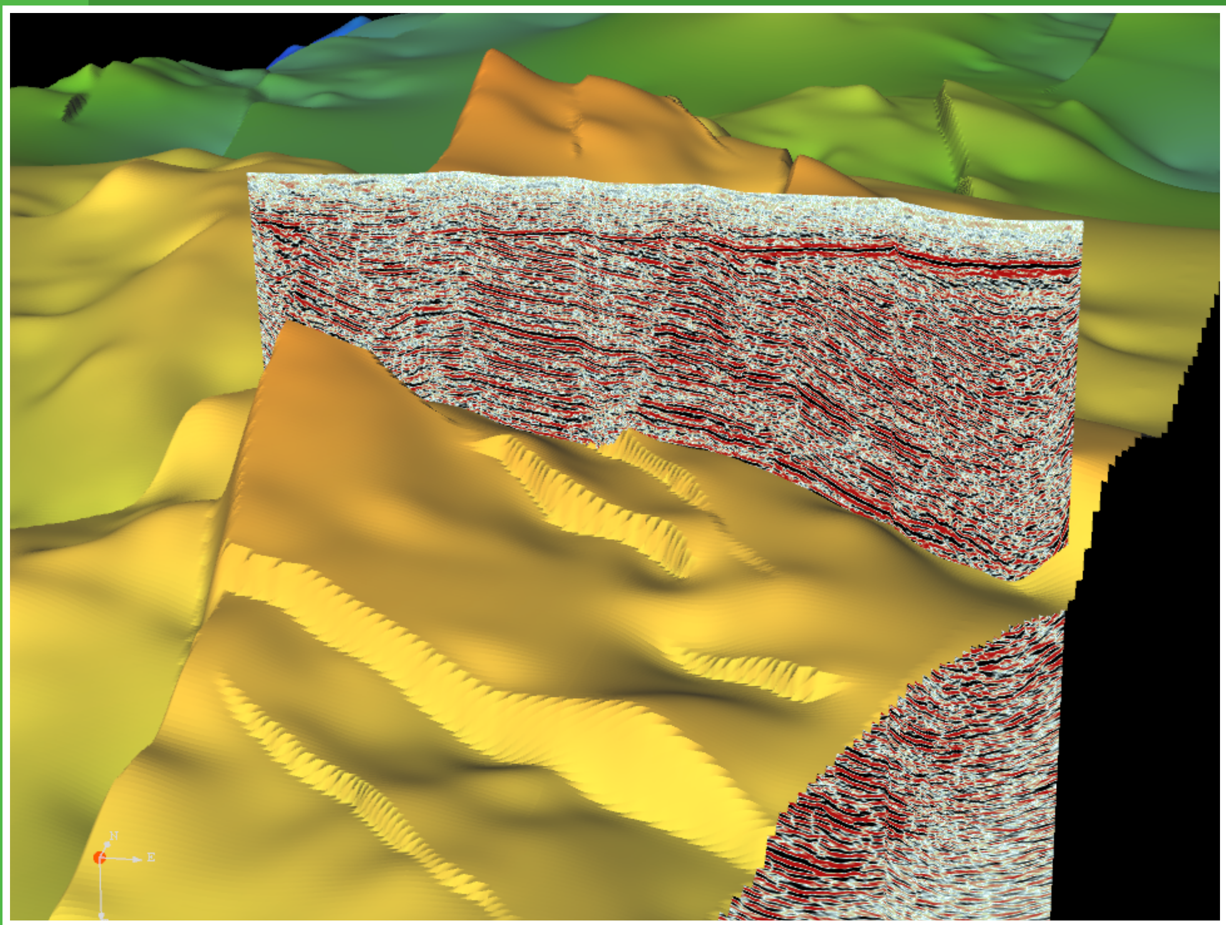
Government of Western Australia

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

REPORT 184

REGIONAL SEISMIC INTERPRETATION AND STRUCTURE OF THE SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

by CM Thomas



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PERTH 2018

Geological Survey of
Western Australia

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Cover photograph: 3D surface of Top Wonnerup Member looking northwest over the crest of the Harvey Ridge

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Regional seismic interpretation and structure of the southern Perth Basin, Western Australia

by

CM Thomas

Abstract

The southern Perth Basin represents the southernmost extent of the Gondwanan interior rift in Western Australia, and now forms part of the passive margin of Australia. Presented here is a new seismic interpretation of the basin that is tied to revised well formation tops constrained by recent resampling for palynology and re-evaluations of historical palynology reports. Newly reprocessed legacy seismic data and recent seismic data acquisition have helped image the deepest depocentres of the basin, and have resulted in identification and confirmation of the tectonic events that shaped the basin.

The southern Perth Basin saw almost uninterrupted sedimentation from at least the early Permian (or possibly earlier) until Early Cretaceous breakup. Three sedimentary intervals in particular show thickening into the major faults, suggesting at least three phases of extension: pre-Permian or earliest Permian extension, Late Triassic to Early Jurassic extension, and Late Jurassic to Early Cretaceous rifting. The north-striking Darling Fault and the Badaminna Fault system, and the north- to north-northwesterly striking Busselton and Dunsborough Faults, played significant roles during basin tectonism.

Late Jurassic to Early Cretaceous oblique rifting saw intense basinwide normal faulting, rapid subsidence and localized contractional structures along major faults. It also led to extrusion of the Bunbury Basalt and continental breakup between the Australia–Antarctic continent and Greater India.

KEYWORDS: rift basins, rift faults, sedimentary basins, seismic interpretation, tectonics

Introduction

The Perth Basin is a north–south trending rift basin between the Archean Yilgarn Craton and oceanic crust of the Indian Ocean that now forms part of the passive margin of Western Australia (Fig. 1). The basin resulted from multiple phases of rifting that culminated in the breakup of Gondwana in the Early Cretaceous (Valanginian–Hauterivian; Gibbons et al., 2012). It contains mostly Permian to Lower Cretaceous pre-breakup strata deposited over Proterozoic basement gneisses and granitic rocks of the Pinjarra Orogen. Within the northernmost Perth Basin, an ?Ordovician to latest Carboniferous succession overlies basement; this succession appears to be absent in the southern Perth Basin. The post-rift succession is thin onshore, but it thickens considerably offshore. Permian sedimentary rocks of the Perth Basin once extended over the western part of the Yilgarn Craton, but much was completely eroded before breakup, except within the Collie, Boyup and Wilga Sub-basins, and around Donnybrook (Fig. 1). Within the Perth Basin, metamorphic rocks of the Pinjarra Orogen have been exposed through uplift and erosion of large footwall blocks to form the Leeuwin Inlier in the southern Perth Basin and the Mullingarra Inlier in the northern Perth Basin. Due mainly to its proximity to infrastructure and population centres, the Perth Basin is currently, and has historically been, an important source of hydrocarbon, mineral, construction material, geothermal and groundwater resources; however, only the northern Perth Basin has seen commercial development of hydrocarbons.

This Report focuses on the southern Perth Basin, an informal name taken here to be that part of the Perth Basin south of Perth city including the southern part of the offshore Vlaming Sub-basin (Fig. 1). The southern Perth Basin contains proven petroleum systems that have yet to be developed, and although exploration began in the 1960s, patchy seismic survey coverage and poor seismic data quality due to near-surface noise and vintage has obscured stratal geometries and many aspects of the major structures. Prior to this project, the most recent subsurface maps based on original interpretation of both onshore and offshore seismic were published in 1993 (Iasky, 1993); newly acquired and reprocessed seismic data and new well and drillhole data warranted a fresh interpretation of this part of the basin.

Previous work

There is very limited outcrop of Perth Basin strata south of the Perth metropolitan area (Lowry, 1965); much of the exposure is Cenozoic and unconsolidated sediments. Therefore, much of the stratigraphy (Fig. 2) and structure has been established from subsurface and geophysical data (Figs 3–5). The regional seismic interpretation of Iasky (1993) determined the broad structural architecture of both the onshore and part of the offshore southern Perth Basin, and identified major inconsistencies in previous stratigraphic correlations between existing wells. Since then, more well and seismic data have been acquired, and the stratigraphic nomenclature has been refined and redefined.

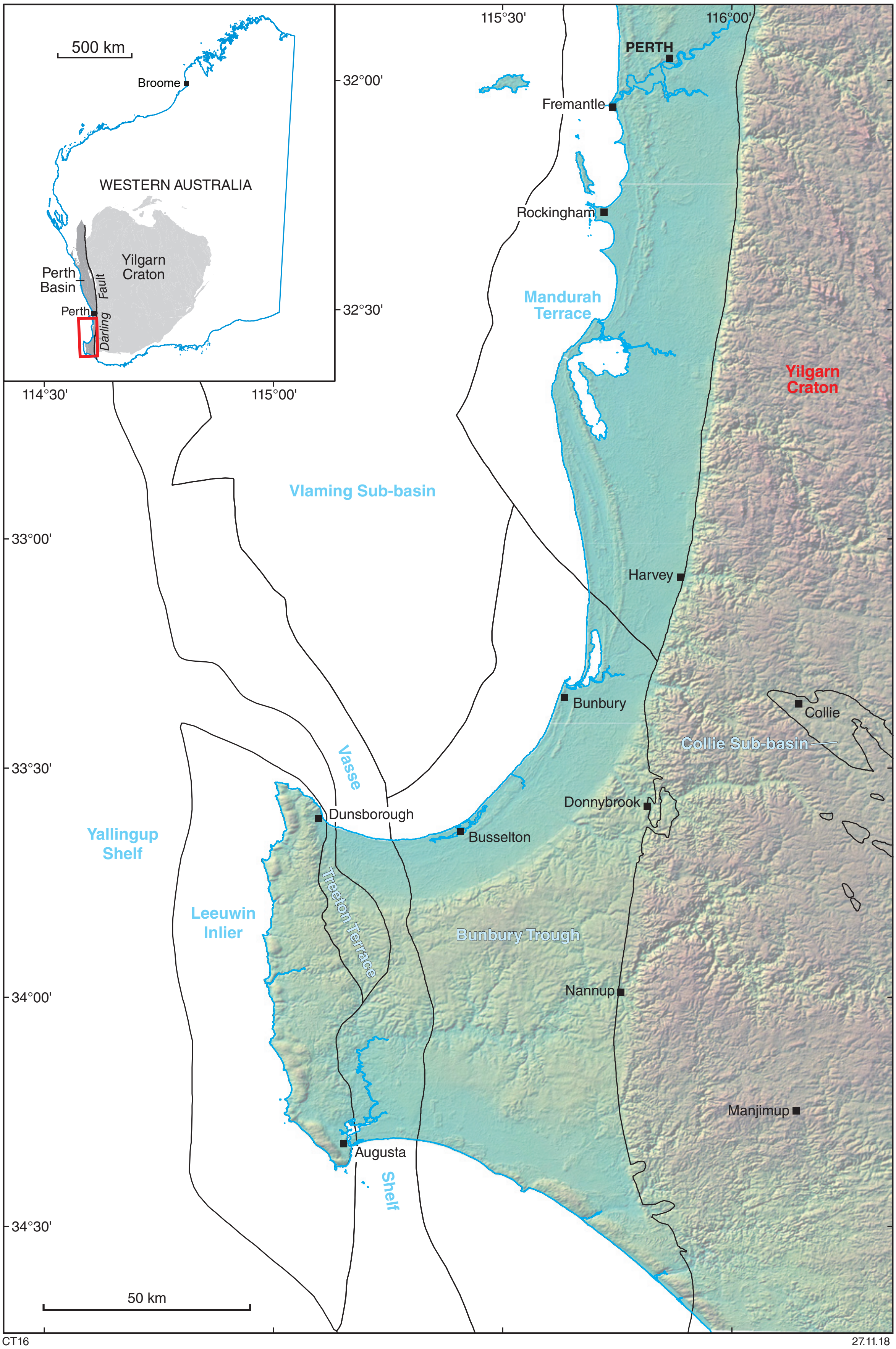

Figure 1. **Location of study area, showing outlines of sub-basins comprising the southern Perth Basin, and digital elevation model (DEM) of present-day elevation. Sub-basin boundaries are from GSWA (2017a)**

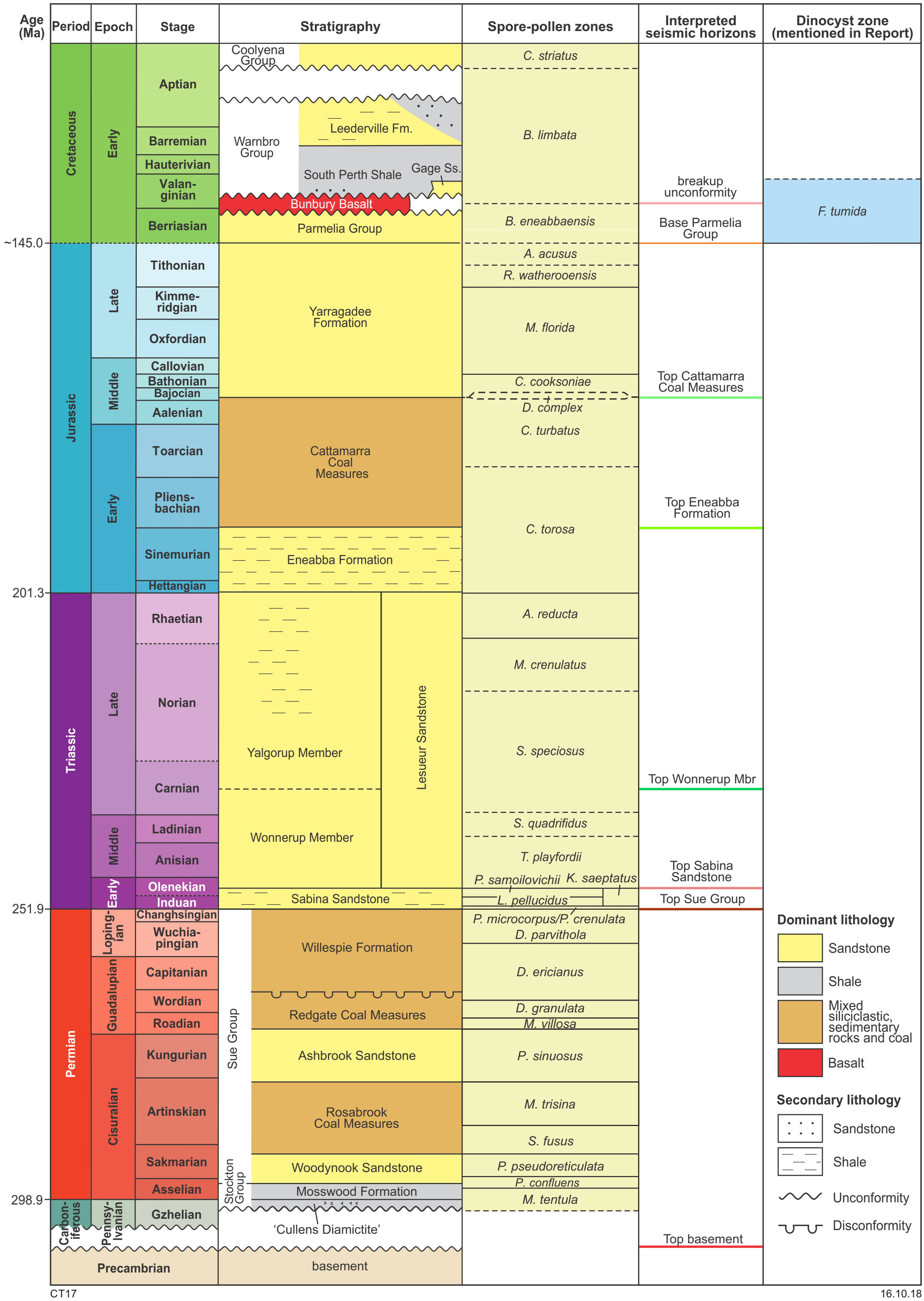

Figure 2. Stratigraphy of southern Perth Basin and interpreted seismic horizons (modified from Thomas, 2014)

The areal extent covered by this Report expands on the area interpreted by Iasky (1993) by including more of the Vlaming Sub-basin and the Mandurah Terrace (Fig. 1). The Vlaming Sub-basin has previously been comprehensively mapped from seismic data (e.g. Marshall et al., 1989, 1993; Nicholson et al., 2008) but, due to the great depth of pre-breakup (pre-Early Cretaceous) strata in this sub-basin and the focus on petroleum prospectivity, those campaigns focused only on the Late Jurassic and younger succession.

The Permian to Cenozoic stratigraphy was formally defined by Playford et al. (1976), with a specific nomenclature defined for the Permian and Early Triassic succession in the southern Perth Basin. Nomenclature for the Mesozoic succession was adopted from the northern Perth Basin (Fig. 2). Le Blanc Smith and Kristensen (1998) refined the Permian stratigraphy, based on detailed work on coal drillholes in the Vasse Shelf. Crostella and Backhouse (2000) redefined portions of the Mesozoic stratigraphy, and reinterpreted formation tops in all petroleum wells based on their new scheme. They applied the Triassic to Jurassic stratigraphic nomenclature for the northern Perth Basin, defined in Mory and Iasky (1996), to wells in the southern Perth Basin. However, their correlations relied too heavily on lithostratigraphy and ignored biostratigraphy, resulting in packages assigned to the same formation but not equivalent in age. This is particularly a problem for the three formations representing the Upper Triassic – Middle Jurassic section which, in the southern Perth Basin, contain similar lithofacies. Furthermore, they did not take into consideration faults interpreted in seismic profiles, and thus any missing sections in wells. Therefore, no reliable set of formation tops exists for this interval.

Various tectonostratigraphic schemes and basin tectonic phases have been proposed for the Perth Basin (summarized in Thomas, 2014). Most schemes recognize a synrift succession in the Permian, although interpretations of the timing of onset and duration differ markedly, (e.g. Harris 1994; Tupper et al., 1994; Song and Cawood, 2000; Jones et al., 2011). Iasky (1993) interpreted a phase of regional folding and uplift associated with a pulse of heat due to igneous intrusions at the end of the Permian. This was based on the interpretation that the vitrinite reflectance trends of Permian rocks in two wells — Sue 1 and Lake Preston 1 — differ from those for overlying Upper Triassic and Jurassic rocks. However, the interpretation of Sue 1 is doubtful, because not only are the Permian measurements highly scattered, but the different trend for Permian rocks is based on just one outlying measurement. Vitrinite reflectance measurements of Permian rocks in Lake Preston 1 do appear to lie on a markedly different trend to Upper Triassic and Jurassic measurements above, but measurements towards the bottom of the well are much higher than Permian rocks at similar depths in other wells (cf. Whicher Range 1). This raises the question of whether this is truly indicative of a regional event. Further, there is a large gap in sampling between the Permian and the Upper Triassic in this same well, so an uplift and erosion event is not conclusive. Although the elevated paleotemperatures of Permian rocks can be explained by an igneous intrusion present just below the well, as first suggested by Kantsler and Cook (1979) and later Iasky (1993), the timing of heating cannot be determined from available vitrinite measurements alone. The vitrinite reflectance profile in Lake Preston 1 could be produced by an underlying intrusive body of any age after deposition of Permian strata. As yet, there is no evidence for Permian igneous activity anywhere in the southern Perth Basin and an intrusion, if present, is more likely to be associated with the Early Cretaceous volcanism at breakup.

