within which the Latrobe Group was deposited. This rifting phase was punctuated by a series of minor uplift events that lead to the development of unconformities - those recognised between the four subgroups of the Latrobe Group - the Emperor, Golden Beach, Halibut and Cobia subgroups - followed by a period of drift. The Baragwanath Anticline and related structural fabric of the prominent NE to ENE-trending anticlines (Smith, 1988), which form the main hydrocarbon traps offshore, developed as a result of Late Eocene uplift and compression. The regional sealing facies of the Oligocene Seaspray Group was deposited during the post-rift sag phase following the conclusion of Tasman Sea rifting in the Eocene and the onset of fast spreading between Australia and Antarctica.

Tectonism has continued to overprint the basin as documented by localised uplift during the late Pliocene to Pleistocene. This is also reflected in the uplift of Pliocene sediments on the Barracouta, Snapper and Marlin anticlines as well as around Lakes Entrance.

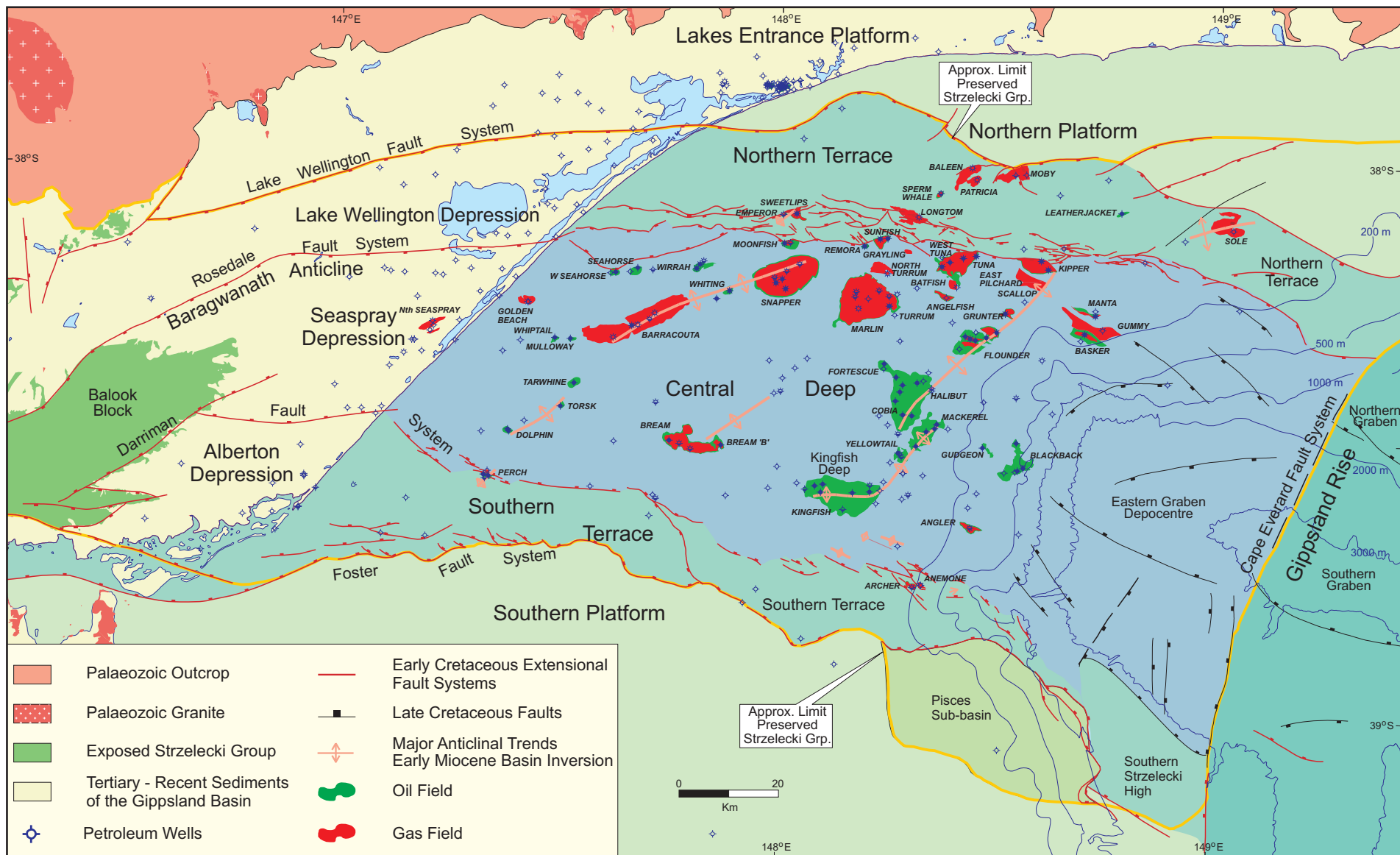


Figure 3.1 Structural elements map of the Gippsland Basin.

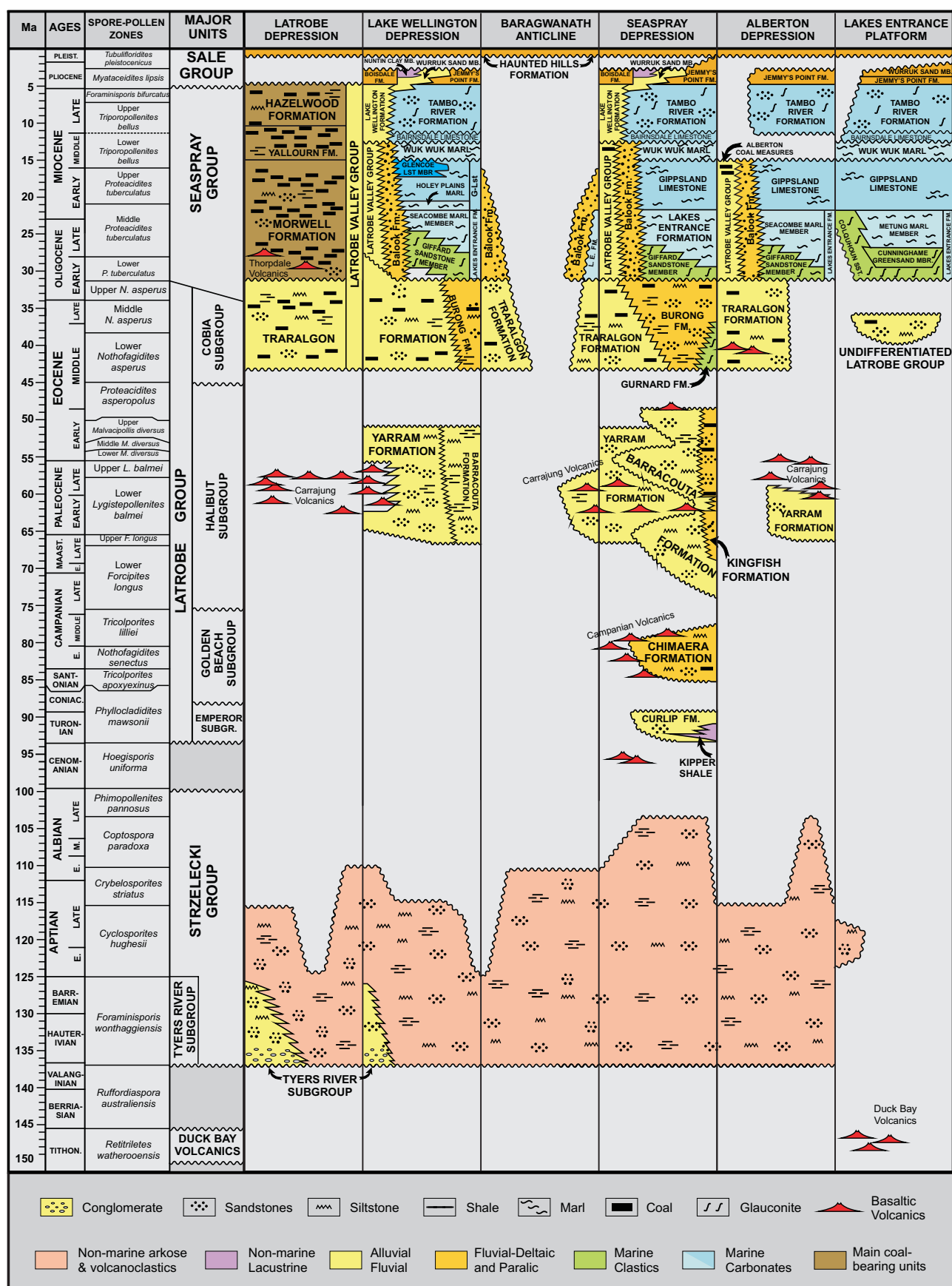


Figure 3.2 Gippsland Basin Onshore Stratigraphy (compiled from Bernecker & Partridge, 2001; Chiupka, 1996; Gallagher & Holdgate, 1996; Holdgate & Gallagher, 2003; Partridge, 2006a; Partridge, 2006b & Tosolini et al., 1999). Left to right in each column = west to east.

3.2 Stratigraphy

Based on lithological variations, three broad stratigraphic successions are recognised in the Gippsland Basin (Figure 3.2). These stratigraphic groups comprise a) the Strzelecki Group, a thick sequence of non-marine, volcanoclastic-rich sediments; b) the Latrobe Group, a sequence of marine and non-marine siliciclastics that host all the known hydrocarbon occurrences in the offshore; and c) the Seaspray Group, a carbonate-dominated succession that is the regional seal to the top Latrobe Group oil and gas accumulations.

Strzelecki Group

The Strzelecki Group represents non-marine syn-rift sedimentation and unconformably overlies Palaeozoic igneous and folded sedimentary rocks. The Strzelecki Group has strong affinities with the Otway Group in the Otway Basin (Duddy & Green, 1992), and includes a basal unit of alluvial fan conglomerates and fluvial coarse quartzose sandstones of Neocomian age (the Tyers River Subgroup). The remainder of the Strzelecki Group is an undifferentiated sequence of interbedded lithic, volcanoclastic sandstones and mudstones, including several coal-rich horizons, all of which accumulated under a fluvial depositional regime (Holdgate & McNicol, 1992; Tosolini *et al.*, 1999). The total thickness of the Strzelecki Group is ill-defined, but is likely to exceed 1500 m (Gilbert & Hill, 1994); it may be up to 3000 m in places (Duddy, 2003). Offshore, the group is regarded by the industry as 'economic basement', although considered to have potential for hydrocarbon generation and accumulation, in particular in the onshore part of the basin (Mehin & Bock, 1998), where the tight gas accumulations of the North Seaspray and Gangell fields are reservoirised in the Strzelecki Group. The burial history and diagenetic alteration of the volcanoclastic detritus that comprises the majority of the Strzelecki Group sediments has resulted in generally low permeability characteristics, which may exclude this group as a potential CO₂ storage formation.

Tyers River Subgroup

The Tyers River Subgroup has previously been identified as a potential hydrocarbon and CO₂ reservoir, sealed by the overlying tight Strzelecki volcanoclastic sequence (Chiupka, 1996). This is the basal unit of the Strzelecki Group, and comprises the Tyers Conglomerate, a quartz-rich fluvial conglomerate derived from the Palaeozoic basement present around the northern margin of the Gippsland Basin (Tosolini *et al.*, 1999), overlain by the quartzose Rintoul's Creek Sandstone. These were deposited around the basin margins and against the footwalls of the half grabens that developed during the initial rifting phase and they thin out towards the basin centre. The Rintoul's Creek Sandstone has been suggested as a potential target for GCS, as it is the lateral equivalent of the Pretty Hill Group in the Otway Basin, which has been identified as a potentially good geological storage reservoir. However, more recent analysis of Rintoul's Creek

Sandstone suggests that it has limited lateral distribution, and thins rapidly towards the basin centre (Tosolini *et al.*, 1999).

Latrobe Group

The Latrobe Group hosts all currently known hydrocarbons in the offshore part of the basin. Four subgroups are discriminated, each of which is bound by basin-wide unconformities and each consists of formations that are distinguished according to their main depositional facies assemblages (Figure 3.2).

Emperor Subgroup

The Emperor Subgroup is the oldest depositional unit of the Latrobe Group and is separated from the underlying Strzelecki Group by the 97-91 Ma Otway Unconformity. Large amounts of erosional material were delivered to the evolving rift-valley in which one or several deep lakes emerged as the depocentre. The Emperor Subgroup (Bernecker & Partridge, 2001) has only been intersected around the basin margins in the vicinity of the bounding faults of the Northern and Southern terraces. Onshore, this subgroup is intersected in several wells close to the coast in the Seaspray Depression only.

The Emperor Subgroup comprises coarse-grained alluvial fan/plain as well as lacustrine facies associations, and comprises four formations, of which only the lacustrine Kipper Shale (Lowry & Longley, 1991) and the fluvial-deltaic Curlip Formation (Bernecker & Partridge, 2001) have been intersected in the onshore Gippsland Basin. The Kipper Shale is dominated by mudstones with intercalated fine- to medium-grained sandstones (Marshall & Partridge, 1986; Marshall, 1989; Lowry & Longley, 1991) and is a potential sealing facies. The Curlip Formation (Bernecker & Partridge, 2001) consists of sandstones and conglomerates that are interbedded with thin shales and minor coals. The formation overlies and interfingers with the Kipper Shale; the top marked by the basin-wide Longtom Unconformity that terminates Emperor Subgroup deposition.

Golden Beach Subgroup

The Golden Beach Subgroup has been recognised by Chiupka (1996) as a potential hydrocarbon reservoir, and is considered here as a potential target for GCS. It is essentially confined to the Central Deep, including the onshore Seaspray Depression, where it is represented by the fluvial-deltaic Chimaera Formation (Bernecker & Partridge, 2001). The Chimaera Formation is a non-marine succession that comprises coarse-grained alluvial/fluvial sediments as well as fine-grained floodplain deposits including some coals (Bernecker & Partridge, 2001), and can exceed 300 m in thickness. The Chimaera Formation has been intersected in wells close to the coast and near the Rosedale Fault System in the Seaspray Depression, but is absent from the Lake Wellington Depression. The Golden Beach Subgroup also contains several volcanic horizons that have been identified as Campanian, which are possibly intersected in the

Darriman-1 well in the Seaspray Depression. These volcanics terminate the Golden Beach Subgroup and signal another depositional hiatus represented by the Seahorse Unconformity (Bernecker & Partridge, 2001).

Halibut Subgroup

The Halibut Subgroup hosts the bulk of the hydrocarbons in the Gippsland Basin and comprises five formations that are distinguished according to their dominant depositional facies regimes. These formations document the changes from non-marine to marine environments in a west-east or onshore-offshore direction, and are outlined by Goldie Divko *et al.* (2009). Two of these formations are intersected in the onshore basin, the Barracouta Formation (revised and formalised by Hocking, 1976) which is characterised by fluvial siltstones, sandstones and minor coals and was deposited on an upper coastal plain. The Kingfish Formation is only intersected in Golden Beach West-1, and Golden Beach-1A in the 3 nautical mile zone immediately offshore, and is a typical lower coastal plain, coal-rich facies.

Cobia Subgroup

The middle Eocene to early Oligocene Cobia Subgroup (formerly the Cobia Group of Thompson, 1986) comprises the coal-bearing, lower coastal plain facies of the Burong Formation (Partridge, 1999), which is reasonably well-developed across the eastern part of the onshore Gippsland Basin and the shallow to open marine Gurnard Formation (James & Evans, 1971). The Gurnard Formation is a condensed section composed of fine- to medium-grained glauconitic siliciclastics and acts as a top seal for some of the giant hydrocarbon fields offshore (as shown by Daniel, 2005), so is considered to be a potential sealing facies for GCS, at least in some areas. Deposition of the Cobia Subgroup ceased during the early Oligocene, as a consequence of a marked decline in sediment supply. Large areas of the central basin were left with starved or condensed sections, which led to the development of what is traditionally known as the 'Latrobe Unconformity' (Partridge, 1999). On seismic sections, this surface is expressed by a prominent reflector marking the boundary between siliciclastic and calcareous rocks, which should be considered a composite of several, separate erosional events based on biostratigraphic data (Partridge, 1999).

Seaspray Group

The Seaspray Group consists of calcareous sediments that unconformably overlie the siliciclastics of the Latrobe Group and includes the basal Lakes Entrance Formation and overlying Gippsland Limestone. Onshore, the Cunningham Greenstone Member, Giffard Sandstone Member, Colquhoun Sandstone Member, Seacombe Marl and the Metung Marl are identified as constituent units of the Lakes Entrance Formation (Hocking, 1976). The shift from siliciclastic to cool-water carbonate deposition in the Gippsland Basin occurred in the early Oligocene, as a

consequence of a change in ocean circulation along the southern Australian margin (Holdgate & Gallagher, 1997). Since then, cool-water carbonate production resulted in progradation of the shelf edge. Onshore, in the Lake Wellington and Seaspray Depressions, a marine sequence of middle Miocene to Pliocene aged sediments rests unconformably on the Gippsland Limestone. This sequence is comprised of the Wuk Wuk Marl, Bairnsdale Limestone, Tambo River Formation and Jemmys Point Formation.

The Seaspray Group, in particular the Lakes Entrance Formation, is considered a basin-wide, high quality regional top seal to the oil and gas accumulations at the top Latrobe Group reservoirs, and it is this sequence that will provide the regional top seal for geological carbon storage. The Lakes Entrance Formation is the lowermost unit of the Seaspray Group and is composed predominantly of smectite-rich calcareous mudstones and claystones (see section 4.3), with some variation in composition across the basin (Bernecker *et al.*, 1997, Hocking, 1976, Holdgate & Gallagher, 1997). The Lakes Entrance Formation is considered to provide excellent top seal containment offshore and in parts of the onshore Gippsland Basin (O'Brien *et al.*, 2008; Goldie Divko *et al.*, 2009). Onshore, to the west of the current coastline, the Lakes Entrance Formation interfingers with the Balook Formation, a barrier sand system that laterally separates the marine Seaspray Group carbonates from the back-barrier swamp and coastal plain Latrobe Valley Coal Measures. The Balook Formation is generally limited in lateral extent but contains tongues that extend up to 30 km into the coal measures (Holdgate & Gallagher, 2003). It is significant as it marks the edge of the sealing facies of the marine Lakes Entrance Formation.

Latrobe Valley Group

The Latrobe Valley Group (as distinct from the Latrobe Group) is the term now accepted for the coal-bearing sediments and volcanics in the onshore Gippsland Basin (Holdgate & Gallagher, 2003). The main coal-bearing formations are the Yallourn, Morwell and Traralgon formations and are summarised by Holdgate & Gallagher (1997) and Holdgate & Clarke (2000). In the Lake Wellington, Seaspray and Alberton Depressions, and around the margins of the Baragwanath Anticline, the Traralgon Formation overlies tuffs and basalts of the Carrajung Volcanics. Underlying the volcanics, there is a sequence of fluvial/alluvial conglomerates, sandstones, thin coals and shales of the Yarram Formation, which is equivalent in age to the Halibut Subgroup offshore.

3.3 Burial and Uplift History

The onshore Gippsland Basin experienced significant erosion after the deposition of the Strzelecki Group, with the uplift associated with Mid-Cretaceous tectonism at approximately 95 Ma (Duddy, 2003). Further Cenozoic erosion has been inferred immediately to the north of the Gippsland Basin (Duddy, 2009) but is not considered in detail here. It is important to understand the burial and uplift history, as it can have a critical effect on preservation of porosity and permeability within potential GCS storage formations (both via elevated temperatures and compactional effects). Consequently, a brief assessment of the regional burial-uplift histories have been made in the current study.

Figure 3.3 shows measured vitrinite reflectance values at a depth of 1000 m across the onshore Gippsland Basin. Evidence for deeper burial, uplift and erosion, probably prior to the deposition of the Latrobe Group, is provided by anomalously high vitrinite reflectance values, coloured

orange and red. The western onshore data comes from the Strzelecki Group and indicates that the samples have experienced significantly higher temperatures than present and has been subjected to significant compaction and diagenesis.

Kilometre-scale erosion is indicated at the top of the Strzelecki Group, which is supported by the generally older stratigraphic age of the top Strzelecki surface for these wells (Figure 3.4). The Megascolides-2 well has elevated vitrinite levels (Figure 3.5) and an indicative burial history is shown and is broadly consistent with a model of Megascolides-1 by Duddy (2005). In contrast, within the Seaspray Depression the vitrinite reflectance data in the Strzelecki Group (North Seaspray-1) is consistent with burial at maximum temperatures now. Figure 3.6 shows the burial history and maturity profile of the North Seaspray-1 well. Vitrinite reflectance data from Wellington Park-1 is consistent with being at maximum temperatures now [note Duddy & Green (1992) refer to a different set of VR data to the DPI dataset] – further work is required to reconcile the data.

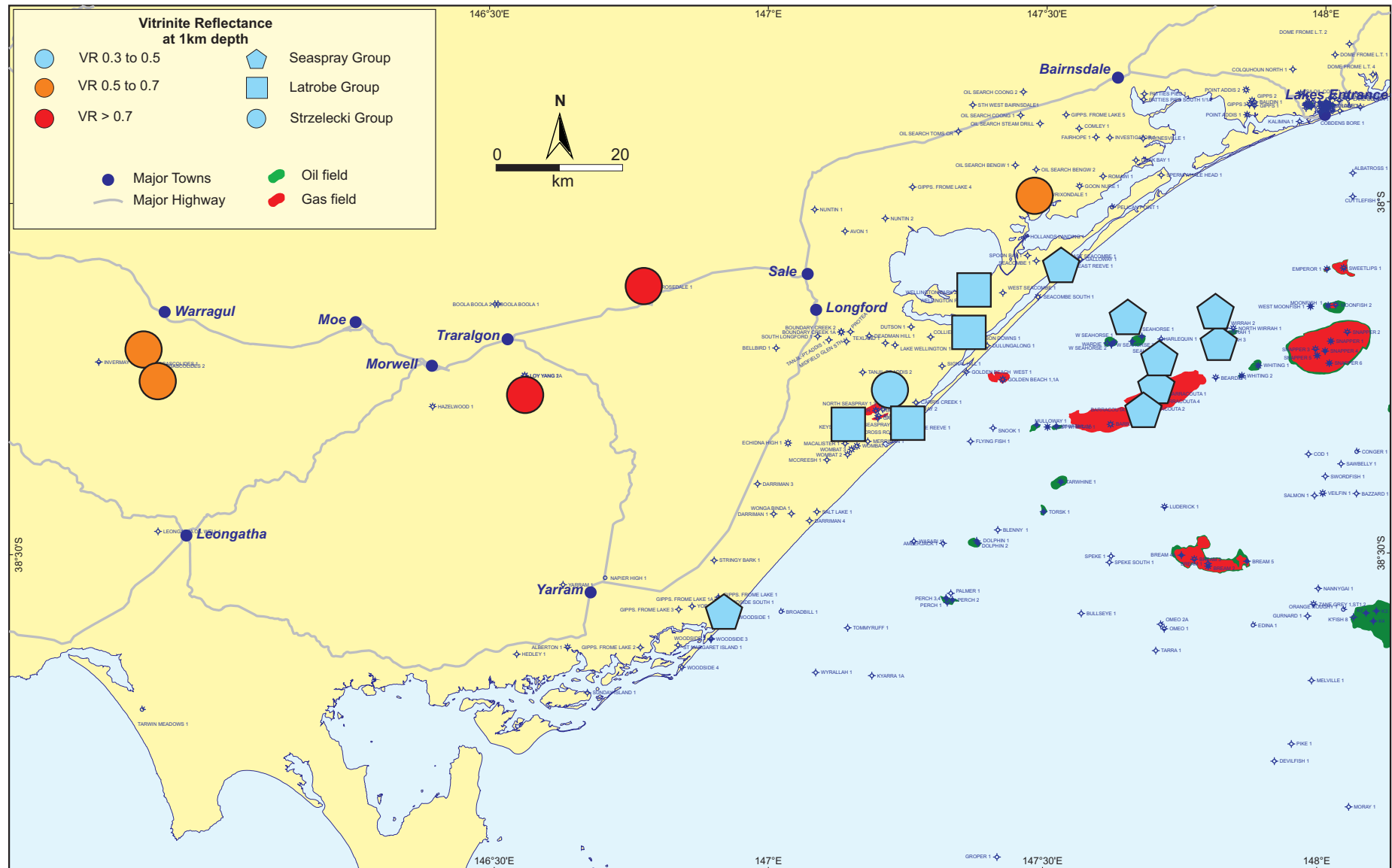


Figure 3.3 Vitrinite reflectance values at 1000 metres depth across the onshore Gippsland Basin.

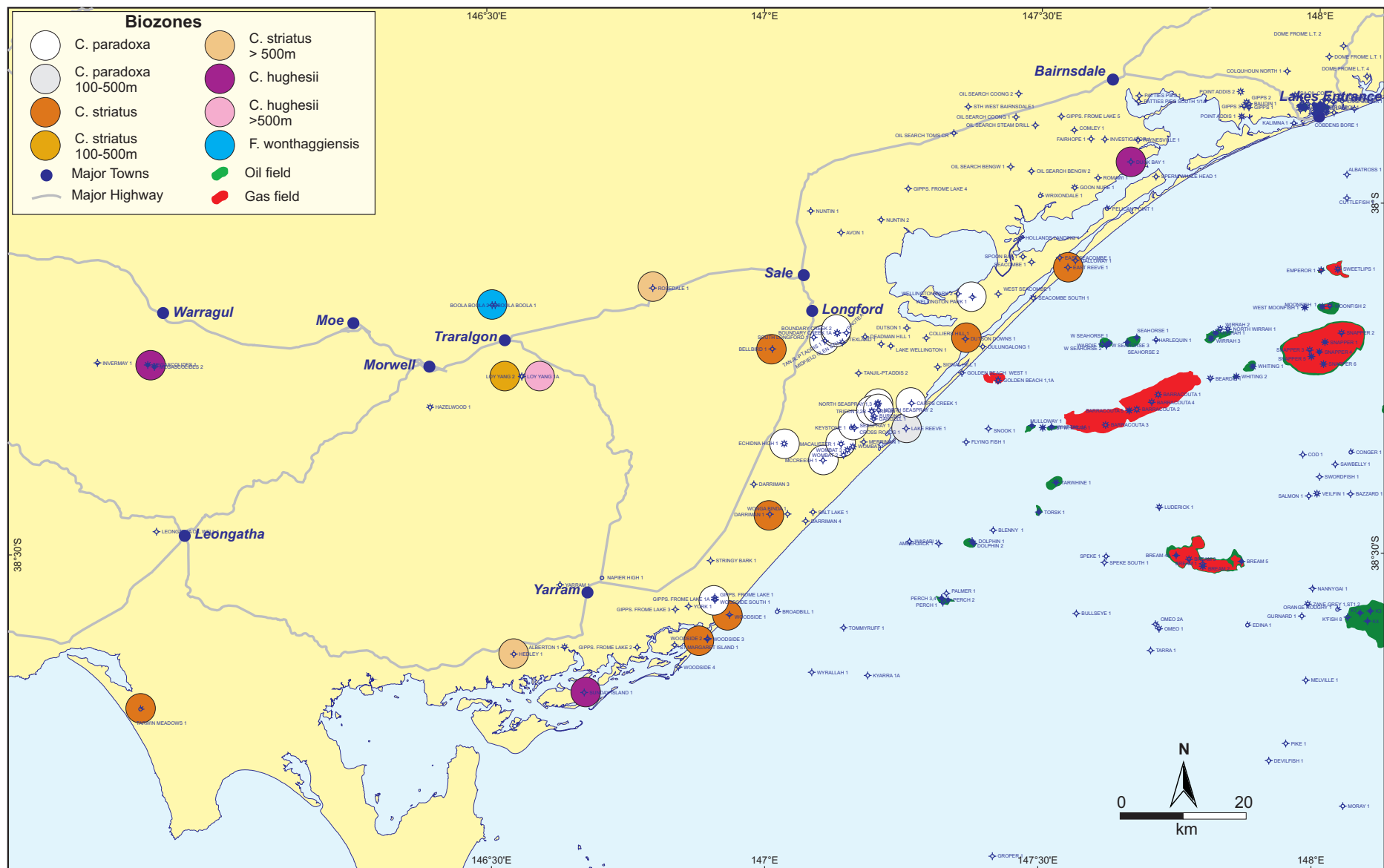


Figure 3.4 Age of top Strzelecki surface as indicated by palynological biozones.

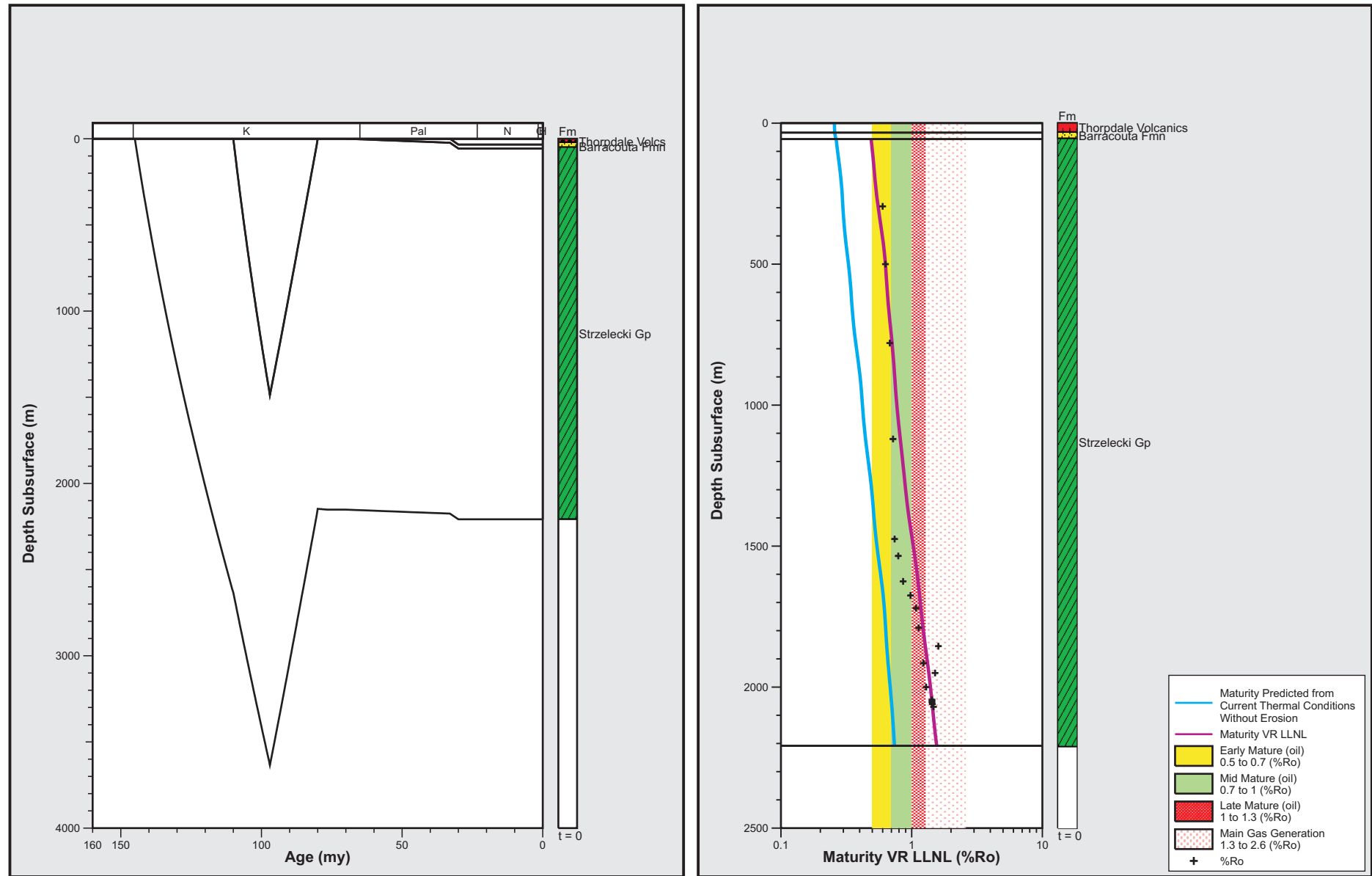


Figure 3.5 Burial history and maturity profile for Megascoolides-2.