Song and Cawood (2000) recognized the Lower Jurassic sequence as a synrift deposit in the onshore northern Perth Basin based on changes in thickness of the Lower Jurassic Eneabba Formation across normal faults. Whether thickening at this time is evident in the southern Perth Basin has yet to be determined. The Upper Jurassic and the lowermost Cretaceous strata are widely accepted to be synrift successions (Iasky, 1993; Harris, 1994; Song and Cawood, 2000; Nicholson et al., 2008; Jones et al., 2011). This final rifting event led to breakup and separation of Greater India from the Australia–Antarctic continent to form the Indian Ocean, with the oldest sea floor in the adjacent oceanic crust (Perth abyssal plain) recognized to belong to Chron M9, with an interpreted age of c. 131 Ma (Gibbons et al., 2012). The breakup unconformity is of Valanginian to Hauterivian age, and sits either just below or within a ~7 Ma period of episodic basalt extrusions (collectively known as the Bunbury Basalt) that range in age from c. 137 to 130 Ma (Olierook et al., 2015).

Rifting between Australia and Antarctica began at 165–160 Ma (Norvick and Smith, 2001; Williams et al., 2011), and sea-floor spreading is interpreted by most authors to have begun at c. 84 Ma (White et al., 2013). How this southern rifting and breakup event affected the stratigraphy and structure of the southern Perth Basin is not clear.

New regional seismic and drillhole interpretation (this Report) has resulted in formation isopach maps that have been used to test whether any of the tectonostratigraphic schemes can be applied to the onshore southern Perth Basin. Previous well correlations and isopach maps of Crostella and Backhouse (2000) were based solely on well data, and did not include seismic mapping, and therefore cannot be used.

Purpose and scope of this Report

This project involved the interpretation of nearly 8000 km of 2D seismic lines tied to petroleum wells, mineral drillholes and water bores within the project area. The objectives of this Report are to:

1. provide a regional set of interpreted seismic horizons tied to formation tops defined using biostratigraphy. The mapped surfaces can be used in future regional projects such as basin modelling
2. identify periods of fault movement and tectonic events based on formation isopach maps and stratal relationships identified in seismic profiles
3. assess the nature of sub-basin boundaries.

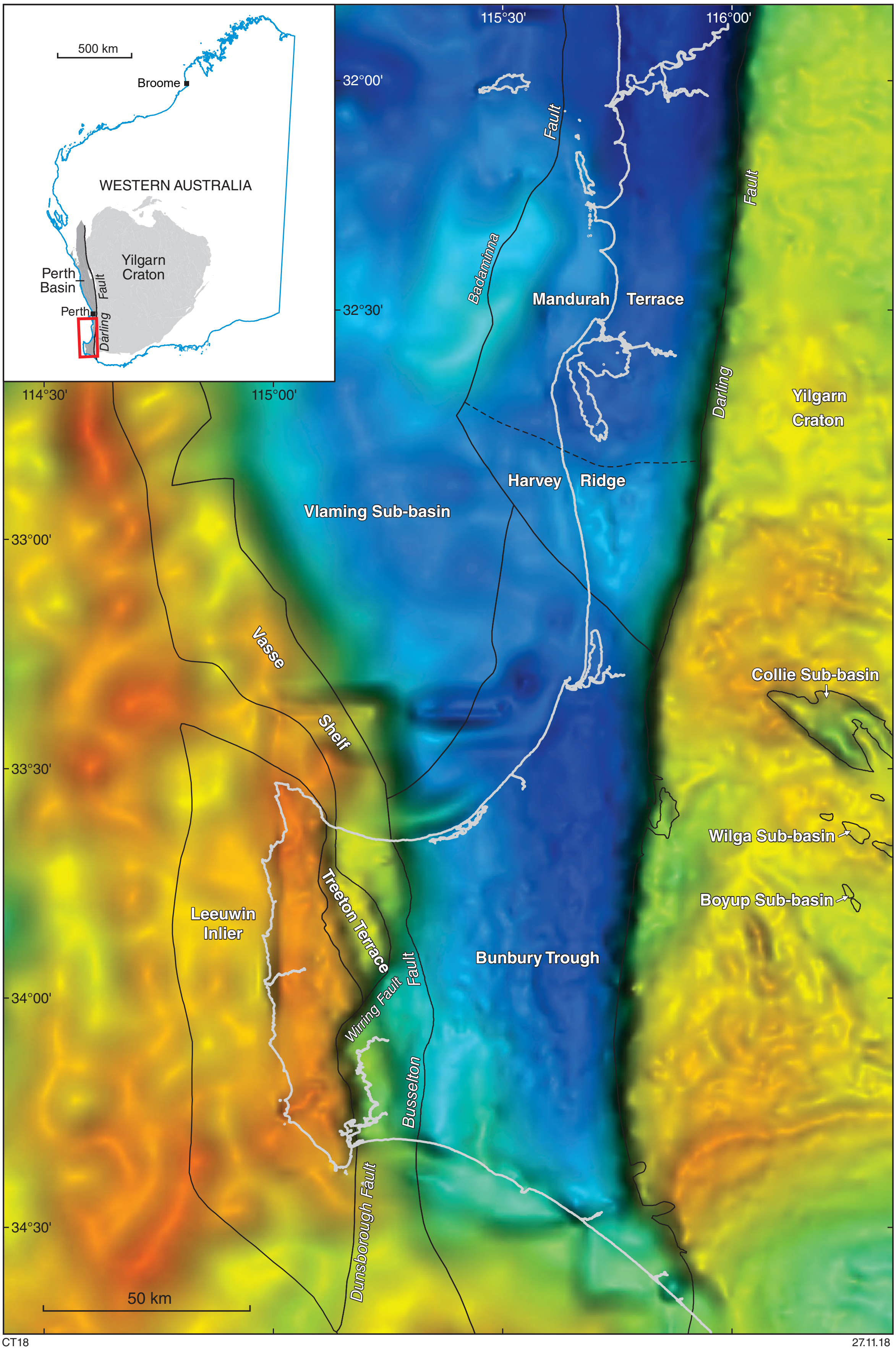

Figure 3. Sub-basins and Precambrian terranes (GSWA, 2017a) overlain on the state Bouguer gravity anomaly image (GSWA, 2017b). Gravity anomaly highs (warmer colours) broadly correspond to shallower or outcropping basement

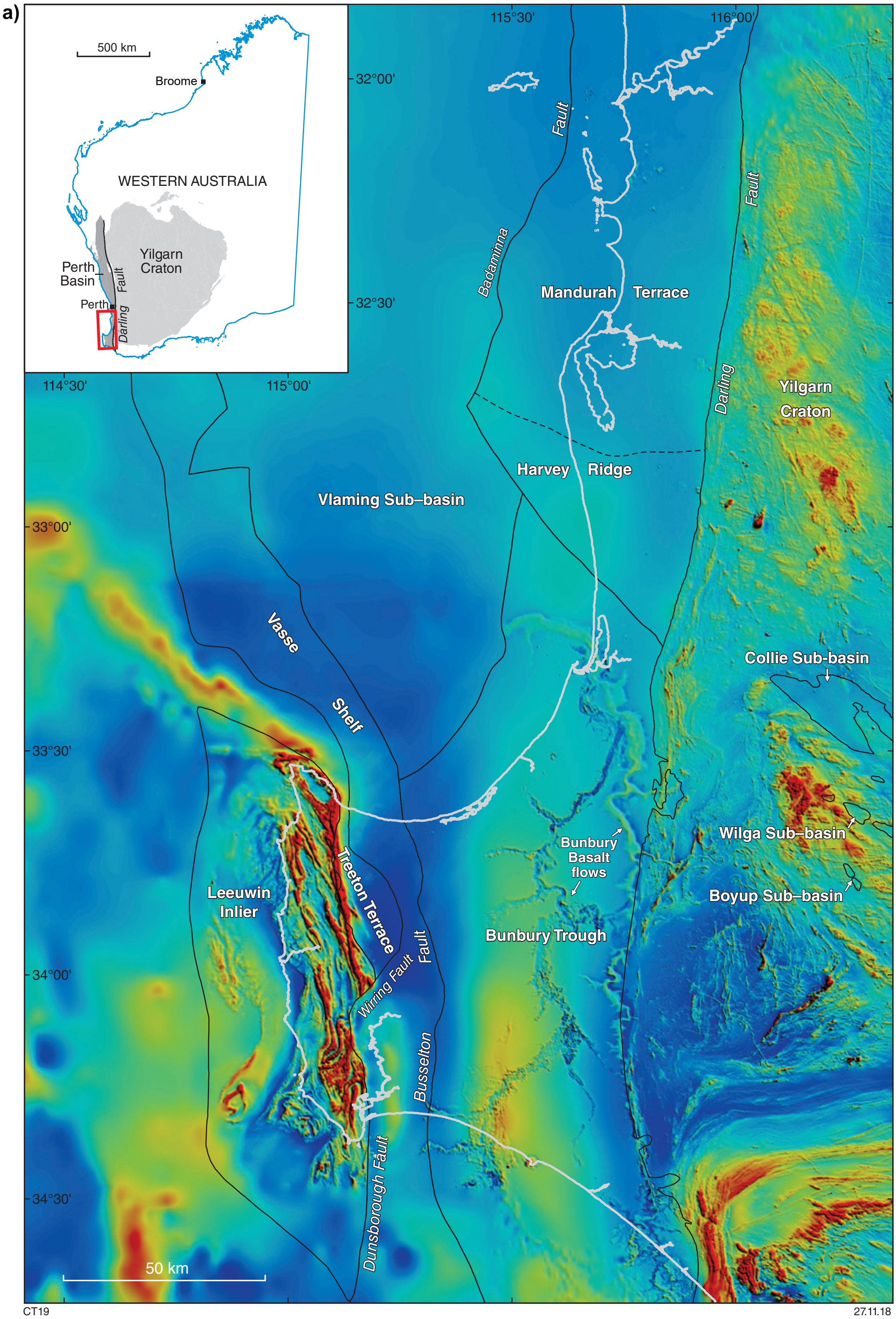

Figure 4. Sub-basins and Precambrian terranes (GSWA, 2017a) overlain on magnetic anomaly grids of Western Australia (GSWA, 2017c): a) total magnetic intensity (TMI) grid; b) first vertical derivative of the TMI grid. Dashed lines in (b) represent 'transfer faults' interpreted by Iasky and Lockwood (2004) from magnetic anomaly data. These transfer faults are considered here to be highly speculative, and not supported by the interpretation of seismic data in this Report or by more recent aeromagnetic data

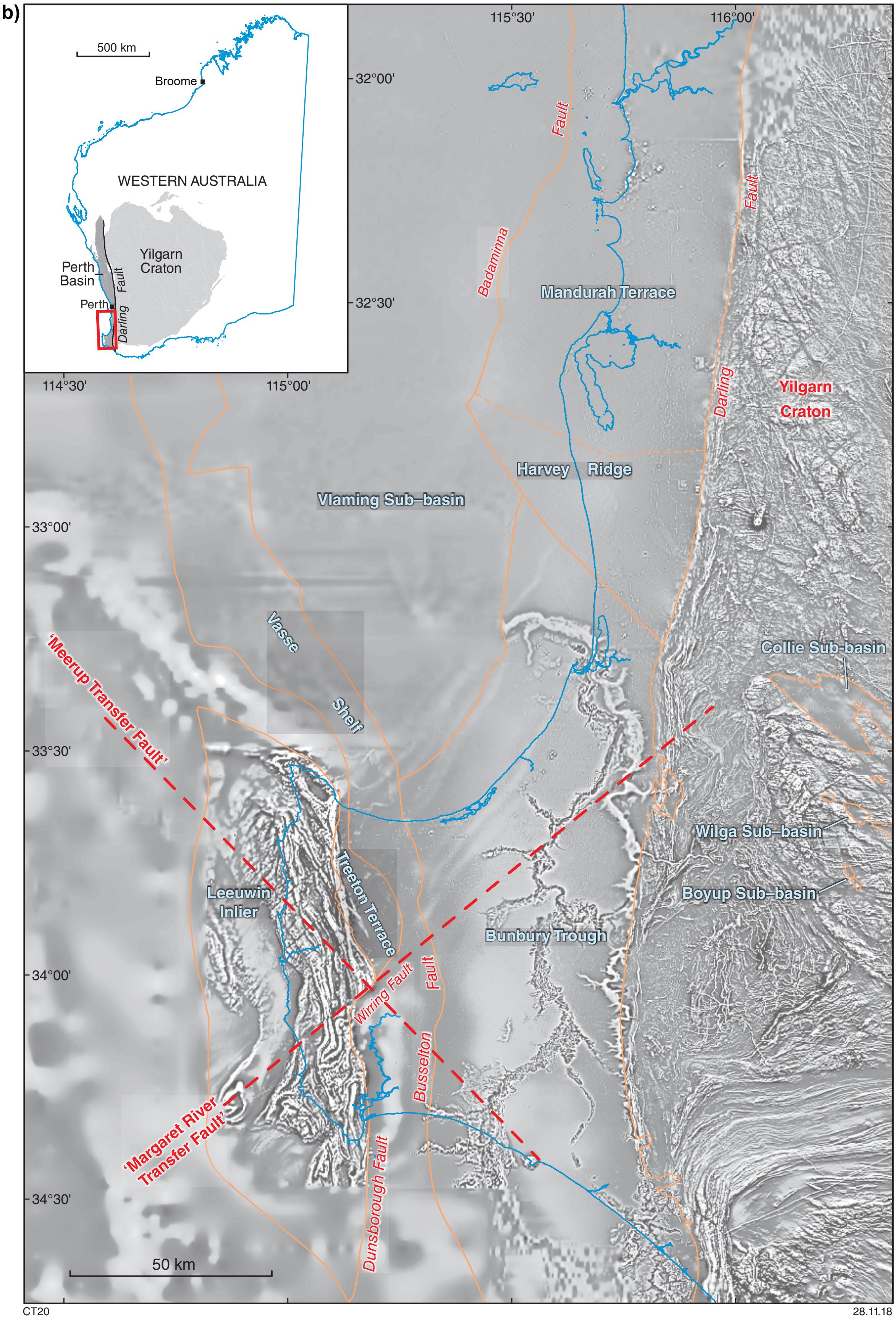

Figure 4. continued

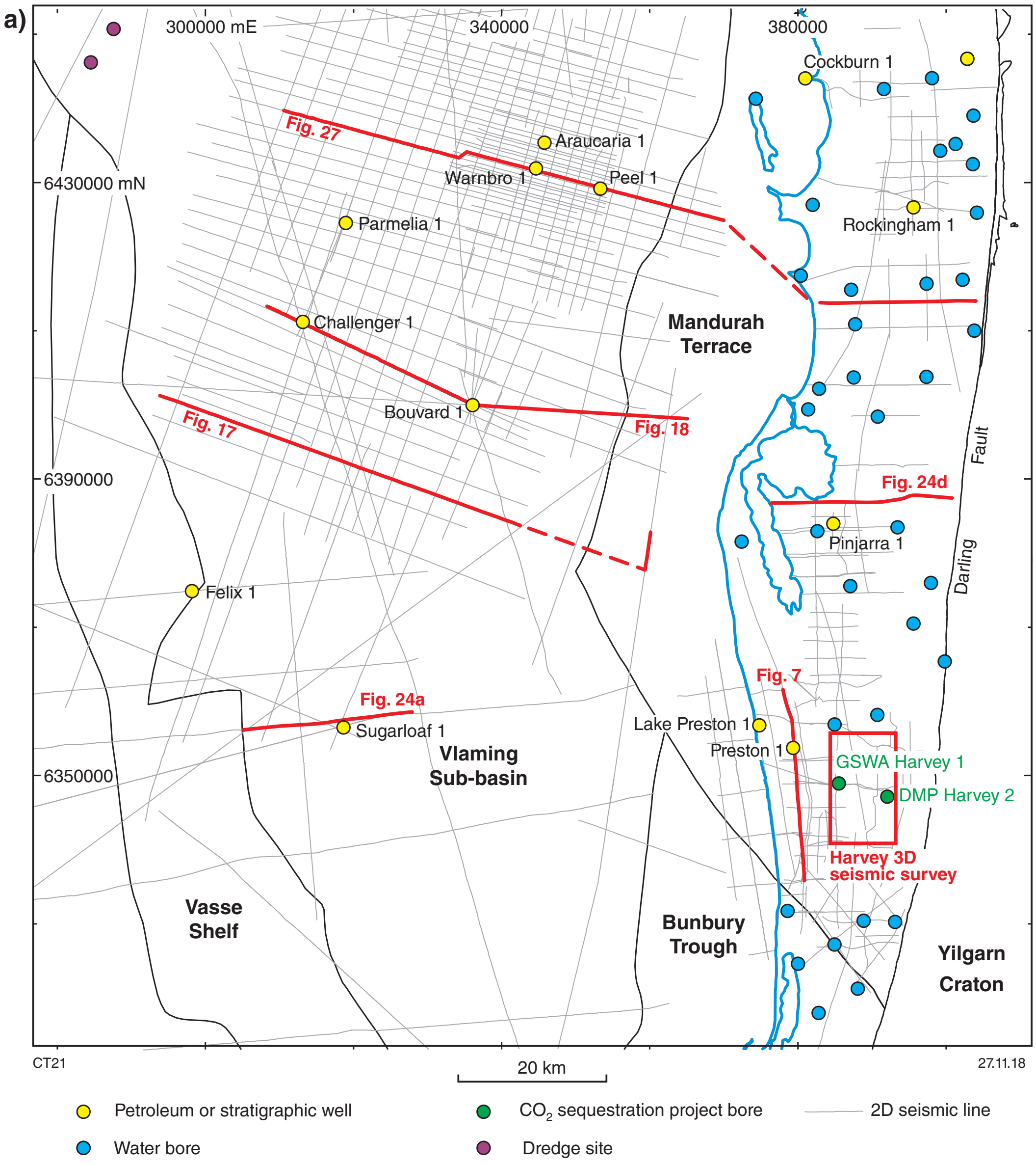

Figure 5. **Seismic survey, petroleum well, water bore and drillhole datasets used for interpretations in this Report: a) northern part of project area; b) southern part of project area. Petroleum wells and bores/drillholes mentioned in text are labelled. Abbreviations: CL, Cowaramup Line; KL, Karridale Line**

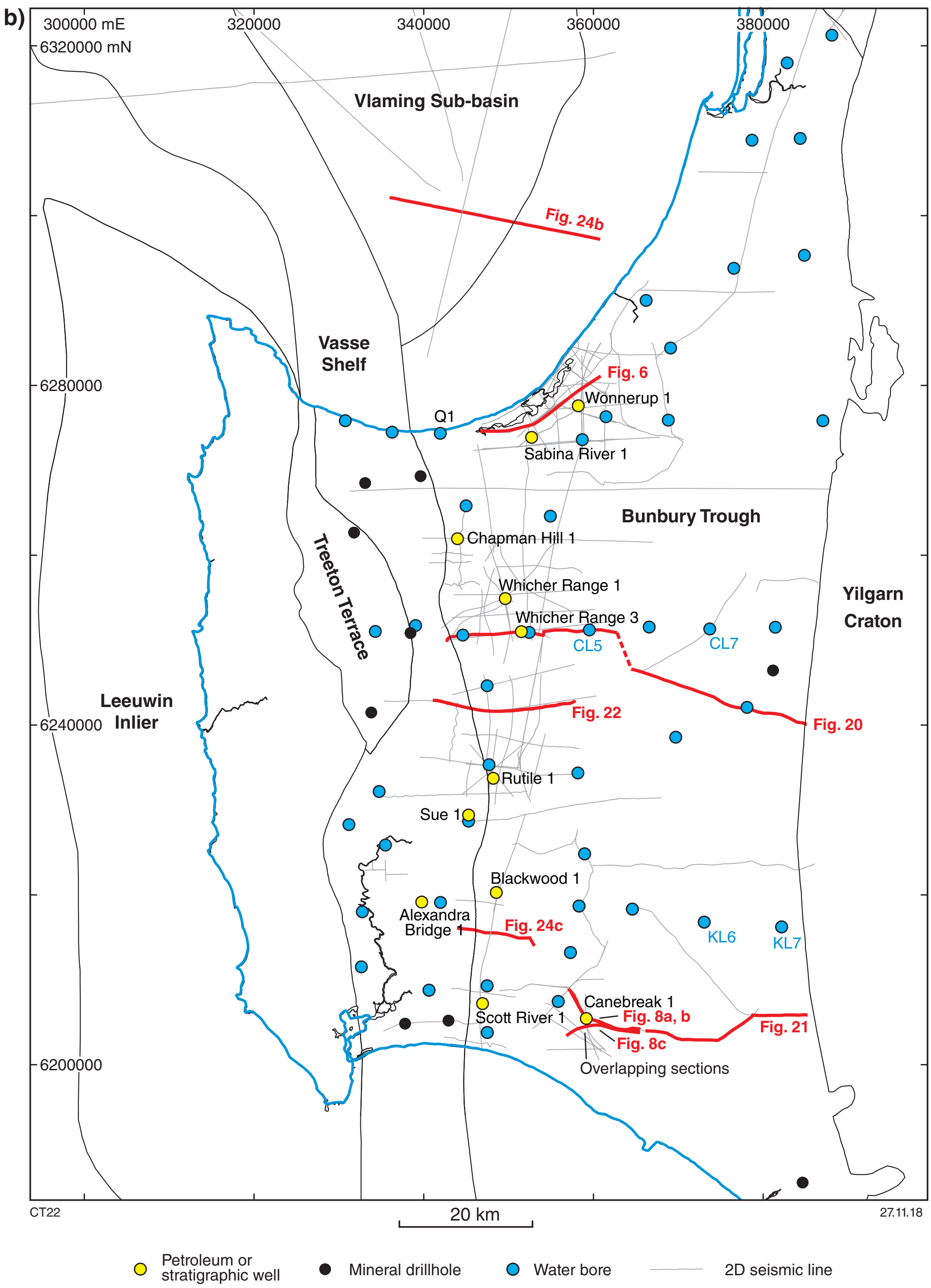

Figure 5. continued

The following seismic horizons were interpreted: Top basement, Top Sue Group (Permian), Top Sabina Sandstone (uppermost Permian to Early Triassic), Top Wonnerup Member (Lower Lesueur Sandstone, Middle to Upper Triassic), Top Yalgorup Member – Eneabba Formation (uppermost Triassic to Lower Jurassic), Top Cattamarra Coal Measures (Lower–Middle Jurassic), Base Parmelia Group (lowermost Cretaceous), and breakup unconformity (Lower Cretaceous). This seismic interpretation project is an update of the work by Iasky (1993), but has included the Parmelia Group as a separate interval, whereas previously Iasky (1993) included this group with either the underlying Yarragadee Formation or the overlying Warnbro Group. The Eneabba Formation and the Cattamarra Coal Measures equivalents have also been separately interpreted, whereas previously they were included as part of the 'Cockleshell Gully Formation' — nomenclature that has been superseded.

This interpretation is also an extension of the seismic interpretation (Zhan, 2014), which focused on the Harvey Ridge. However, a new 3D seismic survey has since been acquired, three deep wells have been drilled, and the palynology of all water bores and petroleum wells in the Harvey Ridge area has been reassessed and placed into modern zonation schemes (Martin, 2018). Therefore, the interpretation of Zhan (2014) has been modified to take account of the new data.

This project has extrapolated the onshore horizon interpretation of the Permian to Middle Jurassic section to the offshore, which had not previously been interpreted.

Regional geology

Stratigraphy

The Perth Basin formed as part of the East Gondwana interior rift–sag system. The southern Perth Basin was situated in a more interior position of the East Gondwana rift compared to the northern Perth Basin and the Carnarvon Basin (Haig et al., 2014), which was more proximal to the then continental–oceanic crust boundary. This meant that the marine incursions that deposited the latest Permian – Early Triassic Kockatea Shale and the Middle Jurassic Cadda Formation in the northern Perth Basin did not reach the southern Perth Basin, and a continental depositional environment was maintained throughout its entire evolution until breakup. The Cockburn 1 petroleum well at the northern edge of the study area has a marine influence in the Middle Jurassic (Western Palynoservices, 1991), marking the southernmost limit of this marine incursion.

The oldest known strata in the southern Perth Basin are of early Permian age (Fig. 2), and are intersected only in wells and drillholes in the Vasse Shelf and Treeton Terrace (Figs 3–5), where they overlie basement. Similar units are also present as scattered outcrop or shallow subsurface pockets over the western Yilgarn Craton, and sections up to 1200 m-thick are preserved in the Collie Sub-basin, and up to 300 m are preserved in the Wilga and Boyup Sub-basins. The greater depth of the Bunbury Trough and Mandurah Terrace means only the upper Permian succession has been intersected by drilling, and the Permian succession has not been penetrated in the offshore Vlaming Sub-basin, where this interval is buried much deeper. The basal Permian section is assigned to the Stockton Group, which is a glacial unit dominated by diamictite and shale. The overlying section, also Permian, is assigned to the Sue Group, which comprises interbedded sequences of thick coal, sandstone and shale deposited in a postglacial fluvial environment (Le Blanc Smith and Kristensen, 1998). These groups are interpreted to be conformable, but there may be a disconformity between the uppermost unit of the Sue Group (Willespie Formation) and underlying formations within the same group. This is based on the presence of a regional unconformity at a similar level in the northern Perth Basin.

The Willespie Formation is overlain by the Sabina Sandstone, which, based on palynological assemblages, is equivalent in age to the Kockatea Shale and part of the overlying Woodada Formation in the northern Perth Basin. The Sabina Sandstone was deposited in a fluvial environment (Crostella and Backhouse, 2000). Its basal contact with the Sue Group is interpreted to be conformable (Crostella and Backhouse, 2000), but a regional unconformity at the base of the Kockatea Shale in the northern Perth Basin raises the possibility that an unconformity also exists at this position in the southern part of the basin.

Lithostratigraphic units defined in the northern Perth Basin have been recognized in the Mesozoic section in the southern Perth Basin, except for the transgressive Middle Jurassic Cadda Formation. The Lesueur Sandstone was divided by Crostella and Backhouse (2000) into the Wonnerup Member (a clean, light-coloured, sandstone-dominated lower unit) and the Yalgorup Member (formerly 'Myalup' Member; an interbedded sandstone and multicoloured mudstone–paleosol upper unit). The overlying Eneabba Formation resembles the Yalgorup Member in wireline log character and in lithology, but in some wells in the southern Perth Basin the Eneabba Formation also contains thin coal layers and dark-coloured, unoxidized mudstones. This led Crostella and Backhouse (2000), taking a purely lithostratigraphic approach, to assign these units to the overlying Cattamarra Coal Measures where coal was encountered, despite the palynology indicating they have an earlier Jurassic age. This highlights the problem with using lithostratigraphy only, particularly in continental fluvial sequences. The overlying Yarragadee Formation is a fluvial sandstone-dominated unit, and rocks equivalent in age to the Cadda Formation (*Dictyosporites complex* Spore-Pollen Zone) are included within the Yarragadee Formation. The Parmelia Group is a fluviolacustrine unit containing thick distinctive shales that locally have a marine influence (Crostella and Backhouse, 2000).

No major depositional hiatuses have been identified in the Permian to Lower Cretaceous section in the southern Perth Basin, apart from localized uplift and erosion over the Vasse Shelf and Treeton Terrace after deposition of the Upper Triassic succession but before deposition of the Parmelia Group. There were three phases of mafic volcanism just before and just after Valanginian continental breakup, resulting in numerous dykes and sills that have been penetrated by wells in the Bunbury Trough, Vlaming Sub-basin and the Vasse Shelf. The Bunbury Basalt was also extruded from several vents, filling paleovalleys incised into the underlying Parmelia Group and Yarragadee Formation. The Bunbury Basalt is an obvious feature in the total magnetic intensity (TMI) and first vertical derivative (1VD) of TMI images (Fig. 4a,b), and is a significant source of noise in seismic data in the region.

Tectonic elements

The southern Perth Basin is divided into the Mandurah Terrace, the Bunbury Trough, the Vasse Shelf, the Treeton Terrace, the offshore Vlaming Sub-basin, and the Collie, Wilga and Boyup Sub-basins (Figs 1, 3, 4), the boundaries of which are taken from Geological Survey of Western Australia (GSWA, 2017a). These sub-basins have been defined partly based on seismic interpretation of where the bounding normal faults intersect either the breakup unconformity or the land surface, and hence reflect late rift tectonism and were not necessarily depocentres during pre-breakup sedimentation. One of the aims of this project was to determine if these bounding faults also controlled deposition of earlier strata. Some boundaries are less well defined and are based on magnetic or gravity anomalies. Broadly, the gravity signature of the sub-basins corresponds well with depth to basement as imaged in seismic sections or intersected by wells.

Crostella and Backhouse (2000) and Iasky and Lockwood (2004) interpreted two lineaments from magnetic data that they inferred to be transfer faults extending from the Leeuwin Inlier and into the Vasse Shelf and Bunbury Trough (Fig. 4b). These were: 1) the northwest-trending Meerup Transfer Fault, which they interpreted to extend westwards into the Mentelle Basin and to laterally offset the Leeuwin Inlier and the Darling Fault; 2) the northeast-trending Margaret River Transfer Fault, which they interpreted to extend into the Yilgarn Craton (Fig. 4b). These were both interpreted to be basement faults, and were proposed to have controlled structures in the overlying developing basin. No new information from seismic data has been presented to confirm the existence of the structures since those interpretations.

Mandurah Terrace

The Mandurah Terrace is broadly a half-graben bounded to the west by the Badaminna Fault system and to the east by the Darling Fault. Pre-breakup (Permian to Early Cretaceous) strata generally become deeper with age towards the north, and are shallowest in the south where they were uplifted to form the Harvey Ridge. The Harvey Ridge is associated with a high gravity anomaly relative to adjacent sub-basins (Fig. 3). The Upper Jurassic Yarragadee Formation and possibly the Parmelia Group are absent from the Harvey Ridge, but whether this is due to erosion or non-deposition is unknown. The boundary between the Mandurah Terrace and the Bunbury Trough is not a fault; rather, it is arbitrarily placed where the strata forming the Harvey Ridge begin to plunge deeply towards the south. The mechanism responsible for the formation of the Harvey Ridge is not fully understood.

Bunbury Trough

The Bunbury Trough corresponds to a gravity low, with the lowest gravity anomaly adjacent to the Darling Fault (Fig. 3). This reflects the greater depth to basement relative to adjacent sub-basins. The Bunbury Trough is an asymmetric graben between the Darling and Busselton Faults to the east and west, respectively, with more throw accumulated on the Darling Fault than on the easterly dipping Busselton Fault. A complete Mesozoic section is preserved in the sub-basin; however, there is localized erosion of the Yarragadee Formation and Cattamarra Coal Measures, and the Parmelia Group is thin and not as fully developed as it is in the Vlaming Sub-basin.

A series of northeasterly trending lineaments (positive anomalies) can be seen in the tilt-angle processed aeromagnetic image (Fig. 4b). Iasky and Lockwood (2004) interpreted these to be dykes or structures in basement associated with the Margaret River Transfer Fault. These have yet to be confirmed with more recently acquired or reprocessed seismic data.

Vasse Shelf and Treeton Terrace

The Vasse Shelf and Treeton Terrace together comprise a half-graben between the east-dipping Dunsborough and Busselton Faults. Permian rocks are much shallower here compared to the adjacent Bunbury Trough and Vlaming Sub-basin, with thin to no Triassic and Jurassic section preserved. Basement is much shallower in the Treeton Terrace than in the Vasse Shelf, with lower Permian and basement rocks subcropping beneath the Valanginian breakup unconformity. The Treeton Terrace is delineated from the Vasse Shelf by the easterly and southeasterly dipping Wirring Fault (Figs 3, 4).

No seismic data are available as SEG-Y over the Treeton Terrace; therefore, mapping over this sub-basin is based on well or drillhole data only. Seismic coverage over the Vasse Shelf is sparse, so maps presented in this area are not as detailed as the rest of the project area. The main constraints on horizon structure and thickness maps are sparse drillhole, bore and petroleum well data. Faults are inferred from the limited seismic data and extrapolated using potential-field data.

Vlaming Sub-basin

The Vlaming Sub-basin is located completely offshore in the study area, and is bounded by the Badaminna Fault system to the east and by an offshore extension of the Busselton Fault to the west. Its boundary with the Bunbury Trough does not correlate with any mapped major faults in Iasky (1993) or Nicholson et al. (2008), but instead coincides with linear positive magnetic anomalies. The Vlaming Sub-basin was the main depocentre for Late Jurassic and Early Cretaceous sedimentation (Nicholson et al., 2008). Basement and Permian rocks are too deep to be imaged adequately in the current seismic data, although FrOG Tech (2005) estimated depth to basement to reach ~15 km in the sub-basin using potential-field data.

Collie, Wilga and Boyup Sub-basins

Lower to mid-Permian rocks once extended across the western Yilgarn Craton, of which the Collie, Wilga and Boyup Sub-basins are preserved outliers. Lower to mid-Permian rocks subcrop beneath the breakup unconformity, and there is no intervening upper Permian to Jurassic section. Vitrinite reflectance data suggest an approximately 2 km-thick section was removed (Norvick, 2004), but the age of eroded strata has yet to be determined. Permian strata were preserved through normal faulting after the Permian – most likely just before breakup. These sub-basins are not included in the interpretation that follows.

Resource exploration history

Petroleum

The onshore and offshore southern Perth Basin has been much less explored compared to the onshore northern Perth Basin. In the southern Perth Basin, 30 conventional petroleum wells (27 in study area) and six coal seam gas exploration wells (only on Vasse Shelf and Treeton Terrace) have been drilled. Three shallow wells were drilled in the early 1900s after reports of oil seeps in the Warren River district in the south of the basin area near the Darling Fault (outside study area), without finding any hydrocarbons. The reports of oil seeps were treated as dubious by early government geologists (Woodward et al., 1915), and remain unsubstantiated. More focused petroleum exploration began onshore in the mid-1960s with the drilling of Alexandra Bridge 1, Sue 1, Pinjarra 1 and Preston 1 by WAPET. Alexandra Bridge 1 and Preston 1 (Fig. 5a,b) were the first stratigraphic tests in their respective areas, which previously had only shallow water bores as stratigraphic constraints. Sue 1 and Pinjarra 1 tested anticlines inferred from seismic data (later mapping using subsequently acquired and better quality seismic data indicated Sue 1 did not test a valid trap; Crostella and Backhouse, 2000). Success came in 1968 when Union Oil Development drilled Whicher Range 1 in the Bunbury Trough and discovered a gas accumulation in the upper Permian Willespie Formation of the Sue Group, which is equivalent in age to the producing hydrocarbon reservoirs of the Dongara Sandstone and Wagina Formation in the northern Perth Basin. The Whicher Range trap is a hangingwall anticline (four-way dip closure). The gas is understood to be sourced from coal and carbonaceous shale within the lower Sue Group, and sealed by a shale at the top of the Willespie Formation (Crostella and Backhouse, 2000).

Since the discovery of the Whicher Range accumulation, nearly all petroleum wells in the onshore southern Perth Basin have focused on this upper Permian play. Chapman Hill 1 unsuccessfully tested a different play concept whereby Permian gas would migrate up to shallower levels and get trapped in younger Jurassic stratigraphy. Rockingham 1 and Cockburn 1 in the central Mandurah Terrace — where the Permian was known to be too deep to target — aimed to test the upper ‘Cockleshell Gully Formation’, now designated as the Cattamarra Coal Measures (Mory and Iasky, 1996), in the hope of finding a Gingin-like accumulation; but these too were unsuccessful. Whereas Gingin 1 is a well-imaged anticline in seismic data with stacked sandstone reservoirs and intervening thick sealing shales within the Cattamarra Coal Measures, Cockburn 1 had poor trap definition on seismic sections due to sparse coverage and poor quality, and was likely not within depth closure. Rockingham 1 intersected relatively thin mudstones, and depth closure depended on fault seal (Crostella and Backhouse, 2000), and therefore probably failed due to lack of seal. The drilling history of the onshore southern Perth Basin has demonstrated that the highest risks to exploration are lack of fault seal and breaching of thin top and intraformational seals by faulting. These risks are exacerbated by the characteristically poor seismic data quality in the area, which hampers the identification of small faults.

Four more wells (Whicher Range 2–5) have appraised the Whicher Range accumulation, which remains the only accumulation that was ever under consideration for development in the southern Perth Basin. It remains uncertain whether Wonnerup 1 intersected a gas accumulation (Crostella and Backhouse, 2000).

The offshore Vlaming Sub-basin contains a younger petroleum system (Cretaceous and Upper Jurassic) compared to the onshore section. The Parmelia Group and the post-rift Gage Sandstone have proven their reservoir potential (Nicholson et al., 2008). The source for oil and gas is proposed to be lacustrine shales of the Yarragadee Formation and the Parmelia Group (Volk et al., 2004).

Minerals and construction material

Perth Basin sedimentary rocks and post-rift sediments in the study area have been explored for coal, heavy mineral sands, phosphate, iron and gold. Heavy mineral sands in Cenozoic sediments have been the most commercial and explored for mineral commodities. There are current and formerly operating mines on the southern Swan Coastal Plain in the Capel–Bunbury region, and on the Scott Coastal Plain near Karridale. Extensive coal exploration has taken place on the Vasse Shelf and Treeton Terrace, where Permian coal seams are shallow and subcrop beneath the breakup unconformity, coming within 200 m of the ground surface (Le Blanc Smith and Kristensen, 1998).

An outlier of Permian sedimentary rocks overlying Archean granitic rocks along the westernmost edge of the Yilgarn Craton around Donnybrook hosts epithermal gold mineralization (Ward, 1986), whereby hot mineralizing fluids migrated up the deep crustal Darling Fault and into porous sedimentary rocks. Mineralization appears to be associated with volcanism in the Valanginian during the breakup of Gondwana (Morant, 1988), making it the youngest known gold deposit in Western Australia. Small-scale production from several shafts began in the late 1800s.

Iron mineralization has occurred through lateritization of post-rift sediments and possibly pre-rift sedimentary rocks in the southern Bunbury Trough (Scott Coastal Plain). Although not yet commercially exploited, it has intermittently aroused interest due to its relatively high ore grade and proximity to infrastructure.