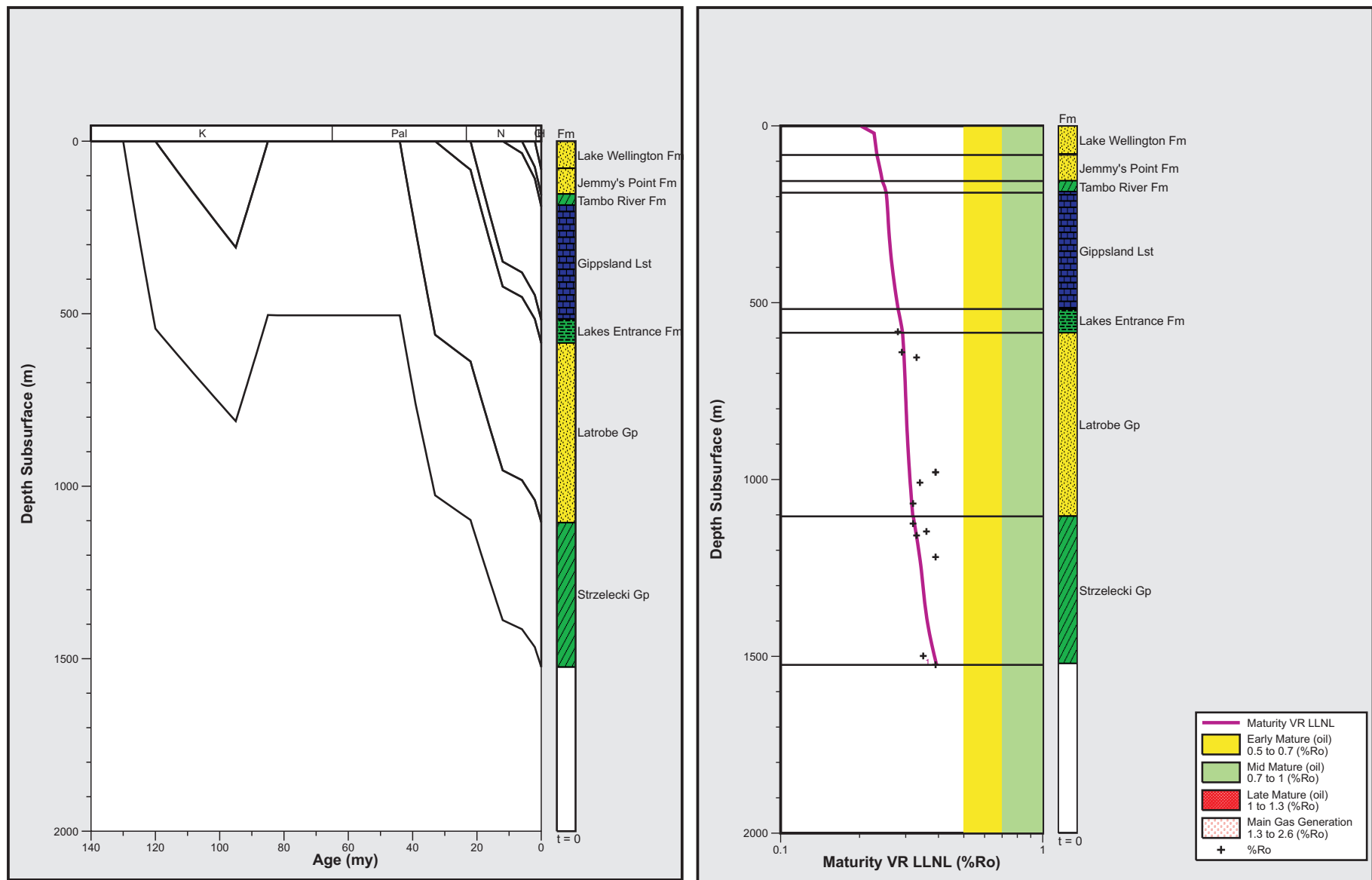


Figure 3.6 Burial history and maturity profile for North Seaspray-1.

4 Top Seal Containment

The assessment of containment is a vital component in the process of evaluating a sedimentary basin for the purpose of Geological Carbon Storage. In the Gippsland Basin, regional containment is provided by the regional top seal, the Lakes Entrance Formation. In this section, top seal potential - the ability for a top seal to contain fluids and prevent fluid migration into overlying rock units or to the surface - is derived from an understanding of seal characteristics (geometry, capacity, and mineralogy). In addition, evidence for seal failure (the presence of hydrocarbons as detected in soil gas anomalies, lake-bottom sediments, gas chimneys, radiometrics surveys and hydrocarbon shows) is integrated with seal characteristics to construct a qualitative interpretation of CO₂ sealing potential.

4.1 Seal Geometry

The Lakes Entrance Formation provides the primary regional top seal for the majority of the hydrocarbon resources at the top of the Latrobe Group in the offshore Gippsland Basin. In previous Gippsland Basin containment studies (e.g. Daniel, 2005; O'Brien *et al.*, 2008; Goldie Divko *et al.*, 2009), the characterisation of the Lakes Entrance Formation has provided the basis for the evaluation of top seal containment.

A regional seal study of the onshore Gippsland Basin, however, requires a different approach, as porous and permeable glauconitic and pyritic sandstones are found at the base of the Lakes Entrance Formation across most of the onshore portion of the basin. The Cunninghame Greensand or Colquhoun Sandstone members are present at the base of the Lakes Entrance Formation in most wells on the Lakes Entrance Platform (see Figures 3.1 & 3.2), and are in fact the reservoir for all oil discoveries in this area (e.g. the Lakes Entrance oil field). The Giffard Sandstone Member is found in the same stratigraphic position in the Lake Wellington, Seaspray and Alberton depressions and is differentiated from the Cunninghame Greensand Member on the basis of lithology (Hocking, 1976). The inclusion of these sandstone members in the determination of seal thicknesses and a base of seal structural contour map onshore would lead to an erroneously thicker seal and deeper structural contours. Where identified, the Cunninghame Greensand, Colquhoun Sandstone and Giffard Sandstone members have been excluded from the data set, therefore leaving the Seacombe Marl (Lake Wellington, Seaspray and Alberton depressions, and the Baragwanath Anticline) and the Metung Marl (Lakes Entrance Platform).

Lakes Entrance Formation thicknesses, bases and tops were previously determined for a basin-wide GCS assessment of containment potential in the Gippsland Basin (Goldie Divko *et al.*, 2009). The onshore wells and water bores used in the

previous study were incorporated into the data for this report (Appendix 2). In total, data from 125 petroleum wells and water bores from the onshore area were combined with offshore well data and used to generate a base of seal grid and thickness point data in Petrosys mapping software.

The limit or margin of the regional top seal onshore is delineated in Figure 4.1. In general, the thickness of the regional top seal increases everywhere onshore from the limit of the top seal towards the near and offshore portions of the basin (Figure 4.1). The thickness of the regional seal ranges from 15 to 247 m, with this maximum reached in Bengworden South-6 in the Lake Wellington Depression. The seal attains its minimum recorded thickness in the Alberton Depression in Gippsland Frome Lakes-2 and thicknesses of less than 50 m are commonly recorded across the onshore Gippsland Basin near the seal margin. On average, seal thicknesses between 100 and 200 m are common in the Lake Wellington and Seaspray depressions but the seal thins on the Lakes Entrance Platform, in the Alberton Depression and across the Baragwanath Anticline.

The depth to the base of the regional top seal onshore increases from the limit or margin of the formation towards the nearshore/offshore portions of the basin (see Figure 4.1 for base of top seal colour-fill grid). In the central eastern Lake Wellington Depression, the base of the seal occurs at around 1000 m sub-sea, with the deepest intersection of seal base recorded in East Reeve-1 (1154 m) on the present day coast. Also near the coast in the Seaspray and Alberton depressions, the deepest points are located in Lake Reeve-1 (903 m) and Woodside-12 (864 m) respectively. Towards the margin of the onshore Gippsland Basin, subsurface depths between 100 and 200 m are typical of the Lakes Entrance Platform and across the Baragwanath Anticline. The depth to the base of the regional top seal is considered significant as it is regarded that for CO₂ to remain in supercritical phase, it is necessary to inject at depths of greater than 800 m (e.g. van der Meer, 1992; Holloway & Savage, 1993). However, Bachu (2003), for example, notes that the depth at which supercritical conditions are met may vary significantly depending on surface temperature and geothermal gradients. Bunch *et al.* (2009) investigated the depth of the CO₂ critical surface in the onshore Gippsland Basin using calculated mean surface temperature and modified geothermal gradient data. This analysis suggests that the depth to the critical surface rises to approximately 750 m over most of the onshore, with the exception of areas to the far west of the Seaspray Depression and a small area located on the current day central coast of the Alberton Depression, where the depth to the critical surface increases to over 1000 m.

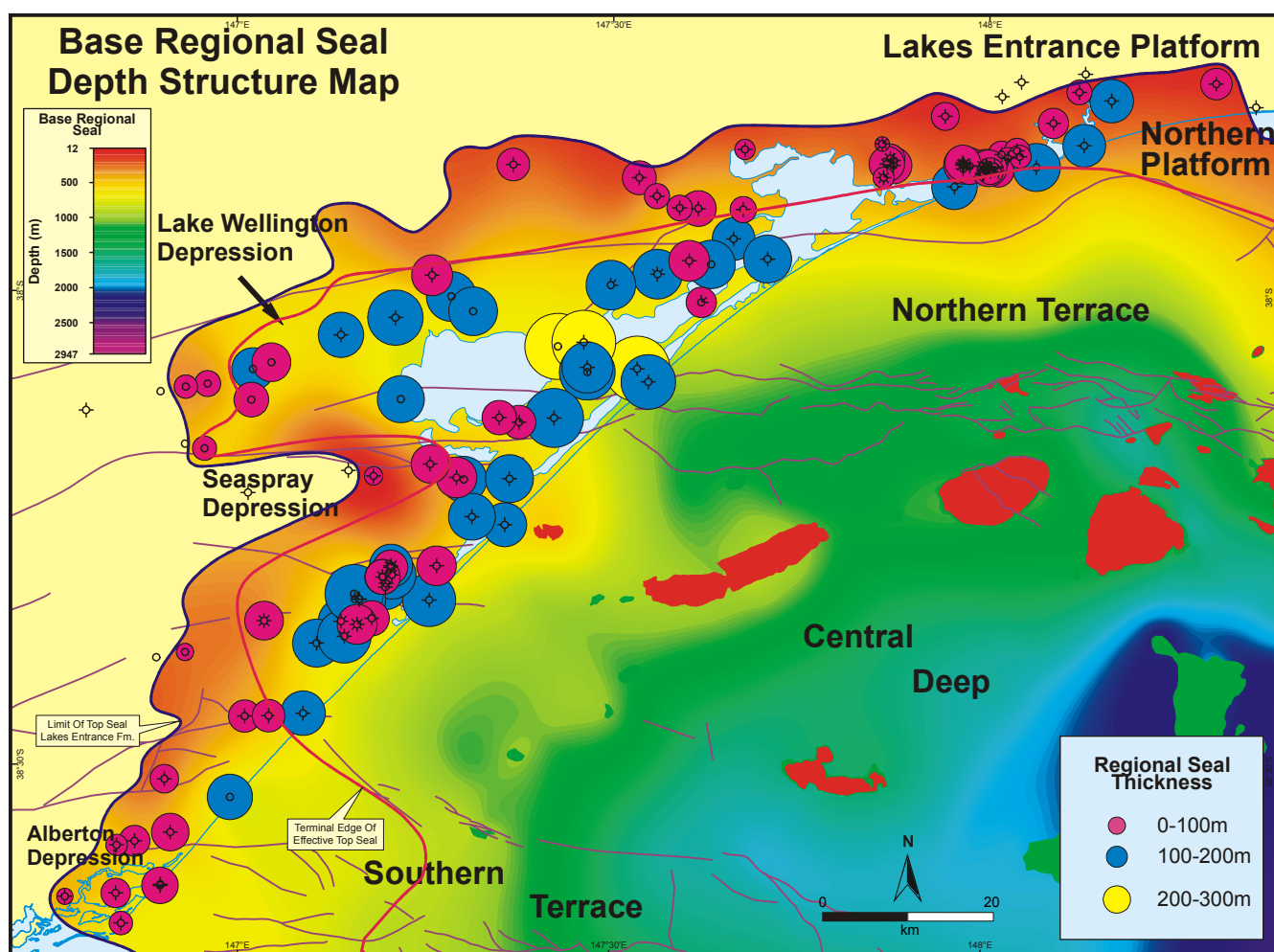


Figure 4.1 Regional seal thickness and base of regional seal depth grid.

4.2 Seal Capacity

Maximum column retention capacities for oil, gas and CO₂ are routinely derived from Mercury Injection Capillary Pressure (MICP) analysis of sealing lithologies. The maximum column height that can be contained by a seal is known as seal capacity and is an important factor in the evaluation of seal potential for the geosequestration of carbon dioxide (Kaldi & Atkinson, 1997). Twenty-four new samples were submitted to Weatherford Laboratories in Perth for MICP analysis. Previous MICP data from O'Brien *et al.* (2008) and Goldie Divko *et al.* (2009), processed through ACS Laboratories in Perth, have been combined with these new data. A total of 47 MICP data sets (Table 4.1) covering the onshore Gippsland Basin, were therefore available for analysis for the present study.

Maximum column retention capacities for oil and gas were determined using standard ACS/Weatherford Laboratories methodologies. CO₂ retention capacities were determined after the method outlined in Daniel (2005). A table of values used for CO₂ column height calculation is provided in Appendix 3. The number of suitable core samples available for study was limited, as exploration companies do not routinely acquire conventional cores within sealing lithologies. However, due to the availability of cores from water bores, in addition to those from petroleum wells, there are more samples for analysis from the onshore area. Samples were chosen close to the base of the formation; otherwise, samples were selected as near as possible to the base of the available cored interval. Where suitable lithologies within the Lakes Entrance Formation (Seacombe Marl or Metung Marl) were not available, samples from the Gippsland Limestone were chosen; these are indicated in Table 4.1.

Table 4.1 Supportable MICP column heights (m) for onshore Gippsland Basin seal samples. ** denotes Gippsland Limestone.

Well	Sample Depth (m)	LEF Thickness (m)	Location	Lithology	Column height (m)		
					Gas	Oil	CO ₂
Bairnsdale-15005	479.29	-	Lake Wellington Depression	Smectite-rich claystone with silt sized quartz, intergranular porosity	13	20	21
Bengworden South-1	947.92	-	Lake Wellington Depression	Smectite-rich claystone with minor silt sized quartz	481	773	411
Bengworden South-6	819	247	Lake Wellington Depression	-	999	1607	957
Bengworden South-6	882.35	247	Lake Wellington Depression	Smectite-rich claystone	481	773	384
Bengworden South-6	914.9	247	Lake Wellington Depression	Fossiliferous smectite-rich claystone, mouldic porosity with calcite cemented and uncemented intergranular porosity	302	486	282
Bengworden South-6	943.1	247	Lake Wellington Depression	Smectite-rich silty claystone with intergranular porosity	481	773	381
Bundalaguah-10**	599.8	-	Lake Wellington Depression	Smectite-rich claystone with intergranular porosity	10	16	41
Colquhoun East-6	180.7	35	Lakes Entrance Platform	Indurated fossiliferous limestone	123	198	164
Coolungoolun-101**	449.15	-	Lake Wellington Depression	Silty claystone with pyritised fossils and intergranular porosity	7	12	14
Dulungalong-2	478.1	120	Seaspray Depression	Smectite-rich claystone, fossiliferous	69	110	78
Dutson Downs-1**	551.68	-	Seaspray Depression	Fossiliferous smectite-rich calcareous claystone	110	171	90
Gippsland Frome Lakes-4	503.5	95	Lake Wellington Depression	Smectite-rich claystone with silt sized quartz and alkali feldspar, vuggy porosity	17	28	18
Gippsland Frome Lakes-4	506.6	95	Lake Wellington Depression	Smectite-rich claystone with minor silt sized quartz	93	150	120
Glencoe South-4	418.8	43	Seaspray Depression	Fossiliferous smectite-rich claystone with glauconite	200	322	187
Glencoe South-4	425.05	43	Seaspray Depression	Fossiliferous smectite-rich claystone with minor silt and intergranular porosity	59	94	84
Golden Beach West-1	667.68	109	Seaspray Depression	Fossiliferous smectite-rich claystone with minor mouldic porosity	22	35	87
Goon Nure-1	769.31	139	Lake Wellington Depression	Fossiliferous smectite-rich claystone	246	393	231
Goon Nure-2	731.21	94	Lake Wellington Depression	Fossiliferous smectite-rich claystone	255	410	232
Goon Nure-2	785.77	94	Lake Wellington Depression	Fossiliferous smectite-rich claystone	277	443	254
Goon Nure-9	726.3	132	Lake Wellington Depression	Fossiliferous smectite-rich claystone	251	404	213
Holey Plains-185**	538.2	-	Lake Wellington Depression	Dolomitised fossiliferous silty smectite-rich claystone	56	90	52
Hunters Lane-1	377.00	76	Lakes Entrance Platform	Indurated smectite-rich silty claystone	6	10	18
Meerlieu-4	633.2	134	Lake Wellington Depression	Fossiliferous silty smectite-rich claystone with dolomite cement	108	173	105
Meerlieu-4	722	134	Lake Wellington Depression	Fossiliferous smectite-rich claystone	222	358	186

Well	Sample Depth (m)	LEF Thickness (m)	Location	Lithology	Column height (m)		
					Gas	Oil	CO ₂
Meerlieu-4	769	134	Lake Wellington Depression	Indurated smectite-rich claystone	331	532	301
Meerlieu-15001	699.9	140	Lake Wellington Depression	Fossiliferous smectite-rich claystone with intergranular porosity and glauconite peloids	74	119	95
Mullungdung-7	363	17	Seaspray Depression	Smectite-rich mudstone with poorly sorted detrital quartz	5	9	12
Nuntin-2	869.28	211	Lake Wellington Depression	Fossiliferous silty smectite-rich claystone with minor vuggy porosity	271	435	241
Nuntin-2	885.74	211	Lake Wellington Depression	Fossiliferous silty smectite-rich claystone	382	615	325
Sale-13	748.1	125	Lake Wellington Depression	Smectite-rich claystone with isolated vuggy porosity	174	279	172
Sale-13	795.6	125	Lake Wellington Depression	Glauconitic mudstone, pyritic	214	343	170
Sale-15**	628.6	-	Lake Wellington Depression	Smectite-rich claystone with intergranular porosity	57	91	53
Seacombe-7	649	176	Lake Wellington Depression	Fossiliferous smectite-rich calcareous claystone with mouldic porosity	194	313	166
Seacombe-7	947.6	176	Lake Wellington Depression	Smectite-rich claystone with isolated porous fossil moulds	377	607	306
Sperm Whale Head-1	653.8	130	Lake Wellington Depression	Smectite-rich claystone with calcite and ankerite cement infilling mouldic and intergranular porosity	230	370	196
Sperm Whale Head-1	671.47	130	Lake Wellington Depression	Fossiliferous smectite-rich claystone	237	379	203
Sperm Whale Head-1	718.1	130	Lake Wellington Depression	Fossiliferous smectite-rich claystone	316	509	285
Woodside-3**	410.87	-	Alberton Depression	Porous silty dolomite-rich limestone	3	5	8
Woodside-4**	610.81	-	Alberton Depression	Muddy limestone	3	5	5
Woodside South-1	522.12	80	Alberton Depression	Fossiliferous smectite-rich calcareous claystone with mouldic porosity	3	5	6
Wooundellah-10**	389.3	-	Lake Wellington Depression	Siderite-rich limestone with mouldic porosity	5	8	4
Wooundellah-11**	389	-	Lake Wellington Depression	Fossiliferous limestone with mouldic and vuggy porosity	8	12	11
Wulla Wullock-5	699.6	192	Seaspray Depression	Smectite-rich silty claystone	317	510	263
Wurruk Wurruk-1**	562.35	-	Lake Wellington Depression	Muddy limestone	101	163	116
Wurruk Wurruk-1	647.39	-	Lake Wellington Depression	Smectite-rich mudstone	23	37	27
Wurruk Wurruk-13	584.9	68	Lake Wellington Depression	Glauconite bearing smectite-rich claystone with mouldic porosity	19	30	21
Yeerung-1	402.33	-	Lake Wellington Depression	Fossiliferous calcareous and smectitic mudstone	7	11	10

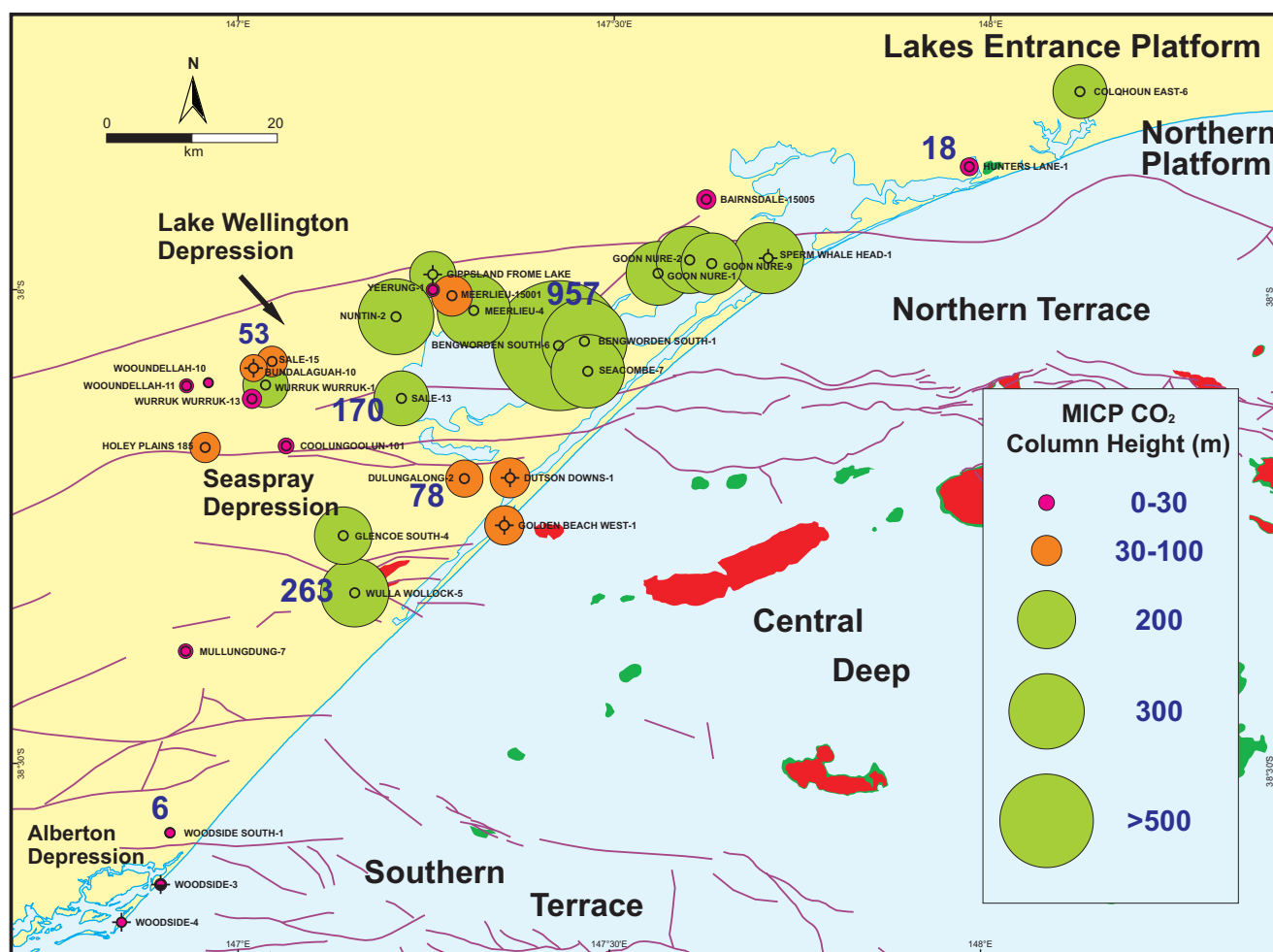


Figure 4.2 Retention capacities for CO₂: Combined results from the Lakes Entrance Formation and Gippsland Limestone.

The seal capacity results for the regional top seal (marl members of the Lakes Entrance Formation) and Gippsland Limestone are summarised in Figures 4.2, 4.3 and 4.4. It is clear from these figures that the majority of samples available for analysis are located in the Lake Wellington Depression and that there is a spatial relationship between the seal capacity and proximity to the margin of the regional top seal. The seal capacity in the near shore and central Lake Wellington Depression is excellent. Column retention heights for gas and CO₂ in this area typically range from 200 to 300 m, with the greatest capacity of 999 m in Bengworden South-6. Towards the margin of the Lake Wellington Depression, the seal capacity decreases and is at its lowest in Wurruk Wurruk-1 (i.e. MICP column retention heights of 19 m for gas and 21 m for CO₂). Similarly lower MICP capacity results are characteristic of Gippsland Limestone samples taken from near the basin margin in the Lake Wellington Depression; the lowest of which is found in Wooundellah-10 at 389 m down-hole depth, where MICP column retention heights of 5 m (gas) and 4 m (CO₂) are recorded. At greater depths in the Lake Wellington Depression (i.e. 599 m in Bundalaguah-10 and 628 m in Sale-15), retention capacities of the Gippsland

Limestone increase relative to those at shallower depth (i.e. respective column heights of 41 m and 53 m for CO₂).

Although there are fewer MICP capacity results available for the Seaspray Depression, a similar pattern is present to that seen in the adjacent Lake Wellington Depression. Maximum column retention heights for gas (317 m) and CO₂ (263 m) were recorded in Wulla Wullock-5 in the Seaspray Depression, near the North Seaspray and Gangell gas fields. To the north of the depression, near the Baragwanath Anticline, the seal capacity decreases to column heights of around 100 m in Dutson Downs-1. This sample from Dutson Downs-1, taken from the Gippsland Limestone, has a greater MICP capacity than samples from nearby wells Dulungalong-2 and Golden Beach West-1, which were sampled from the Lakes Entrance Formation. At the western extent of the seal, capacity is further reduced to a 5-metre gas and a 12-metre CO₂ column in Mullungdung-7.

From the three samples available along the present day coast in the Alberton Depression, the area appears to have poor sealing capacity. The sample from Woodside South-1, from the Lakes Entrance Formation, could retain

a gas column height of 3 m and a 6-metre CO₂ column height. The samples from Woodside-3 and Woodside-4 were taken from the Gippsland Limestone as there were no samples available in the underlying Lakes Entrance Formation. The maximum MICP capacity recorded from these two wells was 8 m of CO₂.

Similar values are also characteristic of the Lakes Entrance Platform, which also has poor sealing capacity, with the exception of results from Colquhoun East-6 (i.e. 123 m of gas and 164 m of CO₂). In this location, it is possible that localised diagenetic processes may have increased sealing capacity.

Seal capacity values are greatest in the central eastern Lake Wellington Depression, where the seal attains its

maximum thickness and is at its greatest down-hole depths. These relationships are common across the onshore Gippsland Basin (see figures 4.5 and 4.6). There is a strong positive relationship between MICP column height and the thickness of the regional seal. In the central and eastern Lake Wellington Depression, where the seal is thicker, its retention capacity is high. In contrast, in marginal parts of the basin, the thickness of the seal decreases and retention capacity tends to decrease (Figure 4.5). The positive relationship between depth and retention capacity (Figure 4.6) is probably due to the fact that the Lakes Entrance Formation was deposited in an early post-rift setting, where it progressively filled the palaeo-topographic lows. The strong relationship between the thickness of the seal and the depth of the base of seal surface is evident from Figure 4.1.

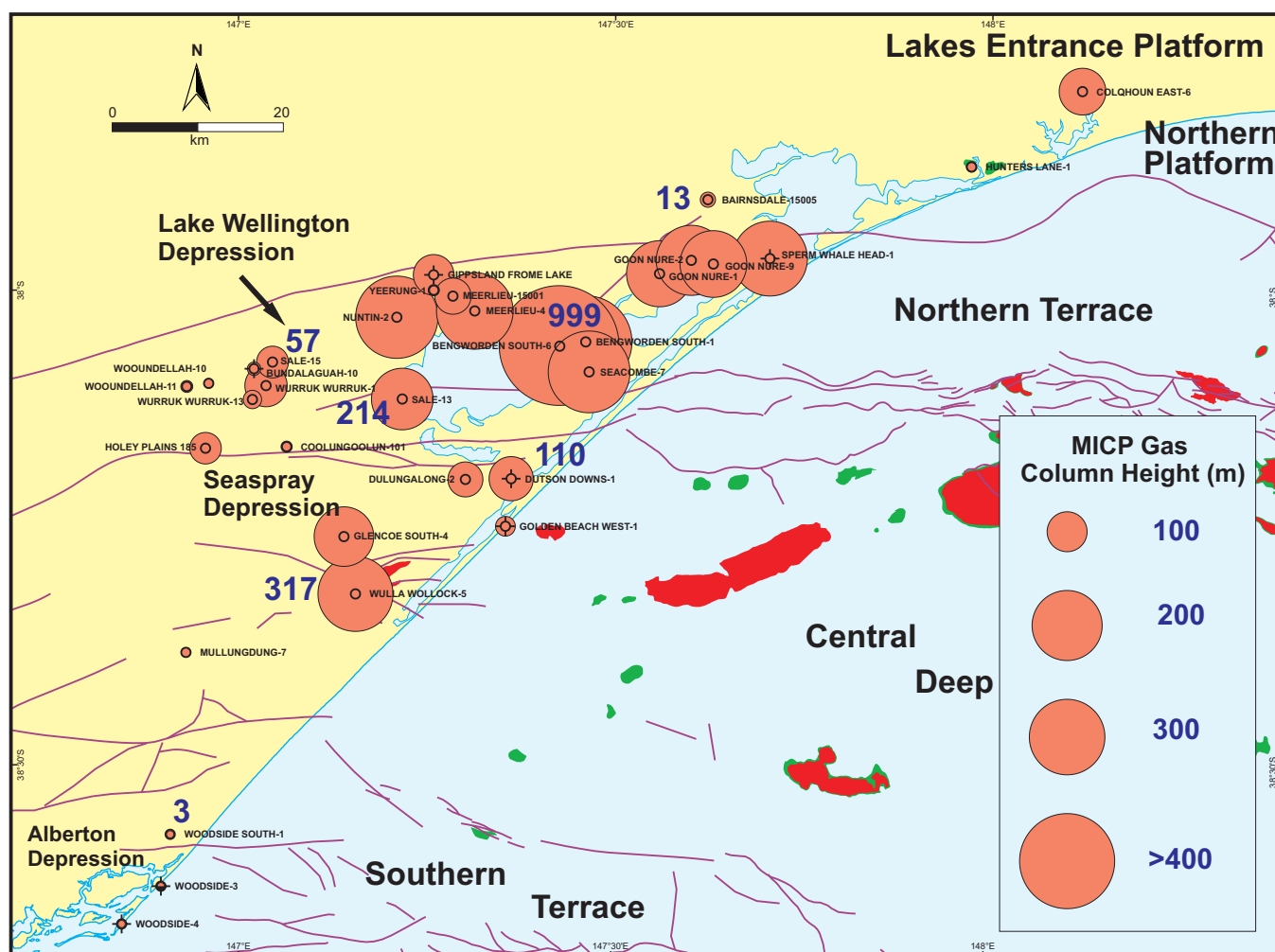


Figure 4.3 Retention capacities for gas: Combined results from the Lakes Entrance Formation and Gippsland Limestone.

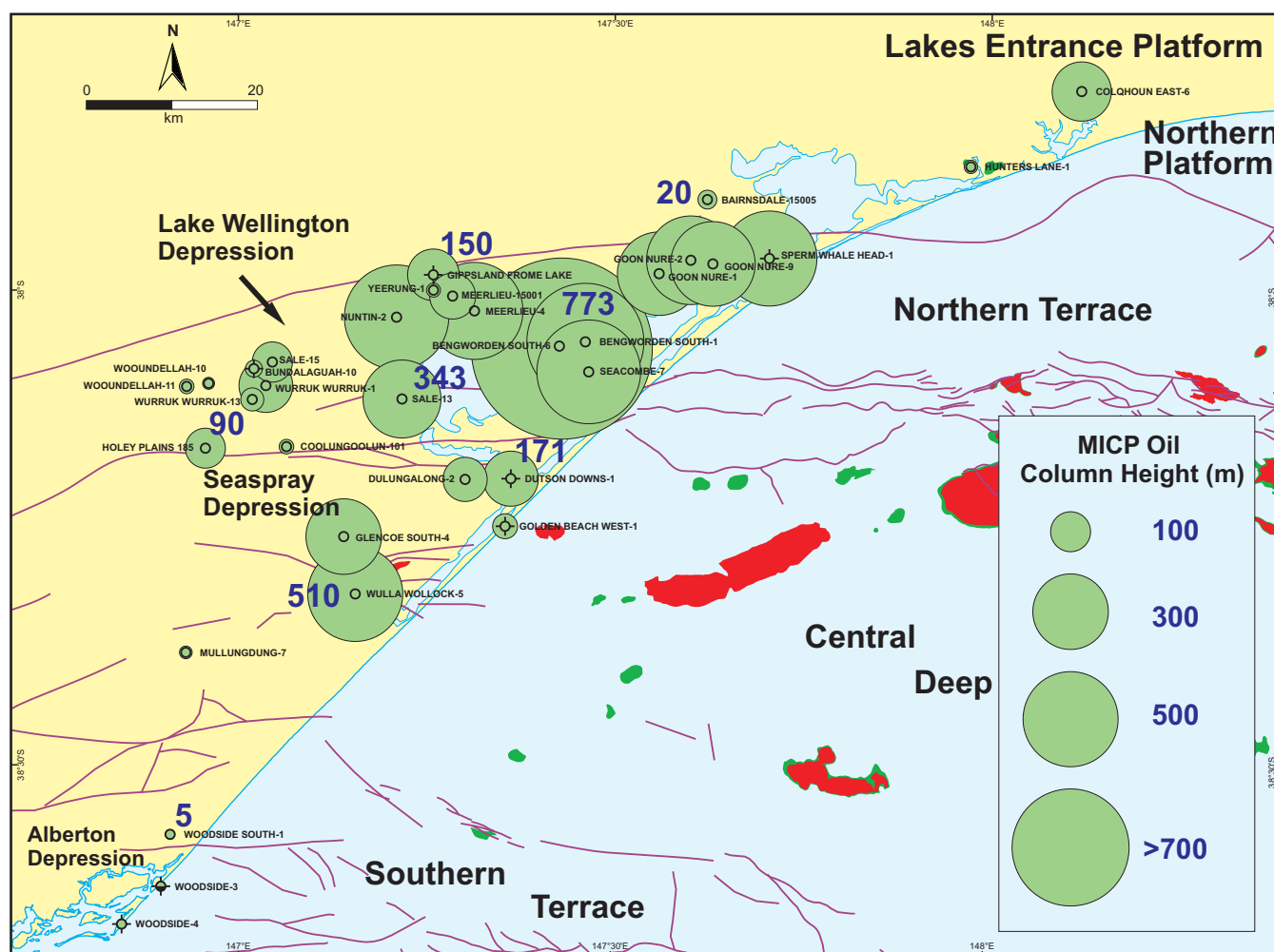


Figure 4.4 Retention capacities for oil: Combined results from the Lakes Entrance Formation and Gippsland Limestone.

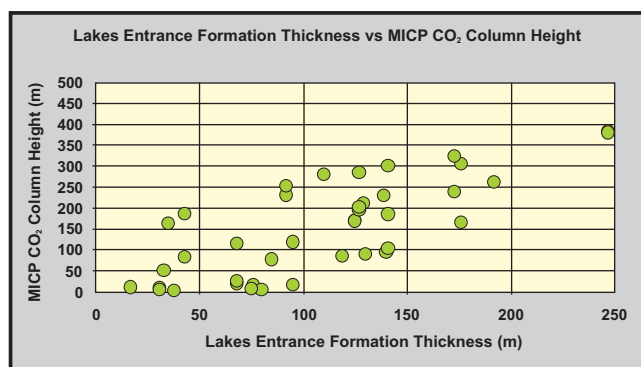


Figure 4.5 Relationship between the thickness of the Lakes Entrance Formation and its MICP retention capacity.

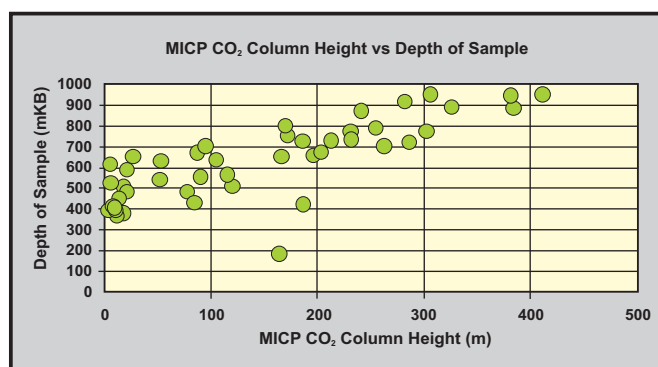


Figure 4.6 Relationship between the depth of the Lakes Entrance Formation and its MICP retention capacity.

4.3 Seal Mineralogy

A total of 46 samples were submitted to AMMTEC Ltd in Perth, Western Australia, for Automated Mineral Analysis (AMA). AMA is a quantitative X-Ray Diffraction technique, which uses automated analysis to identify mineral groupings. Mineralogies from samples of the Lakes Entrance Formation and Gippsland Limestone were represented within the sample suite. The same samples were used for both the MICP and AMA analysis to allow for correlation between the two datasets and to allow a detailed understanding of the relationships between MICP capacity, mineralogical composition, and diagenetic history to be established.

Samples were measured on an E430 QEMSCAN® at a pixel spacing of 5µm. This instrument comprises an electron microscope with four x-ray detectors. FEI iDiscover image analysis software was used to process the data. X-ray diffraction (XRD) was used for clay mineral identification of <2 µm and 2-10 µm size fractions in three of the AMA samples for calibration purposes. During automated analysis, mineral groupings were assigned to point data and modal mineral abundances were calculated. The mineralogical compositions for each well are displayed in Appendix 4. Colour-coded and greyscale mineral maps of samples (shown in Figure 4.7, field of view = 0.5cm²) were produced to aid in the visualisation of porosity distribution and textural relationships between mineral phases. Together with calculated modal mineral abundances, these datasets help to better characterise the regional top seal.

Of the 18 mineral groupings identified and tabled in Appendix 4, smectite was the most abundant mineral recorded in 40 out of the 46 samples in the suite. In over two-thirds of the samples, smectite accounted for at least 70% of the rock mass. The next most abundant minerals were calcite and quartz. Smectite, calcite and quartz are all visible in Figure 4.7; smectite is dark green, the calcite is light blue and the quartz is yellow. Black in the greyscale images represents porosity in the samples. From the greyscale images in Figure 4.7, it appears that sample A is less porous than samples B and C, where vuggy and intergranular porosity are clearly visible as black patches in the greyscale image.

The new quantitative XRD mineral mapping also shows that the Lakes Entrance Formation, often described as a 'marl', is actually a smectite-rich claystone. Onshore, the smectite content of samples increases with increasing depth (Figure 4.8). Smectite-rich samples occur throughout the Lakes Entrance Formation, irrespective of stratigraphic position within the formation (Figure 4.9). Mineral maps and composition bar charts shown in Figure 4.9 display a similar abundance of smectite, although overall their compositions are slightly different.

Overall, samples that are most calcite-rich are typically from the Gippsland Limestone. Some Gippsland Limestone samples are more abundant in smectite, although they have

a relatively higher percentage of calcite than the Lakes Entrance Formation samples.

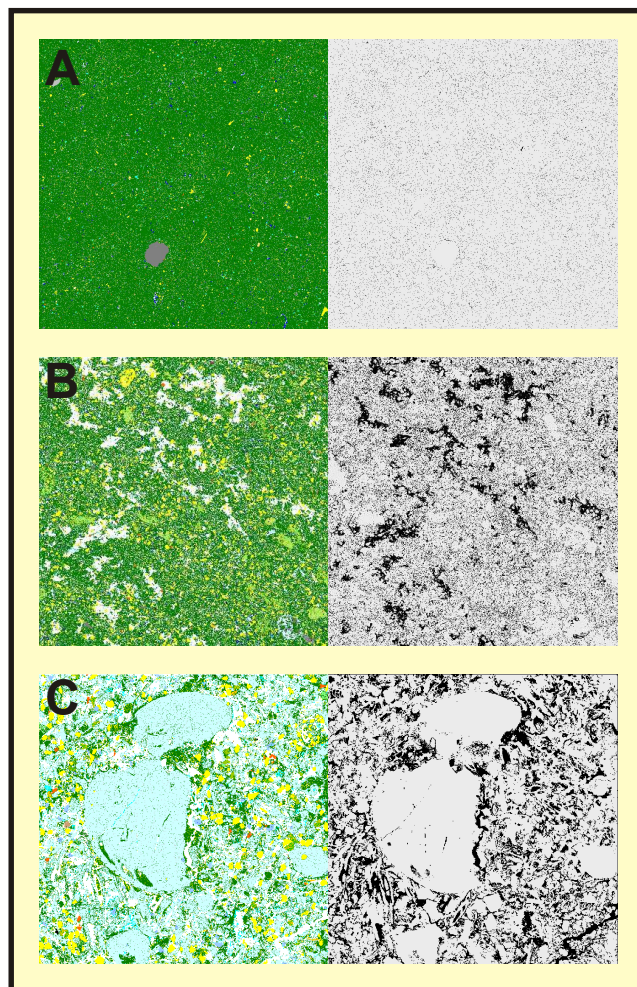


Figure 4.7 Colour coded and greyscale mineral maps of samples from **A** the Lakes Entrance Formation, Meerlieu-4 (769m), Lake Wellington Depression – an excellent seal, **B** the Lakes Entrance Formation, Gippsland Frome Lakes-4 (503.5m), Lake Wellington Depression – a poor seal **C** the Gippsland Limestone, Woodside-4 (610.81m), Alberton Depression – a poor seal.

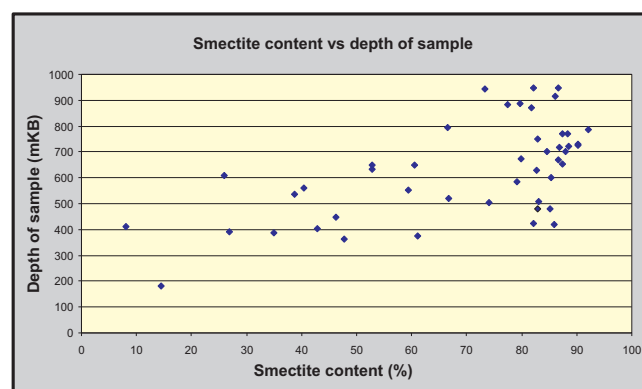


Figure 4.8 Smectite content versus depth of samples, onshore Gippsland Basin.

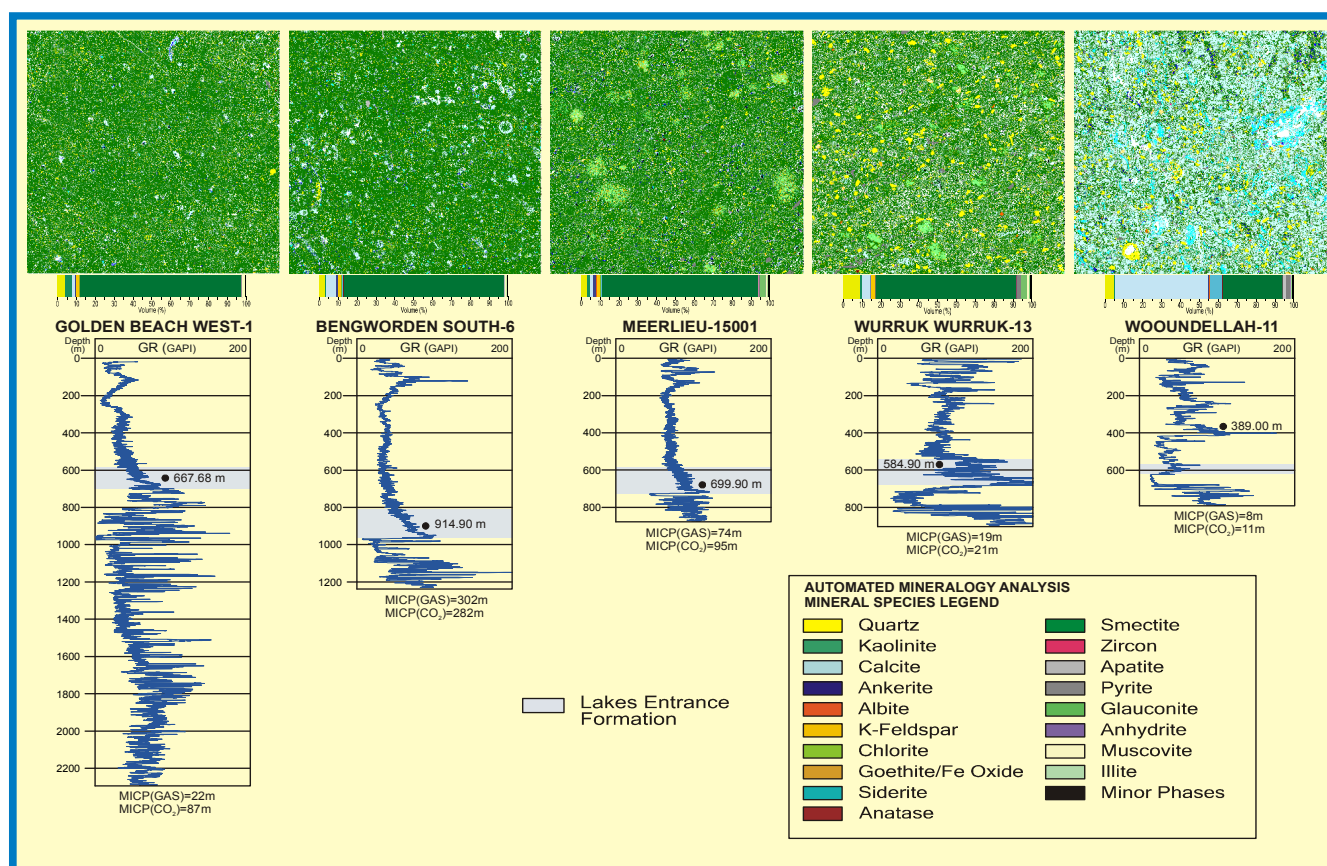


Figure 4.9 A compilation of MICP and AMA sample data from the onshore Gippsland Basin: AMA mineral maps, mineral composition bar charts and gamma ray curves showing MICP and AMA sample depths and relative positions of samples within the Lakes Entrance Formation.

Mineralogical composition and MICP seal capacity

Smectite-rich samples at depths greater than 700 m have a good seal retention capacity (e.g. Figure 4.7A). This sample of the Lakes Entrance Formation from the Lake Wellington Depression is an excellent seal, with a CO₂ column retention capacity of 301 m. By comparison, two samples from much shallower depths, near the terminal edge of the seal in the Lake Wellington Depression (Figure 4.7B) and the Alberton Depression (Figure 4.7C), are both poor seals and could hold vertical columns of only 18 and 5 m of CO₂ respectively.

MICP seal capacities and smectite abundances increase with increasing depth, and seals from depths greater than 700 m that also have greater than 70-80% smectite have much better seal capacity than those with lower smectite content at shallower depths (Figures 4.9 & 4.10). At greater depths, sediments are likely to be more compacted and this compaction is likely to be contributing in part to the higher MICP capacities.

In samples with low smectite content, there is typically a greater abundance of either quartz or carbonate minerals. Samples with higher abundances of carbonate, such as Wooundellah-11 (Figure 4.9), are invariably located at

shallower depths and are representative of the Gippsland Limestone. These samples also have poor MICP seal capacities and well-developed intergranular and vuggy porosity. The only exception is from Colquhoun East-6, where substantial late-stage diagenesis has resulted in enhanced cementation and a high sealing capacity. This higher sealing capacity is offset against the inherently highly brittle nature. Regardless of formation and mineralogy, samples at shallower depths are more likely to have poor MICP seal capacities and to have more visible porosity (i.e. Figure 4.7B & C). It is likely that these shallower samples have come in to contact with the freshwater lens or wedge (Kuttan *et al.*, 1986), which has infiltrated through the onshore and near-shore regions in the Neogene. Freshwater-induced diagenetic processes have resulted in the dissolution and/or modification of carbonates and other components and thereby compromised seal capacity.

In summary, this new data set shows that the regional top seal is principally a smectite-rich claystone within which seal capacity increases with both smectite content and (particularly) depth of burial. Within the onshore Gippsland Basin, at depths shallower than 700 m, freshwater diagenesis of seals has substantially degraded their seal capacities.

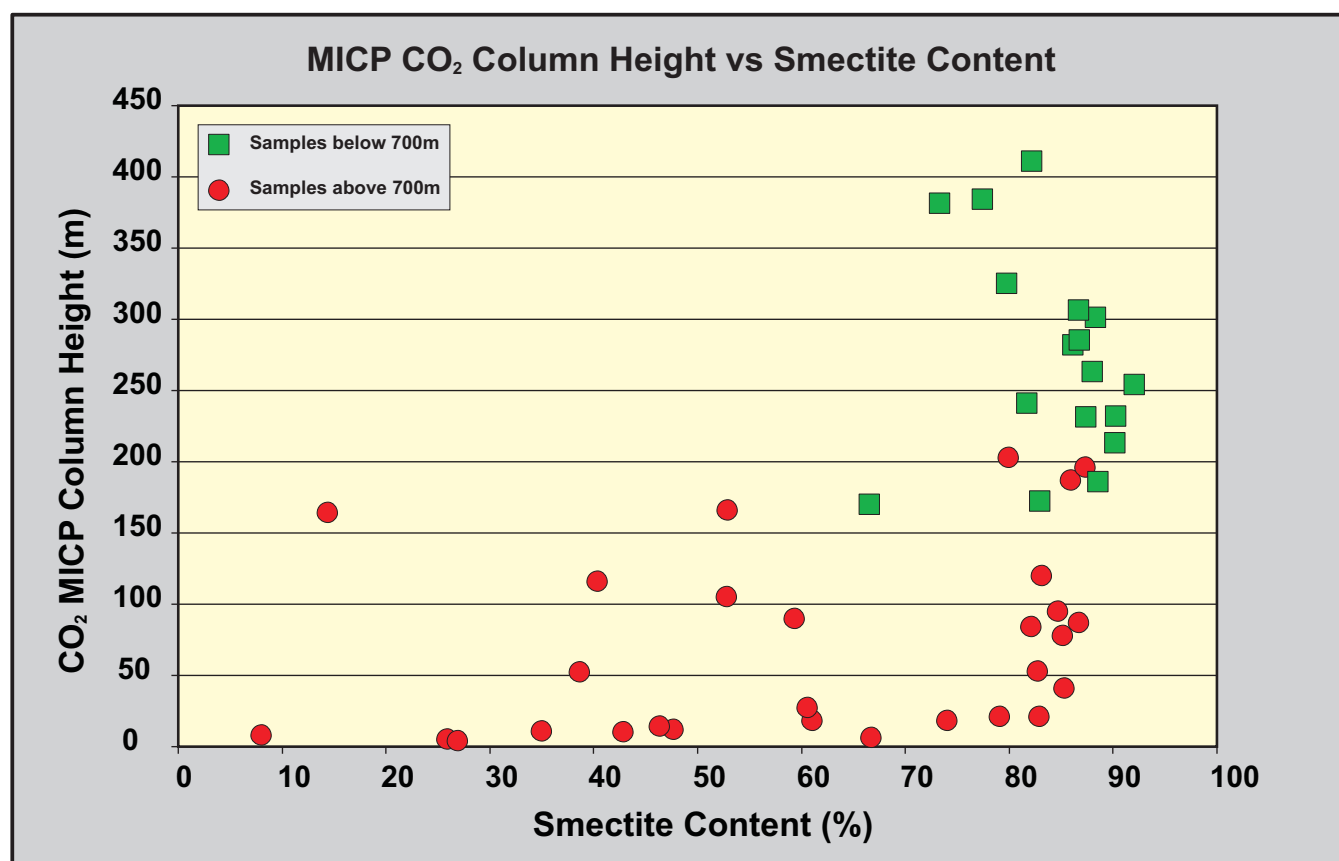


Figure 4.10 Smectite content versus MICP Column Height for CO₂, colour coded for depths below 700 metres (red) and depth above 700 metres (green).

4.4 Leakage and Seepage Indicators

Hydrocarbon leakage and seepage are unequivocal indicators of top or fault seal failure and are therefore particularly relevant to the assessment of containment potential. In the present study, potential gas chimneys, fluid flow zones, shallow amplitude anomalies as well as archival seepage data (including those derived from soil gas, airborne geochemical and radiometric surveys), have been integrated with data on hydrocarbon shows (located above and within the regional top seal) to provide an independent assessment of seal potential throughout the onshore Gippsland Basin.

Soil Geochemical Surveys

Numerous soil gas geochemical surveys have been conducted over the onshore Gippsland Basin in the last 35 years. These cost-effective surveys are used in the

exploration of hydrocarbon accumulations onshore, where anomalous levels of geochemical constituents in the shallow subsurface are considered possible indicators of deeper hydrocarbon accumulations. This rationale comes from the notion that all sealing cap-rocks are not totally impermeable and that some hydrocarbons can escape from the reservoir, by means of diffusion, buoyancy and/or pore pressure gradients, and migrate vertically into the shallow subsurface (Schumacher, 1996). These hydrocarbons create chemically reduced environments in the shallow subsurface, which are able to be identified in soil gas geochemical surveys.

There have been 11 ground and two airborne geochemical surveys conducted in the onshore Gippsland Basin (see Table 4.2), with the earliest dating back to 1974. The airborne surveys were undertaken to determine whether there were any geochemical anomalies present in the air, whilst the ground surveys tested the soil for anomalous levels of hydrocarbons. This table has been updated from the one previously compiled by Chiupka (1996).

Table 4.2 Details of airborne and ground soil hydrocarbon geochemical surveys conducted over the onshore Gippsland Basin.

Year	Survey	Permit(s)	Contractor	Operator	Survey Type	Sampling
1974	GW74A	PEP89	Geoservices Australia	Woodside Oil	Ground	1117 samples
1980	MGS80	PEP98	?	Mincorp Ltd	Airborne	1732 km
1984	GV84A	PEP99	Petrosearch	Base Resources Ltd	Ground	220 samples
1984	GV84B	PEP99	Petrosearch	Base Resources Ltd	Airborne	~500 km
1984	GV84C	PEP99	Petrosearch	Base Resources Ltd	Ground	173 samples
1985	GBR85A	PEP114 & PEP115	Petrofocus	Base Resources Ltd	Ground	528 samples
1987	GOR87A	PEP98	Petrofocus	Ocean Resources N.L.	Ground	337 samples
1988	GT87A	PEP107	Petrofocus	TCPL Resources Ltd	Ground	408 samples
1989	GT88B	PEP107	Petrofocus	TCPL Resources Ltd	Ground	216 samples
1989	GPN89A	PEP109 & PEP110	Petrofocus	Poseidon Oil Pty Ltd	Ground	243 samples
1989	GPN89A	PEP109 & PEP110	Stradbroke	Poseidon Oil Pty Ltd & Cluff Resources Pacific Ltd	Ground	231 samples
1990	GCRP90A	PEP109	Amdel	Cluff Resources Pacific Ltd	Ground	145 samples
1991	GCR91A	PEP120 & PEP123	Amdel & Fugro	Crusader Resources N.L.	Ground	244 samples

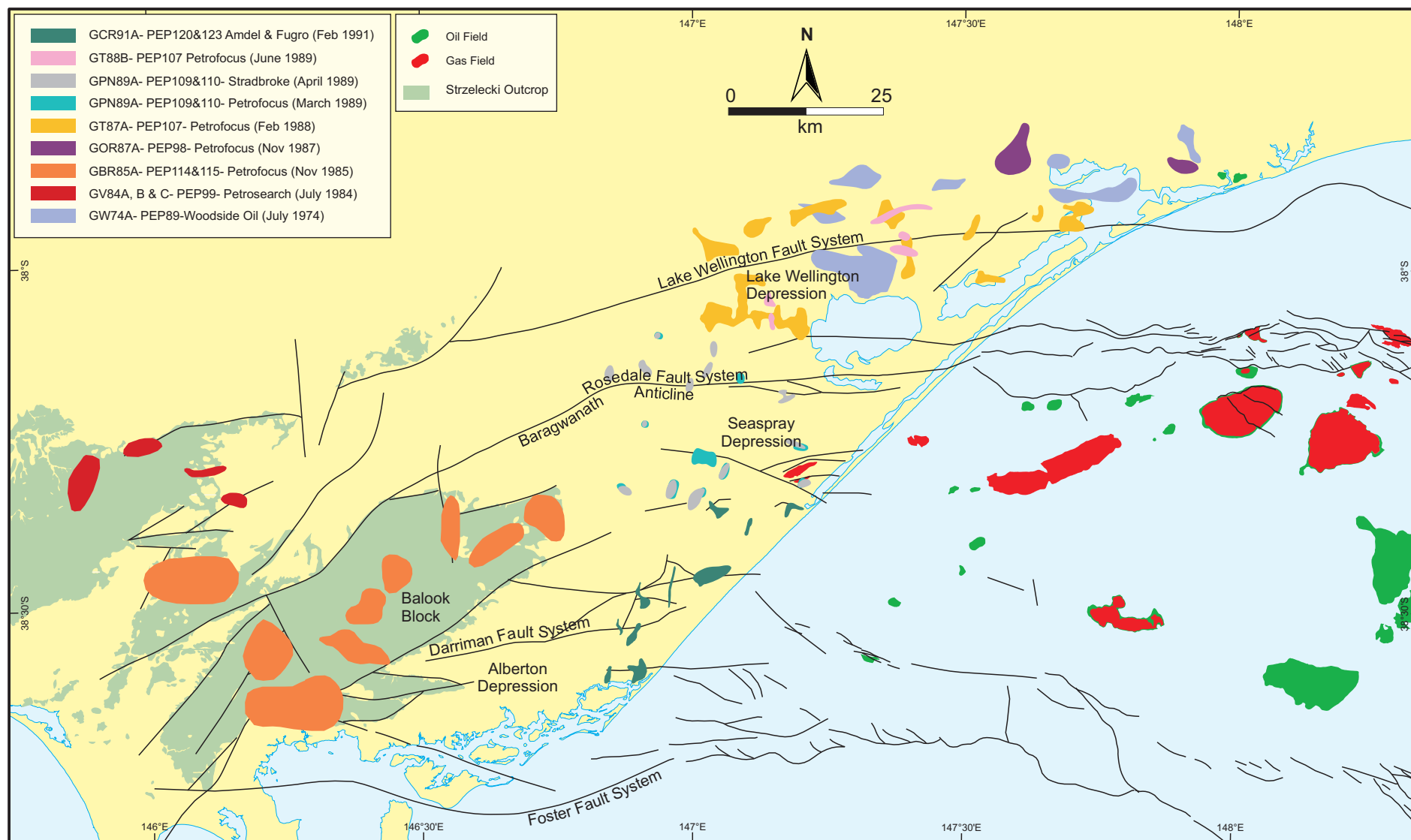


Figure 4.11 Mapped geochemical anomalies in the onshore Gippsland Basin.

In the onshore portion of the Gippsland Basin, the presence of soil geochemical anomalies may indicate the presence of either active hydrocarbon migration in the sub-surface or even deeper accumulations. In terms of containment, and GCS in particular, the presence of these anomalies may potentially indicate that the top seal in these areas is somewhat ineffective, and that gases and/or fluids are able to migrate to the surface.

In the present report, the interpretative results, i.e. the location of hydrocarbon anomalies, have been compiled (Figure 4.11). No attempt has been made to reinterpret the original interpretations provided by the companies that collected the original surveys. Consequently, the presence of “false-positive” anomalies cannot be discounted.

The interpretation of any anomaly relied heavily on increased concentrations of the heavier hydrocarbon gases, rather than simply increased concentrations of methane, for example. This fact is crucial because methane can be produced from numerous sources in the shallow subsurface, and cannot be used on its own as a reliable indicator of hydrocarbon seeps. The one exception, however, are the blue/grey anomalies mapped from the GW74A survey, where the interpretation of the anomalies was based on samples containing above background levels of one or several of methane (C₁), ethane (C₂), propane (C₃), iso-butane (iC₄) and n-butane (nC₄). For this reason, interpretations from survey GW74A, conducted over the Lakes Entrance Platform and part of the Lake Wellington Depression may well be misleading.

Four surveys (GV84A, GV84B, GV84C and GBR85A) were conducted in the far western part of the onshore Gippsland Basin. For the most part, the interpreted anomalous areas from all these surveys were located where Strzelecki Group sediments outcrop at the surface. As the uplift history suggest that the Strzelecki Group sediments in this area were previously buried deep enough to have been in the generative window, prior to being uplifted and exposed at the surface at the present day (see section 3.3), the source of these anomalies is perhaps from this earlier phase of hydrocarbon generation. In addition to this, a high proportion of the anomalies mapped from the surveys are located at, or near, the intersection of mapped faults, a possible indication that the faults are providing a conduit for fluids to migrate to the surface.

Two soil geochemical surveys (GOR87A and GT87A) and a follow-up survey (GT88B) were carried out across the Lakes Entrance Platform and the northern part of the Lake Wellington Depression. Based upon these data, numerous soil geochemical anomalies were interpreted in an area broadly extending from east to west along the Lake Wellington Fault System. High concentrations of light alkanes were detected over the Gippsland oil accumulation

to the west of the Lakes Entrance oil field. Further to the west of the Gippsland oil accumulation, anomalies from surveys GOR87A and GT87A are not associated with hydrocarbon accumulations or shows but may possibly be associated with the migration of fluids along the Lake Wellington Fault itself.

Further to the south, two GPN89A surveys were conducted over the Seaspray Depression and Baragwanath Anticline. Here, soil samples were analysed by different companies using two different techniques. Approximately half of the interpreted anomalies were detected by both techniques, the majority of these located in the southern part of the Seaspray Depression, immediately north of the Darriman Fault System. Numerous anomalies were also detected over the Baragwanath Anticline and along the Rosedale Fault System, providing further evidence that faults in the onshore region may be playing a crucial role in providing conduits for fluid migration. A follow-up survey (GCR90A) conducted to test the validity of anomalies close to the coast in the Seaspray Depression replicated the three anomalies closest to the shoreline, further increasing confidence in these results.

A survey conducted across the Alberton Depression, the Darriman Fault System and the Seaspray Depression (GCR91A) detected ten anomalous areas, with the majority of them situated very close to mapped faults in the area, with a strong cluster of anomalies occurring right above the Darriman Fault System.

Lake Bottom Sediment Dredging

A lake-bottom dredging program was undertaken in 1997 by AGSO (now known as Geoscience Australia) to test for hydrocarbons in recent sediments at the bottom of the numerous lakes in the onshore Gippsland Basin. Four sediment samples, from Lake Wellington, Lake Victoria and Lake King (Figure 4.12) were analysed by gas-chromatography-mass spectrometry (GCMS). Murray (1997) and Summons *et al.* (1998) detected possible thermogenically-derived petroleum in sediments from the floor of Lake Wellington. This oil was interpreted to be geochemically similar to that in the offshore Turrum Field (Murray, 1997). Summons *et al.* (1998) suggested that the results did not constitute proof of natural petroleum seepage into the Gippsland Lakes from the offshore basin. However, if this seepage were to be confirmed, migration from the northern spill-fill-chain across the Rosedale Fault and into the Lake Wellington Depression could have significant implications for assessing the seal potential at the southern margin of the depression.

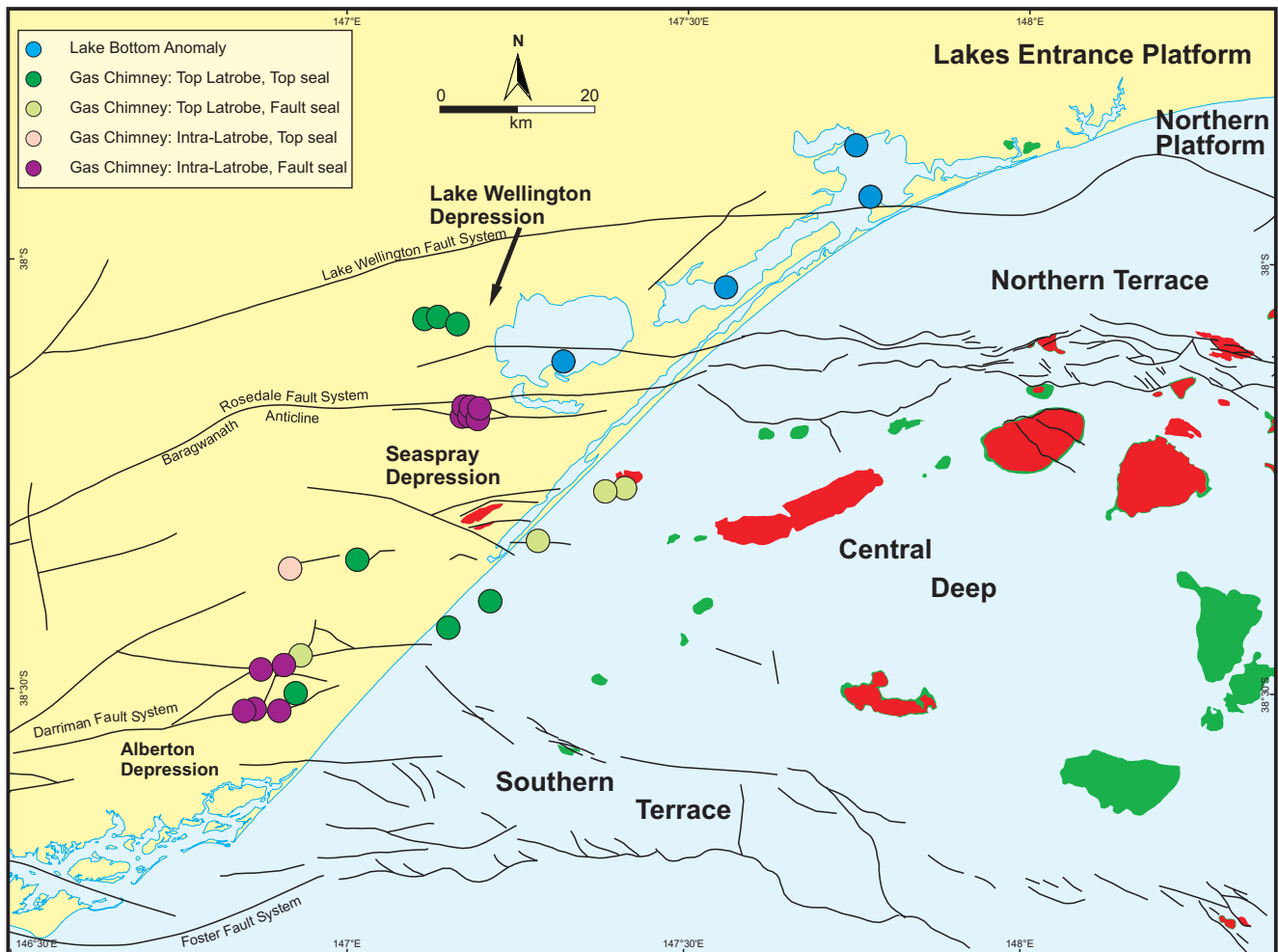


Figure 4.12 Location of anomalous lake-bottom sediment samples and gas chimneys within the onshore Gippsland Basin.