Pleistocene limestone, the Early Cretaceous Bunbury Basalt, the 'Maxicar Beds' of the Lower Cretaceous Warnbro Group, and the Donnybrook Sandstone of uncertain age are quarried for use as construction materials.

Groundwater

The study area is densely populated compared to most of the State and is important for food production; thus, there is very high demand for freshwater. The Jurassic Yarragadee Formation, the Lower Cretaceous Leederville Formation of the Warnbro Group, and the Triassic Lesueur Sandstone are important freshwater aquifers in the region. Many exploratory deep water bores have been drilled in the study area by government agencies and private landholders, which have proven useful for this interpretation project.

Dataset and methods

Well and drillhole data

This study utilized 24 conventional petroleum exploration wells drilled in the basin, as well as selected water bores, CO_2 geosequestration investigation bores, stratigraphic holes and mineral drillholes (Fig. 5). Only those water bores and mineral drillholes that were sufficiently deep and had biostratigraphic data or geophysical logs were used. These are listed in Appendix 1.

The process of interpreting new formation tops used historical palynology data from selected wells and bores, some of which have recently been reclassified into modern spore-pollen zonation schemes (e.g. Martin, 2018). In many wells, a definitive zone assignment could not be given due to penecontemporaneous oxidation of sediments, particularly within the Mesozoic section, where many of the mudstone facies are paleosols.

The majority of water bores and mineral drillholes could not be tied to seismic data because they do not have sonic or density logs, or checkshot data. However, they still were useful as a rough guide for interpreting the seismic horizons, and the revised formation tops were used as control points for the final gridding of depth surfaces. Due to their greater abundance and denser palynological sampling of the shallower stratigraphy, they proved invaluable for constraining Mesozoic formation picks in nearby petroleum wells, which typically were not as densely sampled at these levels. The palynology data from water bores proved that the basal formation of the Parmelia Group, although thin, is much more widespread onshore than previously thought and is likely present in some petroleum wells.

Seismic data

The locations of seismic lines for which SEG-Y data are available are shown in Figure 5a,b. The details of acquisition and processing for seismic surveys used in the interpretation are listed in Appendix 2.

Onshore seismic data quality across the basin is generally very poor. This is due to high-velocity layers in the shallow subsurface, such as Pleistocene limestone, laterite and the Bunbury Basalt that each have varying thicknesses across their distribution. In some areas, the poor quality of data is attributable to poor survey design, such as crooked line geometries and short line lengths in areas that are structurally complex (WA:ERA, 2012). However, much of the poor quality is simply due to the age of the data, as much of it was acquired during the 1960s to 1980s, and is usually either 6-fold or 12-fold data. Seismic data quality has significantly improved with modern processing techniques (e.g. Figs 6, 7); however, the limestone and Bunbury Basalt still create significant noise in seismic data leading to extremely poor reflection continuity (Fig. 8). Unfortunately, increased urbanization across the study area means that further new seismic acquisition is unlikely. Seismic data acquired offshore is much better quality but degrades where the acquisition environment is shallow nearshore.

Onshore seismic data available in SEG-Y format are derived from a mixture of original processing and reprocessing campaigns by petroleum exploration companies or government agencies. Most of the SEG-Y data of surveys acquired in the 1960s to 1980s in the Bunbury Trough and over the Harvey Ridge come from reprocessing campaigns in the early to mid-1990s, whereas the seismic data near Rockingham 1 and Cockburn 1 are from the original processing, and quality is poor. GSWA reprocessed selected lines in the Stirling Rapids Seismic Survey and the Charla Seismic Survey to improve imaging around key wells. Field data were incomplete or missing, preventing reprocessing of the remainder of the vintage data. All processed and reprocessed seismic lines are available for download from the Western Australian Petroleum and Geothermal Information Management System (WAPIMS).

Most of the marine seismic data used in this study was reprocessed by Roc Oil in 2008 and Geoscience Australia in 2004. These reprocessed data cover the entire Vlaming Sub-basin in the study area, and the reprocessing of different vintages in one campaign ensured they had the same phase and polarity. Roc Oil specified a SEG normal polarity in their interpretation report and in SEG-Y headers, and although the lines reprocessed by Geoscience Australia do not specify polarity, they match that of intersecting Roc Oil lines.

Well-to-seismic data ties

Synthetic seismograms were generated using the Kingdom Suite software for wells with sonic logs, checkshot data, and which are located on a seismic line with SEG-Y data. Checkshot survey data are available for most wells. For many wells, a definitive synthetic tie to the seismic data was not possible because well locations are offset from the seismic line, or the seismic data were poor quality. In these cases, only checkshot data were used to tie the well to the seismic data.

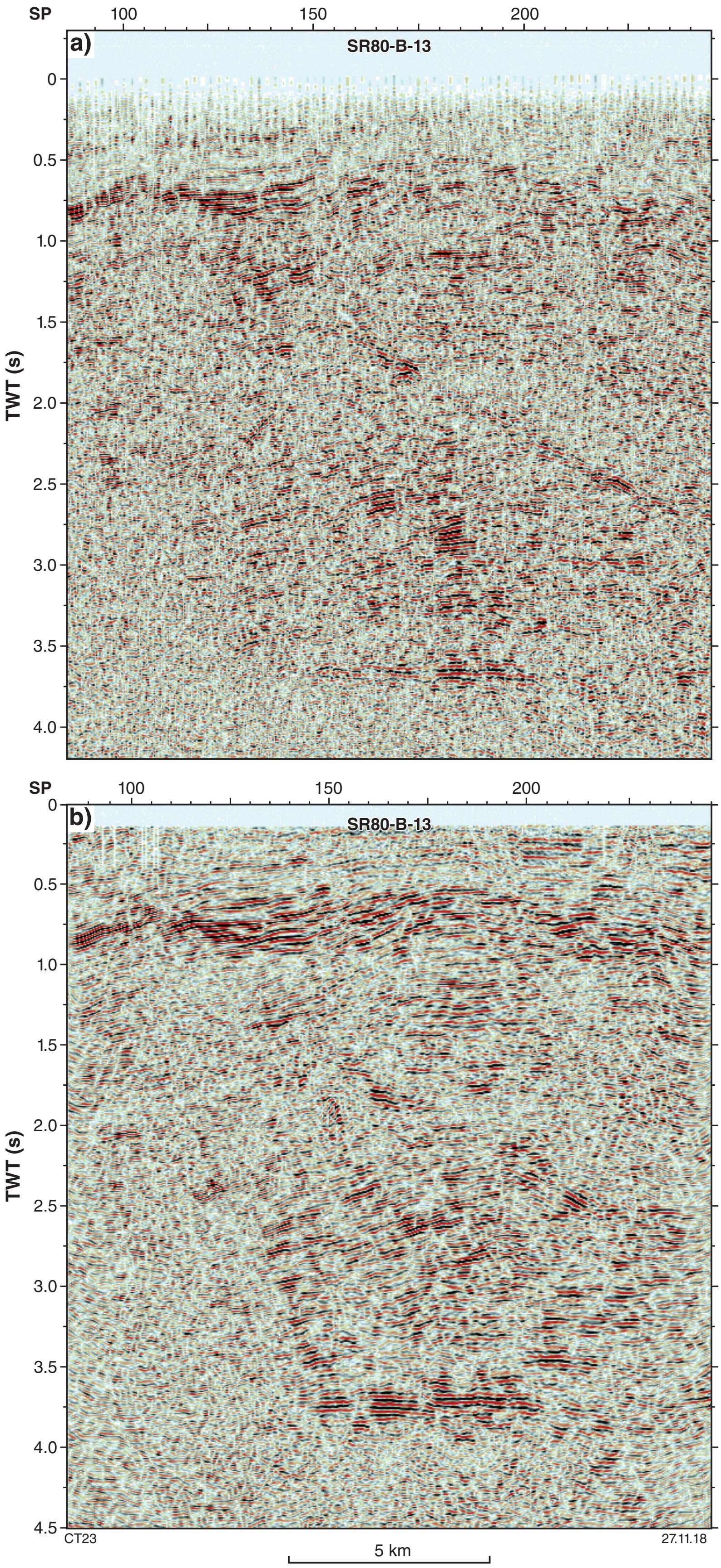

Figure 6. **Comparison of original and reprocessed line SR80-B-13 from the Stirling Rapids seismic survey, onshore Bunbury Trough (see Fig. 5b for location). Although there is no improvement in resolution, the 2014 reprocessing b) shows better continuity of shallower reflectors than the original processed stack section a). Urbanization of the area means new acquisition is unlikely**

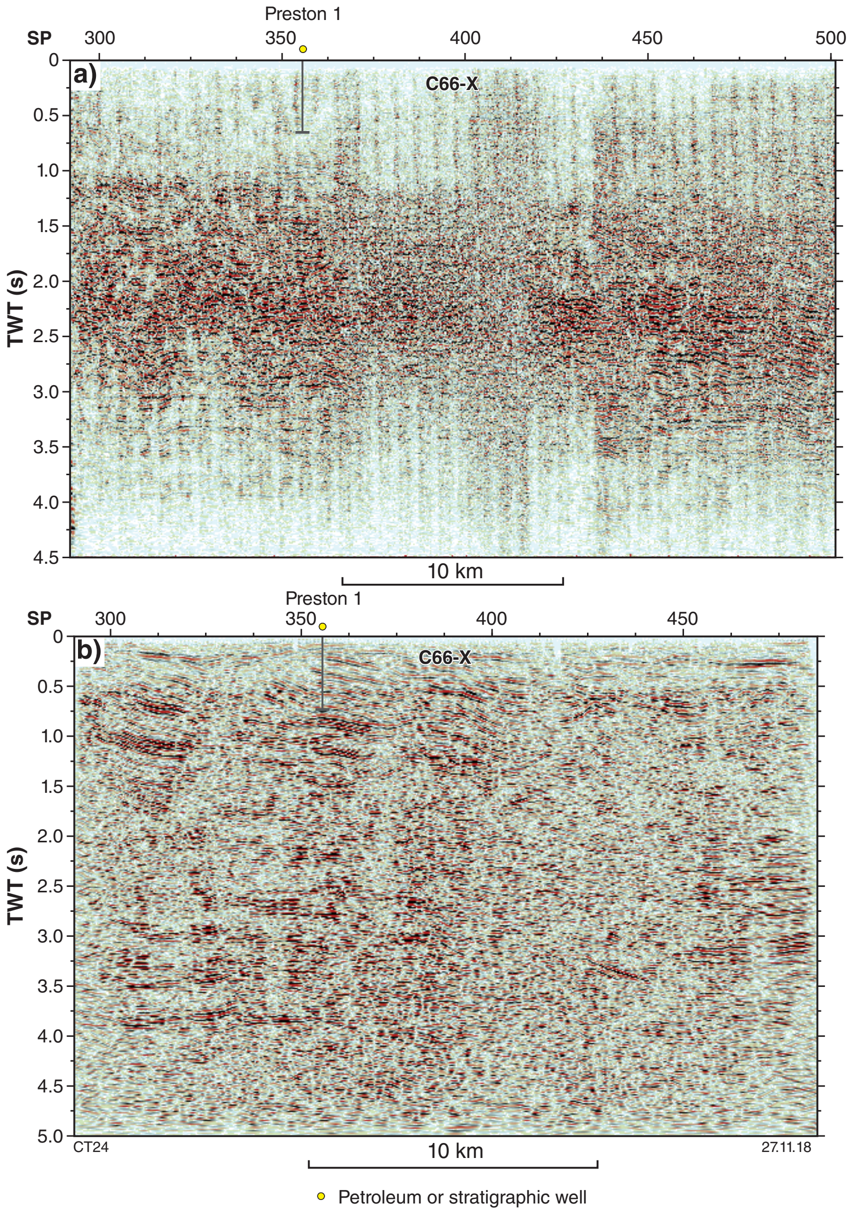

Figure 7. Comparison of original and reprocessed line C66X from the 2D Charla survey, onshore Harvey Ridge (see Fig. 5a for location): a) original 1966 processing; b) 2014 reprocessing, which shows significant improvement, with the breakup unconformity and faults more clearly imaged. Line C66X is the only line to intersect the Preston 1 well

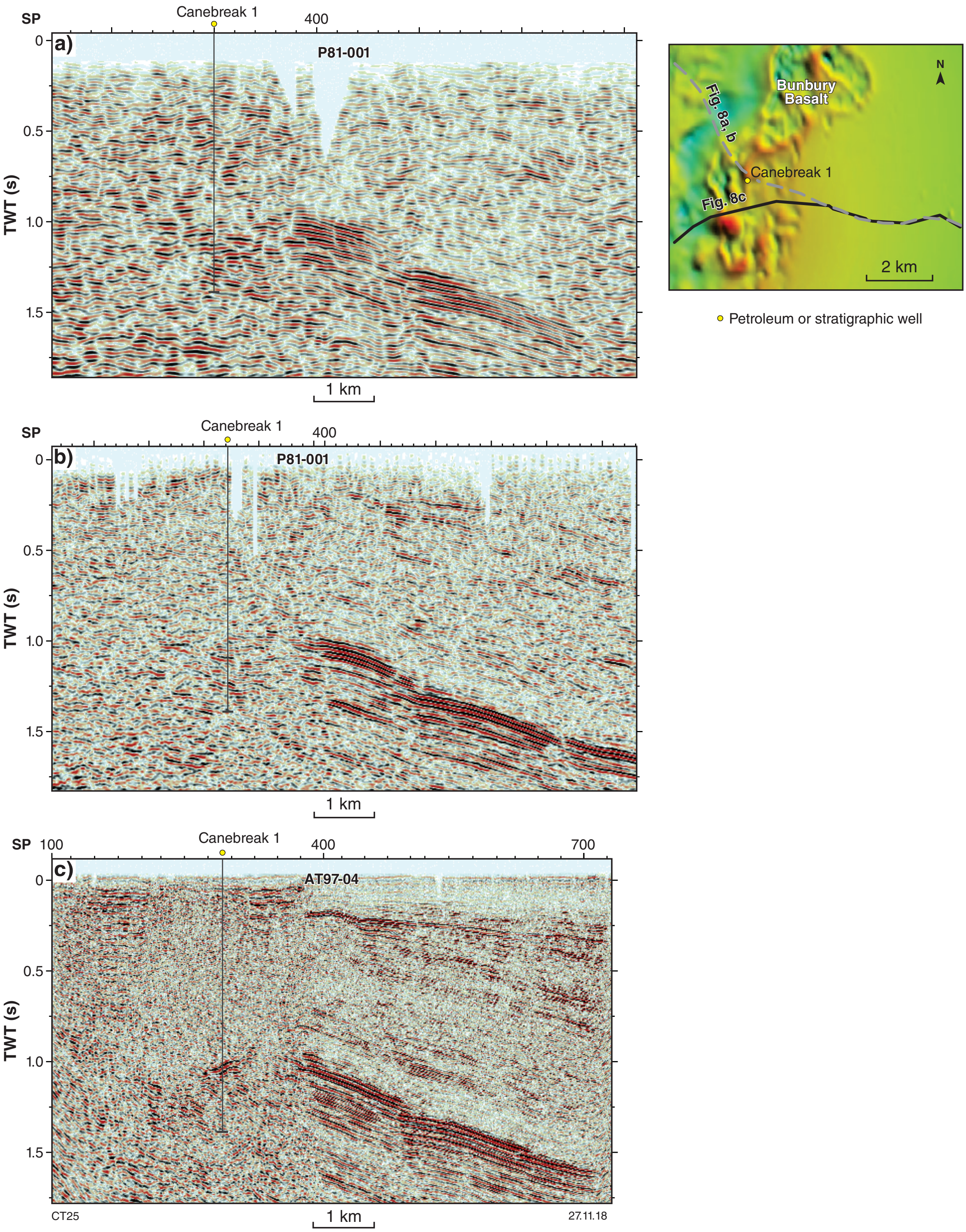

Figure 8. **Comparison of original and reprocessed seismic lines near Canebreak 1, southern Bunbury Trough: a) original 1981 processing of 2D line P81-1; b) 1996 reprocessing of line P81-1 (dashed grey line on map); c) line AT97-4 (solid black line) acquired in 1997, which partially overlaps P81-1. The newly acquired line better resolves the stratal relationships in the east compared to the reprocessed P81-1. However, the Bunbury Basalt, which is too shallow to be imaged in seismic profiles, creates significant noise in the western half of both lines**

Depth conversion

Average velocities to each horizon were first computed from root mean square (RMS) stacking velocities using the Inverse Dix equation and then gridded in the Petrosys software. These data were available either as text files downloadable from WAPIMS, or were entered manually from scanned stack sections. The average velocity grids were then adjusted to tie with the average well velocities. Final well-tied average velocity maps for each horizon were imported into the Kingdom Suite. The Dynamic Depth Conversion module in Kingdom was used to perform the final depth conversion.

Interpretation of seismic horizons and ties to well formation boundaries

Eight seismic horizons corresponding to significant formation boundaries (identified in Fig. 2) were interpreted; these are Top basement, Top Sue Group, Top Sabina Sandstone, Top Wonnerup Member (Lower Lesueur Sandstone), Top Yalgorup Member – Eneabba Formation, Top Cattamarra Coal Measures, Base Parmelia Group, and breakup unconformity. Where present, the top of the Yarragadee Formation coincides with the base of the Parmelia Group, or the breakup unconformity where the Parmelia Group is absent.

The formation boundaries for Top basement and Top Sue Group interpreted by Crostella and Backhouse (2000) in the onshore petroleum wells, were used in this interpretation as there is confidence in the consistent age correlation of these picks. However, formation tops for the remaining Mesozoic formations in onshore wells have been revised in the new interpretation (this Report), due to the biostratigraphic inconsistencies in the correlations of Crostella and Backhouse (2000). All interpreted formation boundaries of Crostella and Backhouse (2000) in the offshore wells are used in this project because, apart from Felix 1, those wells did not penetrate deeper than the Yarragadee Formation, and the overlying Parmelia Group (the Otorowiri Formation) is a distinctive unit with good biostratigraphic age control. This study uses previously defined lithostratigraphic nomenclature for consistency with published stratigraphy; however, the seismic horizon picks represent chronostratigraphic boundaries constrained by palynology. The new interpretation (this Report) incorporates recent palynological reviews that included analysis of new samples from several petroleum wells. Due to a lack of distinctive lithology and biostratigraphy, some formation tops in some wells could not be definitively interpreted. In this case, the depths were refined during seismic interpretation to ensure they did not result in obvious horizon mis-ties from nearby wells which have better stratigraphic control. Correlations of formation boundaries between selected onshore wells, water bores and mineral drillholes are given in Figures 9–12. Formation tops for all onshore wells and water bores used in this interpretation project are listed in Appendix 1.

The seismic characters of all interpreted horizons are itemized in Table 1. Note that the qualitative description of pick confidence relates to the confidence of interpreting the event away from well control. The Top basement and Top Sue Group seismic horizons were only picked in the Vasse Shelf and Bunbury Trough, and in a few lines over the Harvey Ridge. Elsewhere these horizons are too difficult to interpret because they are very deep and therefore have no well control. All other seismic horizons were interpreted throughout the entire study area.