Gas Chimneys

Forty-five 2D seismic surveys and a single 3D seismic survey have been conducted in the onshore Gippsland Basin. There are approximately 3835 line kilometres of 2D seismic data of various vintages that have been acquired, with the first seismic line shot in 1952 (see Appendix 1 for details). As part of the present study, the entire suite of 2D seismic data were examined to determine whether gas chimneys, or similar leakage-seepage features, might or were present in the area of interest. Gas chimneys result from density variations between vertically migrating fluids/hydrocarbons through sediments and appear as vertical disturbances (discrete noisy zones) in seismic reflection data. The chimney mapping was undertaken “aggressively”, in other words the intention was to avoid false-negatives rather than false-positives; as a result, some of the interpreted chimneys are almost certainly not genuine chimneys but are rather poor data zones above reactivated faults. The locations of the possible chimneys are indicated on Figure 4.12.

Seismic reflection data line GCRP91a-09 (Figure 4.13) reveals two possible gas chimneys above two separate faults along the Rosedale Fault System. They occur in close proximity to the interpreted fill-spill chain at top Latrobe Group

level that extends onshore from the Barracouta and Golden Beach gas fields (O'Brien *et al.*, 2008). Seismic reflection data over the nearshore Golden Beach gas field indicates the presence of a small fault cutting the top of the Latrobe Group horizon (Figure 4.14). Although there is no apparent gas chimney associated with this fault, there are various anomalous amplitudes close-by at shallow depth, which may indicate the presence of shallow migrated hydrocarbons.

Other possible gas chimneys detected in the vicinity of the Darriman and Rosedale fault systems commonly occur on steeply dipping overturned limbs of fault-related anticlines. Whether these anomalous zones are the result of leaking hydrocarbons or poor data quality associated with acquisition over steeply-dipping strata is uncertain. Irrespective, however, there is a high probability that such areas within the structures would constitute critical leak points.

Possible gas chimneys mapped within the three-nautical mile zone of the Seaspray Depression and to the west of Lake Wellington occur in an area with little faulting and appear as noisy zones through otherwise continuous reflectors. Due to the poor quality of this data, a definitive interpretation of seal failure at these locations would require significant additional corroboration.

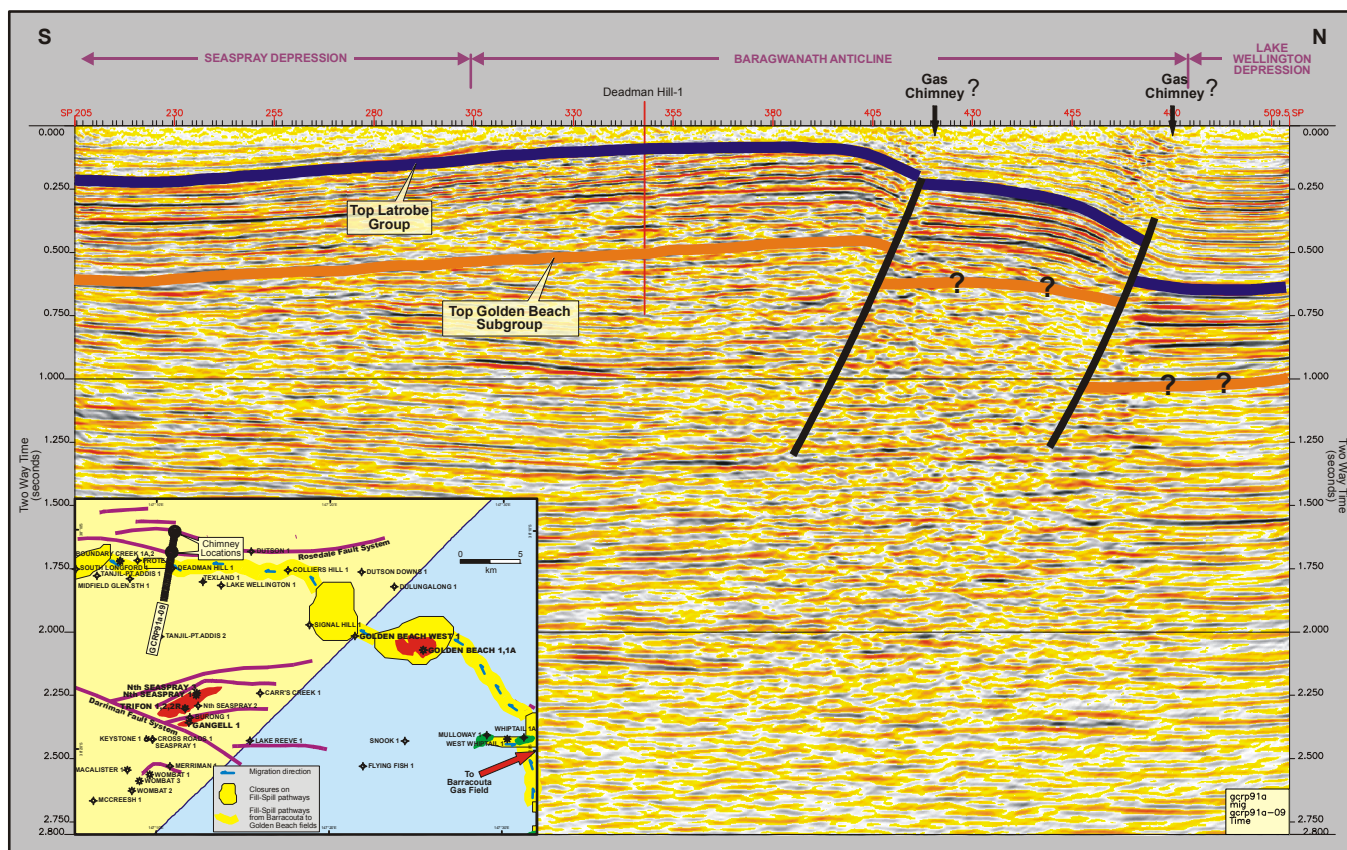


Figure 4.13 Seismic reflection line GCRP91a-09 showing possible gas chimneys above high-angle reverse faults of the Rosedale Fault System (RFS).

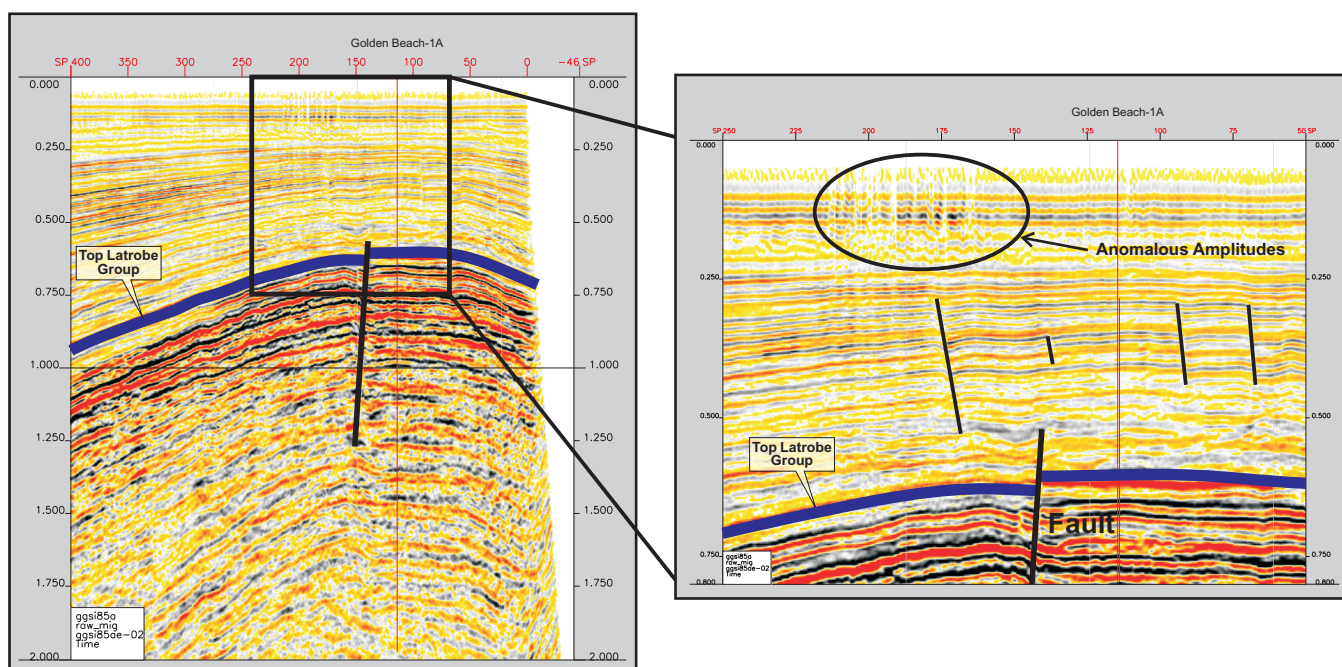


Figure 4.14 Seismic data over the Golden Beach gas field revealing evidence of possible hydrocarbon seepage.

Radiometrics Survey

Lakes Oil N.L. tested for oil shows in the vicinity of a seep approximately 10km southeast of Sale (Mulready, 2002). The location of this seep is consistent with an anomaly present on the radiometrics data from Geoscience Australia's 1999 airborne survey and possible gas chimneys in this area (see Figure 4.12 and 4.13). All data suggests that an active hydrocarbon seep occurs either along or close to the fill-spill chain at top-Latrobe Group level, up-dip from the Golden Beach and Barracouta gas fields, through the Seaspray Depression and on to the Baragwanath Anticline. From the radiometrics image (Figure 4.15), the uranium counts peak in

and around the seep, which is located 1-2.5km north or northeast of the mapped fill-spill chain. Whether this seep, or seepage chain, is principally the result of seepage directly up the Rosedale Fault or seepage along the broader fill-spill chain, or perhaps a combination of both, is currently uncertain. Nearby, seal capacity results from Dulungalong-2 and Dutson Downs-1 (see Table 4.1) at the northern extent of the Seaspray Depression indicate a reduction in the effective containment relative to central and near shore areas within the Seaspray Depression.

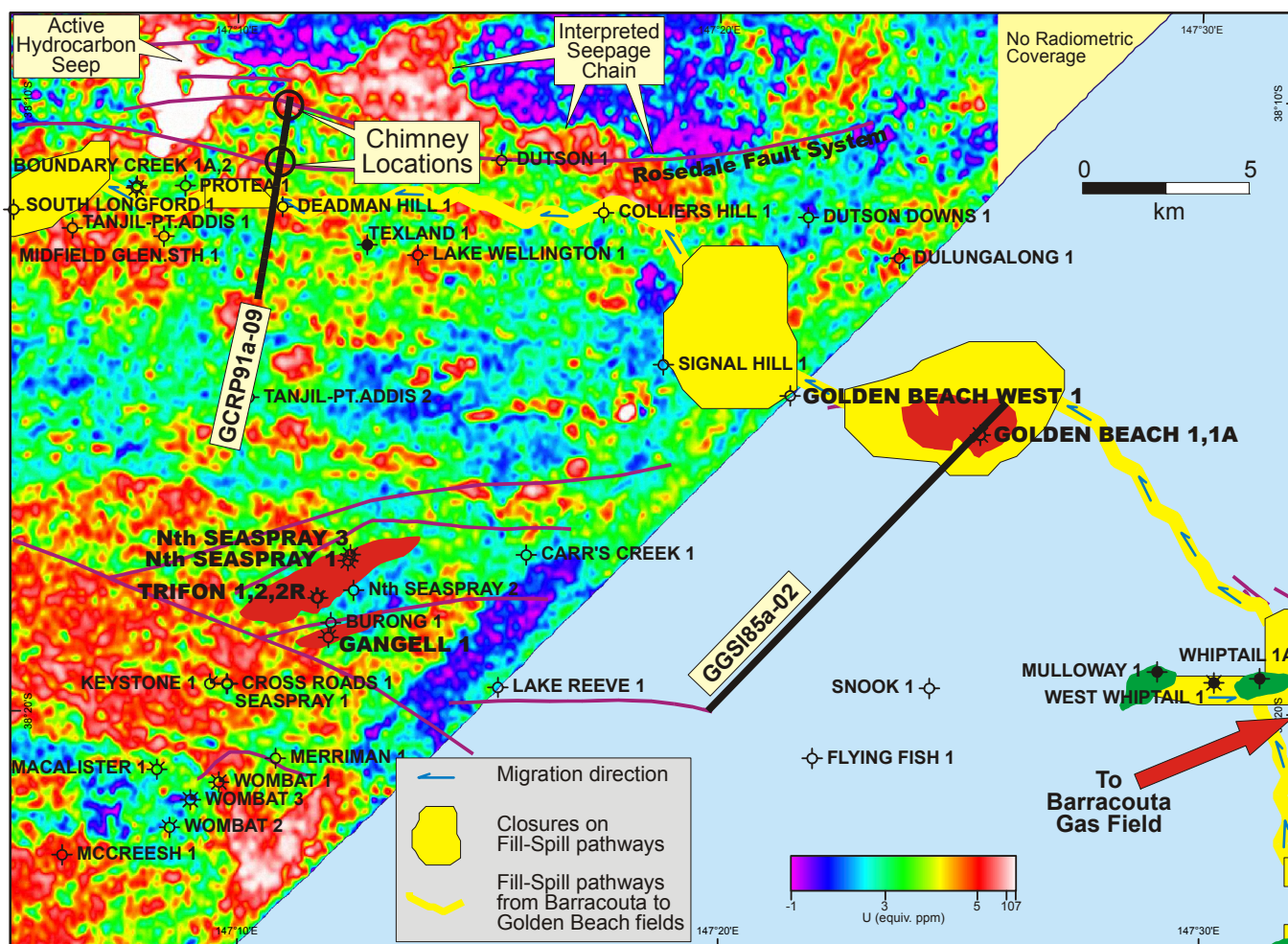


Figure 4.15 Radiometrics data (uranium) for the onshore Gippsland Basin, along with modelled fill-spill chain from Barracouta. Known and interpreted hydrocarbon seeps correspond to a broadly east-southeast trending zone exhibiting strongly anomalous radiometrics response. Zone of active to significant seepage appears to relate very closely to location of Rosedale Fault; other anomalies may also relate to seepage although this has not yet been confirmed.

Hydrocarbon Shows

One hundred and ninety one petroleum exploration wells have been drilled in the onshore Gippsland Basin. Previous classification of hydrocarbon shows from onshore wells tabled the most significant shows encountered within the well only. In this study, all hydrocarbon shows over the depth range of the well were recorded from well completion reports and mudlogs.

The distribution of hydrocarbon shows or indications above the regional top seal, the Lakes Entrance Formation (Figure 4.16) are principally from the Gippsland Limestone and equivalents. In general, the wells with hydrocarbon indications above the regional seal are located on the northern margin of the basin (the Lakes Entrance Platform)

and also in several wells near the present day coastline. All of these locations coincide with areas of apparent poor top seal quality (see Figure 4.18). Two exceptions occur in the Lake Wellington Depression (West Seacombe-1 and Pelican Point-1). The gas indication in West Seacombe-1 is only slightly above the background gas level and is not considered significant. The oil shows in Pelican Point-1 appear to be significant but the well data are old – associated with drilling reports from 1931. The distribution of shows from the top third of the Lakes Entrance Formation (Figure 4.17) is broadly similar to those in Figure 4.16. Goon Nure-1 has shows in the top third of the Lakes Entrance Formation but owing to the drill date of 1931, documentation is poor and there is no corroborative data.

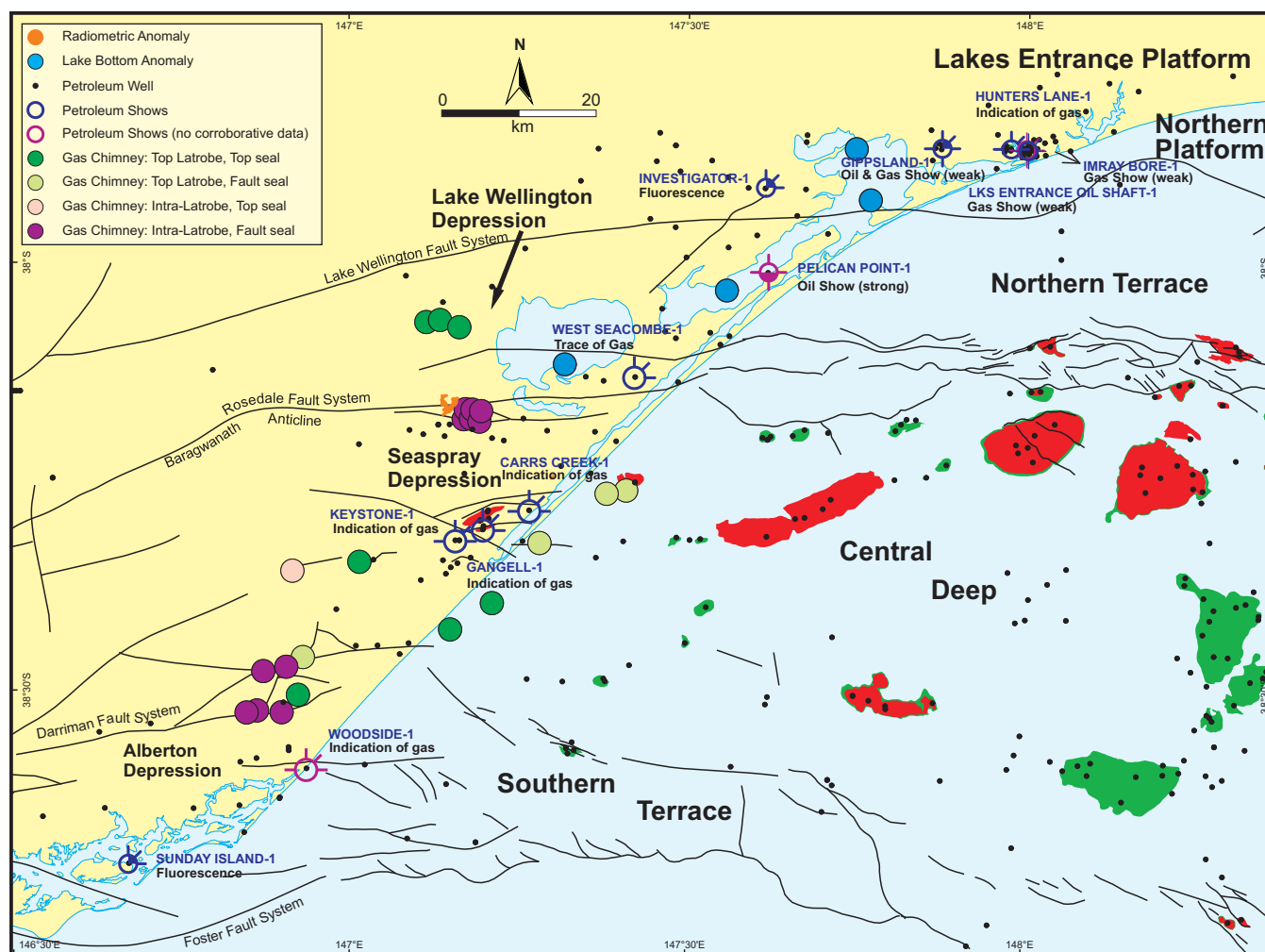


Figure 4.16 Hydrocarbon shows above the regional top seal (in the Gippsland Limestone).

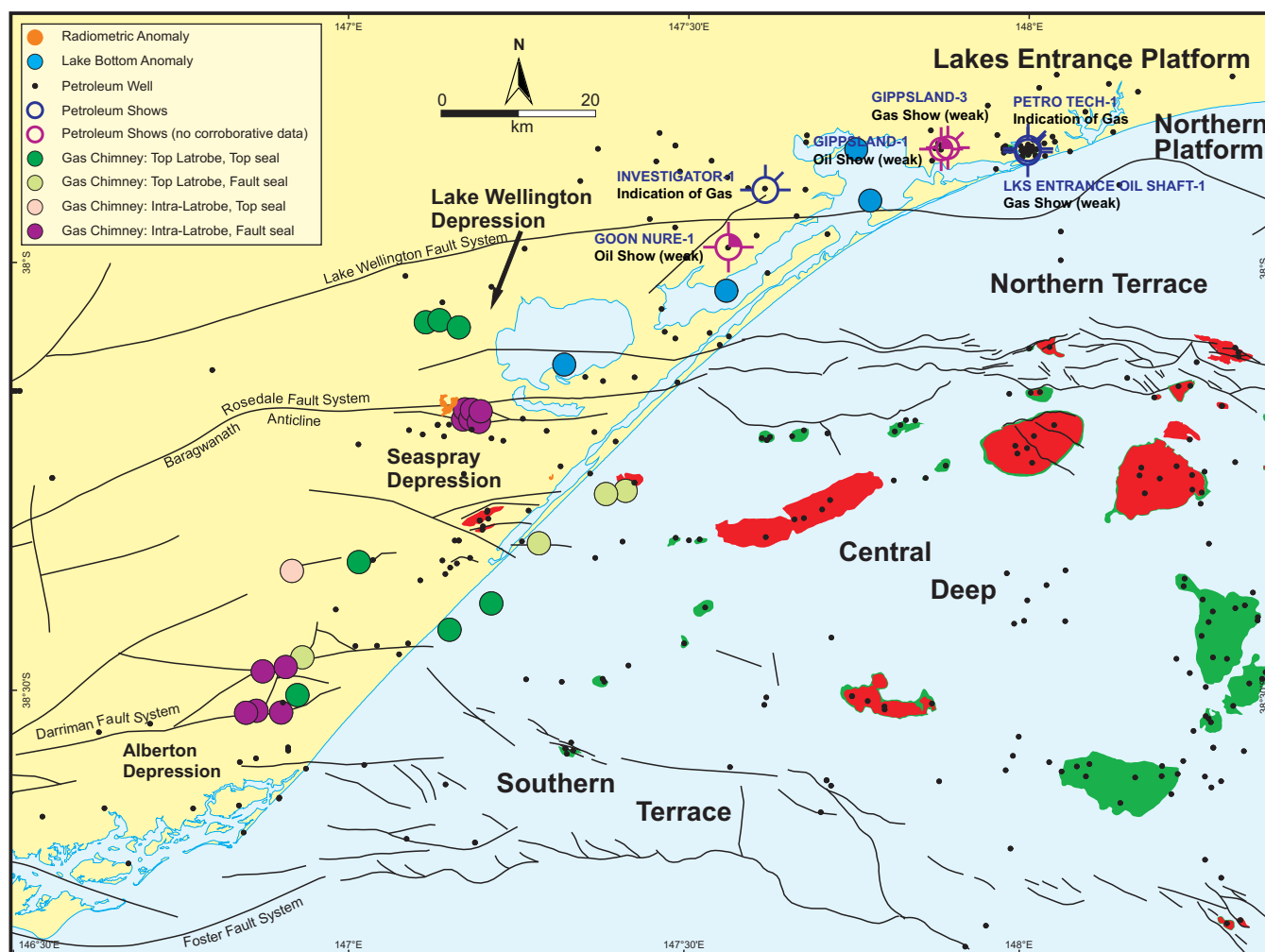


Figure 4.17 Hydrocarbon shows within the top third of the Lakes Entrance Formation.

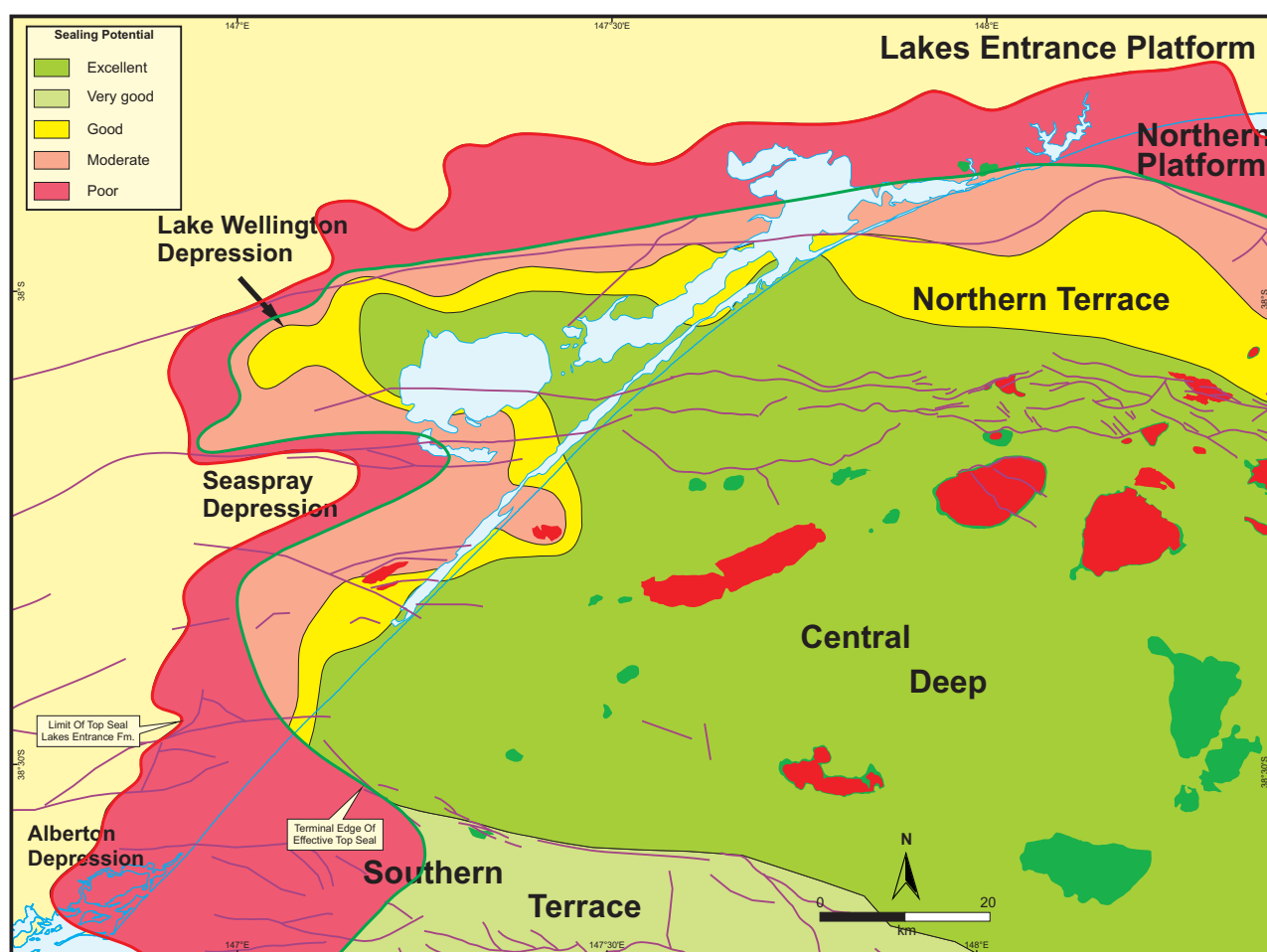


Figure 4.18 An interpretation of top seal potential for CO₂, onshore Gippsland Basin.

4.5 Seal Potential

An interpretation of top seal potential for CO₂ in the onshore Gippsland Basin is presented in Figure 4.18. This interpretation is largely based on the depth to the base of the seal and MICP capacity data. In addition, direct indicators of seal failure (soil gas anomalies, gas chimneys, seepage and hydrocarbon shows) have all been factored into this interpretation.

An assessment of seal potential as 'excellent' is based largely on the depth to the base of the regional top seal (being at or below 800 m). At all depths below 800 m, seal capacities are more than sufficient for the containment of CO₂ or hydrocarbons (i.e. vertical column heights above 100 m, and commonly around 200 m in the Lake Wellington Depression). An area with 'good' seal potential has a depth to the base of seal of between 700 and 800 m and variable seal capacity (ranging from 53 to 285 m). The seal has 'moderate' potential above 700 m, with variable seal capacity (10 to 187 m) and a greater likelihood of the occurrence of hydrocarbon shows, chimneys and soil gas anomalies. In areas with poor seal potential, very low capacities are characteristic (i.e. below 20 m), the base of the seal is quite shallow (around 300 to 400 m) and the seal is thinning

towards its zero edge. There are also more seal failure indicators in areas with poor sealing potential than in any other. Exceptions in areas with poor seal potential are the depth to the base of seal in the Alberton Depression and an exceptionally high MICP capacity value on the Lakes Entrance Platform (which apparently relates to an anomalously cemented, brittle sample).

Lake Wellington Depression

Seal potential in the near shore and central Lake Wellington Depression is excellent. MICP capacities, depth to base of seal, seal thickness and smectite content are greater in this area than in any other area of the onshore Gippsland Basin. However, these values all decrease gradually towards the margin of the depression in the north, south and west. Where seal potential decreases to good/moderate in the Lake Wellington Depression, these areas correspond with possible soil gas geochemical anomalies, leakage of hydrocarbons in the form of gas chimneys and hydrocarbon shows in and above the regional seal. Interestingly, in the Lake Wellington Depression, many indicators of seal failure do not coincide. For instance, to the immediate east of Lake Wellington, there is a cluster of soil gas anomalies and possible evidence of leakage of fluids through the regional seal. There are,

however, no hydrocarbon shows in this area and the three petroleum wells drilled in this region (Nuntin-1, Nuntin-2 and Avon-1) were dry.

On the northern margin of the Lake Wellington Depression, numerous shows and soil geochemical anomalies are very likely to indicate a decrease in seal potential. At the north-eastern extremity of the Lake Wellington Depression, seal capacity in wells such as Goon Nure-1, -2 and -9, and Sperm Whale Head-1, are all around or over 200 m vertical columns for CO₂. This suggests that containment will not be lost due to the capacity of the seal, nor lithology (based on high smectite content in these wells). Rather, it is more likely that seal integrity close to the Lake Wellington Fault could be more of an issue as it is to the south of the depression on the Baragwanath Anticline (see Figures 4.13, 4.14 and 4.15).

Seaspray Depression

The potential of the regional seal in the Seaspray Depression is good to moderate. Although sealing capacity results in the central nearshore area of the depression are excellent (i.e. 263 m of CO₂ in Wulla Wullock-5), the depth to the base of the seal decreases to above 700 m over most of this area. The evaluation of seal potential in this area is therefore 'good' rather than 'excellent'.

Within the Seaspray Depression, seal potential decreases towards the margin, as it does in the Lake Wellington Depression (i.e. north, south and west). The top seal is generally around 100 m thick adjacent to the current day coastline in the Seaspray Depression, attaining a maximum thickness of 159 m in Lake Reeve-1 on the coast about 16 km to the northwest of the Golden Beach gas field. The depth to the base of the regional seal is greater than 800 m at Lake Reeve-1 but reduces to less than 800 m further onshore to the west and towards both the Baragwanath Anticline to the north and the Alberton Depression to the southwest. The same distribution is true of seal capacity values for hydrocarbons and CO₂.

There are no known hydrocarbon accumulations under the base of the regional seal in the Seaspray Depression and the gas accumulations in the North Seaspray and Gangell fields are found within Strzelecki Group sands rather than at the top of the Latrobe Group. Whether the lack of accumulations is due to an absence of effective seal over the Latrobe Group in the Seaspray Depression or inadequate migration pathways into the top Latrobe Group structures is unknown.

Alberton Depression

The Alberton Depression has very little, if any, potential for sealing either hydrocarbons or CO₂ at the base of the regional seal. The regional seal is very thin where it is present, close to the present day coast and the top seal capacity is poor (i.e. values of less than 10 m for CO₂) in the three wells for which capacity results are available in the area.