Top basement

Basement was intersected only in Sue 1 on the Vasse Shelf and in several mineral drillholes in the Treeton Terrace; however, neither of these intersections were drilled on a seismic line for which SEG-Y data were available. This resulted in basement being picked using seismic character at the base of obvious sedimentary reflectors in the Bunbury Trough and the Harvey Ridge (Fig. 13). Basement could only be interpreted in a few of the better quality lines in the Bunbury Trough and the Harvey Ridge. In the northern Mandurah Terrace and Vlaming Sub-basin, basement is too deep to be adequately imaged.

The Top basement horizon pick over the Whicher Range area differs from that of the WA:ERA (2012) study, where it was placed shallower at around 2.7 s two way time (TWT) at the Whicher Range 1 well location (see Fig. 13a). Although their seismic event is a strong reflector as would be expected for a basement–sediment interface, there are clear, continuous reflectors below it that are likely to be sedimentary (Fig. 13a). The seismic event picked by WA:ERA (2012) appears to be a very low-angle angular unconformity, which is considered here to lie within the Permian section. An unconformity between the upper Permian and lower to mid-Permian sections exists in the northern Perth Basin, and it is possible that the low-angle unconformity inferred from the WA:ERA image represents the same event.

Figure 14b is a depth structure map of the Top basement horizon. The grid and contours have been smoothed across faults.

Top Sue Group

The depths of the Top Sue Group interpreted in petroleum wells by Crostella and Backhouse (2000) are used in this study as they are consistent with biostratigraphy and no new analyses were conducted to refine them. They interpreted the top of the uppermost unit — the Willespie Formation — at the top of a thick shale, overlain by the Sabina Sandstone, which is a distinctive lithological unit.

The Top Sue Group horizon was interpreted only in seismic lines in the Bunbury Trough, Vasse Shelf and Harvey Ridge, the only areas where it is intersected by drilling. There is significant uncertainty on the eastern side of the large fault east of Preston 1 as there are no drillhole or well intersections of this group. The uncertainty is increased due to the extremely poor quality of seismic data intersecting Lake Preston 1 – the only well to have intersected the Sue Group in the Mandurah Terrace – as well as the large distance to the next nearest well intersection (Wonnerup 1).

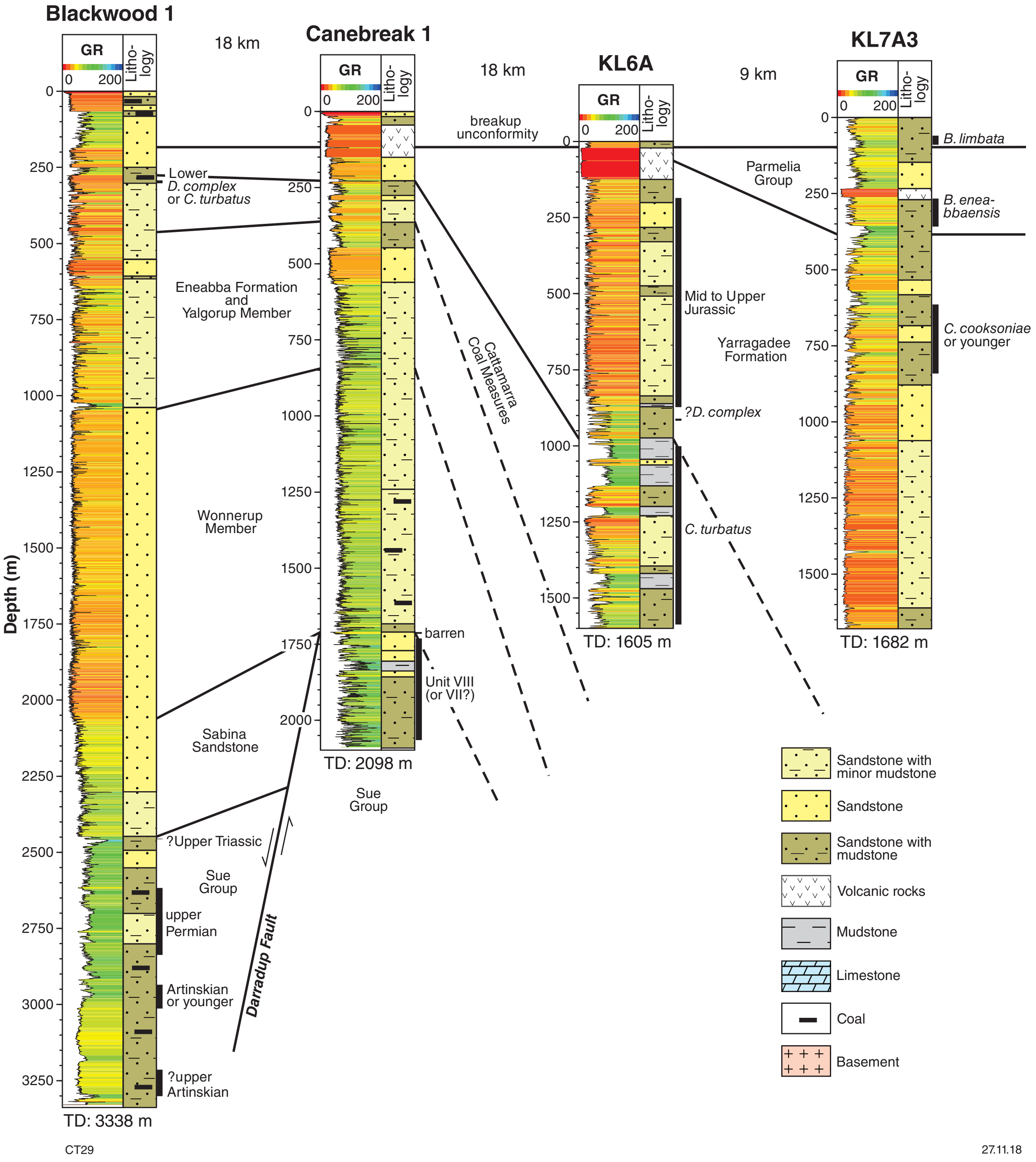

Figure 9. Regional west–east stratigraphic correlation of selected onshore wells and water bores in the southern Bunbury Trough. Flattened on the breakup unconformity. See Figure 5 for well locations

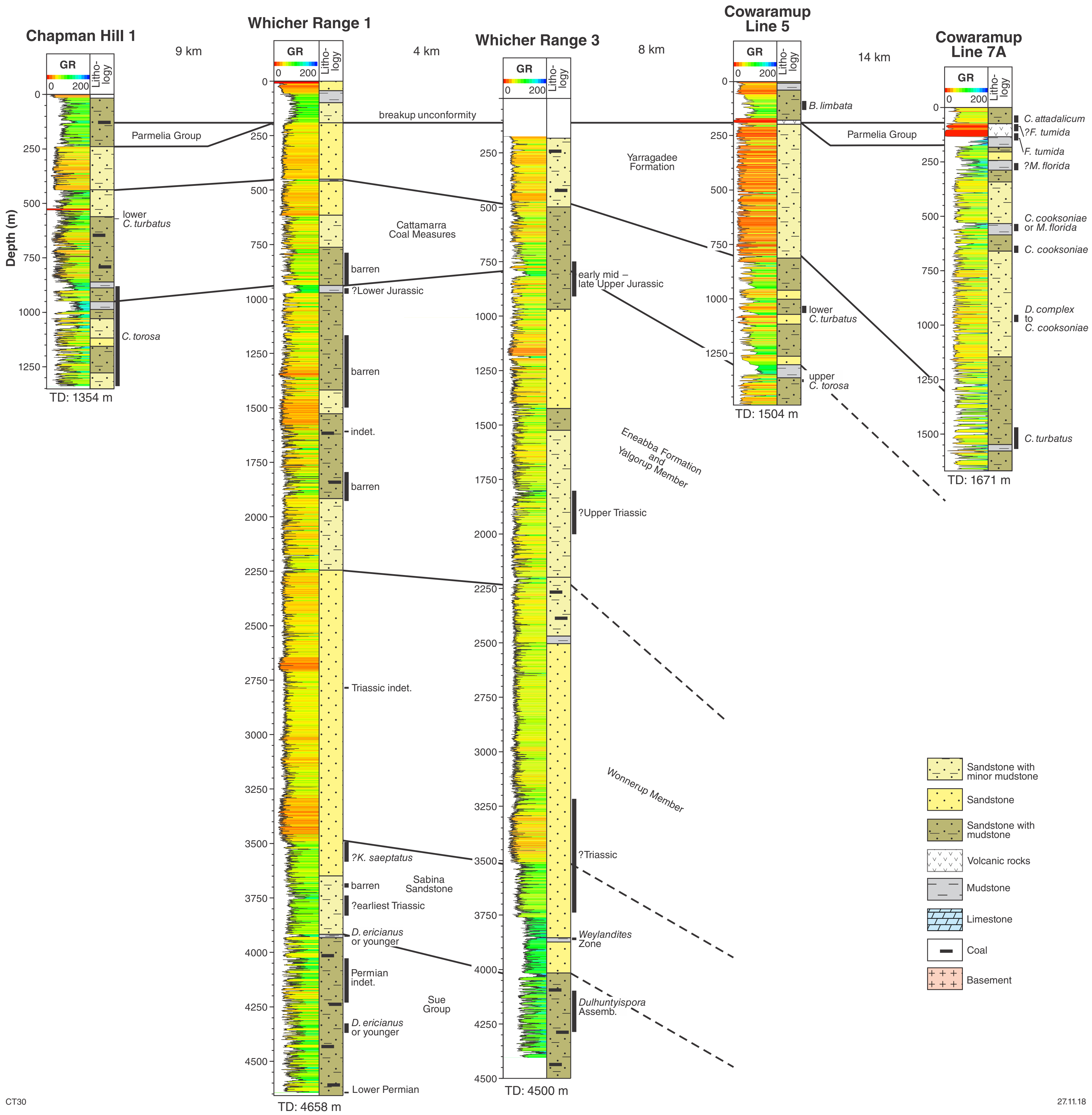

Figure 10. Regional west–east stratigraphic correlation of selected onshore wells and water bores in the central Bunbury Trough. Flattened on the breakup unconformity. See Figure 5 for well locations

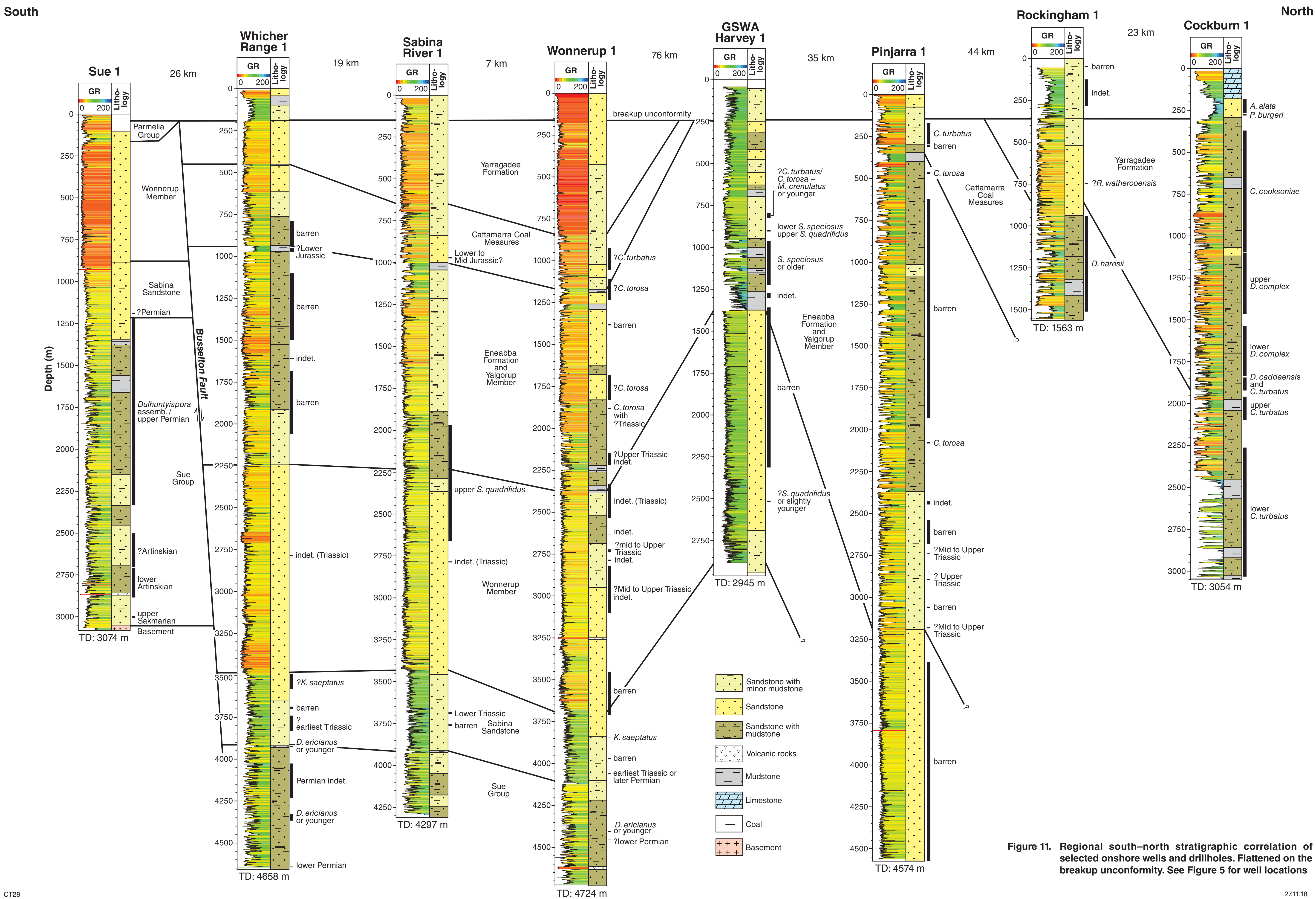

Figure 11. **Regional south–north stratigraphic correlation of selected onshore wells and drillholes. Flattened on the breakup unconformity. See Figure 5 for well locations**

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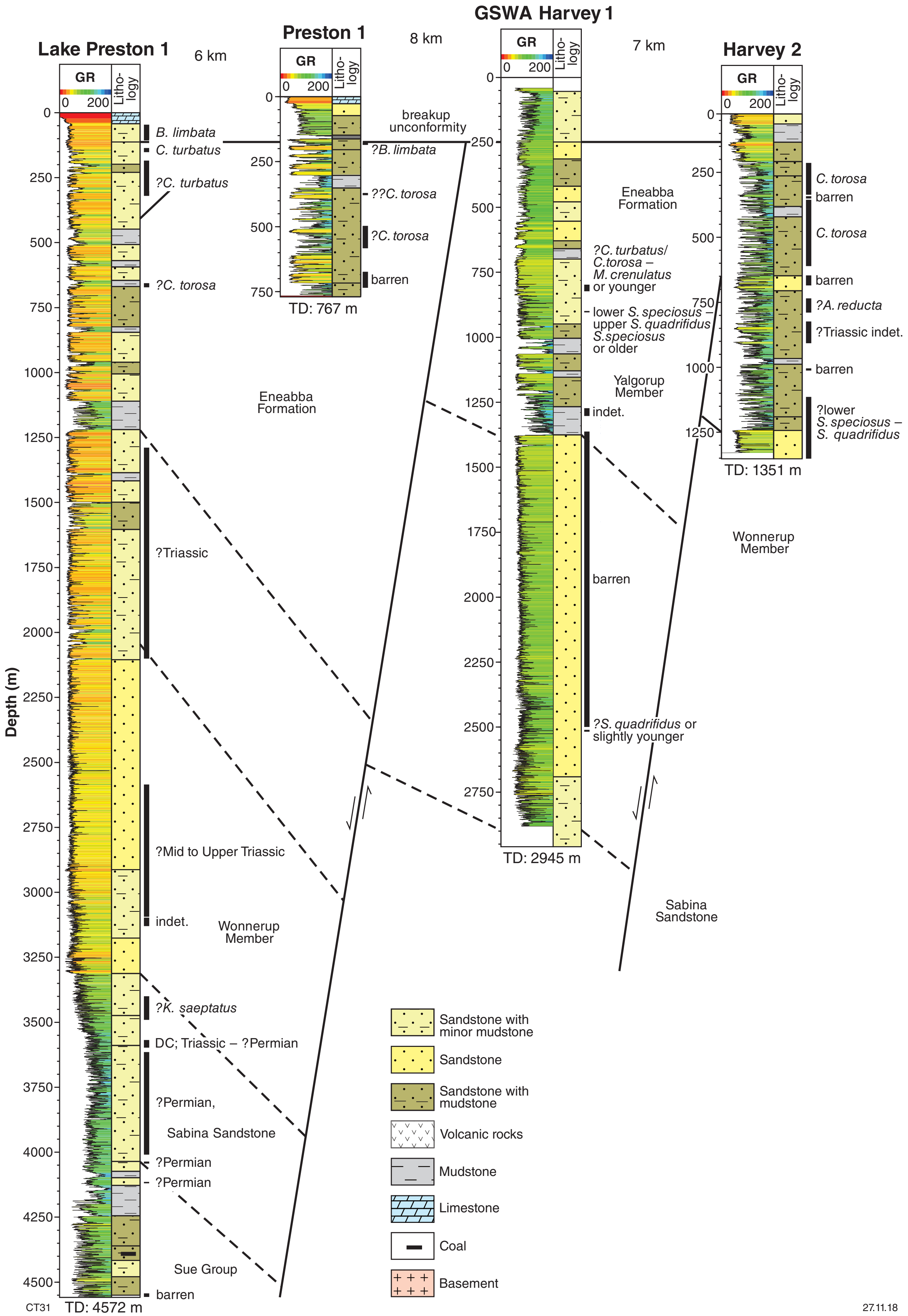

Figure 12. Regional west–east stratigraphic correlation of selected onshore wells and geosequestration wells in the Harvey Ridge. Flattened on the breakup unconformity. See Figure 5 for well locations