Lakes Entrance Platform

The seal potential of the Lakes Entrance Formation on the Lakes Entrance Platform is poor. There is no effective seal in this part of the onshore Gippsland Basin, as that limit is found further to the south offshore (see Figure 4.18). In this area, the seal is thin and is encountered at subsurface depths too shallow to contain supercritical CO₂. The presence of numerous shows in the top of the Lakes Entrance Formation and above, in the Gippsland Limestone (Figures 4.16 and 4.17) attest to the poor nature of the seal across the Lakes Entrance Platform.

Baragwanath Anticline

The Lakes Entrance Formation top seal is absent over the Baragwanath Anticline (between the Lake Wellington and Seaspray depressions) and top seal containment has been lost east of the anticline. Cover across the top of the Latrobe horizon on the anticline is thin (see Thomas & Baragwanath, 1949 and Hocking, 1988). For example, in Deadman Hill-1 the top of the Latrobe Group is intersected at around 100 m down-hole with only a 19-metre cover of Lakes Entrance Formation with overlying Gippsland Limestone and Haunted Hill Formation. The presence of a hydrocarbon seep (O'Brien *et al.*, 2008), based upon the radiometrics data (Figure 4.15) and the presence of numerous possible gas chimneys (Figure 4.12) over the anticline provide further evidence of likely loss of containment across the Baragwanath Anticline.

In summary, the potential of the regional top seal over the central eastern Lake Wellington Depression and the southern to central near shore areas in the Seaspray Depression are most suitable for the containment of supercritical CO₂. Further toward the margin of the regional seal in these two areas, containment of supercritical CO₂ is less likely.

Given the decrease in potential of the regional top seal around the margin of the Lake Wellington and Seaspray depressions, investigation of Latrobe Group intraformational seals in these areas may play an important role in further delineation of carbon storage plays. Previous work in the offshore Gippsland Basin has demonstrated sufficient occurrence and capacity of intraformational seals (Daniel, 2005; Gibson-Poole *et al.*, 2008) to warrant similar analysis in the onshore portion of the basin.

5 Capacity-Injectivity

Potential CO₂ storage capacity and injectivity are governed by the volume, distribution and connectivity of sand bodies within the reservoir. These have been assessed by reviewing existing information regarding formation distribution and thickness. The porosity and permeability of the Latrobe and Strzelecki Groups was assessed through an analysis of existing data from onshore petroleum wells held by GeoScience Victoria, with additional information from a suite of core plug samples which were analysed by Weatherford Laboratories in Perth (Table 5.1). A petrophysical analysis of wireline log porosity was also conducted at the Australian School of Petroleum by Natt Arian.

It is also important to identify the potential for CO₂ mediated mineralogical reactions within the reservoir, especially once the CO₂ has dissolved into the formation waters. These reactions have the potential to both increase (dissolution of carbonate cements) and decrease (precipitation of new minerals) porosity (Watson *et al.*, 2004). In the offshore Gippsland Basin, the juxtaposition of the glauconitic Gurnard Formation immediately beneath the regional seal and overlying the Latrobe Group reservoir, which is poor in reactive minerals, has been identified as having good potential for mineralogical trapping of injected CO₂ (Watson & Gibson-Poole, 2005; Gibson-Poole *et al.*, 2006). A similar geometry may be present in the onshore basin where the glauconitic Giffard Sandstone (basal unit of the Lakes Entrance Formation, Figure 3.2) lies in a similar stratigraphic position to the Gurnard Formation in the offshore basin. In order to evaluate the range of minerals present in the Latrobe Group reservoir, a study is currently underway to characterise the mineralogy of the Latrobe Group.

5.1 Latrobe Group Reservoir Characterisation

Distribution and connectivity

The Late Cretaceous to Cenozoic siliclastic Latrobe Group is considered to be the best reservoir candidate for GCS in the Gippsland Basin, as it is generally has excellent porosity-permeability characteristics and is host to the giant petroleum fields in the offshore area. It is dominated by non-marine alluvial, fluvial and coastal plain facies onshore (as outlined in Section 3) and has extensive porous sand bodies present. However, there is limited detailed analysis of the distribution and characteristics of the Latrobe Group in the onshore area.

The Latrobe Group thins to the west from the coast (Figure 5.1) where it has a thickness of about 800 metres. Within the Lake Wellington Depression, its thickness reduces to less

than 300 metres within 10km of the coast, with local thickening associated in the vicinity of the Rosedale Fault. In the Seaspray Depression, the Latrobe Group is thickest and most complete (Figure 3.2), as the Emperor, Golden Beach, Halibut and Cobia subgroups are all present. In this area, the Latrobe Group thins from greater than 1000m to less than 300m thick within 25km of the coast, although more than 1586m of Latrobe Group is present at Golden Beach West-1, where the base of the group is not reached.

Overlain on Figure 5.1 is the line showing the 800 m depth contour for the base of the Lakes Entrance Formation seal, which severely restricts the region onshore in which supercritical CO₂ can be ultimately contained to a lobate area within the Lake Wellington Depression. Within the Seaspray Depression, there is a limited region onshore with Lakes Entrance top seal at a suitable depth and intraformational seals are clearly needed to contain any injected CO₂ prior to it reaching the top of the Latrobe Group. However, it should be noted that within the three-nautical mile limit, there is a greater region with top seal at ≥ 800 m depth. The Latrobe Group reservoir in the Alberton Depression has not been further considered as seal is very poor over this area (see Figure 4.18).

Sand bodies within the Traralgon and Yarram Formations of the Latrobe Valley Coal Measures are also considered to be part of the Latrobe Group reservoir, as they are similar in lithology and age (Holdgate *et al.*, 2000). These formations make up most of the Palaeocene – Eocene sequence in the Alberton, Lake Wellington and Seaspray Depressions (Figure 2.2).

The onshore Latrobe Group is dominated by non-marine alluvial, fluvial and coastal plain facies, with extensive development of coal seams, especially in the Latrobe Valley (Chiupka, 1996). Fluvial and coastal plain facies tend to be more heterogeneous than shoreface facies, as they contain a higher proportion of finer grained units such as crevasse splays and floodplain deposits. Fluvial sandstone bodies tend to have poorer vertical and lateral connectivity.

Fine-grained lacustrine and floodplain deposits form intraformational baffles within the Latrobe Group. These are an important feature of the reservoir, as their presence increases the length and complexity of migration pathways of injected CO₂, which increases the storage efficiency of the reservoir. However, considerable work remains to be done in order to characterise the distribution of these units.

Previous work has identified the Golden Beach Subgroup as a potential hydrocarbon reservoir (Chiupka, 1996). From this, it has been suggested as having potential as a GCS reservoir (Hooper *et al.*, 2005) and was used as a case study

to estimate CO₂ storage capacity in the onshore basin (Bunch *et al.*, 2009). The current study re-assesses the distribution and thickness of the Golden Beach subgroup (Figure 5.2) and while it remains confined to the Seaspray Depression, it extends further west along the Rosedale Fault than previously recognised (Bernecker & Partridge, 2001),

reaching a thickness of more than 300 m in the area between Colliers Hill-1 and Deadman Hill-1 wells. However, the regional seal in the Seaspray Depression is only rated as 'moderate' (Figure 4.18), so further characterisation of intra-Latrobe seals is required to establish whether a Golden Beach play is possible in this area.

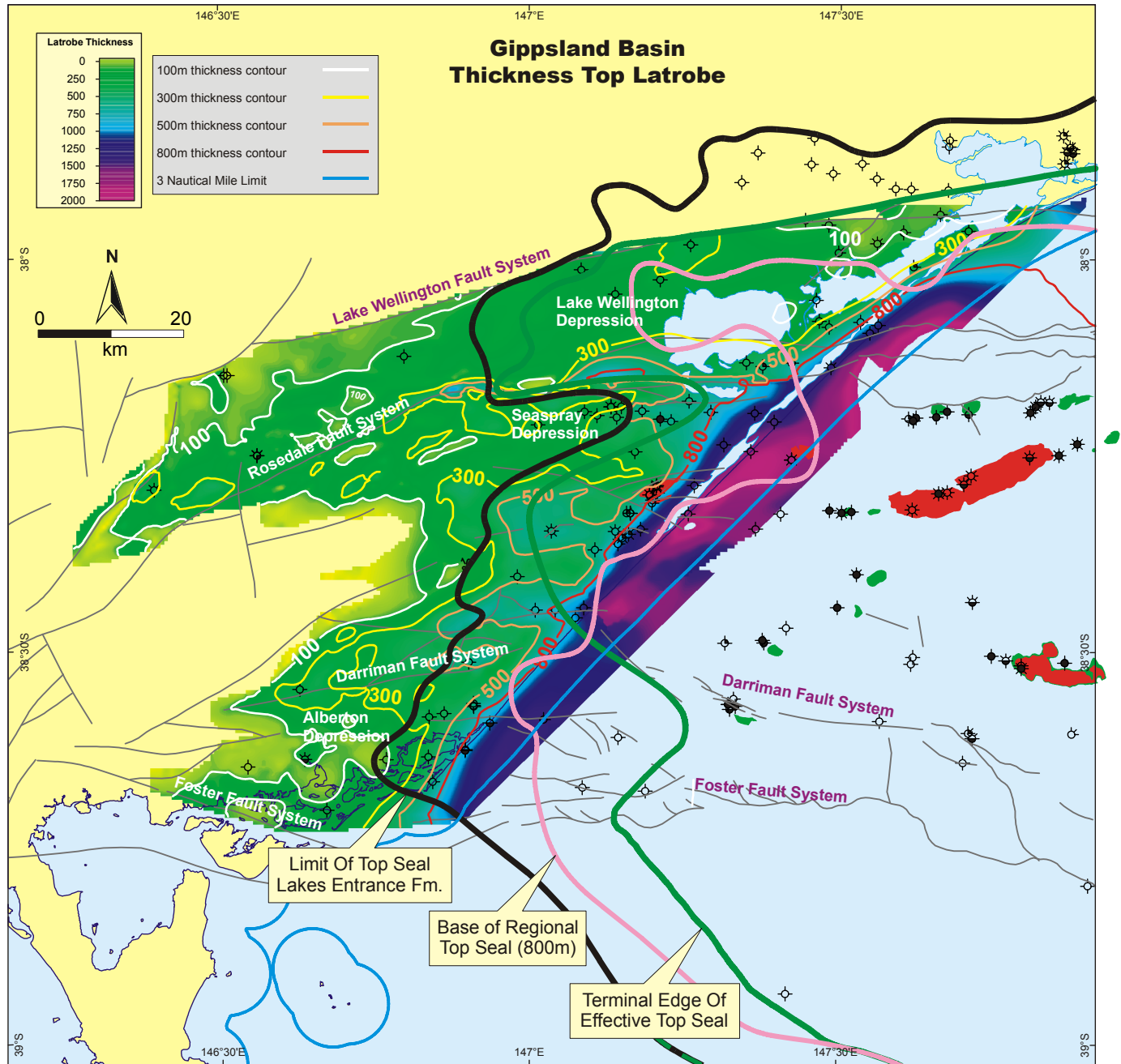


Figure 5.1 Distribution and thickness of the Latrobe Group in the onshore and nearshore areas (offshore thickness not shown completely).

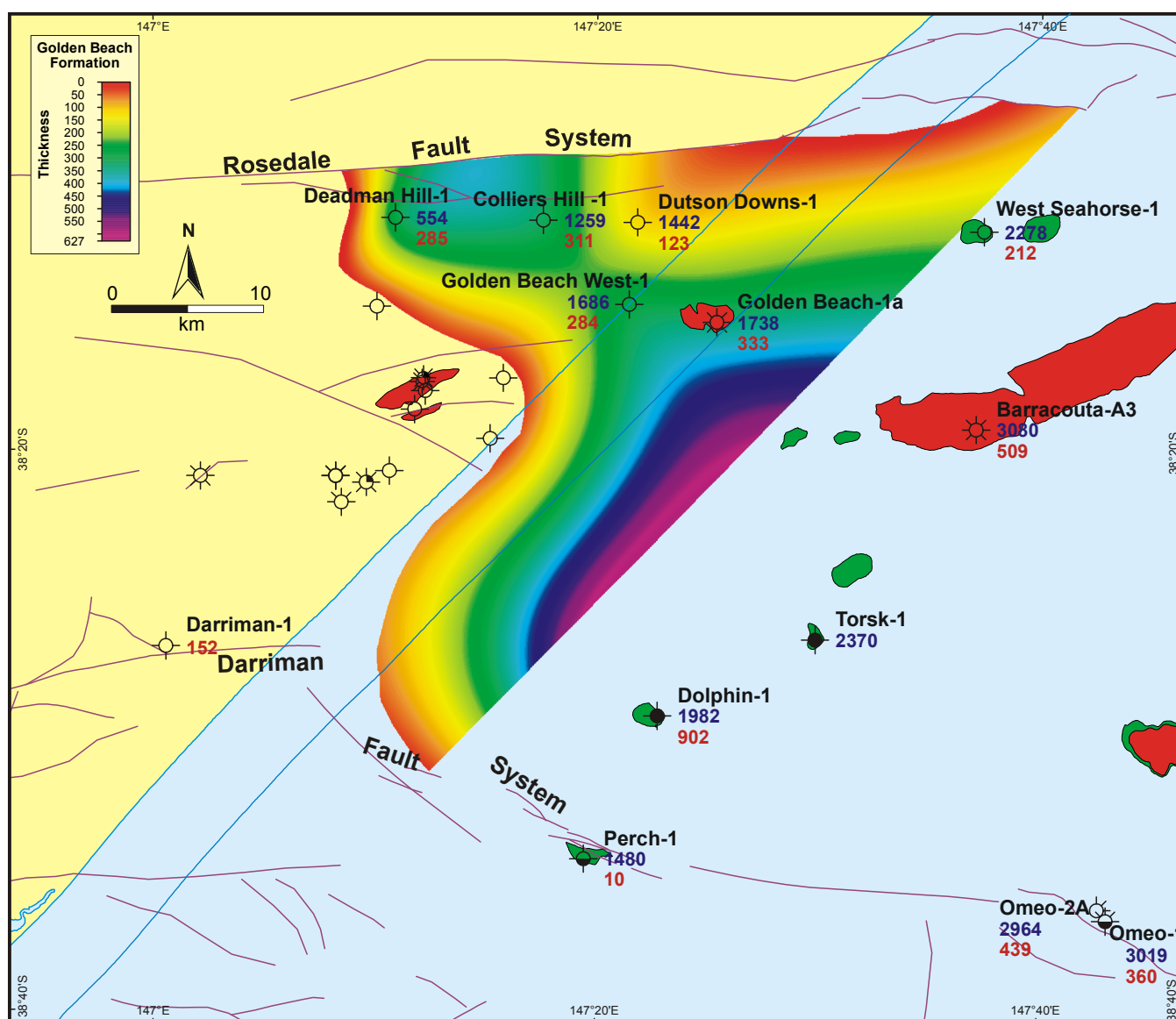


Figure 5.2 Distribution and thickness of the Golden Beach Subgroup in the onshore and nearshore areas. Around Darriman-1 there are volcanics of equivalent age to the Golden Beach Subgroup (Campanian). The blue number is the depth (mKB) of the subgroup top and the red number is the thickness; oil fields are shown in green and gas fields are red. Unnamed wells indicate where the Golden Beach Subgroup is absent onshore.

Porosity and permeability

The porosity and permeability characteristics of the reservoir are critical to potential injectivity and capacity, as they determine the rate and pressure of injection and the storage volume available. An analysis of existing data derived from wells showed that information about the Latrobe Group was sparse, especially with regard to permeability (Figure 5.3B). To a large extent, this is due to the friable nature of the sands, which made analysis difficult technically, as the more porous sands are often not sufficiently consolidated to analyse. A suite of 43 samples were taken from cores from petroleum wells and water bores and submitted to Weatherford Laboratories in Perth, Western Australia, for analysis of porosity and permeability. These were analysed using the standard methodology of Weatherford Laboratories (porosity via Helium and permeability to air) (Table 5.1). Unfortunately many of the samples were not suitable for

permeability analysis as they were too friable and disintegrated during testing.

In general, the overall porosity of the reservoir sands within the Latrobe Group is reasonable, with most samples having porosity above 20%, with the exception of the Emperor Subgroup and samples below ~1100 m (Figure 5.3A). Two samples show very low porosity, one of these (yellow square) is from Bengworden South-6 and is an indurated dolomitised sandstone, and the other (triangle) is from Golden Beach West-1 and is likely to have low porosity due to the presence of an argillaceous matrix.

The Emperor Subgroup samples consistently have lower porosity than younger Latrobe subgroups, due in part to the greater depth of the Emperor Subgroup and the associated additional compaction. These samples have been plotted

separately in Figures 5.3B & C. The permeability of the samples from the Emperor Subgroup also follow a different trend to the rest of the Latrobe Group samples, retaining higher permeability at greater depth than suggested by the general Latrobe Group trend, although permeability of these samples are still well below values considered suitable for CO₂ injection.

Permeability data for the Latrobe Group in the onshore Gippsland Basin is even sparser than porosity data, especially for depths greater than 800m. The relationship between permeability and depth and permeability versus porosity have been provided (Figures 5.3 B & C), but it is important to note that the dataset these relationships are drawn from is very limited, so caution needs to be taken with interpretation.

In addition to the core sample measurements, a petrophysical analysis of the sonic log from Golden Beach West-1 petroleum well (Figure 5.4) indicates that the majority of sands with reasonable porosity are found between depths of ~1400 to 1100 m, in the top half of the Halibut Subgroup. Porosities were derived using the Hunt-Raymer equation

(Raymer *et al.* 1980) from sonic log data. Gamma-ray and sonic log filters (55 API and 110 μ s/ft cut-offs) were utilised to exclude shales and coaly sections. Additional information was also used from composite logs and analysis of facies and depositional environments, to determine sand dominated sections, especially those that were unconsolidated. However, values above 40% on this graph are likely to be related to poor borehole condition, rather than reflect the true porosity.

The Latrobe Group sands have relatively high porosity (>30%) above ~1400 m, while the lower part of the Halibut Subgroup has markedly poorer porosity. The Golden Beach Subgroup appears to have relatively few clean sand units, although overall it has reasonable porosity. The porosity of the core plug derived samples (red squares, Figure 5.4) plot well below the maximum porosity for that depth when compared to log-derived data, which is probably due to the lack of porous sands that are consolidated enough to sample for core plug analysis. This is an important aspect to consider when making an assessment of the porosity of the Latrobe Group based on the core plug data provided in Figure 5.3

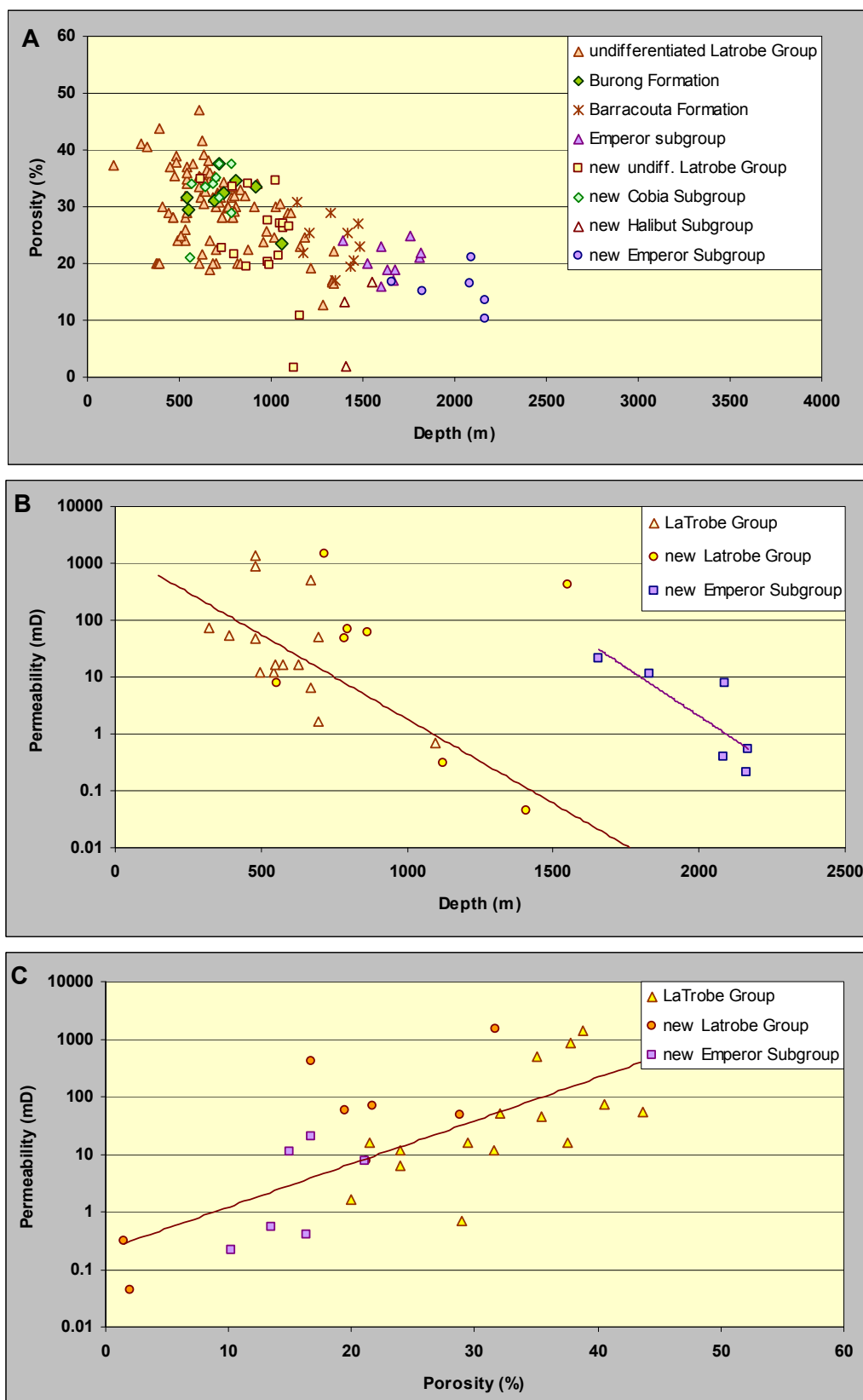


Figure 5.3 Porosity and permeability plots from the Latrobe Group in the onshore Gippsland Basin. Data are a compilation of new analyses (indicated by 'new' in the legend; Table 5.1) and existing petroleum well data held by GSV. **A:** porosity versus depth for the Latrobe Group; **B:** permeability versus depth for the Latrobe Group; **C:** porosity versus permeability for the Latrobe Group.

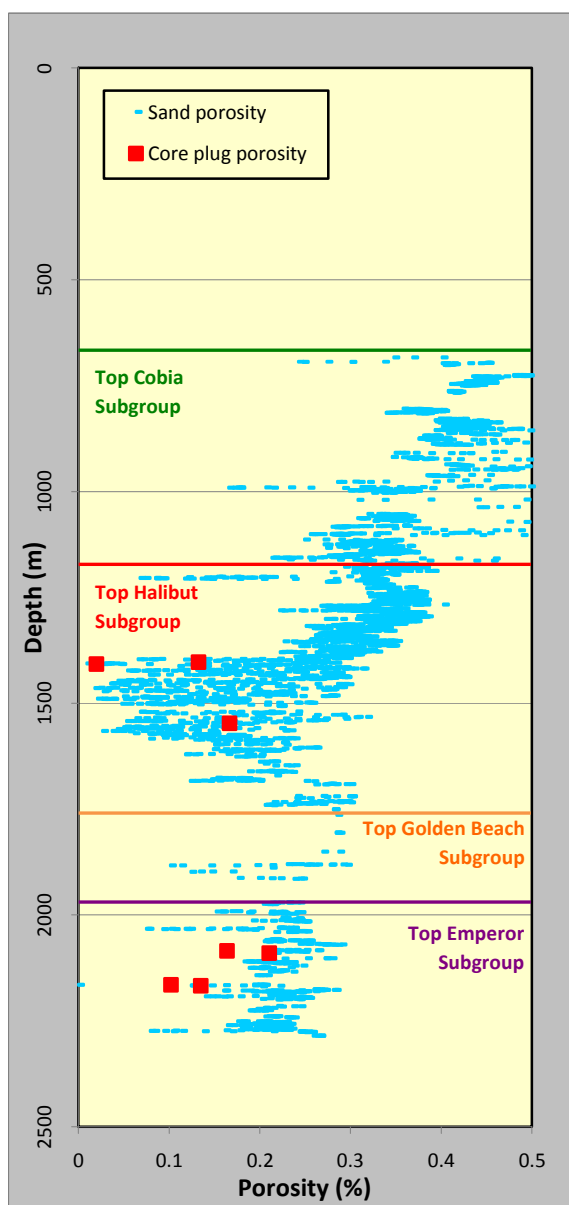


Figure 5.4 Average sand porosity derived from wireline log analysis of the Golden Beach West-1, with additional data from core samples.

There is more information available regarding Latrobe Group porosity and permeability in the offshore Gippsland Basin, including an extensive database compiled by ESSO (Moreton, 1990 a, b, c). In the offshore basin, depositional environment affects the porosity in a predictable manner (Moreton, 1990b). Marginal marine sands, upper shoreface, lower shoreface and estuarine facies preserve porosity better as depth increases rather than coastal plain or fluvial facies

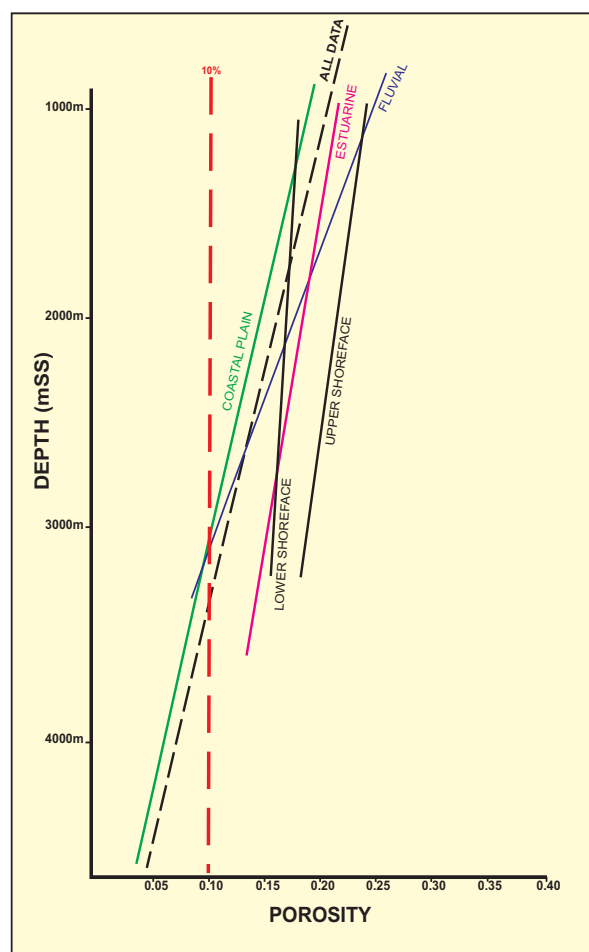


Figure 5.5 Average sandstone porosity depth trend for the offshore Gippsland Basin by depositional environment. Modified from Moreton, 1990b).

(Figure 5.5), as the former are more mineralogically and texturally mature. As the onshore Gippsland Basin has a higher proportion of fluvial and coastal plain facies than found offshore, it is predicted that porosity is likely to decline more rapidly with depth than may be the case in the offshore area.

The basal Giffard Sandstone and Cunningham Greensand members (Figure 3.2) of the Lakes Entrance Formation, have been interpreted in this study as part of the reservoir, as they lie beneath the smectite-rich sealing facies as described in Section 4.1. This is supported by the porosity and permeability measurements from Darriman-1 (531 m and 536 m) and Goon Nure-9 (763.4 m) wells, which plot within values of the Latrobe Group rather than the clay (smectite) and carbonate dominated Seaspray Group (Figure 5.6).

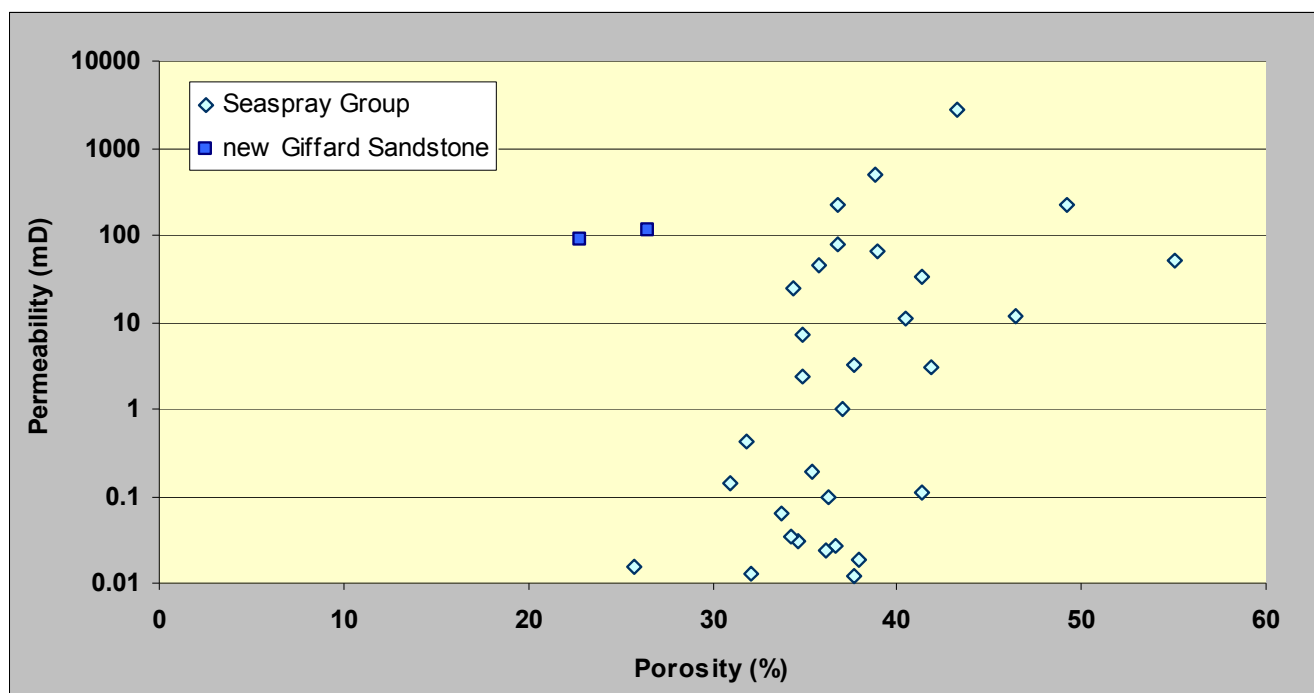


Figure 5.6 Porosity versus permeability of the Seaspray Group in the onshore Gippsland Basin. Data are a compilation of new analyses (indicated by 'new' in the legend; Table 5.1) and existing petroleum well data held by GSV.

5.2 Strzelecki Group Reservoir Characterisation

Rintoul's Creek Sandstone (Tyers River Subgroup)

The Strzelecki Group, especially the basal Hauterivian-Barremian Tyers River Subgroup (Figure 3.2), has been recognised as an additional target for GCS (Bunch *et al.*, 2009), as the relatively clean quartzarenite of the Rintoul's Creek Sandstone have good porosity and permeability in outcrop (Holdgate & McNichol, 1992), which was thought to be maintained at depth (Chiupka, 1996; Tosolini *et al.*, 1999). However, the reservoir capacity of the Rintoul's Creek Sandstone is questionable given that the quartz-arenite facies appears to be of limited extent and laterally discontinuous (Holdgate, *pers. comm.*, 2009), with it probably being confined to the basin margin and fault footwall deposition. A thin unit of coarse quartzose sandstone of equivalent age to the Rintoul's Creek Sandstone is found in Megascollides-1 at 1883m (Grosser, 2005), although it is only seven metres thick. The sands are coarse and poorly sorted, with a white argillaceous matrix and also strongly cemented, factors which all indicate that it is not a particularly good reservoir at this location. Porosity and permeability are correspondingly low (Grosser, 2005), with a single sample at 1889 mRT having 10.5% porosity and 56 mD permeability.

"Undifferentiated Upper Strzelecki Group"

In general, the "undifferentiated Upper Strzelecki Group" (*sensu* Tosolini *et al.*, 1999) is considered to have poor porosity and permeability characteristics, resulting from a combination of its volcanoclastic lithology and its burial and thermal history prior to 90 Ma (see Section 3.3). Porosity and permeability data from onshore petroleum wells confirm this (Figure 5.7), with porosities of generally less than 20%, and permeabilities below 10 mD at depths below 500 m (Figure 5.7B). Low porosity was also found by petrological analysis of a suite of five samples from Wellington Park-1, which were found to have porosity ranging from 3-7% from petrological observations (Phillips, 2009), with an extensive chlorite matrix.