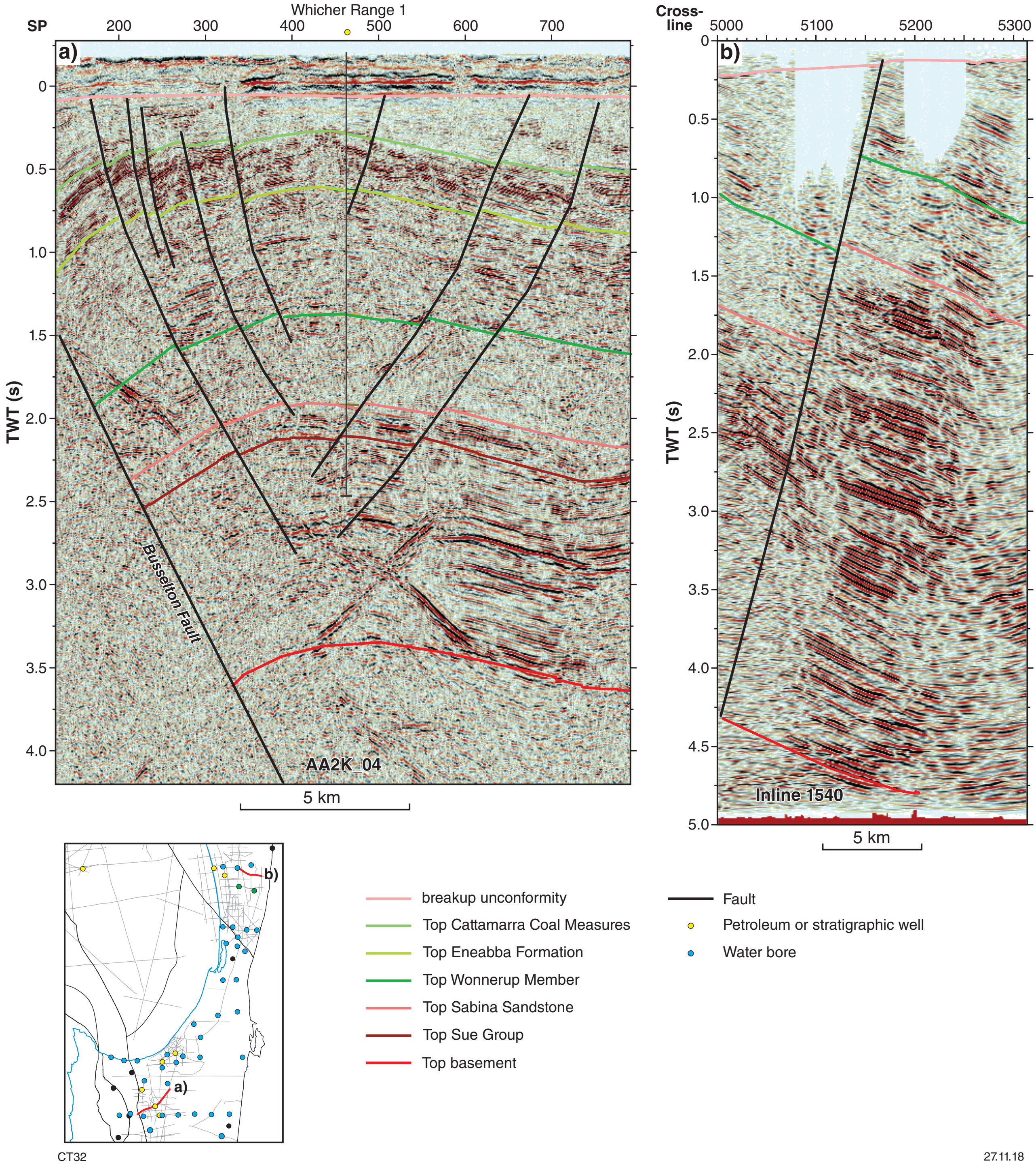

Figure 13. Comparison of basement character in the southern Perth Basin: a) 2D seismic survey line AA2K-04 over the Whicher Range gas accumulation, western Bunbury Trough; b) interpreted Harvey 3D seismic survey inline 1540 through the Harvey Ridge. The top of the basement is not a strong reflector and is picked at the base of near-conformable reflectors interpreted to be Perth Basin sedimentary rocks

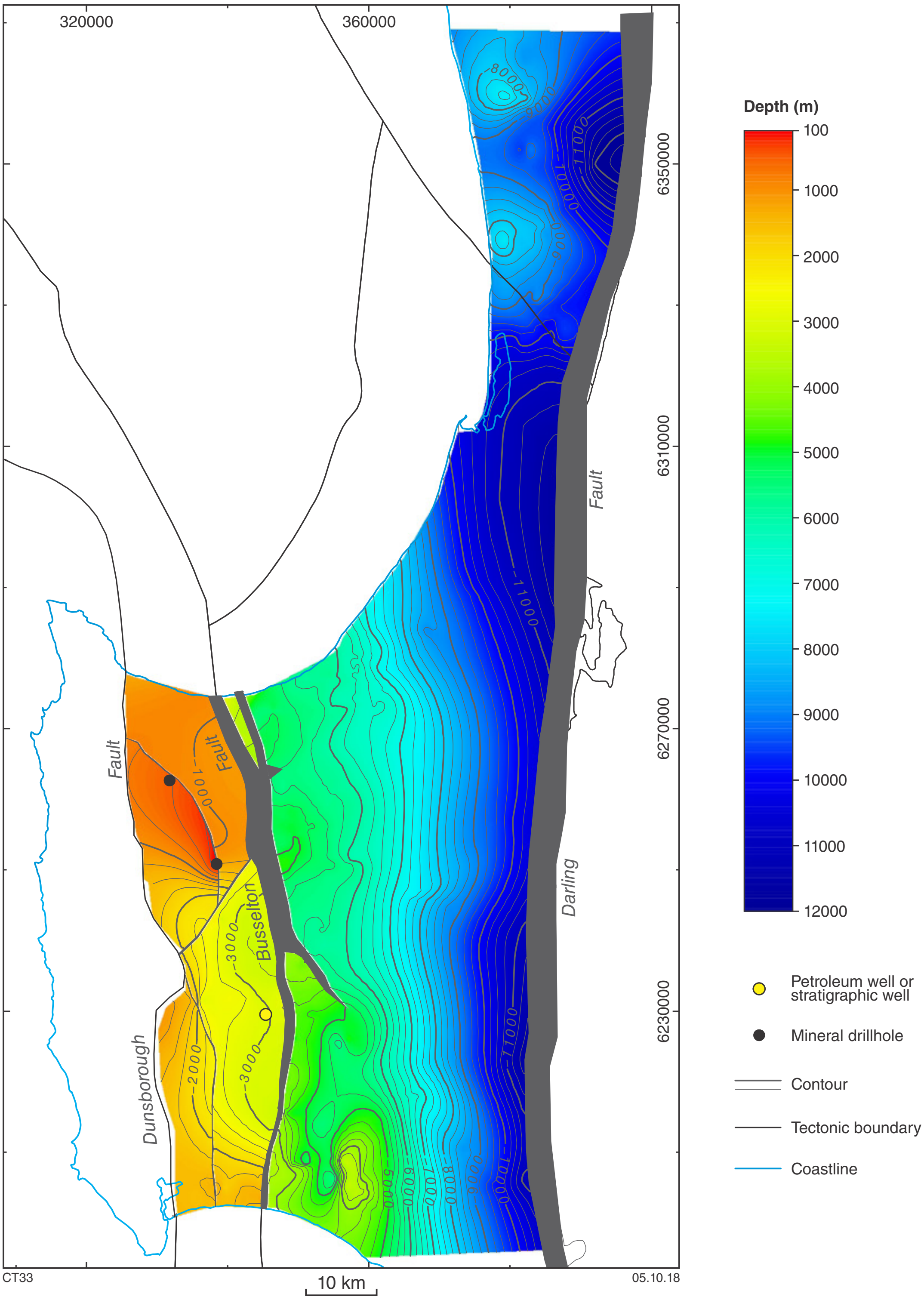

Figure 14. Depth to Top basement structure map in onshore Bunbury Trough and Harvey Ridge; elsewhere the basement was too deep to be imaged or confidently interpreted. Grid is smoothed through faults

Table 1. Interpreted seismic horizons and seismic character (based on SEG normal polarity)

Horizon	*Character of seismic event*	*Comments*
Breakup unconformity	Variable strong trough through to peak	Moderate- to high-confidence pick. Not interpreted in older, low-fold seismic data onshore where it is too shallow, thus not resolvable or lost to the seismic mute.
Base Parmelia Group	Strong trough in Vlaming Sub-basin. Weak trough onshore or variable	High-confidence pick in Vlaming Sub-basin. Only interpreted on a few lines onshore where it is a low-confidence pick. Not interpreted in older, low-fold seismic data onshore where it is too shallow, thus not resolvable or lost to the seismic mute.
Top Cattamarra Formation	Weak to moderate peak at base of bland seismic zone	Moderate confidence onshore, low confidence offshore.
Top Eneabba Formation	Weak to moderate trough	Low to moderate confidence onshore, low confidence offshore and northern Mandurah Terrace.
Top Lower Lesueur Sandstone	Moderate to weak peak at top of bland seismic zone	Moderate- to high-confidence pick in Bunbury Trough and Harvey Ridge. Low-confidence pick northwards and offshore.
Top Sabina Sandstone	Weak peak at base of bland seismic zone	Moderate-confidence pick in Bunbury Trough. Low-confidence pick northwards and offshore.
Top Sue Group	Weak event; variable	Moderate-confidence pick. Only interpreted in the Bunbury Trough and Harvey Ridge.
Top basement	Variable	Low- to moderate-confidence pick. Only interpreted on a few lines in Bunbury Trough and Harvey Ridge at the base of obvious stratigraphic layering.

Top Sabina Sandstone

The Sabina Sandstone is a distinctive unit both in lithology and geophysical log character. Crostella and Backhouse (2000) placed the top of the Sabina Sandstone where there is a downhole increase in gamma ray response and in sonic travel time. The high gamma response is likely due to the high mica content in the sandstone. The basal Sabina Sandstone is the nonmarine equivalent of the Kockatea Shale in the northern part of the basin.

On seismic profiles, the Top Sabina Sandstone is a weak peak (positive reflector) at or near the base of a regionally consistent bland data zone that represents the overlying Wonnerup Member. This bland zone is present throughout the study area, which aids the interpretation of this horizon, especially in seismic data of poorer quality and in offshore data. Confidence in the interpretation of the top of the Sabina Sandstone decreases offshore and in the northern Mandurah Terrace where there are no well intersections. The interval representing the formation appears to become thinner offshore, but does not disappear completely, as rocks of the same age were dredged from the sides of the Perth Canyon just 33 km northwest of the study area (Marshall et al., 1989; Fig. 5a).

Figure 15 shows TWT to the top of the Sabina Sandstone, with labelled faults. Plate 1 includes larger scale TWT and depth maps to the top of the Sabina Sandstone.

Top Wonnerup Member

The Wonnerup Member is a homogeneous, coarse-grained quartzofeldspathic sandstone that Crostella and Backhouse (2000) introduced as the basal member of the Lesueur Sandstone. The Top Wonnerup Member picks of Crostella and Backhouse (2000) for wells on the Harvey Ridge (Lake Preston 1 and Pinjarra 1) are used in this interpretation project because they coincide with the same seismic reflector in GSWA Harvey 1 and DMP Harvey 2. DMP Harvey 2 is the only well in the basin that contains a cored section of the Wonnerup Member – Yalgorup Member contact and that has good biostratigraphic control across this contact.

The boundary between the Wonnerup Member and the overlying Yalgorup Member in the Harvey Ridge is a medium to strong seismic reflector, which marks the top of a distinctive seismic bland zone (Fig. 16). This reflector is caused by the sharp impedance contrast between the higher velocity sandstone of the Wonnerup Member and the thick, lower velocity mudstone at the base of the Yalgorup Member above. This seismically bland zone that characterizes the Wonnerup Member is present in all seismic lines throughout the southern Perth Basin, including offshore (e.g. Figs 17, 18), but in the northern Mandurah Terrace it loses this character (Fig. 16). The depth to the top of the Wonnerup Member was reinterpreted in wells in the Bunbury Trough, because the picks of Crostella and Backhouse (2000) (picked only in Sue 1, Whicher Range 1 and Wonnerup 1) were located within the seismic bland zone, not at the top. The new interpreted depths in these wells remain in biostratigraphic zones consistent with DMP Harvey 2 (Martin, 2018).

Plate 2 shows the TWT and depth maps to the top of the Wonnerup Member.

Top Yalgorup Member – Eneabba Formation

The Top Yalgorup Member – Eneabba Formation is picked at the top of a thick mudstone unit that is distinct in several wells in the Bunbury Trough. This mudstone unit falls within the upper part of the *C. torosa* Spore-Pollen Zone, and is close to the boundary with the overlying *Callialasporites turbatus* Zone.

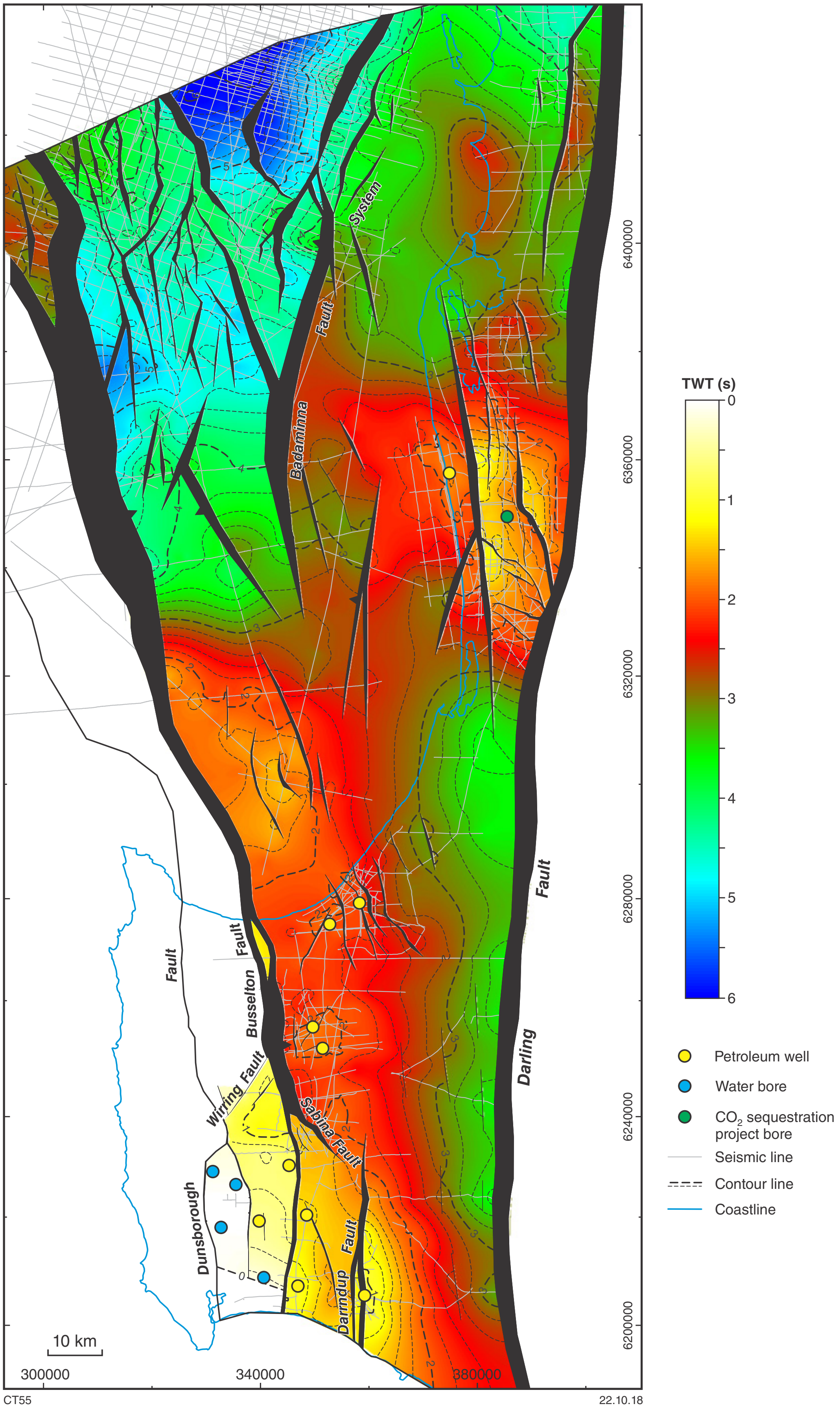

Figure 15. Interpreted TWT structure map for Top Sabina Sandstone. Larger scale TWT and depth structure maps for the Top Sabina Sandstone and other interpreted horizons can be found in Plates 1–6

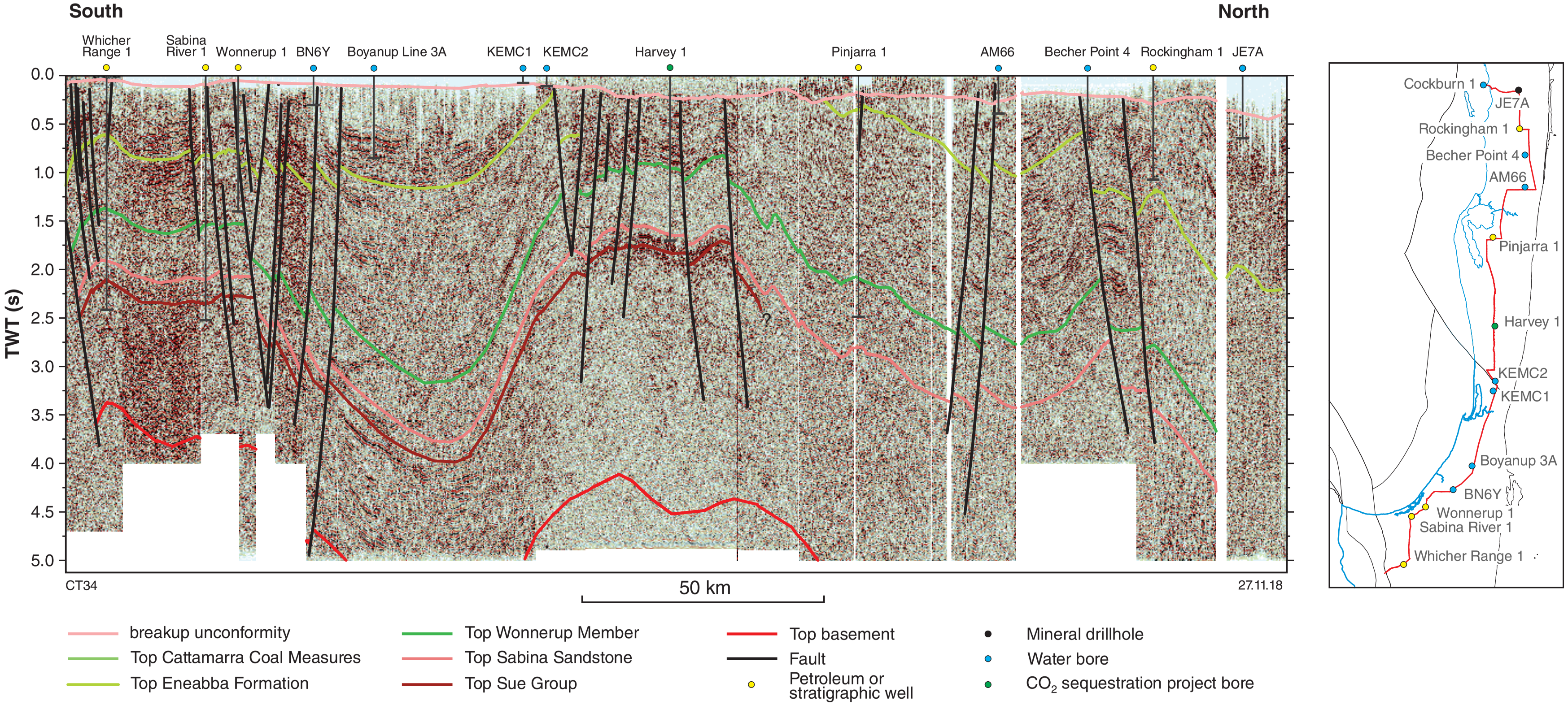

Figure 16. Regional south–north composite seismic section along the axis of the onshore southern Perth Basin