Further evidence indicating low permeability of the Strzelecki Group comes from a comparison of gas geochemistry from Strzelecki sources (North Seaspray and Gangell fields), with gas sourced and reservoir from the Latrobe Group (O'Brien *et al.*, 2008). Gas from relatively shallow (<1,500 m) Latrobe fields is often biodegraded due to the influence of the freshwater wedge, while the Strzelecki fields are not biodegraded, even at shallow depths. This indicates that the Strzelecki reservoir sands are probably discontinuous, with permeabilities too low to allow flushing with fresh water. The corollary of this is that they are probably unsuitable for CO₂ injection.

The exception to the generally poor porosity and permeability of the Strzelecki Group are samples from Boundary Creek-1A (circled in red in Figure 5.7), which have much higher porosity and permeability. The porosity is intergranular primary porosity, with higher porosities corresponding to

coarse-grained sample with higher quartz contents (Duddy & Cook, 2002). The Strzelecki Group in this area does not appear to have undergone burial as deep as experienced elsewhere in the onshore basin. Vitrinite reflectance data from this well is only 0.37, compared to R_o values of 0.5 or more indicating deeper burial elsewhere (see Section 3.3). It is therefore possible that Boundary Creek-1A represents a snapshot of a Strzelecki Group interval that has maintained porosity and permeability characteristics typical of this group prior to deep burial. Further investigations need be carried

out to determine the causes of these locally improved reservoir properties.

Overall, there is limited information regarding the reservoir potential of the Strzelecki Group, although the indicators are that this group either unsuitable or poorly suited for GCS. The group's burial history has typically destroyed reservoir quality where $R_o > 0.5\%$, and permeability in the onshore region are expected to be $< 10\text{mD}$, indicating that reservoir stimulation would be required for CO_2 injection.

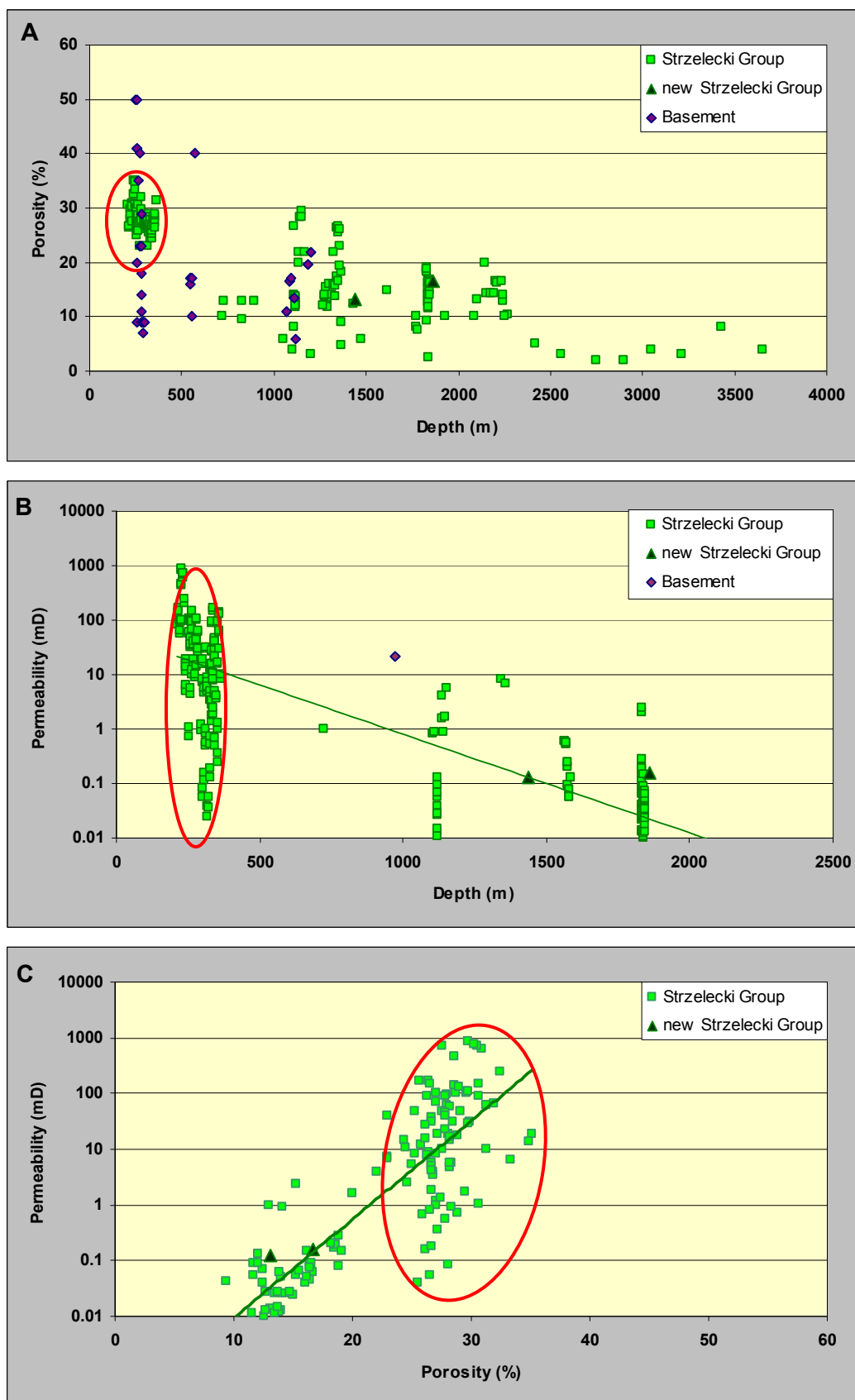


Figure 5.7 Porosity and permeability plots from the Strzelecki Group and the basement in the onshore Gippsland Basin. Data are a compilation of new analyses (Table 5.1) and existing petroleum well data held by GSV. **A:** porosity versus depth for the Strzelecki Group and the basement; **B:** permeability versus depth for the Strzelecki Group; **C:** porosity versus permeability for the Strzelecki Group. Red ovals indicate data from Boundary Creek-1A.

Table 5.1 Porosity and permeability measurements from selected wells in the onshore Gippsland Basin. * indicates where samples were sleeved and re-tested for permeability.

Well	Depth (m)	Porosity (%)	Permeability to air (mD)	Grain Density (g/cm ³)	Formation	Lithology
Bengworden South-6	993.80	19.8	-	2.60	Latrobe Group (undifferentiated)	medium-grained, layered sandstone
Bengworden South-6	1023.50	34.7	-	2.61	Latrobe Group (undifferentiated)	coarse-grained sandstone
Bengworden South-6	1043.80	21.4	-	2.63	Latrobe Group (undifferentiated)	medium-grained sandstone
Bengworden South-6	1049.90	26.9	-	2.67	Latrobe Group (undifferentiated)	medium-grained sandstone
Bengworden South-6	1065.70	26.5	-	2.64	Latrobe Group (undifferentiated)	coarse-grained pebbly sandstone
Bengworden South-6	1068.40	26.2	-	2.67	Latrobe Group (undifferentiated)	sandstone, organic rich
Bengworden South-6	1069.80	27.0	-	2.61	Latrobe Group (undifferentiated)	pebbly sandstone, organic rich
Bengworden South-6	1098.70	26.5	-	2.62	Latrobe Group (undifferentiated)	sandstone layered with coal fragments
Bengworden South-6	1126.00	1.5	0.30	2.72	Latrobe Group (undifferentiated)	dolomitised sandstone, indurated
Boole Poole-1	875.10	34.0	-	2.69	Latrobe Group (undifferentiated)	coarse sandstone
Carr's Creek-1	703.50	35.2	-	2.63	Latrobe Group (Cobia Subgroup)	medium-grained sandstone, massive, fluvial-deltaic
Carr's Creek-1*	1633.80	13.8	748	2.62	Strzelecki Group	compacted volcanoclastic sandstone, massive
Colliers Hill-1	645.00	33.6	-	2.63	Latrobe Group (Cobia Subgroup)	sandstone with pebbles, fluvial
Colliers Hill-1	680.00	34.1	-	2.67	Latrobe Group (Cobia Subgroup)	pebbly sandstone, fluvial
Colliers Hill-1	714.20	37.7	-	2.65	Latrobe Group (Cobia Subgroup)	sandstone, fluvial
Colliers Hill-1*	718.00	31.7	1471	2.72	Latrobe Group (Cobia Subgroup)	sandstone with organic fragments
Colliers Hill-1*	783.40	28.8	47.7	2.61	Latrobe Group (Cobia Subgroup)	medium-grained coaly sandstone
Colliers Hill-1	786.20	37.5	-	2.61	Latrobe Group (Cobia Subgroup)	medium-grained coaly sandstone
Darriman-1	531.00	32.9	-	2.63	Seaspray Group (Giffard Sandstone)	fine grained sandstone
Darriman-1*	536.00	22.8	87.1	2.62	Seaspray Group (Giffard Sandstone)	fine grained sandstone
Darriman-1*	555.50	21.2	7.6	2.62	Latrobe Group (Cobia Subgroup)	coaly siltstone
Darriman-1	564.00	34.1	-	2.62	Latrobe Group (Cobia Subgroup)	fine sandstone, organic rich
Darriman-1	1440.00	13.1	0.13	2.63	Strzelecki Group	volcanic sandstone
Duck Bay-1	970.20	19.3	-	2.65	Permian	fine sandstone
Dutson Downs-1	1860.40	16.7	0.16	2.72	Latrobe Group (Cobia Subgroup)	compacted sandstone, volcanigenic clays

Well	Depth (m)	Porosity (%)	Permeability to air (mD)	Grain Density (g/cm ³)	Formation	Lithology
Golden Beach West-1	1403.00	13.3	-	2.67	Latrobe Group (Halibut Subgroup)	coarse sandstone
Golden Beach West-1	1408.00	2.0	0.04	2.68	Latrobe Group (Halibut Subgroup)	pebbly sandstone
Golden Beach West-1*	1548.00	16.7	415	2.64	Latrobe Group (Halibut Subgroup)	coarse sandstone
Golden Beach West-1	2085.00	16.4	0.39	2.66	Latrobe Group (Emperor Subgroup)	sandstone, layered
Golden Beach West-1	2090.00	21.1	7.6	2.68	Latrobe Group (Emperor Subgroup)	sandstone
Golden Beach West-1	2165.00	10.2	0.21	2.74	Latrobe Group (Emperor Subgroup)	coarse sandstone
Golden Beach West-1	2167.00	13.5	0.53	2.69	Latrobe Group (Emperor Subgroup)	coarse sandstone, rip-ups
Goon Nure-9*	763.40	26.6	111	2.62	Seaspray Group (Giffard Sandstone)	mudstone with pebbles, sandstone
Goon Nure-9	795.20	33.5	-	2.66	Latrobe Group (undifferentiated)	fine sandstone, unconsolidated
Goon Nure-9*	862.90	19.5	59.0	2.67	Latrobe Group (undifferentiated)	fine sandstone, unconsolidated
Holey Plains-185	1158.00	10.9	-	2.66	Latrobe Group (undifferentiated)	fine sandstone
Merriman-1	1656.90	16.7	20.8	2.65	Latrobe Group (Emperor Subgroup)	coarse sandstone
Merriman-1	1828.80	15.0	11.2	2.66	Latrobe Group (Emperor Subgroup)	coarse sandstone
North Seaspray-1	616.00	34.9	-	2.63	Latrobe Group (undifferentiated)	medium grained sandstone
North Seaspray-1	980.00	20.3	-	2.67	Latrobe Group (undifferentiated)	pebbly coarse sandstone, semi-consolidated
North Seaspray-1	980.50	27.7	-	2.61	Latrobe Group (undifferentiated)	coarse sandstone, semi-consolidated
Woodside South-1	732.70	22.7	-	2.63	Latrobe Group (undifferentiated)	pebbly coarse sandstone
Woodside South-1*	796.70	21.7	68.8	2.61	Latrobe Group (undifferentiated)	pebbly coarse sandstone

5.3 Storage Capacity

Given the early stages of greenhouse gas exploration in the onshore Gippsland Basin, basin storage capacity estimates are all based upon U.S. Department of Energy (2006) saline formation methodology and have large uncertainties associated with them. Storage capacity estimates for the onshore Gippsland Basin are based upon estimates of the fraction of porosity available for storage and currently involve no detailed site characterisation. Therefore, simulation of storage capacity can be expected to change with the inclusion of more detailed data.

Based on the current state of knowledge of the Gippsland Basin, GeoScience Victoria has estimated that the CO₂ storage potential is between 0 and 350 Mt for the onshore component of the basin. Senergy, using a significantly lower efficiency factor, has recently estimated a storage capacity of 65 Mt for the onshore Gippsland Basin (Gunn *et al.*, 2009).

Prospective estimates between 17 and 101 Mt have been made for carbon storage leads associated with intraformational Golden Beach and the basal Halibut Sub-Group sands (Bunch *et al.*, 2009).

6 GCS Plays and Impacts

6.1 Carbon Storage Plays

Carbon storage plays in the onshore Gippsland Basin vary across the exploration areas to reflect the geology in the basin. Work to date has been at a high level, possible reservoir–seal pairs and storage leads have been identified but further investigations are needed to identify structures and/or locations where saline aquifer trapping can occur. Sparse seismic data over the western edge of GCS09-2 and the western part of GCS09-1 limits the delineation of structures. Much of the recent work (i.e. Gibson-Poole *et al.*, 2006; Bunch *et al.*, 2009) relies heavily on the geological results and interpretations of Chiupka (1996). Bunch *et al.* (2009) has extended the work of Gibson-Poole *et al.* (2006) by screening potential storage sites in the onshore Gippsland Basin. Bunch *et al.* (2009) has also reviewed the seismicity and hydrological issues associated with the onshore Gippsland Basin.

In this study, six plays (Figure 6.1) covering the Strzelecki Group, Latrobe Group and Latrobe Valley Group are discussed. Each play is summarised in Table 6.1.

(1) Tyers River Subgroup- Strzelecki Group

The ideal Tyers River Subgroup reservoir-seal pair consists of quartzose sandstone reservoirs in the lower part of the Strzelecki Group sealed by intraformational seals and the overlying volcanigenic Strzelecki Group. Potential for this play occurs in both exploration tender areas. However, the distribution of quartzose siliciclastics interpreted by Chiupka (1996) is significantly less extensive than has been previously discussed. The only intersections of quartzose reservoirs are in outcrops illustrated in Chiupka (1996) and in Megascolides-1 and -2. Highly cemented quartzose siliciclastics have also been intersected in Boola Boola-2 and Hazelwood-1, which are likely to be from the Tyers River Subgroup (O'Brien & Sun, 2007; Sun & O'Brien, 2007). Age equivalent successions have been penetrated (e.g. Wellington Park-1, Loy Yang-1A) but have intersected volcanoclastic sandstones similar to those in the upper part of the Strzelecki Group. Figure 6.1 illustrates locations where the Tyers River Subgroup facies has been found. Megascolides-1 and -2 have encountered quartzose sandstones, but to date the best permeability is 0.27 mD (Tolliday, 2007). One permeability measurement of uncertain quality gave a value of 56 mD (Arditto, 2009).

New data are needed to identify regions where better reservoir conditions can be found at the base of the Strzelecki Group. In addition, the current models suggest that the storage capacity appears to be significantly less than indicated by the data in Chiupka (1996). Bunch *et al.* (2009) have discussed the Tyers River Subgroup play utilising Chiupka's (1996) petroleum plays (one located on the northern basin margin and another developed over a basement high in the vicinity of the Bellbird-1 well). The second play should be treated with caution, given the current understanding that the Tyers River Subgroup is locally developed along the northern and southern edges of the basin. Petroleum exploration leads have been discussed in Chiupka (1996) and are also discussed in terms of CO₂ storage by Bunch *et al.* (2009).

Key Technical Uncertainties

The main technical uncertainty with the Tyers River Subgroup play is locating quartzose reservoir facies with acceptable permeability. Current depositional models (e.g. Tosolini *et al.*, 1999) suggest that the reservoir facies is localised in nature. If suitable reservoir can be found, then suitable top sealing lithologies are likely to be present in the overlying Strzelecki Group. The main risk with regards to containment is likely to be related to fault seal and the attendant geomechanical issues associated with injection into a relatively isolated hydrological unit.

(2) Strzelecki Reservoir – Intra Strzelecki Group Seal

The Strzelecki storage play is the most widespread across the two exploration tender areas (shaded light green across GCS09-1 and GCS09-2 in Figure 6.1) and numerous petroleum structural leads have been presented by Chiupka (1996).

Key Technical Uncertainties

The key uncertainty for this storage play is the probable lack of reservoir with permeability greater than 100 mD, at depths greater 1000 m (see Figure 5.7). Containment is a subsidiary risk but the presence of the North Seaspray and Gangell gas fields demonstrates that suitable intraformational seals are present. In terms of a saline aquifer play, the faulted nature of the Strzelecki Group and the widespread distribution of hydrocarbon shows indicate that regional containment will be difficult to confirm. Soil gas geochemical surveys across the Strzelecki Group also indicate that seal failure is a possibility (see Section 4.4). Delineation of faulting and geomechanical issues associated with injection also present significant technical challenges.

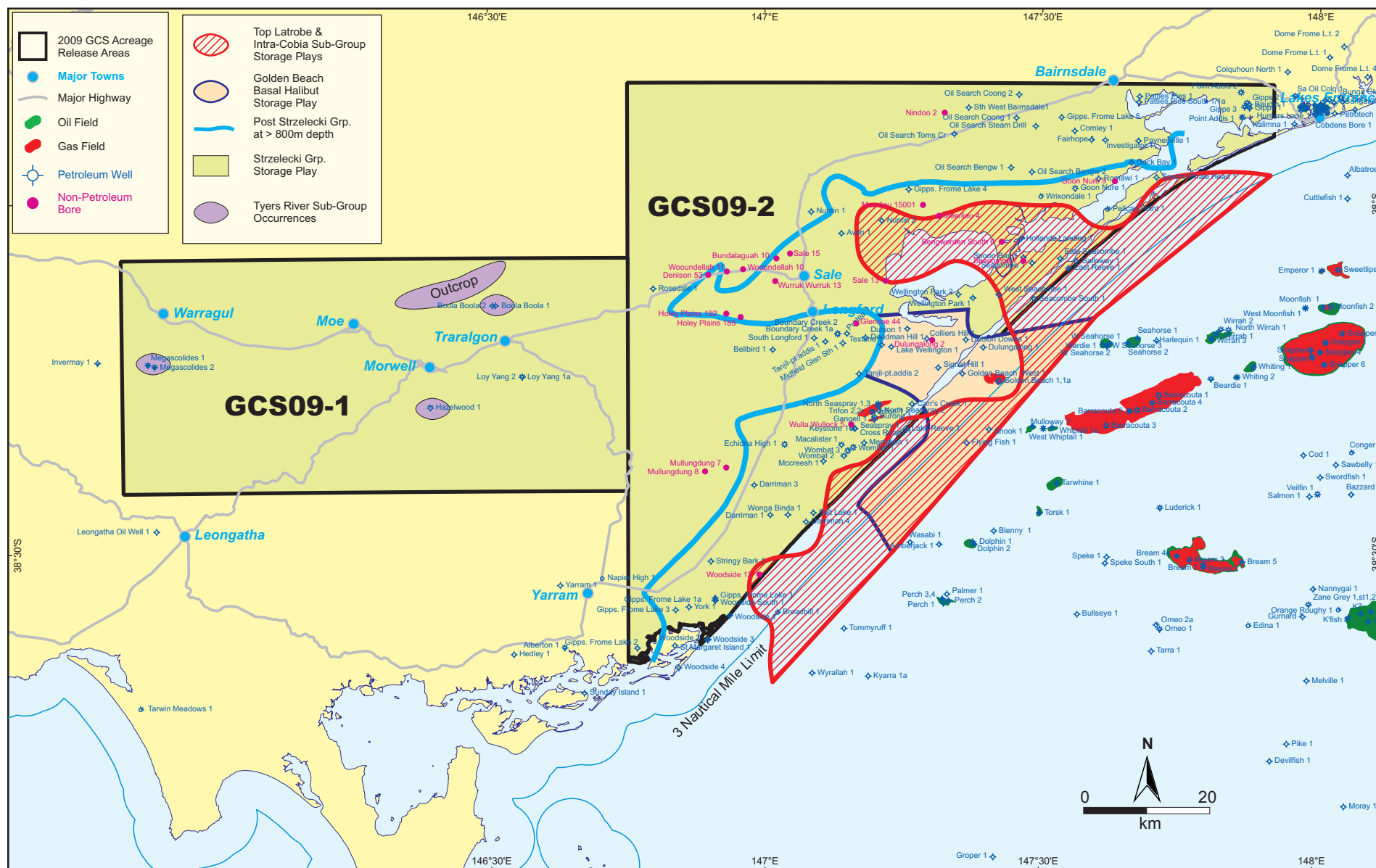


Figure 6.1 Carbon Storage Play Fairways.

(3A) Golden Beach Reservoir – Intraformational Golden Beach Subgroup seal

The Golden Beach Subgroup has restricted storage potential in the northeastern part of the Seaspray Depression within GCSO9-2 (Figure 6.1). In Golden Beach West-1 and Dutson Downs-1, a sand approximately 150 metres thick, with a porosity of around 25% (Figure 5.4), appears to be sealed by intraformational and basal Halibut Subgroup seals. This lead has been discussed by Bunch *et al.* (2009) and has potential for pinch out and structural closure against the Rosedale Fault (Chiupka, 1996). DST results indicate good reservoir quality for the Golden Beach reservoir (Chiupka, 1996).

Key Technical Uncertainties

The key technical uncertainty for this play is the geometry and capacity of the intraformational seals. A sequence stratigraphic and depositional environment framework is needed to better understand this play. Petrophysical data are also needed to delineate the reservoir and seal distribution. A geomechanical assessment of the Rosedale Fault is outlined in Bunch *et al.* (2009).

(3B) Halibut Subgroup Play

A 100-metre thick sand occurs in Golden Beach West-1, which has intraformational top seal and lateral seal associated with deeper units. Porosity in these sands appears high (around 30%, Figure 5.4). The intraformational ‘top’ seal is approximately 50 m thick. For further information, see Bunch *et al.* (2009).

Key Technical Uncertainties

The distribution of reservoir sands is unknown, as is the lateral continuity of the intraformational seal and seal quality.

(4) Cobia Subgroup – Intraformational Sands and Shales

Three *N. asperus* sands, 15 metres thick in the Lake Wellington Depression (in East Reeve-1 and Spoon Bay-1), with seals approximately 30 metres thick have been identified as a potential hydrocarbon play (Chiupka, 1996) and a carbon storage lead (Bunch *et al.*, 2009). These sand-shale pairs dip offshore and may have petroleum potential (Chiupka 1996)

Key Technical Uncertainties

The main technical uncertainty for a Cobia Subgroup play is the distribution and quality of the intraformational ‘top’ seals for the *N. asperus* sands.

(5) Top Latrobe Sands-Lakes Entrance Formation Top Seal

Sands of approximately 100 m total thickness are present in Spoon Bay-1 in the Lake Wellington Depression. These have good porosities, greater than 30% and are sealed by the Lakes Entrance Formation. In this area, the regional top seal is present at depths greater than 1000 metres and the sealing capacity is excellent (i.e. a vertical column of 306 m of CO₂ could be held by the seal). In the Lake Wellington and Seaspray depressions, only small areas satisfy the requirement for good seal and reservoir depths below 800 m.

Chiupka (1996) has argued that there is limited hydrocarbon potential at top Latrobe Group level due to water washing and dissolution of hydrocarbons. As such, the lack of hydrocarbons is explained and potential traps could still be found at this level, although the size of traps would be expected to be relatively small.

Key Technical Uncertainties

A satisfactory top Latrobe Group site would require better delineation of traps and migration pathways for CO₂ plume spread. The limited area of the play reduces the potential storage capacity.

(6) Latrobe Valley Group reservoirs and intraformational seals

Bunch *et al.* (2009) has examined the storage potential of the Latrobe Valley Group in the vicinity of the open-cut coal mines of Yallourn, Hazelwood and Loy Yang. The coals in the open-cut mines are present to depths of around 200 to 300 metres. These depths are too shallow for the storage of supercritical CO₂ (below approximately 800 metres), which allows conventional buoyancy trapping. Containment is clearly the major issue given the shallow depths. Storage within coals in the Cenozoic section is not considered to have significant potential and may have significant impacts on coal and water resources. Further details are given in Bunch *et al.* (2009).

Table 6.1 A summary of carbon storage plays in the Onshore Gippsland Basin.

Reservoir/Seal Pair	Trap	Location	Potential Impacts	Key Technical Uncertainties	References
1. Tyers River Subgroup	Structural and stratigraphic traps Saline aquifer trapping	GCS09-01 & GCS09-02 Seaspray Depression	Coal and potential hydrocarbon and geothermal resources, limited groundwater impact	Trap/migration path definition, locating suitable reservoir facies, and fault seal	Tosolini <i>et al.</i> , 1999; Holdgate & McNicol, 1992; O'Brien <i>et al.</i> , 2008; Arditto, 2009
2. Strzelecki Group	Structural and stratigraphic traps Drape over basement highs	GCS09-01 & GCS09-02	Coal and localised petroleum resources and potential geothermal resources Limited impact on groundwater	Trap/migration path definition, locating suitable reservoir facies Proven seal locally but regional distributed soil anomalies and gas chimneys suggest widespread leakage and seepage associated with fault seal	Chiupka, 1996; Bunch <i>et al.</i> , 2009; this study
3. A Intraformational Golden Beach Subgroup B Halibut Subgroup	Structural and stratigraphic traps Saline aquifer trapping	GCS09-02 Seaspray Depression	Moderate hydrocarbon resource potential Proximity to Golden Beach gas field Potential water resource impact	Trap/migration path definition, unproven intraformational seal and fault seal	Chiupka, 1996 ; Gibson-Poole <i>et al.</i> , 2006 ; Bunch <i>et al.</i> , 2009; this study
4. Intraformational Cobia Subgroup	Structural and stratigraphic traps Saline aquifer trapping	GCS09-02 Lake Wellington Depression	Hydrocarbon exploration resource potential Water and geothermal resources	Trap/migration path definition, proven intraformational seal, fault seal Probable onshore migration direction	Chiupka, 1996 ; Gibson-Poole <i>et al.</i> , 2006 ; Bunch <i>et al.</i> , 2009; this study
5. Top Latrobe reservoir - Lakes Entrance Formation seal	Small closures Stratigraphic traps Saline aquifer trapping	GCS09-02 Central eastern Lake Wellington Depression and limited areas nearshore-onshore Seaspray Depression	Limited petroleum potential Water and geothermal resources	Trap/migration path definition Limited area Short migration path to edge of seal Storage capacity	Chiupka, 1996; this study; Bunch <i>et al.</i> , 2009
6. Latrobe Valley Group intraformational reservoirs and seals	Structural and stratigraphic traps	GCS09 -1 Latrobe Valley	Potentially high impact on coal, water and geothermal resources	Insufficient depth for supercritical CO ₂ storage	Bunch <i>et al.</i> , 2009

Assuming the following technical criteria for a low risk carbon storage play: reservoir depth greater than 800 m, proven top seal potential and a high probability of the presence of reservoir rocks with >100 mD permeability, then only the top-Latrobe play is close to meeting these criteria, and the geographic area within which the criteria are met for this play is limited. The other plays have significant technical risks associated with top seal/fault seal containment and/or reservoir potential, which need to be addressed by future exploration activities. Structures and migration pathways suitable for CO₂ storage also need better characterisation. Chiupka (1996) considered that petroleum structures in the onshore basin had an upper range of 70 Mbls (approximately 11 MMm³), which can be used as an upper guide to the potential pore volume of traps yet to be found. Clearly, the storage of significant volumes of CO₂ onshore will rely primarily upon aquifer trapping.

6.2 Potential Impacts

In this report, potential impacts are limited to discovered and potential geological resources. These resources include hydrocarbon resources, geothermal resources and potable water resources. As investigations move from exploration to detailed site assessment, the potential for a wider range of impacts (e.g. upon surface features) should also be considered.

For greenhouse gas storage exploration activities, the range of potential impacts are expected to be similar to those currently associated with petroleum and geothermal exploration.

Table 6.2 indicates the operators of the permits shown in Figure 6.2. GCS09-1 and GCS09-2 are covered by geothermal exploration permits. The eastern part of the area covered by GCS09-1 has a petroleum exploration licence and coal mining licences. GCS09-2 is partially covered by two petroleum exploration licences and includes a petroleum retention lease. GCS09-2 is adjacent to a petroleum retention lease associated with the Golden Beach gas field.

In terms of the carbon storage plays discussed above, all plays have some potential impact with undiscovered petroleum resources as both permits contain the Strzelecki Group, which has reached maturities suitable to generate petroleum. Similarly, there is some geothermal prospectivity associated with both exploration areas. The Strzelecki Group and Tyers River Subgroup plays could potentially affect overlying coal resources in some locations but would probably involve lower potential impacts on ground water resources if sites have suitable containment. The Latrobe Group storage plays probably have limited potential impact on petroleum prospectivity but potentially high impact on water resources due to possible hydraulic connection with shallower groundwater resources.

Table 6.2. Petroleum and geothermal resource permits associated with GCS09-1 and 2.

Petroleum Exploration Permits	Operator (% interest)
PEP 166	Petro Tech (50)
PEP 158	Petro Tech (100)
Petroleum Retention Leases	
PRL 2	Petro Tech (100)
PRL 3	Petro Tech (100)
VIC/RL 1(V)	Cape Energy Victoria (100)
Geothermal Exploration Permits	
GEP 11	Granite Power Ltd (100)
GEP 12	Greeneearth Energy Ltd (100)
GEP 13	Greeneearth Energy Ltd (100)
GEP 24	MNGI Pty Ltd (100)

An important aspect of potential carbon storage plays is the geometry of the top seal and potential migration directions of free CO₂ under buoyancy. Currently a depth-corrected surface is only available for the top Latrobe Group horizon. Migration paths for buoyant fluids (density less than water) are shown (Figure 6.3) for selected injection sites near the coast within GCS09-2. Also shown on Figure 6.3 is the outline of the top Latrobe Group storage play and the terminal edge of effective seal. Migration vectors stop at the terminal edge of effective seal as it is assumed that migration will move into the regional seal at this boundary. Any scenario involving CO₂ migration to the edge of effective seal would be likely to lead to loss of CO₂ containment and potential impacts on shallow ground water resources.

The migration pathways show that the prevailing migration directions below the regional seal are onshore. Within the northern part of the Wellington Depression, migration is predominantly NNW. If sufficient buoyant fluid were injected in the vicinity of East Reeve-1, it would travel approximately 15 km prior to reaching the point where the base of the seal would be less than 800 m depth. After this point, free CO₂ would begin to expand and have a lower density and migrate a further 5 km before reaching the edge of effective top seal. It should be noted that the buoyancy migration paths are based on simple geometric modelling and are not the result of rigorous simulation. Nevertheless, they indicate that the area that can be used for the top Latrobe Group play is spatially limited and migration pathways are typically shorter than 10 km within the Lake Wellington Depression.

Within the Seaspray Depression, migration pathways beneath the regional seal are also onshore but occur at depths less than 800 m, which means that CO₂ density reduction would also occur. In the vicinity of Dulungalong-1, migration pathways move towards the Baragwanath Anticline. Further south, migration pathways proceed

towards top Latrobe Group closure above the North Seaspray and Gangell gas fields before heading north. Migration pathways further south are also affected by a top Latrobe Group structure overlying the Wombat gas accumulations.

The influence of these top Latrobe Group structures illustrates that potential impacts on future gas production would need to be considered in any scenario where free CO₂ was present at top Latrobe Group level in these regions.

It should be noted that the top Latrobe Group and deeper Strzelecki reservoir systems are effectively compartmentalised and that little potential exists for direct contamination of a Strzelecki gas reservoir (such as North Seaspray or Gangell) with CO₂ injected into a top Latrobe or even intraformational Latrobe Group reservoir. Deleterious impacts would probably be most likely restricted to potential damage to well completions by CO₂.

The most significant direct and immediate impact of CO₂ injection into the top Latrobe or intraformational Latrobe Group reservoirs would probably be on the groundwater resources within this aquifer system. These resources are currently un-utilised and relatively little is known about them. Based upon the available limited data, it appears that groundwater within the Latrobe Group over most of the onshore and indeed near shore areas is very fresh (i.e. <5000 ppm Na⁺; Figure 6.4). Examination of the relationship between Na⁺ concentration and sub-surface depth (Figure 6.5) indicates that the groundwaters are basically fresh to depths of approximately 1350 m. Below these depths, salinities increase progressively but Na⁺ is typically still <5000 ppm (Figure 6.4). GeoScience Victoria is currently investigating the composition of the deeper groundwater resources in both the onshore and offshore Gippsland Basin so that a better understanding of possible impacts and mitigation strategies can be developed.

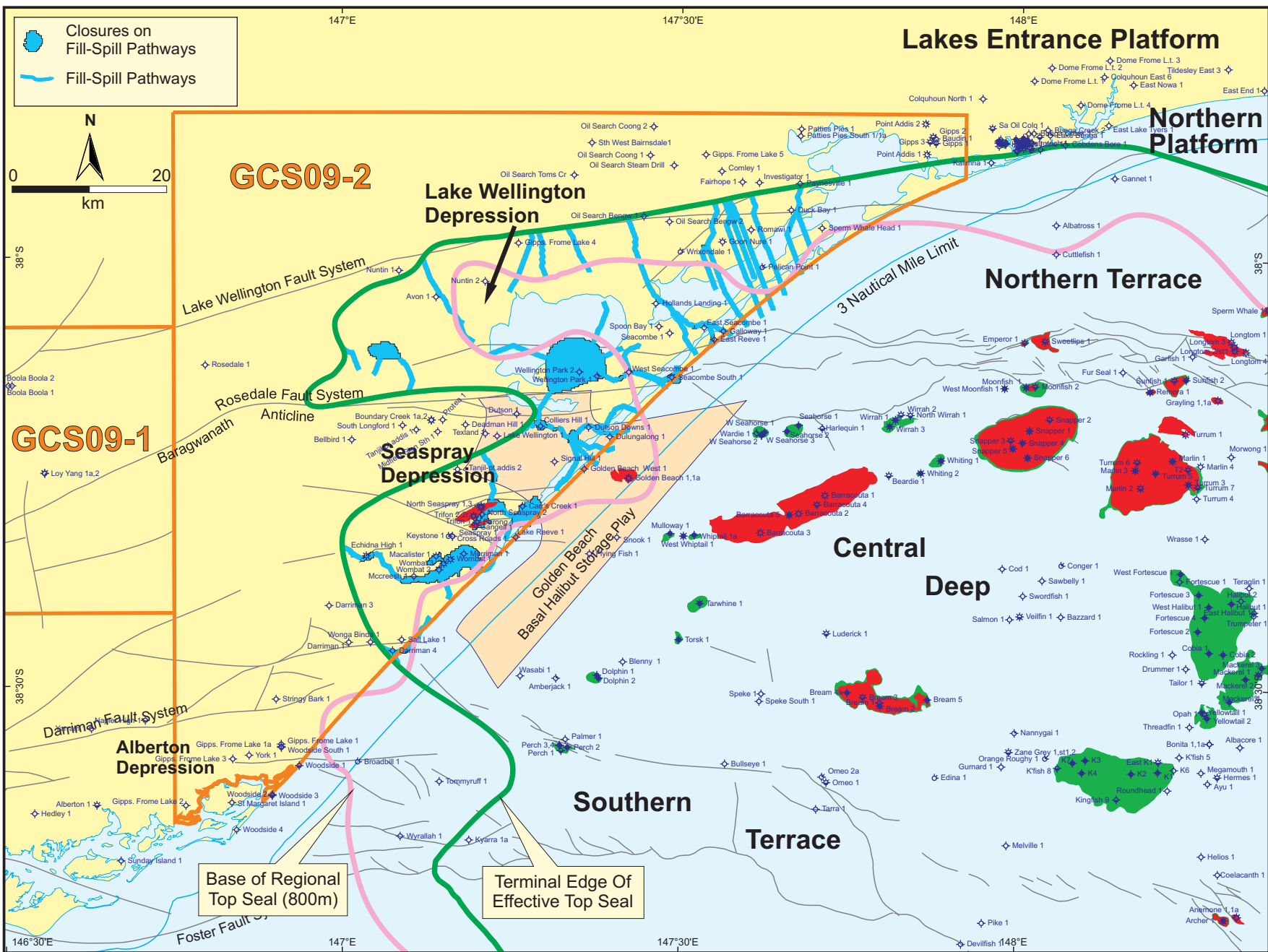


Figure 6.3 Migration paths for buoyant fluids for selected injection sites near the coast within GCS09-2.

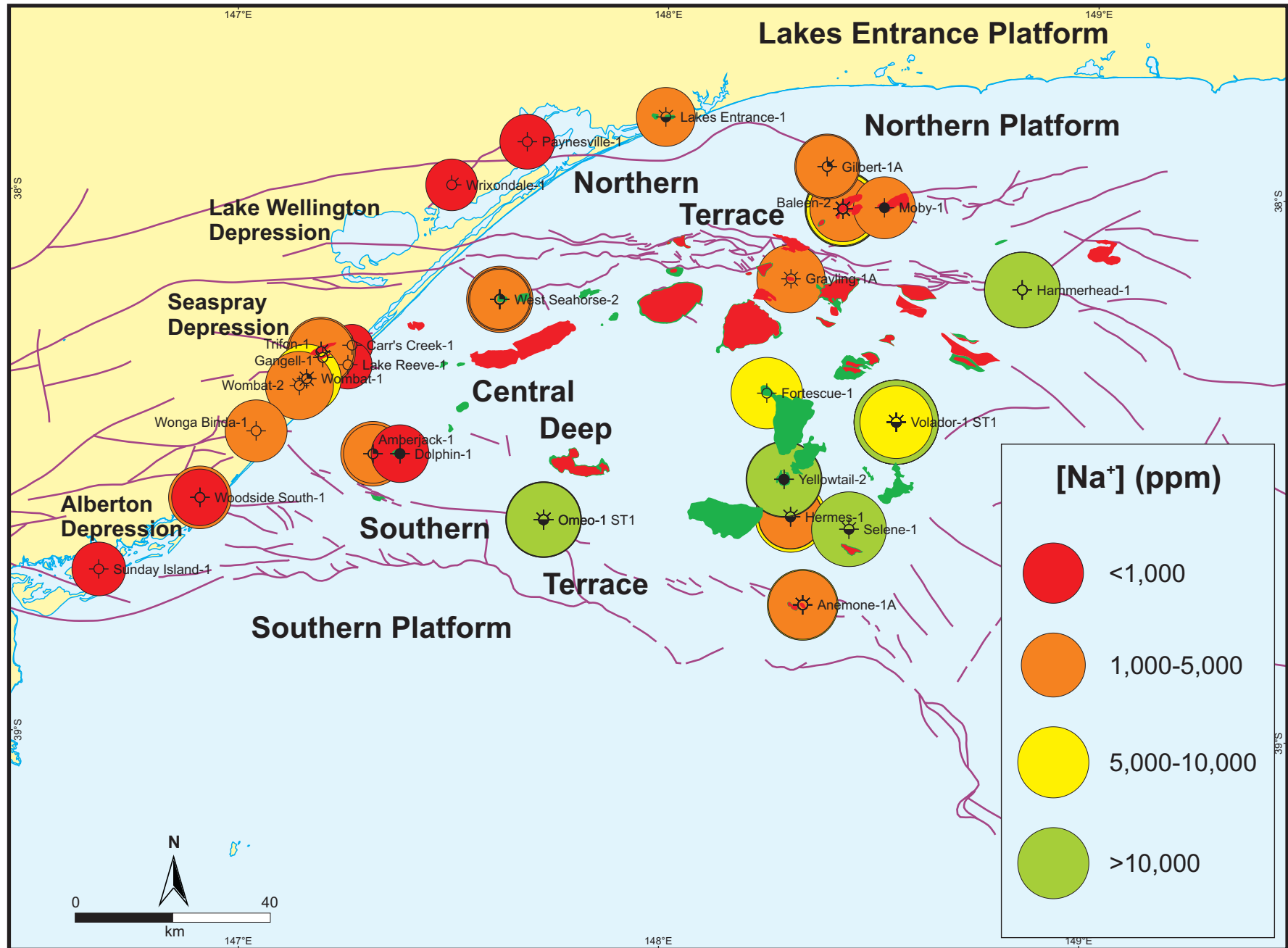


Figure 6.4 Sodium concentration ($[Na^+]$ ppm) of groundwater systems in the Gippsland Basin.

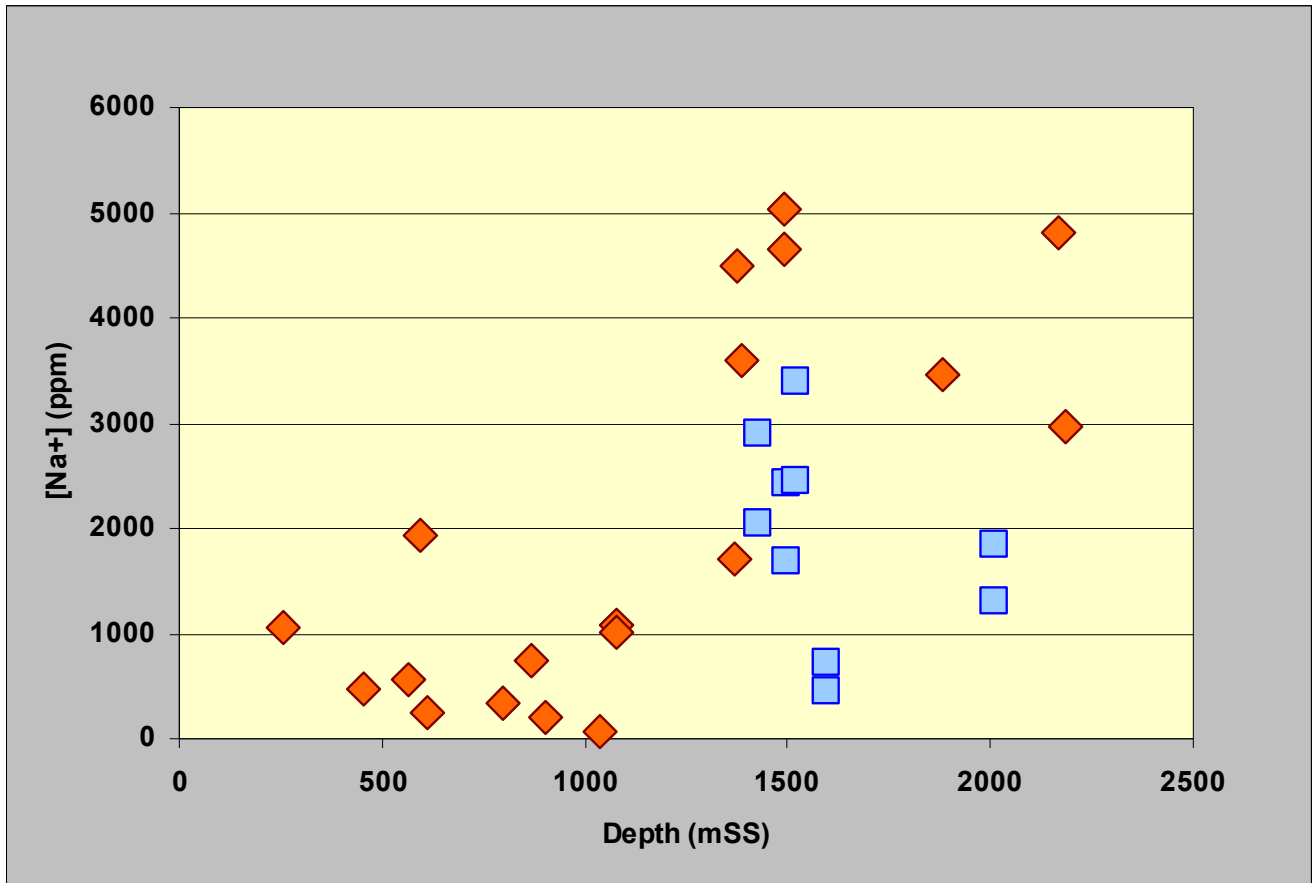


Figure 6.5 Sodium concentration ($[Na^+]$ ppm) versus depth (mSS) in the onshore (orange diamonds) and nearshore (3 nautical mile zone; blue squares) groundwater systems, Gippsland Basin.

7 Summary and Recommendations

This study has provided an overview of the available information regarding the geological carbon storage potential of the onshore Gippsland Basin. The analysis of these data has also highlighted key areas for future investigation. The findings of this study are as follows:

- Carbon storage play fairways have been identified within exploration tender areas GCS09-1 and GCS09-2. Strzelecki Group carbon storage plays are located in both areas and Latrobe Group carbon storage plays are located close to the coast in GCS09-2.
- Current information indicates that the Strzelecki Group reservoir is characterised by tight, volcanoclastic sandstones with low porosity and permeability, with the possible exception of small, localised areas that have not experienced deep burial (e.g. Boundary Creek-1A). The Tyers River Subgroup has been identified as a potential GCS reservoir, although suitable reservoir facies and seals remains to be located.
- The distribution, thickness, porosity and permeability of the Latrobe Group reservoir have been evaluated. The Latrobe Group thins from east to west across the onshore basin, with the thickest successions found in the Seaspray Depression, and in the 3 nautical mile zone offshore, reaching thicknesses of greater than 1000 metres near the coast. The Golden Beach Subgroup is confined to the northern margin of the Seaspray Depression. This data supports the feasibility of Latrobe Group play options previously discussed in the literature.
- The regional top seal in the central eastern Lake Wellington Depression and the southern to central nearshore areas in the Seaspray Depression are most suitable for the containment of supercritical CO₂. It is over these areas that the top Latrobe Group play has a top seal that is suitable for CO₂ containment.
- Possible gas chimneys and soil gas anomalies have been identified along the Darriman, Rosedale and Lake Wellington fault systems and tend to occur where the seals are thin and the structures are reactivated. Fault seal integrity must therefore be considered in any analysis to support site characterisation.
- Storage capacity estimates of the basin reflect the early stage of exploration and have high associated uncertainties. Current mid-range estimates for the onshore Gippsland Basin are between 65 to 1000 million tonnes of CO₂. The majority of CO₂ trapping will utilise unconfined aquifers.
- At this early stage of evaluation, the potential resource impacts of geological storage of CO₂ can be assessed only in a general way. In future work, all sites will need to be assessed for affects on geothermal, petroleum, water and coal resources. Further details on site characterisation and impacts methodology can be found in CO2CRC (2008).
- A significant impact could potentially be upon the freshwater resources contained within the top Latrobe and intraformational Latrobe Group aquifer system across the onshore Gippsland Basin. Potential impacts upon identified hydrocarbon resources within the deeper Strzelecki system at fields such as North Seaspray and Gangel are likely to be minimal.
- It is recommended that further detailed analysis be undertaken on existing data (e.g. wireline log analysis, seismic investigations, depositional framework studies) in order to better understand reservoir and seal geometries, depositional environments, types of storage options available (i.e. conventional traps or saline aquifer storage), and to ascertain sand and shale distribution within the basin and assess the connectivity of reservoir sand bodies. Further porosity determination from logs also needs to be undertaken, given the limitations associated with direct measurement from core.
- The increased definition of sites through further analysis of existing data and future exploration would facilitate new injection and migration simulations. These in turn would allow for more accurate estimates of storage capacity and assessment of potential impacts on other earth resources.
- There are significant seismic data limitations associated with exploration tender areas GCS09-1 and GCS09-2. Acquisition of new seismic data would therefore facilitate more detailed storage site characterisation.
- Given the importance of intraformational Latrobe Group seals, coring and sampling of both seals and reservoirs is recommended.

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Appendix 1

Summary of seismic surveys in the Onshore Gippsland Basin

Year	Survey type	Survey Name	Operator	Line kms
1952	2D	BMR1952- Avon Survey	Bureau of Mineral Resources	16.83
1954	2D	BMR1954- Darriman Survey	Bureau of Mineral Resources	40.48
1958	2D	BMR1958- Experimental Survey	Bureau of Mineral Resources	15.83
1959	2D	BMR1959- Latrobe Valley Survey	Bureau of Mineral Resources	13.98
1960	2D	GWS60A- Bairnsdale/ Sale Survey	Woodside Oil N.L.	176.03
1961	2D	BMR1961- Rosedale Survey	Bureau of Mineral Resources	15.59
1961	2D	GWS61A- Sale/ Lake Wellington Survey	Woodside Oil N.L.	212.6
1962	2D	GAW62A- Sale Extended Survey	ARCO Ltd.	334.24
1963	2D	GAPM63A- Gormandale Survey	APM Development Pty. Ltd.	13.41
1964	2D	GA64- Seaspray Survey	ARCO Ltd.	79.28
1965	2D	GWS65A- Paynesville Survey	Woodside Oil N.L.	114.28
1965	2D	GWS65B- Woodside/ Paynesville Survey	Woodside Oil N.L.	308.44
1968	2D	GAOD68A- Tarwin Survey	Alliance Oil Development Australia N.L.	11
1968	2D	GAPM68A- Toongabbie Survey	APM Development Pty. Ltd.	10.38
1969	2D	GWS69A	Woodside Oil N.L.	115.21
1970	2D	GAOD70A- Tarwin Survey	APM Development Pty. Ltd.	33
1970	2D	GWY70A- Bemm River Survey	WYP Development Pty. Ltd.	24.33
1981	2D	GB81A- Loch Sport Survey	Beach Petroleum N.L.	74.13
1981	2D	GM81A	Mincorp Ltd.	52.14
1982	2D	GB82A- Loch Sport Survey	Beach Petroleum N.L.	109.82
1982	2D	GM82A- Bairnsdale Survey	Mincorp Ltd.	43.91
1982	2D	GSR82A- Balook Dome Survey	Sion Resources (Australia) Ltd.	107.79
1983	2D	GM83A- Forge Creek Survey	Mincorp Ltd.	153.13
1984	2D	GB83A- Bengworden Survey	Beach Petroleum N.L.	237.8
1985	2D	GB85A- Bengworden Detail Survey	Beach Petroleum N.L.	36.24
1985	2D	GHG85A- Rosedale Survey	Hartogen Energy Ltd.	272.8
1987	2D	GCR87A- Monkey Creek Survey	Crusader Resources N.L.	182.85
1987	2D	GCR87B- Kangaroo Swamp Survey	Crusader Resources N.L.	167.38
1987	2D	GCR87C- Seaspray Survey	Crusader Resources N.L.	31.89
1987	2D	GHG87A- Carr Creek Survey	Hartogen Energy Ltd.	28.93
1988	2D	GAP88A	Arena Petroleum	18
1988	2D	GOR88A- Bairnsdale/ Freestone Survey	Ocean Resources Ltd.	64.07
1988	2D	GT88A- Traralgon Survey	TCPL Resources Ltd.	60.93
1989	2D	GAP88B	Arena Petroleum	1.4
1989	2D	GCR89A- Stringy Bark Survey	Crusader Resources N.L.	23.79
1989	2D	GT89A- East Sale Survey	TCPL Resources Ltd.	21.87
1991	2D	GCRP91A- Boundary Creek Survey	SAGASCO Resources Ltd.	109.2
1991	2D	GSG91A- Traralgon Survey	SAGASCO Resources Ltd.	63.43
1992	2D	GSG92A	SAGASCO Resources Ltd.	14.38
1997	2D	GMPV97A- Gippsland Experimental Survey	Department of Natural Resources & Environment	34.06
1999	2D	GBA99A- Yarragon Survey	Bass Petroleum Pty. Ltd.	45.31
2000	2D	GLO00A- Kullingral Survey	Lakes Oil N.L.	6.41
2000	2D	GLO00B- Yarram Survey	Lakes Oil N.L.	24.72
2001	2D	GBA01A- Yarragon Survey (extension)	Bass Petroleum Pty. Ltd.	59.16
2005	2D	GKG05- Korumburra Survey	Karron Gas Pty. Ltd.	254.3
2008	3D	GLO07A- Wombat 3D	Lakes Oil N.L.	28.58 sq km

Appendix 2

Depths for top and base of seal, and seal thickness as identified from well data, onshore and offshore Gippsland Basin (updated October 2009)

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Admiral-1	148 38 55.23E	38 09 06.62S	21	1236	1215	998	977	238
Albacore-1	148 19 58.61E	38 33 54.46S	30	2519	2489	2250	2220	269
Albatross-1	148 03 05.59E	37 57 34.36S	10	707	697	628	618	79
Amberjack-1	147 18 59.71E	38 29 27.94S	21	1259	1238	1136	1115	123
Anemone-1a	148 19 53.25E	38 45 46.92S	27	2581	2554	2401	2374	180
Angelfish-1	148 22 53.40E	38 14 37.38S	21	1648	1627	1477	1456	171
Angler-1	148 26 33.71E	38 39 29.86S	27	2767	2740	2477	2450	290
Archer-1	148 18 41.52E	38 46 01.56S	28	2559	2531	2390	2362	169
Athene-1	148 27 24.78E	38 35 46.60S	23	2760	2737	2475	2452	285
Avon-1	147 08 17.61E	38 02 49.50S	9	726	717	610	601	116
Ayu-1	148 17 07.27E	38 36 29.48S	28	2490	2462	2140	2112	350
Baleen-1	148 26 12.97E	38 00 31.08S	9	638	629	512	503	126
Baleen-2	148 24 42.12E	38 01 50.21S	26	722	696	647	621	75
Banjo-1a	148 28 06.96E	37 46 04.67S	70					0
Barracouta-1	147 42 49.63E	38 16 35.48S	10	1054	1044	940	930	114
Barracouta-2	147 40 30.63E	38 17 52.48S	9	1020	1011	916	907	104
Barracouta-3	147 37 07.63E	38 19 13.48S	9	1094	1085	996	987	98
Barracouta-4	147 42 07.81E	38 17 15.27S	25	1041	1016	976	951	65
Barracouta-5	147 39 40.67E	38 17 58.01S	21	1183	1162	1044	1023	139
Basker-1	148 41 57.77E	38 18 20.94S	25	2120	2095	1807	1782	313
Basker-2	148 42 30.94E	38 17 58.81S	22	2088	2066	1755	1733	333
Basker-5	148 42 23.80E	38 17 59.35S	22	2103	2081	1786	1764	317
Basker South-1	148 41 26.13E	38 19 05.84S	25	2210	2185	2067	2042	143
Batfish-1	148 24 17.58E	38 13 28.48S	10	1454	1444	1225	1215	229
Baudin-1	147 52 23.60E	37 51 35.47S	42	330	288	304	262	26
Beardie-1	147 48 29.26E	38 15 10.69S	25	1195	1170	1176	1151	124
Bellbird-1	147 00 50.77E	38 12 48.69S	134					0
Bengworden South-6	147 25 40.04E	38 03 31.18S	2	962	960	715	713	247
Bignose-1	148 36 10.07E	38 21 15.86S	25	2523	2498	2260	2235	263
Billfish-1	148 33 19.23E	38 40 07.45S	31	2887	2856	2705	2674	182
Blackback-1	148 33 46.72E	38 32 57.98S	21	2897	2876	2570	2549	327
Blackback-2	148 32 40.69E	38 33 22.70S	22	2779	2757	2543	2521	236
Blackback-3	148 31 10.10E	38 33 29.30S	25	2821	2796	2540	2515	281
Blenny-1	147 24 56.69E	38 28 18.15S	23	1230	1207	1100	1077	130
Bonita-1a	148 17 14.31E	38 33 41.86S	30	2440	2410	2162	2132	278
Bream-3	147 46 19.64E	38 30 41.48S	28	1847	1819	1615	1587	232
Bream-5	147 52 03.58E	38 30 49.51S	21	1864	1843	1560	1539	304
Bream-2	147 47 50.73E	38 31 16.19S	9	1802	1793	1560	1551	242
Bream-4a	147 44 55.60E	38 30 21.28S	21	1858	1837	1590	1569	268
Broadbill-1	147 01 22.09E	38 35 19.79S	32	850	818	782	750	68
Bullseye-1	147 34 04.12E	38 35 23.84S	10	2072	2062	1697	1687	375
Bundalaguah-10	147 01 14.38E	38 04 59.50S	7	742	735	640	633	102
Bunga Creek-1	148 01 02.19E	37 51 09.73S	61	342	281	300	239	42
Bunga Creek-2	148 02 16.29E	37 50 55.03S	44	303	259	266	222	37
Burong-1	147 11 56.27E	38 18 33.35S	39	655	616	552	513	103
Carrs Creek-1	147 15 59.59E	38 17 26.48S	27	673	646	584	557	89
Chimaera-1	148 43 23.73E	38 15 50.81S	25	1923	1898	1493	1468	430
Cobdens Bore-1	148 03 49.70E	37 51 56.63S	6	459	453	329	323	130
Cobia-1	148 17 05.88E	38 27 21.21S	10	2383	2373	2232	2222	151

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Cobia-2	148 18 20.94E	38 27 25.95S	25	2380	2355	2152	2127	228
Cod-1	147 58 37.62E	38 21 37.47S	10	1882	1872	1597	1587	285
Colliers Hill-1	147 17 34.65E	38 11 50.48S	17	545	528	451	434	94
Colquhoun East-6	148 07 11.56E	37 47 09.46S	40	179	139	144	104	35
Colquhoun North-1	147 56 30.56E	37 48 46.47S	30	178	148	134	104	44
Comley-1	147 33 31.75E	37 53 58.21S	52	474	422	438	386	36
Conger-1	148 03 50.94E	38 21 22.22S	21	1814	1793	1605	1584	209
Crossroads-1	147 09 46.77E	38 19 33.69S	32	815	783	655	623	160
Cuttlefish-1	148 03 06.89E	37 59 35.26S	26	839	813	792	766	47
Darriman-1	147 00 34.61E	38 26 58.49S	36	511	475	452	416	59
Dart-1	148 55 32.78E	38 08 06.40S	10	922	912	731	721	191
Deadman Hill-1	147 10 55.30E	38 11 45.42S	59	101	42	82	23	19
Denison-53	146 53 50.31E	38 06 24.03S	17					0
Devilfish-1	147 55 15.19E	38 47 52.69S	28	1645	1617	1461	1433	184
Dolphin-1	147 22 47.66E	38 29 26.49S	10	1192	1182	1050	1040	142
Dome Frome Lake Tyers-1	148 01 02.54E	37 47 29.45S	39					0
Dome Frome Lake Tyers-2	148 02 34.56E	37 46 33.46S	15					0
Dome Frome Lake Tyers-3	148 07 40.56E	37 46 00.46S	6					0
Dome Frome Lake Tyers-4	148 05 08.57E	37 49 08.46S	43	356	313	304	261	52
Drummer-1	148 15 02.94E	38 28 28.46S	21	2432	2411	2127	2106	305
Duck Bay-1	147 39 40.69E	37 56 39.18S	24	682	658	579	555	103
Dulungalong-2	147 18 09.88E	38 11 57.89S	8	560	552	440	432	120
Dutson-1	147 15 27.76E	38 10 59.68S	18	484	466	402	384	82
Dutson Downs-1	147 21 49.58E	38 11 54.51S	5	708	703	578	573	130
East End-1	148 21 18.52E	37 47 58.45S	3					0
East Halibut-1	148 21 03.13E	38 24 28.96S		2395	2374	2170	2149	225
East Kingfish-1	148 12 41.34E	38 35 01.84S	21	2490	2469	2046	2025	444
East Lake Tyers-1	148 07 37.66E	37 50 32.16S	5	399	394	296	291	103
East Nowa-1	148 09 46.64E	37 47 41.15S	62	335	273	228	166	107
East Pilchard-1	148 33 47.39E	38 11 48.62S	25	1644	1619	1405	1380	239
East Reeve-1	147 32 55.57E	38 05 44.47S	4	1158	1154	989	985	169
East Seacombe-1	147 32 01.73E	38 04 54.66S	5	1076	1071	835	830	241
Echidna High-1	147 02 08.34E	38 20 56.03S	71	485	414	400	329	85
Edina-1	147 52 46.59E	38 36 17.02S	31	2278	2247	1848	1817	430
Emperor-1	148 00 24.60E	38 05 48.46S	9	1517	1508	1372	1363	145
Fairhope-1	147 35 21.07E	37 54 42.52S	43	533	490	496	453	37
Flathead-1	148 32 08.56E	38 01 15.44S	9	447	438	395	386	52
Flounder-1	148 25 33.59E	38 18 46.45S	28	1929	1901	1613	1585	316
Flounder-2	148 26 57.67E	38 19 11.14S	30	1969	1939	1628	1598	341
Flounder-3	148 28 27.68E	38 18 52.14S	30	1996	1966	1634	1604	362
Flounder-4	148 29 51.51E	38 18 18.02S	10	1930	1920	1595	1585	335
Flounder-5	142 00 23.61E	38 12 28.49S	9	1912	1903	1590	1581	322
Flounder-6	148 26 13.75E	38 19 01.53S	25	1932	1907	1538	1513	394
Flying Fish-1	147 21 56.85E	38 20 45.09S	10	1094	1084	946	936	148
Forsters Bore-1	148 00 03.69E	37 52 02.63S	28	374	346			
Fortescue-1	148 14 23.99E	38 22 22.76S	25	2415	2390	2164	2139	251
Fortescue-2	148 16 03.74E	38 25 51.42S	31	2420	2389	2168	2137	252
Fortescue-3	148 16 06.90E	38 23 17.57S	31	2412	2381	2160	2129	252
Fortescue-4	148 16 40.08E	38 24 52.34S	25	2408	2383	2138	2113	270
Gangell-1	147 11 53.14E	38 18 47.85S	40	683	643	568	528	115
Gannet-1	148 08 13.12E	37 54 15.01S	10	675	665	586	576	89
Gippsland-1	147 52 24.70E	37 51 54.64S	75	446	371	370	295	76
Gippsland-3	147 52 08.70E	37 51 28.64S	61	425	364	377	316	48
Gippsland-4	147 51 52.70E	37 51 49.64S	77	389	312	318	241	71
Gippsland-5	147 58 00.70E	37 51 47.63S	70	390	320	314	244	76
Gippsland-6	147 57 55.70E	37 51 50.64S	70	400	330	319	249	73

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Gippsland Frome Lakes-1	147 58 02.70E	37 51 49.63S	11	591	580	536	525	55
Gippsland Frome Lakes-2	146 46 03.82E	38 38 22.71S	5	470	465	455	450	15
Gippsland Frome Lakes-3	146 50 14.81E	38 35 07.70S	9	562	553	536	527	26
Gippsland Frome Lakes-4	147 15 34.59E	37 59 02.51S	38	527	489	432	394	95
Gippsland Frome Lakes-5	147 32 06.72E	37 52 48.65S	77	342	265	277	200	65
Golden Beach-1a	147 25 24.77E	38 15 27.11S	12	645	633	556	544	89
Golden Beach West-1	147 21 27.58E	38 14 49.48S	12	694	682	585	573	109
Goon Nure-1	147 33 36.72E	37 58 54.65S	29	757	728	618	589	139
Goon Nure-9	147 37 53.97E	37 58 16.23S	29	750	721	618	589	132
Great White-1	148 37 42.45E	38 27 01.68S	31	3222	3191	2805	2774	417
Groper-1	147 25 00.69E	38 56 14.50S	10	931	921	808	798	123
Groper-2	147 14 17.53E	38 58 34.44S	10	760	750	687	677	73
Grunter-1	148 31 00.83E	38 16 15.74S	21	1853	1832	1570	1549	283
Gummy-1	148 44 25.85E	38 17 54.00S	28	2081	2053	1755	1727	326
Gurnard-1	147 58 42.63E	38 35 27.47S	10	2185	2175	1890	1880	295
Halibut-1	148 19 01.60E	38 23 52.46S	10	2282	2272	1910	1900	372
Halibut-2	148 19 52.58E	38 23 39.98S	25	2331	2306	2040	2015	291
Hammerhead-1	148 50 03.79E	38 10 28.66S	22	1291	1269	1058	1036	233
Hapuku-1	148 33 00.88E	38 33 14.51S	9	2810	2801	2527	2518	283
Harlequin-1	147 42 32.68E	38 11 54.42S	21	1408	1387	1213	1192	195
Helios-1	148 16 38.68E	38 41 34.91S	23	2574	2551	2180	2157	394
Hermes-1	148 17 58.89E	38 36 02.48S	23	2508	2485	2160	2137	348
Holey Plains-185	146 57 21.53E	38 10 00.90S	34	590	556	557	523	33
Holey Plains-192	146 55 47.72E	38 09 43.24S	12					0
Hollands Landing-1	147 27 44.74E	38 03 14.66S	2	961	959	731	729	230
Hunters Lane-1	147 58 30.00E	37 51 54.21S	50	394	344	318	268	76
Imray Bore-1	147 59 51.69E	37 51 57.63S	41	381	340	313	272	68
Investigator-1	147 36 50.69E	37 54 44.17S	35	582	547	510	475	72
Judith-1	148 33 24.68E	38 09 12.91S	21	1451	1430	1223	1202	228
Kahawai-1	148 22 12.75E	38 10 15.30S	21	1390	1369	1086	1065	304
Kalimna-1	147 57 17.70E	37 53 13.64S	1	422	421	306	305	116
Kalimna-2	147 57 58.70E	37 52 04.64S	49	417	368			417
Keystone-1	147 09 25.77E	38 19 33.69S	35	826	791	645	610	181
Kingfish-1	148 12 39.62E	38 35 44.47S	10	2250	2240	1971	1961	279
Kingfish-5	148 14 34.24E	38 34 39.67S	10	2327	2317	1990	1980	337
Kingfish-7	148 05 04.13E	38 35 08.18S	25	2259	2234	1993	1968	266
Kingfish-8	148 03 42.57E	38 35 30.30S	23	2271	2248	1923	1900	348
Kingfish-9	148 08 59.72E	38 37 39.77S	23	2304	2281	1912	1889	392
Kingfish-2	148 10 17.73E	38 35 51.16S	9	2244	2235	1975	1966	269
Kingfish-3	148 06 11.72E	38 34 57.16S	9	2244	2235	1980	1971	264
Kingfish-4	148 05 53.42E	38 35 49.38S	10	2237	2227	1922	1912	315
Kingfish-6	148 14 05.55E	38 35 34.19S	9	2294	2285	2011	2002	283
Kipper-1	148 35 51.35E	38 10 30.30S	21	1420	1399	1064	1043	356
Kipper-2	148 36 49.77E	38 11 26.03S	22	1539	1517	1235	1213	304
Kyarra-1a	147 11 16.97E	38 40 47.04S	31	1013	982	919	888	94
Lake Reeve-1	147 15 24.60E	38 19 36.50S	5	908	903	749	744	159
Lake View-1	148 01 32.69E	37 51 23.63S	43	325	282	298	255	27
Lake View-2	148 00 28.69E	37 51 55.63S	54	396	342			
Lake View-3	147 59 41.69E	37 52 07.63S	26	382	356			
Lakes Entrance-1	147 59 46.69E	37 51 54.15S	52	388	336	324	272	64
Lakes Entrance Dev-1	148 02 28.69E	37 51 16.63S	3	338	335	308	305	30
Lakes Entrance Dev-2	148 00 46.69E	37 52 13.63S	10	365	355	310	300	55
Lakes Entrance Oil Shaft-1	148 00 00.69E	37 52 01.63S	27	366	339	290	263	76
Leatherjacket-1	148 46 46.38E	38 05 11.29S	21	745	724	635	614	110
Longtom-1	148 18 58.79E	38 05 54.77S	25	1245	1220	1184	1159	61
Luderick-1	147 43 02.49E	38 26 15.10S	21	1777	1756	1529	1508	248