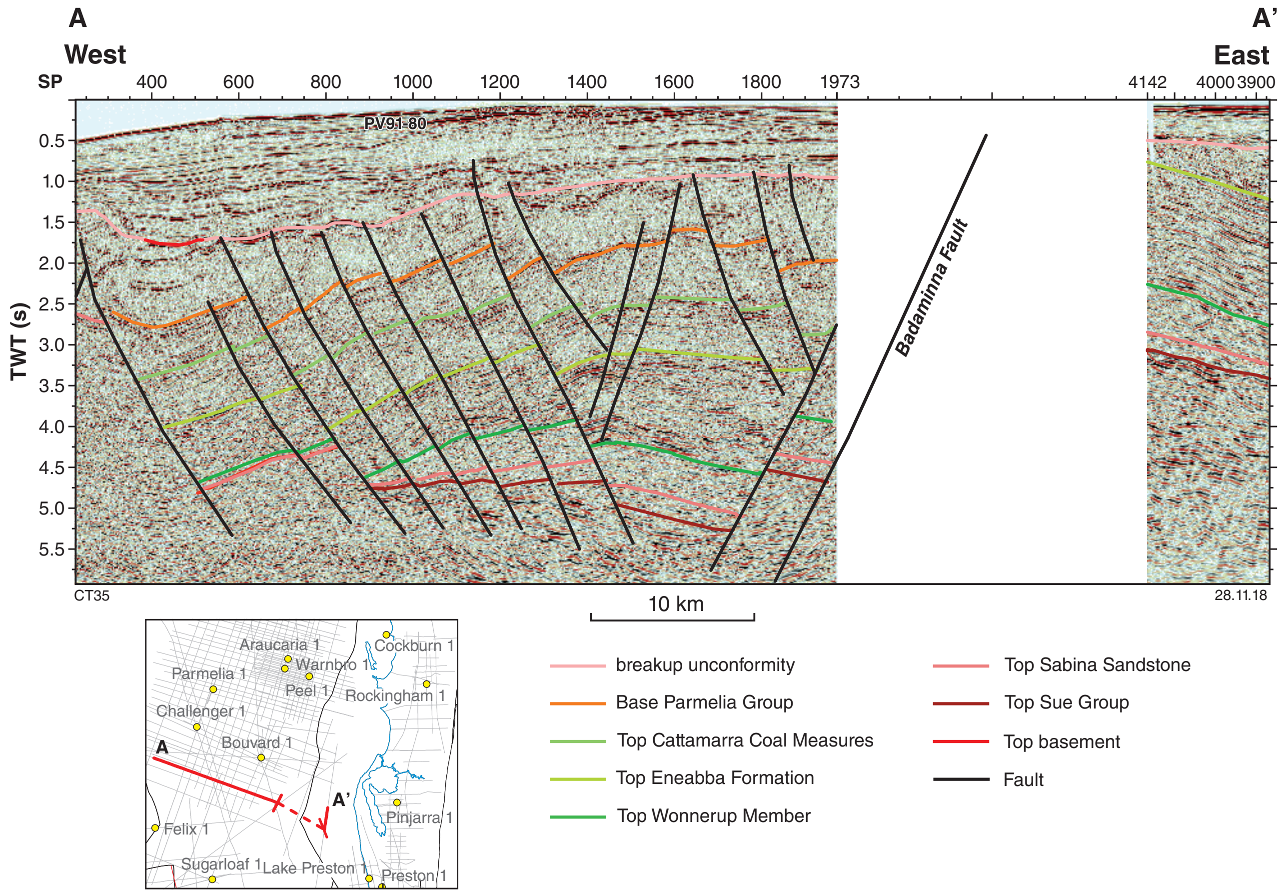

Figure 17. **Composite west–east 2D marine seismic section through the Vlaming Sub-basin and across the inferred Badaminna Fault system into the western Mandurah Terrace. Uncertainty remains for the horizon interpretation below the Top Cattamarra Coal Measures due to lack of drillhole intersections in the Vlaming Sub-basin and the scarcity of coastal lines connecting onshore lines to deeper offshore lines. However, the interpreted Wonnerup Member is consistent in its bland seismic character**

Palynology of this mudstone in Whicher Range 3 suggests a marine influence, although a modern reassessment is still required and is the subject of future study.

In the southern Perth Basin, the Eneabba Formation and the Yalgorup Member are indistinguishable from each other as they have the same lithology and log character, and biostratigraphic control is incomplete. The formation top picks of Crostella and Backhouse (2000) for these two units are dubious, and raises the possibility that in this part of the Perth Basin there is no justification for this interval to be separated into two stratigraphic units.

On seismic profiles, the Top Yalgorup Member – Eneabba Formation horizon is a weak reflector, and generally is the boundary between a more seismically reflective unit above (Cattamarra Coal Measures) and a less reflective interval consisting of the Eneabba Formation and Yalgorup Member below. However, offshore in the Vlaming Sub-basin, this interval becomes more reflective in places, which could be due to the presence of thicker and more extensive coal or mudstone.

Plate 3 shows the TWT and depth maps to the near Top Yalgorup Member – Eneabba Formation.

Top Cattamarra Coal Measures equivalent

The top of the Cattamarra Coal Measures is placed at the boundary between interbedded mudstone and sandstone (Cattamarra Coal Measures) and overlying sandstone-dominated Yarragadee Formation and Cadda Formation equivalent. This formation is placed so that strata below fall within the *C. turbatus* Spore-Pollen Zone and strata above are within the *D. complex* and younger spore-pollen zones, to ensure the pick is consistent in age. In the northern Mandurah Terrace, this boundary becomes increasingly difficult to differentiate based on lithology (e.g. Cockburn 1).

In seismic profiles, this horizon is a weak to moderate peak at the base of a seismic bland zone (Yarragadee Formation). Generally, the Cattamarra Coal Measures equivalent is characterized by stronger reflectors than the underlying Yalgorup Member – Eneabba Formation interval. The Top Cattamarra Coal Measures horizon becomes a much stronger reflector offshore in the northern Vlaming Sub-basin (north of Sugarloaf 1), which could indicate that the shale- and limestone-dominated Cadda Formation, a marine unit between the Yarragadee Formation and the Cattamarra Coal Measures in the northern Perth Basin, is developed there.

Plate 4 shows the TWT and depth maps to the Top Cattamarra Coal Measures equivalent.

Base Parmelia Group

The Base Parmelia Group horizon coincides with the top of the Yarragadee Formation across most of the southern Perth Basin; however, recent water bore drilling on the southern Vasse Shelf suggests that the Parmelia Group is more extensive than the Yarragadee Formation and also unconformably overlies Triassic and possibly Permian strata. Correlation of the Sue 1 and Chapman Hill 1 wells with nearby water bores that have denser palynological sampling suggests these wells intersected the Parmelia Group. It is uncertain which formation of the Parmelia Group was intersected, but in these wells it is a high gamma ray siltstone that was previously assigned to the postrift Leederville Formation, which has a similar lithology and gamma ray signature. Thin Parmelia Group may be present in many wells across the southern Perth Basin, but more palynological analysis is required to confirm its possible widespread distribution. The Parmelia Group is interpreted to rest unconformably on the Wonnerup Member in Sue 1, and in Chapman Hill 1 it is underlain by the Yarragadee Formation. On newer, high-fold seismic data of the Chapman Hill seismic survey, which intersects Chapman Hill 1, the base of Parmelia Group is interpreted as an unconformity at its contact with the underlying Yarragadee Formation (the older line that also intersects this well is too poor quality to resolve this relationship at such shallow depths). In the Vlaming Sub-basin, the Parmelia Group appears to lie conformably on the Yarragadee Formation in the structural lows, but on some footwall highs and the higher flanks of the sub-basin, the Parmelia Group is deposited over paleo-highs where the top of the Yarragadee Formation was eroded (Fig. 18).

The Base Parmelia Group horizon (base of the Otorowiri Formation) creates a sharp impedance contrast with the underlying, more sand-rich Yarragadee Formation and older formations. This boundary is characterized on seismic data by a strong trough in the Vlaming Sub-basin but is more subdued in the Bunbury Trough and the northern Mandurah Terrace, and the seismic event is lost in the seismic mute in older, low-fold lines onshore.

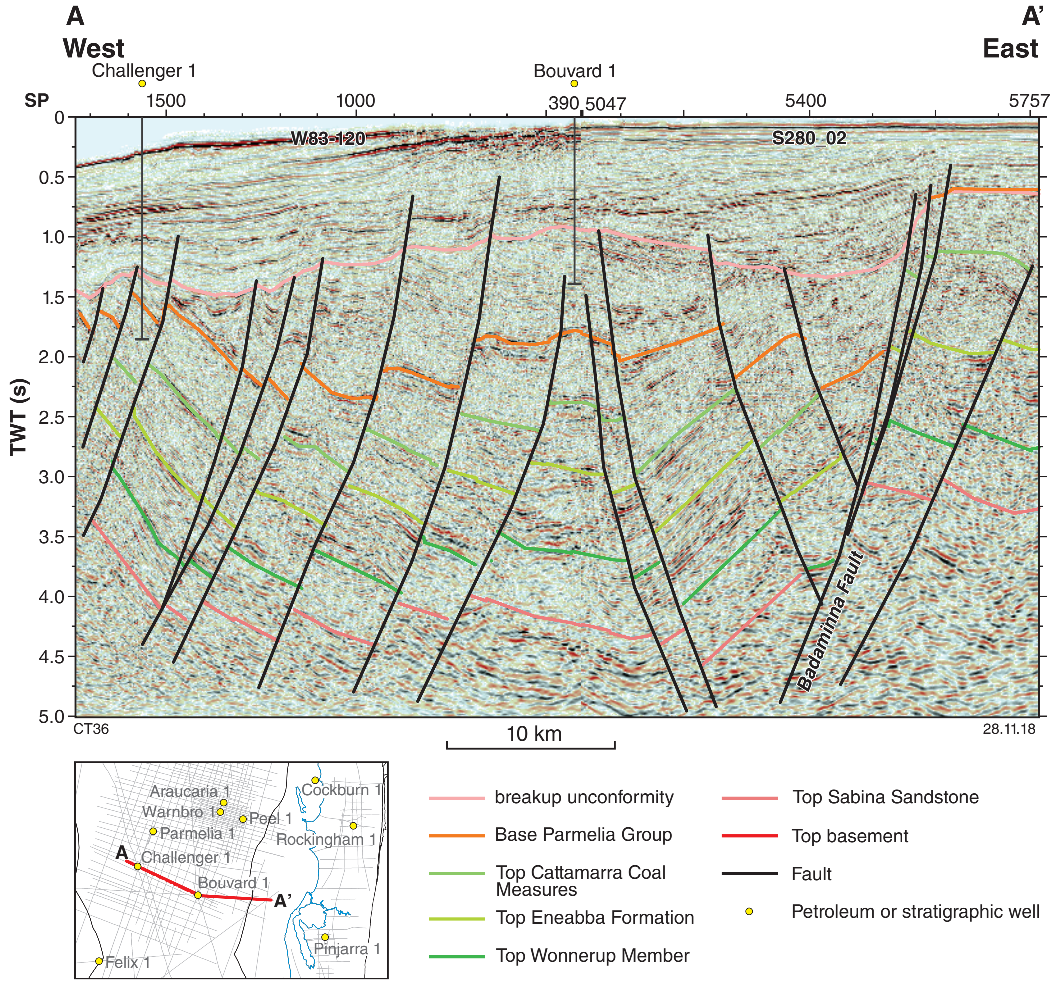

Figure 18. **East–west composite seismic section across the Vlaming Sub-basin and the western edge of the Mandurah Terrace**

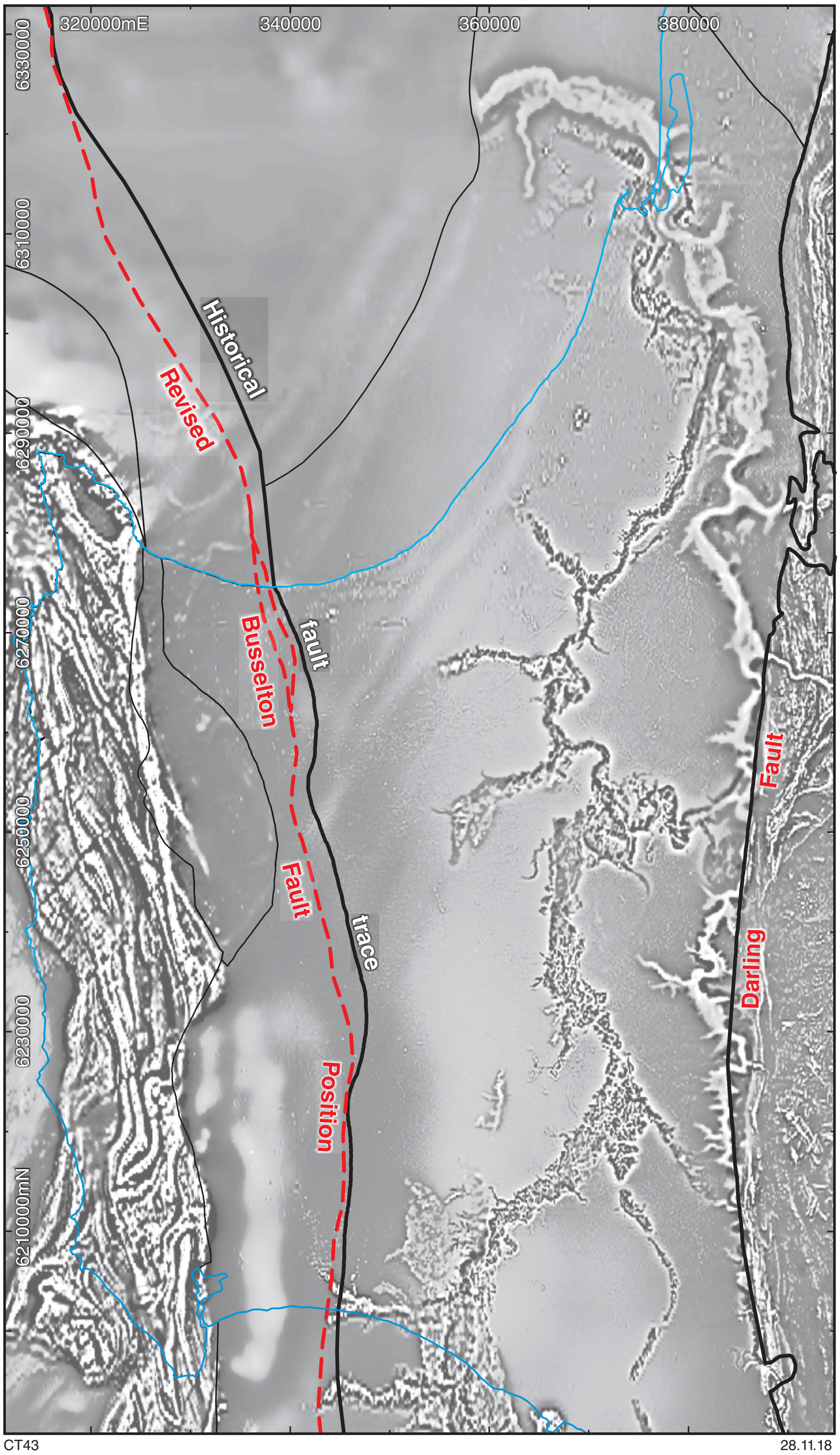

Figure 19. Revised position of the Busselton Fault (red dashed line) corresponding to the western boundary of the Bunbury Trough. New interpretation is based on its shallowest position as mapped from seismic data (generally at breakup unconformity level). Where there are no seismic data, the position is based on the 1VD TMI grid (image)

Onshore, the Parmelia Group is very thin, reaching a maximum onshore thickness of ~300 m in the Bunbury Trough adjacent to the Darling Fault. Offshore it thickens considerably, reaching 3800 m in the central Vlaming Sub-basin.

Plate 5 shows the TWT and depth maps to the Base Parmelia Group horizon.

Breakup unconformity

On seismic profiles, the breakup unconformity is characterized by an angular unconformity or a disconformity in places between the pre-breakup succession and the overlying Warnbro Group. Due to consistently shallow depths to the breakup unconformity onshore it is only recognizable in recent higher-fold seismic data, whereas in lower-fold seismic data it is lost to the seismic mute. In well logs, it is placed typically at the base of a high gamma ray, slow-sonic unit, which is the mud-rich, feldspathic and less consolidated Warnbro Group, which falls exclusively within the *Balmeiopsis limbata* Spore-Pollen Zone. However, where the Parmelia Group is present, it can be difficult to distinguish the boundary on log character alone and palynology is required. The breakup unconformity is Valanginian in age, and related to separation between Greater India and Australia. An unconformity related to the much later Late Cretaceous breakup between Australia and Antarctica is not evident in the study area.

Plate 6 shows the TWT and depth maps to the breakup unconformity.

Structural interpretation

Bunbury Trough

Major faults previously recognized in the Bunbury Trough — the Busselton Fault, Darling Fault, Sabina Fault and Darradup Fault — are identified in this interpretation (Fig. 15). However, their positions are modified compared to previous seismic interpretations (e.g. Iasky, 1993) based on newer seismic, potential-field, and borehole data. There is no evidence that the Sabina Fault connects to the Darradup Fault or maintains the same throw along its length, as was interpreted by Iasky (1993). There is also not enough evidence for the northward continuation of the Darradup Fault as interpreted by Iasky (1993), given the sparse seismic coverage. The location of the Busselton Fault — and therefore the sub-basin boundary — has been moved farther west based on this new interpretation. A comparison of the historical fault location (carried over in the tectonic units map published by GSWA [2017a]) with the new location determined from this interpretation is given in Figure 19. All faults, including the major faults, show normal offset.

Nearly all faults mapped in the Bunbury Trough extend up to the breakup unconformity, indicating movement just before breakup. The minor faults appear to have been initiated just before or during Valanginian breakup. By comparison, the Busselton Fault, Darling Fault, Sabina Fault and Darradup Fault also show earlier movement, as indicated by thickening of Upper Triassic and Jurassic strata in their hangingwalls. Figures 20 and 21 are interpreted east–west composite seismic lines in the southern Bunbury Trough, in which the Upper Triassic – Jurassic succession thickens towards the Darling Fault and the Darradup Fault, respectively. Figure 22 shows slight thickening of this same interval towards the Busselton Fault, suggesting movement during those times. The Busselton Fault may also have been active during the Permian, based on a thinner Permian section in the southern Vasse Shelf around Sue 1 (where a full Permian section is intersected) compared to the interpreted thickness in the Bunbury Trough on seismic profiles (Fig. 23). However, given the poor seismic imaging of basement in the deep trough, and the reliance on stacking velocities only for depth conversion of this horizon in this area, this interpretation remains tentative. The poor imaging also makes it difficult to determine whether Permian strata thicken towards the Darling Fault; this makes it more difficult to assess whether the Darling Fault was active during this time. Further, a comparison in thickness of the Permian across the fault is difficult because the original thickness on the Yilgarn Craton is unknown.

This mapping cannot confirm the existence of the two ‘transfer faults’ proposed by Iasky and Lockwood (2004) traversing both the Bunbury Trough and the Vasse Shelf, nor does it shed light on the northeast-trending linear anomalies in the tilt-angle processed magnetic anomaly image at the coast around Busselton town (Fig. 4b). Neither the ‘transfer faults’ nor the anomalies correlate with faults mapped from seismic data. It is possible the linear anomalies arise from dykes within the basement, which is too deep to be adequately imaged by the seismic data. The seismic mapping also cannot confirm the small faults proposed to offset the Bunbury Basalt (Olierook et al., 2015).