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Macalister-1	147 08 19.90E	38 20 57.82S	20	792	772	675	655	117
Mackerel-1	148 21 30.60E	38 28 48.46S	30	2406	2376	2224	2194	182
Mackerel-4	148 18 58.12E	38 30 44.38S	10	2365	2355	2164	2154	201
Mackerel-2	148 20 22.44E	38 29 08.46S	10	2310	2300	2166	2156	144
Mackerel-3	148 21 48.87E	38 28 19.97S	10	2379	2369	2214	2204	165
Macs-1	147 59 37.70E	37 52 22.63S	12	384	372			384
Macs-2	147 59 32.69E	37 52 24.63S	15	385	370			385
Macs-3	147 59 31.70E	37 52 20.63S	9	381	372			381
Manta-1	148 43 24.26E	38 16 21.75S	25	1956	1931	1534	1509	422
Marlin-2	148 10 49.60E	38 15 53.46S	10	1442	1432	1298	1288	144
Marlin-4	148 16 07.19E	38 14 18.91S	10	1828	1818	1643	1633	185
Marlin-1	148 13 37.68E	38 13 57.17S	10	1379	1369	1244	1234	135
Marlin-3	148 10 20.71E	38 14 38.15S	10	1440	1430	1340	1330	100
Mccreesh-1	147 06 21.75E	38 22 21.21S	31	800	769	670	639	130
Meerlieu-15001	147 17 07.23E	38 00 22.92S	33	720	687	580	547	140
Meerlieu-4	147 18 52.11E	38 01 18.85S	20	818	798	684	664	134
Megamouth-1	148 16 31.85E	38 35 44.23S	22	2465	2443	2087	2065	378
Melville-1	147 59 13.13E	38 40 57.15S	25	2218	2193	1830	1805	388
Merriman-1	147 10 47.59E	38 20 46.51S	24	695	671	625	601	70
Moonfish-2	148 01 23.53E	38 08 52.16S	31	1559	1528	1370	1339	189
Moonfish-1	148 00 35.21E	38 08 54.95S	23	1605	1582	1385	1362	220
Moray-1	148 03 25.25E	38 51 42.58S	10	1640	1630	1422	1412	218
Morwong-1	148 18 49.91E	38 13 37.08S	10	1653	1643	1493	1483	160
Mudskipper-1	148 08 02.84E	38 54 26.07S	27	1475	1448	1220	1193	255
Mullet-1	147 51 26.68E	39 12 56.49S	10	690	680	620	610	70
Mulloway-1	147 29 06.43E	38 19 18.75S	21	1127	1106	990	969	137
Mullungdung-7	146 55 46.63E	38 22 55.09S	85	365	280	348	263	17
Mullungdung-8	146 53 27.94E	38 23 14.87S	131					0
Nannygai-1	147 59 50.63E	38 33 05.47S	10	2192	2182	1932	1922	260
Nindoo-2	147 19 26.90E	37 52 27.71S	75	350	275	292	217	58
North Seaspray-1	147 12 17.77E	38 17 32.68S	27	585	558	518	491	67
North Seaspray-2	147 12 24.77E	38 18 01.68S	27	646	619	515	488	131
North Seaspray-3	147 12 20.46E	38 17 26.60S	24	575	551	470	446	105
Northright-1	149 09 03.41E	37 55 52.46S	25					0
Nuntin-2	147 12 38.74E	38 01 43.67S	2	923	921	712	710	211
Oilco-1	147 57 56.57E	37 51 42.48S	42	393	351	321	279	72
Omeo-1	147 43 06.90E	38 36 39.50S	31	2188	2157	1882	1851	306
Omeo-2a	147 42 43.01E	38 36 16.35S	22	2182	2160	1882	1860	300
Opah-1	148 16 47.17E	38 31 38.87S	25	2405	2380	2152	2127	253
Orange Roughy-1	148 02 35.61E	38 34 51.59S	25	2275	2250	1910	1885	365
Palmer-1	147 19 51.52E	38 33 43.83S	21	1186	1165	1055	1034	131
Patricia-1	148 26 51.83E	38 01 47.44S	22	700	678	655	633	45
Patrobus-1	148 33 18.85E	37 47 44.13S	21					0
Patties Pies-1	147 40 32.11E	37 50 58.46S	5	273	268	250	245	23
Paynesville-1	147 40 25.89E	37 54 47.18S	30	569	539	530	500	39
Perch-1	147 19 28.67E	38 34 31.50S	10	1106	1096	975	965	131
Perch-2	147 20 02.28E	38 34 17.61S	21	1118	1097	1000	979	118
Perch-3	147 19 21.42E	38 34 09.47S	42	1096	1054	974	932	122
Petro Tech-1	147 59 39.67E	37 24 49.48S	49	381	332	301	252	80
Pike-1	147 57 05.37E	38 46 23.53S	10	1828	1818	1611	1601	217
Pilotfish-1a	148 28 13.13E	38 25 52.90S	21	2915	2894	2535	2514	380
Pisces-1	148 30 47.19E	39 03 30.38S	22	1796	1774	1475	1453	321
Point Addis-1	147 51 37.70E	37 52 41.64S	1	365	364	340	339	25
Point Addis-2	147 51 29.70E	37 50 33.64S	1	246	245	234	233	12
Point Addis-3	148 00 08.69E	37 52 12.63S	9	366	357	326	317	40
Point Addis-4	147 59 31.70E	37 51 54.63S	61	399	338			399

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Protea-1	147 08 54.39E	38 11 25.00S	51					0
Remora-1	148 11 33.80E	38 09 08.53S	22	2084	2062	1700	1678	384
Rockling-1	148 13 50.38E	38 27 29.08S	31	2492	2461	2215	2184	277
Romawi-1	147 36 08.32E	37 58 03.05S	20	757	737	663	643	94
Rosedale-1	146 47 51.78E	38 07 34.69S	57					0
Roundhead-1	148 13 32.70E	38 36 59.85S	21	2378	2357	2032	2011	346
Sale-13	147 13 05.71E	38 06 53.64S	1	812	811	687	686	125
Sale-15	147 02 43.03E	38 04 34.17S	12	745	733	660	648	85
Salmon-1	147 59 19.62E	38 25 09.47S	30	1989	1959	1760	1730	229
Salt Lake-1	147 05 16.67E	38 26 47.50S	23	762	739	650	627	112
Sawbelly-1	148 02 10.52E	38 22 25.47S	21	1984	1963	1700	1679	284
Seacombe-7	147 28 01.58E	38 05 08.17S	9	1038	1029	862	853	176
Seacombe South-1	151 39 07.95E	85 17 12.95S	2	1081	1079	960	958	121
Seahorse-1	147 40 26.95E	38 11 42.43S	25	1389	1364	1180	1155	209
Seahorse-2	147 39 24.79E	38 12 07.76S	21	1393	1372	1160	1139	233
Seaspray-1	147 09 47.78E	38 19 33.69S	39	812	773	655	616	157
Selene-1	148 26 15.95E	38 37 19.62S	23	2822	2799	2486	2463	336
Shark-1	149 03 12.05E	38 15 28.73S	28	1816	1788	1526	1498	290
Signal Hill-1	147 18 49.59E	38 14 19.50S	28	679	651	555	527	124
Smiler-1	148 23 21.71E	38 28 49.64S	25	2507	2482	2308	2283	199
Snapper-1	148 00 54.63E	38 11 57.47S	10	1213	1203	1088	1078	125
Snapper-4	148 00 18.62E	38 12 48.85S	21	1260	1239	1046	1025	214
Snapper-2	148 02 41.71E	38 11 10.17S	10	1200	1190	1047	1037	153
Snapper-3	147 59 15.70E	38 12 39.17S	10	1272	1262	1067	1057	205
Snapper-5	147 59 27.08E	38 13 12.13S	21	1292	1271	1102	1081	190
Snapper-6	148 00 46.61E	38 13 50.03S	21	1332	1311	1155	1134	177
Snook-1	147 24 22.52E	38 19 35.95S	21	1127	1106	1000	979	127
Sole-1	149 02 08.94E	38 06 53.92S	10	810	800	640	630	170
Sole-2	149 00 33.55E	38 06 13.08S	25	775	750	570	545	205
South West Bairnsdale-1	147 22 02.60E	37 52 00.48S	72	375	303	315	243	60
Speke-1	147 37 16.39E	38 30 29.13S	22	1820	1798	1622	1600	198
Sperm Whale-1	148 21 56.24E	38 03 20.32S	9	801	792	708	699	93
Sperm Whale Head-1	147 42 24.68E	37 57 54.18S	9	772	763	642	633	130
Spoon Bay-1	147 28 01.88E	38 04 50.68S	9	1022	1013	875	866	147
St Margaret Island-1	146 50 09.83E	38 38 10.21S	8	597	589	548	540	49
Stonefish-1	148 33 39.36E	38 14 56.64S	10	1803	1793	1708	1698	95
Stringy Bark-1	146 54 06.56E	38 30 56.52S	39	366	327	320	281	46
Sunday Island-1	146 40 15.82E	38 42 13.71S	6					0
Sunfish-1	148 13 42.17E	38 08 20.29S	10	1682	1672	1531	1521	151
Sunfish-2	148 14 44.89E	38 08 17.94S	21	1610	1589	1458	1437	152
Sweep-1	148 38 17.54E	38 03 21.17S	25	756	731	615	590	141
Sweetlips-1	148 02 13.26E	38 05 41.76S	21	1505	1484	1361	1340	144
Swordfish-1	148 00 28.63E	38 23 30.53S	25	1999	1974	1730	1705	269
Tailor-1	148 16 29.61E	38 29 26.46S	10	2406	2396	2118	2108	288
Tarra-1	147 42 12.86E	38 38 31.64S	31	2140	2109	1752	1721	388
Tarwhine-1	147 31 45.93E	38 24 11.84S	21	1345	1324	1170	1149	175
Tarwin Meadows-1	145 51 40.87E	38 43 21.25S	11					0
Teraglin-1	148 20 34.73E	38 22 45.45S	21	2421	2400	2135	2114	286
Terakihi-1	148 32 47.78E	38 30 15.13S	21	2837	2816	2537	2516	300
Threadfin-1	148 15 27.07E	38 32 32.17S	25	2397	2379	2178	2153	219
Tildesley East-3	148 18 06.65E	37 46 31.16S	40	208	168	152	112	56
Tommyruff-1	147 08 38.38E	38 36 41.91S	21	897	876	796	775	101
Torsk-1	147 29 54.66E	38 26 43.45S	21	1331	1310	1078	1057	253
Trevally-1	148 23 44.59E	38 17 17.45S	10	1934	1924	1650	1640	284
Trifon-1	147 11 38.45E	38 18 09.16S	30	689	659	620	590	69
Trifon-2	147 11 40.27E	38 18 09.34S	28	688	660	619	591	69

Well Name	Longitude	Latitude	KB	Base seal (MD)	Base seal (MSL)	Top seal (MD)	Top seal (MSL)	Thickness (m)
Trumpeter-1	148 21 02.01E	38 24 42.99S	21	2448	2427	2185	2164	263
Tuna-1	148 25 07.58E	38 10 19.45S	10	1311	1301	1052	1042	259
Tuna-4	148 22 12.68E	38 11 15.45S	21	1370	1349	1100	1079	270
Tuna-2	148 23 18.65E	38 10 46.16S	10	1330	1320	1070	1060	260
Tuna-3	148 26 54.67E	38 10 04.13S	10	1325	1315	1085	1075	240
Turrun-1	148 14 45.60E	38 12 04.46S	30	1942	1912	1600	1570	342
Turrun-4	148 15 48.75E	38 16 34.04S	23	1919	1896	1528	1505	391
Turrun-2	148 15 01.02E	38 14 33.60S	10	1546	1536	1373	1363	173
Turrun-3	148 15 03.57E	38 15 35.50S	21	1571	1550	1323	1302	248
Turrun-5	148 12 08.68E	38 14 50.00S	25	1386	1361	1292	1267	94
Turrun-6	148 10 29.56E	38 14 05.55S	25	1460	1435	1314	1289	146
Turrun-7	148 15 53.91E	38 15 46.42S	26	1764	1738	1520	1494	244
Veilfin-1	148 00 13.00E	38 24 56.90S	21	1986	1965	1708	1687	278
Volador-1	148 32 41.35E	38 25 22.71S	25	2938	2913	2563	2538	375
Wahoo-1	148 44 52.55E	38 01 36.43S	9	429	420	369	360	60
Wellington Park-1	147 22 34.75E	38 08 19.66S	6	719	713	655	649	64
Wellington Park-2	147 20 59.63E	38 08 02.48S	5	691	686	624	619	67
West Fortescue-1	148 14 28.34E	38 21 50.79S	21	2421	2400	2216	2195	205
West Halibut-1	148 17 01.47E	38 24 07.73S	25	2374	2349	2127	2102	247
West Seacombe-1	147 25 22.75E	38 08 03.07S	11	813	802	616	605	197
West Seahorse-1	147 37 26.33E	38 12 11.65S	9	1380	1371	1170	1161	210
West Seahorse-2	147 36 43.16E	38 12 16.32S	9	1405	1396	1193	1184	212
Whale-1	148 33 38.73E	38 01 11.62S	9	439	430	404	395	35
Whaleshark-1	148 53 30.64E	38 23 39.52S	22	2722	2700	2612	2590	110
Whiptail-1a	147 31 14.23E	38 19 24.84S	21	1125	1104	985	964	140
Whiting-2	147 51 19.16E	38 14 59.15S	21	1263	1242	1177	1156	86
Whiting-1	147 53 05.55E	38 14 06.24S	21	1282	1261	1164	1143	118
Wirrah-1	147 49 01.74E	38 11 16.80S	21	1465	1444	1291	1270	174
Wirrah-2	147 49 31.21E	38 10 55.41S	21	1488	1467	1297	1276	191
Wirrah-3	147 48 31.91E	38 11 43.87S	21	1489	1468	1306	1285	183
Wombat-1	147 09 37.19E	38 21 09.71S	15	693	678	603	588	90
Wombat-2	147 08 35.62E	38 21 54.99S	26	776	750	614	588	162
Wonga Binda-1	147 02 30.50E	38 26 57.04S	30	590	560	530	500	60
Woodside-12	146 59 23.36E	38 32 05.64S	4	868	864	752	748	116
Woodside-2	146 53 46.66E	38 37 37.53S	9	759	750	701	692	58
Woodside-3	146 53 44.81E	38 37 41.70S	9	753	744	678	669	75
Woodside-4	146 50 34.82E	38 40 04.70S	2	694	692	663	661	31
Woodside South-1	146 54 34.80E	38 34 19.21S	14	592	578	512	498	80
Wooundellah-10	146 57 36.83E	38 05 54.97S	29	400	371	362	333	38
Wooundellah-11	146 55 51.67E	38 06 06.63S	30	403	373	372	342	31
Wrixondale-1	147 29 52.68E	37 59 37.29S	26	768	742	629	603	139
Wulla Wullock-5	147 09 22.65E	38 19 13.10S	28	843	815	651	623	192
Wurruk Wurruk-13	147 01 06.69E	38 06 56.11S	21	653	632	585	564	68
Wyrallah-1	147 05 09.59E	38 40 31.31S	21	874	853	771	750	103
Yellowtail-1	148 16 31.34E	38 31 28.97S	21	2405	2384	2151	2130	254
Yellowtail-2	148 16 59.55E	38 31 54.14S	21	2408	2387	2163	2142	245
York-1	146 51 41.77E	38 34 52.10S	13	522	509	468	455	54

Appendix 3

Values used in the calculation of CO₂ column heights

Well	Sample Depth (m)	At sample depth		CO ₂ Density (g/cm ³)	Interfacial Tension (mN/m)	Brine Density (g/cm ³)	Threshold Pressure Air-Hg (psi)	CO ₂ column height (m)
		Temperature (°C)	Pore pressure (MPa)					
Bairnsdale-15005	479.29	39.7923	4.354042	0.0937	1.0024	48.17	209	21
Bengworden South-1	947.92	61.1543	9.270016	0.2445	0.9968	34.24	4717	411
Bengworden South-6	914.9	59	8.96	0.2372	34.53	0.9978	3248	282
Bengworden South-6	882.35	57.8234	8.62743	0.2246	0.9981	35.25	4400	384
Bengworden South-6	943.1	60.9095	9.22278	0.2431	0.9969	34.31	4375	381
Bengworden South-6	819	54.6052	8.0066	0.205	0.9994	36.41	10904	957
Bengworden South-6	1076	67.6608	10.5252	0.2807	0.9939	32.72	791	69
Bengworden South-6	1102.7	69.0172	10.78686	0.2877	0.9933	32.47	253	22
Bundalaguah-10	599.8	34	5.87	0.1551	38.85	1.0077	467	41
Colquhoun East-6	180.7	24	1.77	0.0349	59.7	1.0032	1389	164
Coolungoolun-101	449.15	36.2211	4.13707	0.0898	1.0255	48.58	144	14
Dulungalong-2	478.1	36	4.68	0.1065	45.74	1.0048	806	78
Dutson Downs-1	551.68	29.7711	5.357464	0.1393	1.0089	40.2	1020	90
Dutson Downs-1	915	40.816	8.918	0.4265	1.0077	26.39	246	21
Gippsland Frome Lakes-4	503.5	42	4.93	0.1092	45.85	1.0022	185	18
Gippsland Frome Lakes-4	506.6	42	4.96	0.1101	45.71	1.0023	1228	120
Glencoe South-4	418.8	31.1759	3.70244	0.0804	1.0052	49.87	1810	187
Glencoe South-4	425.05	31.4472	3.76369	0.0819	1.0052	49.59	823	84
Golden Beach West-1	667.68	30.6	6.64	0.2133	32.82	1.0288	1138	87
Goon Nure-1	769.31	50.0807	7.255038	0.1827	1.0011	37.88	2606	231
Goon Nure-2	731.21	48.2443	6.881658	0.1706	1.0017	38.85	2589	232
Goon Nure-2	785.77	50.8741	7.416346	0.1879	1.0009	37.49	2883	254
Goon Nure-9	726.3	35	7.11	0.2302	32.25	1.0089	2686	213
Holey Plains-185	538.2	30.7606	4.94116	0.1208	1.0078	42.92	567	52
Hunters Lane-1	377	31.2	3.74	0.0815	49.65	1.0265	182	18
Meerlieu-15001	699.9	53	6.85	0.1611	40.19	0.999	1033	95
Meerlieu-4	722	46.6	7.07	0.1828	37.53	1.0028	2131	186
Meerlieu-4	769	44	7.53	0.2152	34.56	1.0048	3602	301
Meerlieu-4	633.2	40.6708	6.00936	0.1485	1.0046	40.46	1157	105
Mullungdung-7	363	19	3.55	0.0833	47.72	1.0099	126	12
Nuntin-2	869.28	51.2483	8.504244	0.2432	1.0018	33.5	2847	241
Nuntin-2	885.74	51.9726	8.665552	0.2497	1.0016	33.19	3850	325
Sale-13	748.1	53	7.33	0.1795	38.42	0.9995	1922	172
Sale-13	795.6	51	7.79	0.2054	36.06	1.0012	1962	170
Sale-15	628.6	35.4	6.16	0.1657	37.86	1.0075	620	53
Seacombe-7	947.6	61	9.28	0.2459	34.15	0.9969	3520	306
Seacombe-7	649	46.2288	6.272	0.1499	1.002	40.85	1810	166
Sperm Whale Head-1	653.8	40.8	6.4	0.1649	38.67	1.005	2229	196
Sperm Whale Head-1	718.1	44	7.03	0.1877	36.8	1.0042	3241	285
Sperm Whale Head-1	671.47	41.5375	6.492206	0.1676	1.0048	38.45	2312	203
Woodside South-1	522.12	31.2	5.25	0.1329	41.23	1.029	65	6
Woodside-3	410.87	27.3394	3.938326	0.0897	1.0074	47.68	83.4	8
Woodside-4	610.81	39.7535	5.966338	0.1483	1.005	40.38	62.5	5
Wooundellah-10	389.3	36	3.81	0.0809	50.17	1.0032	43	4
Wooundellah-11	389	36	3.81	0.0808	50.19	1.0032	112	11
Wulla Wullock-5	699.6	38.6054	6.58168	0.1791	1.0064	36.93	3075	263
Wurruk Wurruk-1	562.35	35.8314	5.42283	0.1326	1.0061	41.9	1261	116
Wurruk Wurruk-1	647.39	39.284	6.256222	0.1617	1.0056	38.81	308	27
Wurruk Wurruk-13	584.9	36	5.73	0.1449	40.34	1.0065	234	21
Yeerung-1	402.33	36.0535	3.864434	0.0822	1.0033	49.93	94.4	10
Golden Beach West-1	1947	61.4803	18.963	0.6959	1.003	26.23	7656	1251

Corrected temperature gradient from GeoScience Victoria database. Onshore surface temperature =13°C. Pore pressure calculation for onshore wells estimated from depth with correction for KB and assuming freshwater pore fluid density. Pressure gradient = 0.433 psi/ft. CO₂ density from CO2CRC website calculator. Assumed reservoir entry pressure = 0.28 psi.

Appendix 4

Mineralogical compositions as determined by AMA analysis

Onshore Wells	Depth (m)	Quartz	Albite	K Feldspar	Smectite	Kaolinite	Illite/ muscovite	Chamosite	Glauconite	Calcite	Siderite	Dolomite	Ankerite	Pyrite	Goethite	Apatite	Anatase	Zircon	Minor Phases
Bairnsdale-15005	479.29	6.67	0.32	1.83	82.88	2.44	1.3	0.13	0.01	2.43	1.35	0.02	0	0.43	0	0.09	0.08	0	0.02
Bengworden South-6	882.35	3.38	0.15	1.21	77.45	13.14	1.4	0.68	0.01	0.85	0.62	0.06	0.01	0.92	0	0.03	0.03	0	0.06
Bengworden South-6	914.9	2.83	0.09	1.18	86.17	0.34	0.96	0.42	0.04	5.24	0.79	0.76	0.34	0.11	0	0.26	0.04	0	0.44
Bengworden South-6	943.1	8.6	0.26	2.32	73.3	2.15	1.76	0.64	0.08	5.84	1.15	1.26	1.04	1.1	0	0.14	0.08	0.01	0.27
Bengworden South-1	947.92	5.95	0.18	1.65	82.2	1.83	1.63	0.64	0.07	3.01	0.96	0.33	0.27	1.02	0	0.09	0.07	0.01	0.08
Bundalaguah-10**	599.8	4.63	0.11	1.74	85.27	2.46	2.35	0.16	0.03	0.8	0.2	1.16	0.26	0.29	0	0.06	0.06	0.01	0.42
Colquhoun East-6	180.7 1	6.94	0.33	0.5	14.4	0.16	0.46	5.86	0.02	66.26	0.48	0.73	0.24	0	0.01	2.75	0.07	0	0.78
Coolungoolun-101**	449.15	16.79	0.2	3.75	46.33	15.67	4.8	0.2	0.48	2.29	0.21	0.02	0.01	8.47	0	0.14	0.18	0.04	0.43
Dulungalong-2	478.1	2.11	0.67	0.72	85.13	8.37	0.73	0.14	0.01	0.92	0.15	0.35	0.1	0.29	0	0.03	0.03	0	0.26
Dutson Downs-1**	551.68	6.3	0.06	0.49	59.35	0.41	0.3	0.18	0.02	30.2	0.22	1.16	0.11	0.46	0	0.58	0.04	0	0.12
Gippsland Frome Lakes-4	503.5	10.45	0.63	2.89	74.06	1.12	1.63	0.34	1.74	3.87	0.55	0.81	0.44	0.71	0	0.19	0.11	0.02	0.44
Gippsland Frome Lakes-4	506.6	3.78	0.22	1.49	83.11	6.24	1.83	0.42	0.02	1.04	0.11	0.27	0.11	0.93	0	0.03	0.09	0.01	0.29
Golden Beach West-1	667.68	3.41	0.1	1.54	86.69	3.79	1.56	0.28	0.06	1.52	0.22	0.25	0.1	0.12	0	0.05	0.06	0.01	0.23
Glencoe South-4	418.8	3.3	0.07	0.82	85.9	0.17	0.51	0.25	0.88	7.22	0.04	0.1	0.02	0.45	0	0.13	0.05	0	0.08
Glencoe South-4	425.05	4.26	0.08	1.38	82.08	2.07	1.55	0.15	0.21	3.49	2.26	0.04	0	2.08	0	0.17	0.05	0.01	0.12
Goon Nure-9	726.3	1.72	0.14	1.01	90.17	3.5	1.03	0.18	0.03	0.91	0.1	0.25	0.12	0.33	0	0.24	0.02	0	0.24
Goon Nure-2	731.21	2.61	0.04	1.05	90.29	2.3	1.05	0.38	0.02	1.47	0.53	0.02	0	0.15	0	0.04	0.03	0	0.03
Goon Nure-1	769.31	3.95	0.05	1.24	87.44	0.92	1.32	0.43	0.09	2.94	0.31	0.05	0.02	0.99	0	0.1	0.05	0	0.11
Goon Nure-2	785.77	1.77	0.03	0.55	92.04	0.46	0.51	0.99	0.01	2.29	0.87	0.17	0.01	0.2	0	0.06	0.02	0	0.02
Holey Plains-185**	538.2	4.78	0.1	0.57	38.64	0.44	0.4	0.05	0.02	28.58	1.55	21.82	0.28	1.3	0	0.54	0.04	0.01	0.87
Hunters Lane-1	377	8.3	2	8.42	61.04	7.2	8.26	2.34	0.02	0.1	0.09	0.11	0.05	1.54	0	0.08	0.18	0.01	0.27
Meerlieu-4	633.2	1.15	0.03	0.11	52.83	0.07	0.07	0.01	0	38.92	0.18	5.09	0.06	0.53	0	0.76	0.02	0	0.19
Meerlieu-15001	699.9	2.91	0.27	1.68	84.65	1.27	0.87	0.69	3.06	1.61	0.16	0.81	0.47	0.57	0	0.05	0.05	0.01	0.86
Meerlieu-4	722	2.52	0.19	0.6	88.6	2.37	0.5	0.93	0.01	0.45	1.5	1.02	0.4	0.49	0	0.06	0.02	0	0.33
Meerlieu-4	769	2.31	0.37	0.67	88.36	4.62	0.61	0.53	0.01	0.27	0.46	0.39	0.23	0.7	0	0.07	0.03	0	0.35
Mullungdung-7	363	31.45	0.36	1.49	47.7	0.71	1.88	0.02	0.91	5.21	3.65	1.65	1.01	2.88	0	0.45	0.07	0.01	0.53
Nuntin-2	869.28	5.41	0.1	1.12	81.72	0.56	0.88	0.27	0.06	7.51	0.72	0.17	0.05	0.98	0	0.19	0.07	0.01	0.18

Onshore Wells	Depth (m)	Quartz	Albite	K Feldspar	Smectite	Kaolinite	Illite/ muscovite	Chamosite	Glauconite	Calcite	Siderite	Dolomite	Ankerite	Pyrite	Goethite	Apatite	Anatase	Zircon	Minor Phases
Nuntin-2	885.74	5.8	0.09	1.01	79.79	0.38	0.67	0.35	0.38	7.84	0.7	1.51	0.88	0.18	0	0.23	0.06	0	0.13
Sale-13	748.1	6.07	0.16	1.33	82.98	0.39	0.99	0.33	0.16	3.57	0.65	1.2	0.83	0.54	0	0.12	0.08	0.01	0.59
Sale-13	795.6	8.68	0.28	4.01	66.53	6.77	3.77	0.3	2.23	0.87	0.04	0.37	0.26	5.08	0	0.04	0.11	0.02	0.63
Sale-15	628.6	4.01	0.2	1.03	82.72	0.98	0.79	0.08	0.02	2.74	0.02	3.11	1.97	1.27	0	0.12	0.07	0.02	0.84
Seacombe-7	649	0.74	0.01	0.09	52.9	0.01	0.05	0.01	0	44.43	0.15	0.32	0	0.18	0	1.04	0.01	0	0.07
Seacombe-7	947.6	2.02	0.23	0.85	86.7	5.14	0.84	0.64	0	0.49	0.74	0.8	0.38	0.88	0	0.02	0.03	0	0.23
Sperm Whale Head-1	653.8	1.54	0.11	0.39	87.35	0.28	0.28	0.17	0	3.72	0.13	2.67	1.69	0.53	0	0.12	0.03	0	0.98
Sperm Whale Head-1	671.47	3.67	0.09	0.55	79.97	0.37	0.36	0.49	0.01	12.93	0.68	0.24	0.03	0.25	0	0.27	0.03	0	0.05
Sperm Whale Head-1	718.1	3.29	0.38	1.4	86.79	1.48	1.03	0.86	0.02	2.53	0.78	0.42	0.34	0.13	0	0.06	0.03	0	0.46
Woodside-3**	410.87	26.8	1.02	2.23	8.03	0.24	1.5	0.99	0.05	10.51	17.44	28.94	0.24	0.19	0	1.3	0.08	0	0.43
Woodside-4**	610.81	8.78	0.37	0.73	25.89	0.03	0.5	0.34	0.21	57.72	2.56	1.35	0.01	0.01	0	1.25	0.07	0	0.16
Woodside South-1	522.12	4.42	0.21	0.41	66.74	0.2	0.43	0.01	0.01	20.65	2.99	0.62	0.58	0.8	0	0.72	0.06	0	1.15
Wooundellah-10**	389.3	12.1	0.55	2.13	26.88	0.56	1.83	0.14	0.01	23.08	24.28	1.69	0.13	2.91	0	2.38	0.05	0.01	1.26
Wooundellah-11**	389	4.82	0.07	0.36	34.97	0.52	0.47	0.02	0	46.61	6.2	1.03	0.03	2.03	0	1.64	0.05	0	1.16
Wulla Wullock-5	699.6	3.69	0.03	0.59	88.01	2.61	0.39	1.12	0.01	0.92	2.01	0.11	0.02	0.4	0	0.03	0.02	0	0.04
Wurruk Wurruk-1**	562.35	1.33	0.04	0.13	40.32	0.02	0.08	0.01	0	55.65	0.11	0.43	0.01	0.59	0	1.12	0.01	0	0.17
Wurruk Wurruk-1	647.39	26.82	0.61	1.35	60.57	0.8	1.07	0.19	0.05	5.38	0.99	0.76	0.01	1.04	0	0.18	0.09	0.01	0.08
Wurruk Wurruk-13	584.9	7.37	0.11	1.74	79.1	1.29	1.24	0.34	2.35	3.43	0.02	0.04	0	1.91	0	0.14	0.07	0	0.85
Yeerung-1	402.33	22.87	0.08	0.3	42.81	0.9	0.17	0	0.07	27.75	2.51	1.06	0.01	0.5	0	0.7	0.06	0.01	0.19

**Indicates Gippsland Limestone