Seismic coverage in the Bunbury Trough is patchy, with increased density along the western half of the sub-basin compared to the eastern half, where only a few east–west lines reach the Darling Fault (Fig. 5b). Therefore, fault linkages and strike direction are not confidently interpreted between these seismic lines. A northerly strike is inferred for most faults, but a denser seismic coverage is needed to confirm this. The seismic coverage of the sub-basin offshore is extremely sparse, and there is a large gap in data between the onshore and offshore seismic lines.

Several large anticlines (>10 km across) are mapped in the Bunbury Trough adjacent to the Busselton Fault and its offshore extension (Fig. 25). These are strongly faulted compared to nonfolded strata. These anticlines formed after deposition of the Yarragadee Formation, but before the erosional event associated with breakup, and feature crestal collapse normal faults. The Whicher Range gas accumulation proves the potential of these anticlines to trap hydrocarbons; however, Blackwood 1 and Scott River 1 unsuccessfully tested this style of anticline farther south. Similar anticlines have developed in the hangingwalls of the large faults elsewhere in the basin (e.g. Fig. 24) and in the northern Perth Basin (e.g. Song and Cawood, 2000), and it has been suggested they are either flower structures (e.g. Marshall et al., 1993), rollover anticlines (e.g. WA:ERA, 2012), or formed from localized compression during oblique extension (e.g. Nicholson et al., 2008).

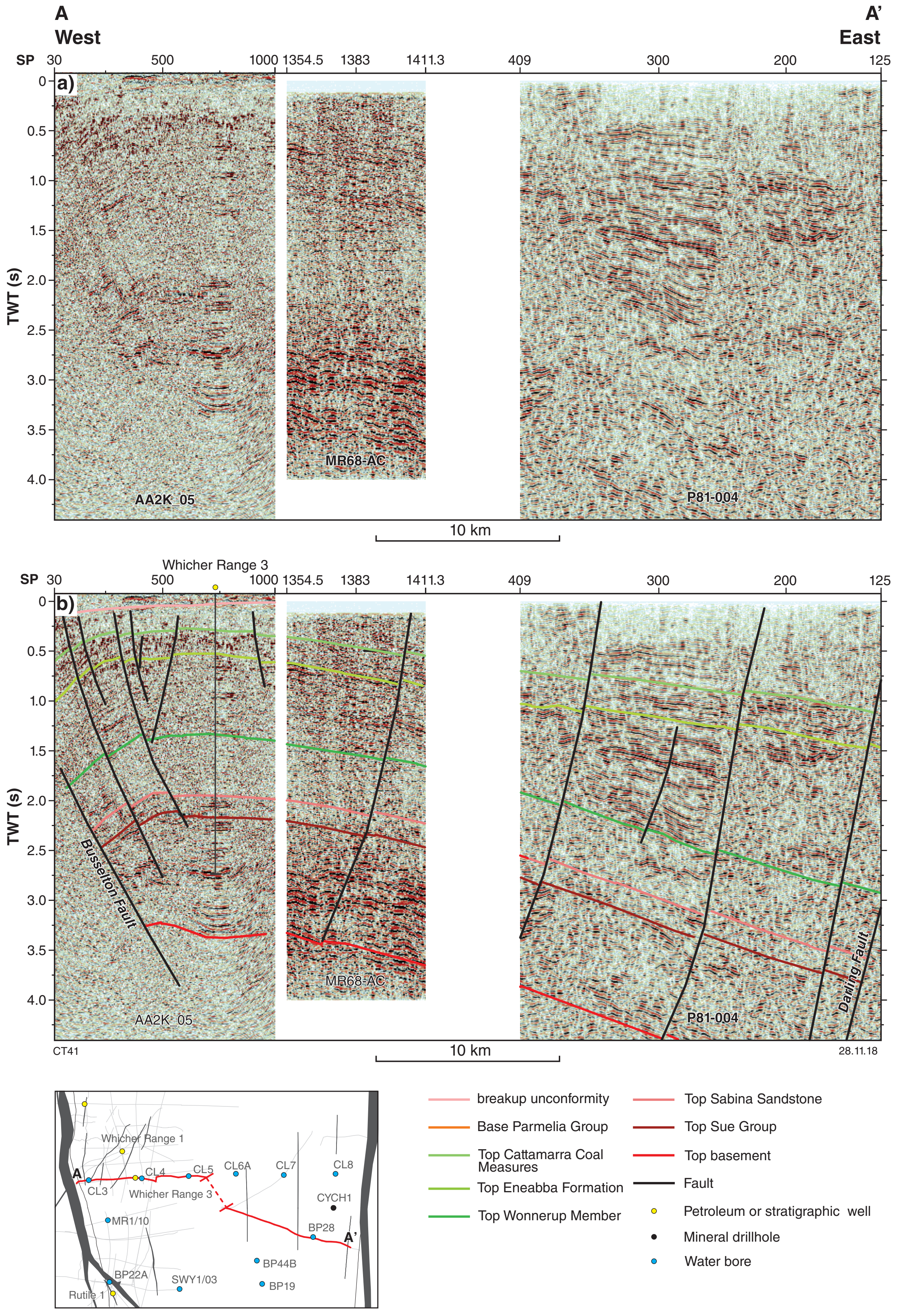

Figure 20. Uninterpreted and interpreted west–east composite seismic section across the Bunbury Trough. Strata interpreted to be the Yalgorup Member – Eneabba Formation unit thicken towards the Darling Fault

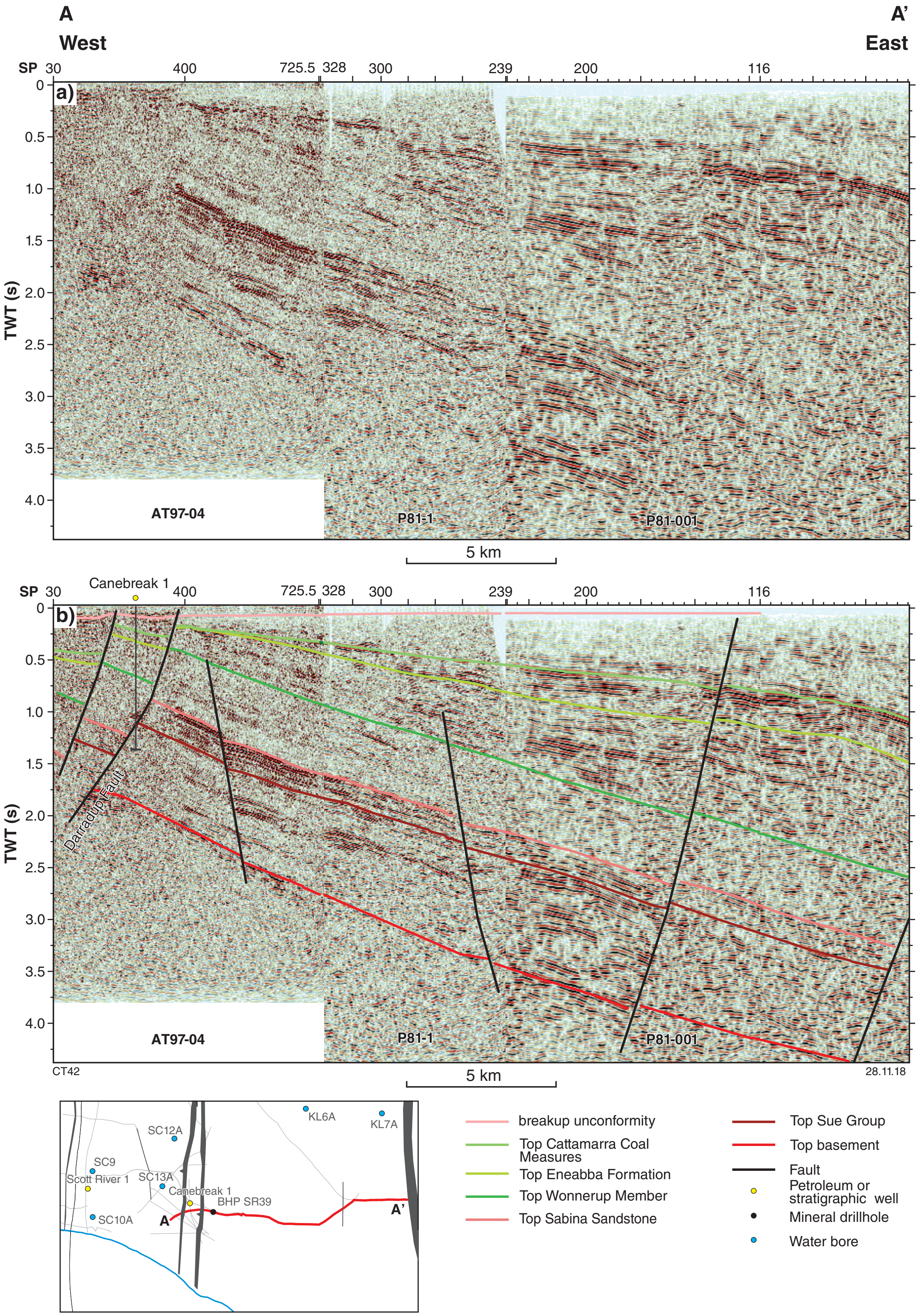

Figure 21. Uninterpreted and interpreted west–east composite seismic section across the southern Bunbury Trough. A thickening of the Upper Triassic and entire Jurassic section towards the Darling Fault is evident

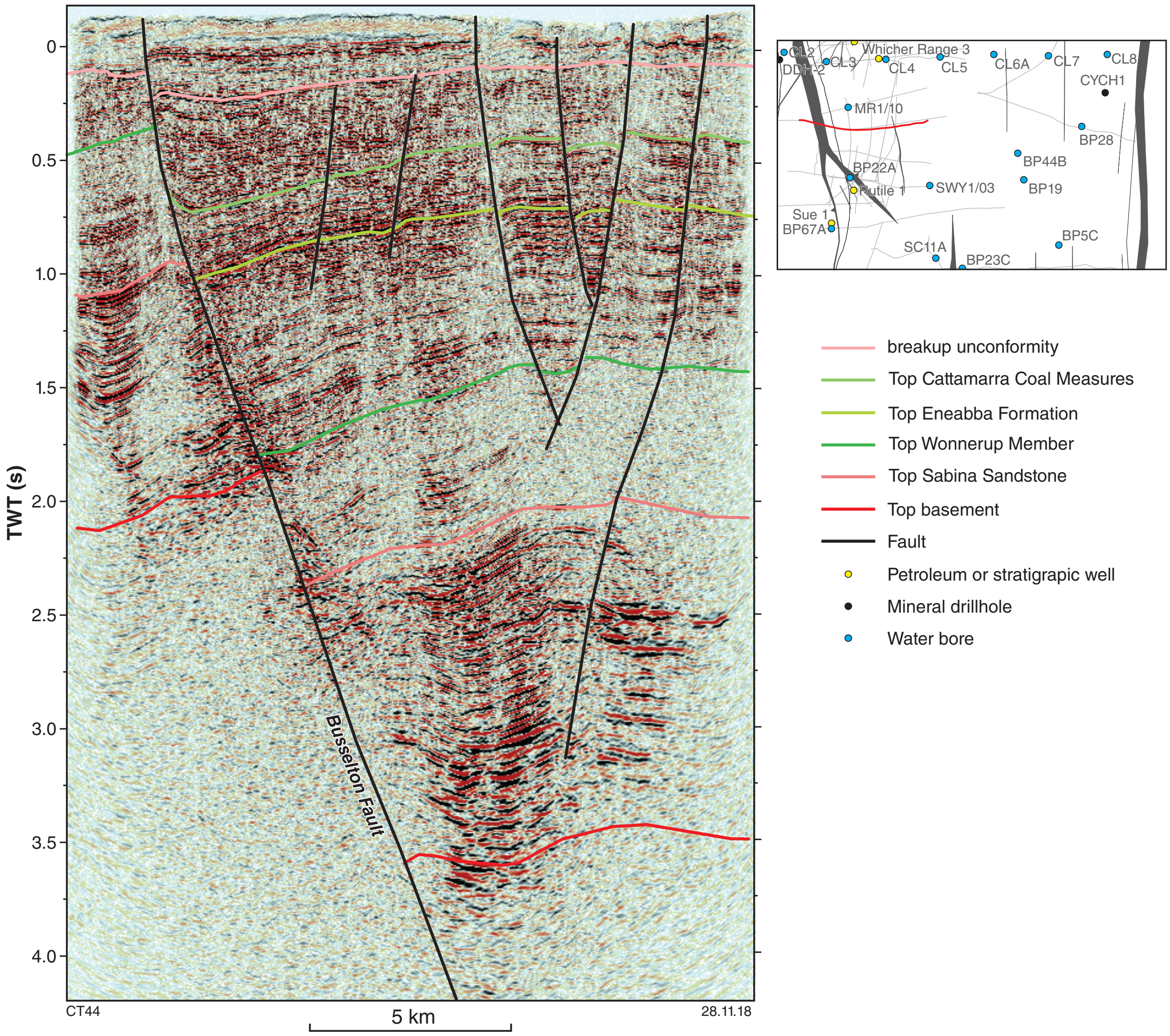

Figure 22. Interpreted line AT97-10 in the western Bunbury Trough, showing slight thickening of the Yalgorup Member – Eneabba Formation unit towards the Busselton Fault, as well as offset of the breakup unconformity by the Busselton Fault

WA:ERA (2012) previously suggested the Whicher Range anticline is a rollover anticline based on the interpreted listric form of the Busselton Fault. However, imaging of the fault plane in this location is very poor.

There are possibly smaller anticlines in the areas with no seismic coverage in the Bunbury Trough. For instance, there may be a small anticline directly east of the Busselton Fault at the Quindalup 1 (Q1) water bore site. This is based on historical palynological assessments that suggest either the Cattamarra Coal Measures or the Eneabba Formation become shallow and possibly subcrop beneath the breakup unconformity. However, this cannot be confirmed due to the lack of seismic coverage in this area, and the shallowing could also be explained by a small, uplifted, fault-bound terrace. There are possibly also anticlines in the hangingwall of the Darling Fault in the east of the sub-basin that the current seismic line coverage misses.

Minor postrift uplift and erosion after Valanginian breakup in the Bunbury Trough is suggested by the depth structure map of the breakup unconformity (Plate 6), and offset of the breakup unconformity in seismic sections across the Busselton Fault (Fig. 22) and the Darradup Fault. Complete erosion of postrift strata in the footwall of the Darradup Fault north of Canebreak 1 (Water Corporation, 2005) but preservation in the hangingwall, even at the same height above sea level, may indicate minor movement on this fault with footwall uplift after breakup. The lack of, or very thin, postrift Cretaceous to Paleogene strata in the Bunbury Trough and Vasse Shelf suggests this area remained relatively high compared to the Vlaming Sub-basin and the central Perth Basin farther north, where thicker sections of this interval are preserved. The TWT and depth structure maps of the breakup unconformity show a subtle shallowing trend towards the south, indicating uplift in that direction. A south-to-north drainage pattern that developed during and just after breakup, indicated by the Bunbury Basalt (Olierook et al., 2015), also suggests more elevated topography towards the south. These observations support the model that there was uplift on the flanks of the developing rift between Australia and Antarctica farther south, where rifting had already commenced at c. 160 Ma, with breakup at c. 83.5 Ma (Williams et al., 2011).

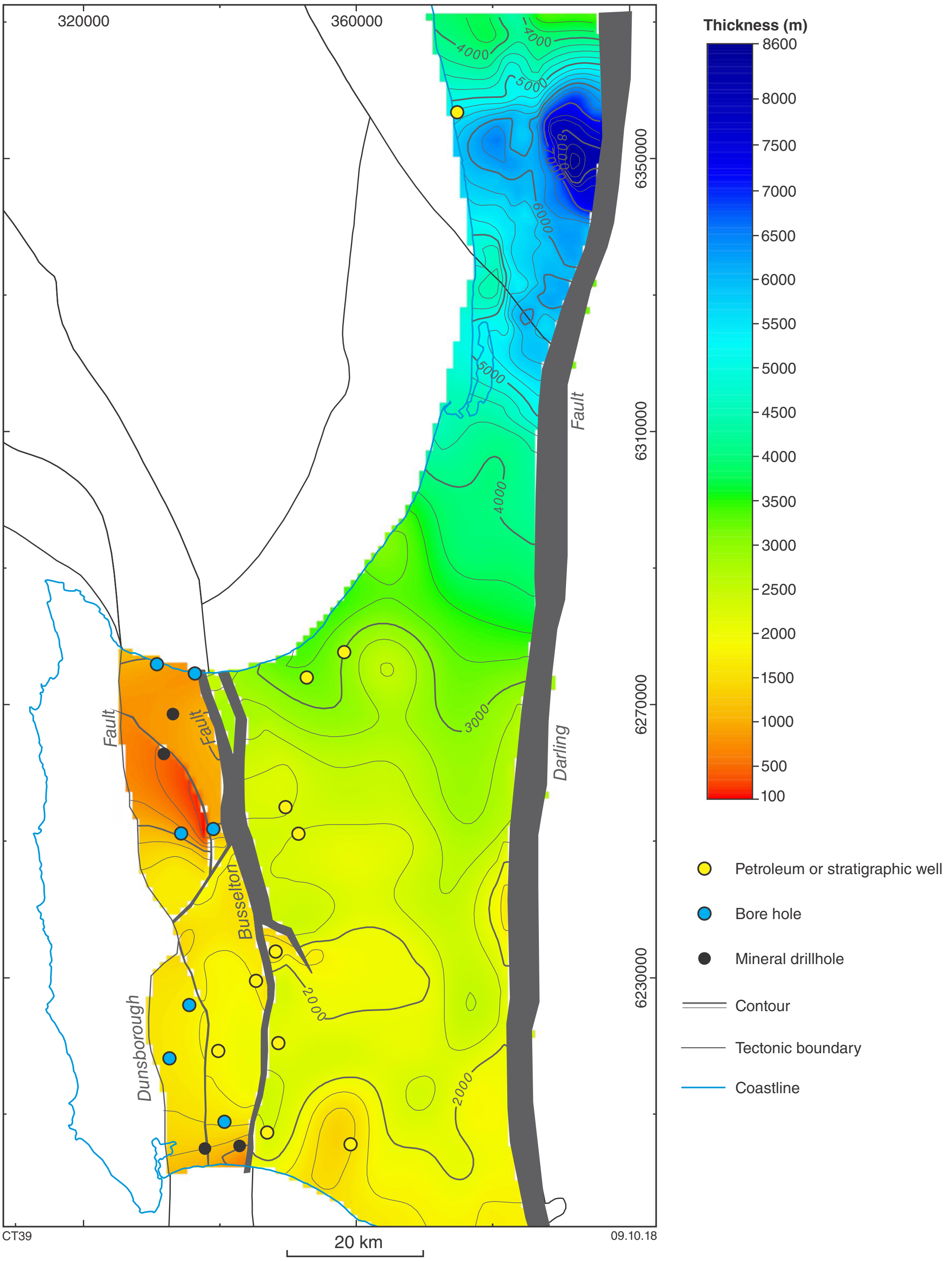

Figure 23. Isopach map of the interval between the Top basement and Top Sue Group grids, showing thickening beneath the Harvey Ridge. It is uncertain whether this is due to thickening of Permian strata, or the presence of an older unit below the Permian in this area

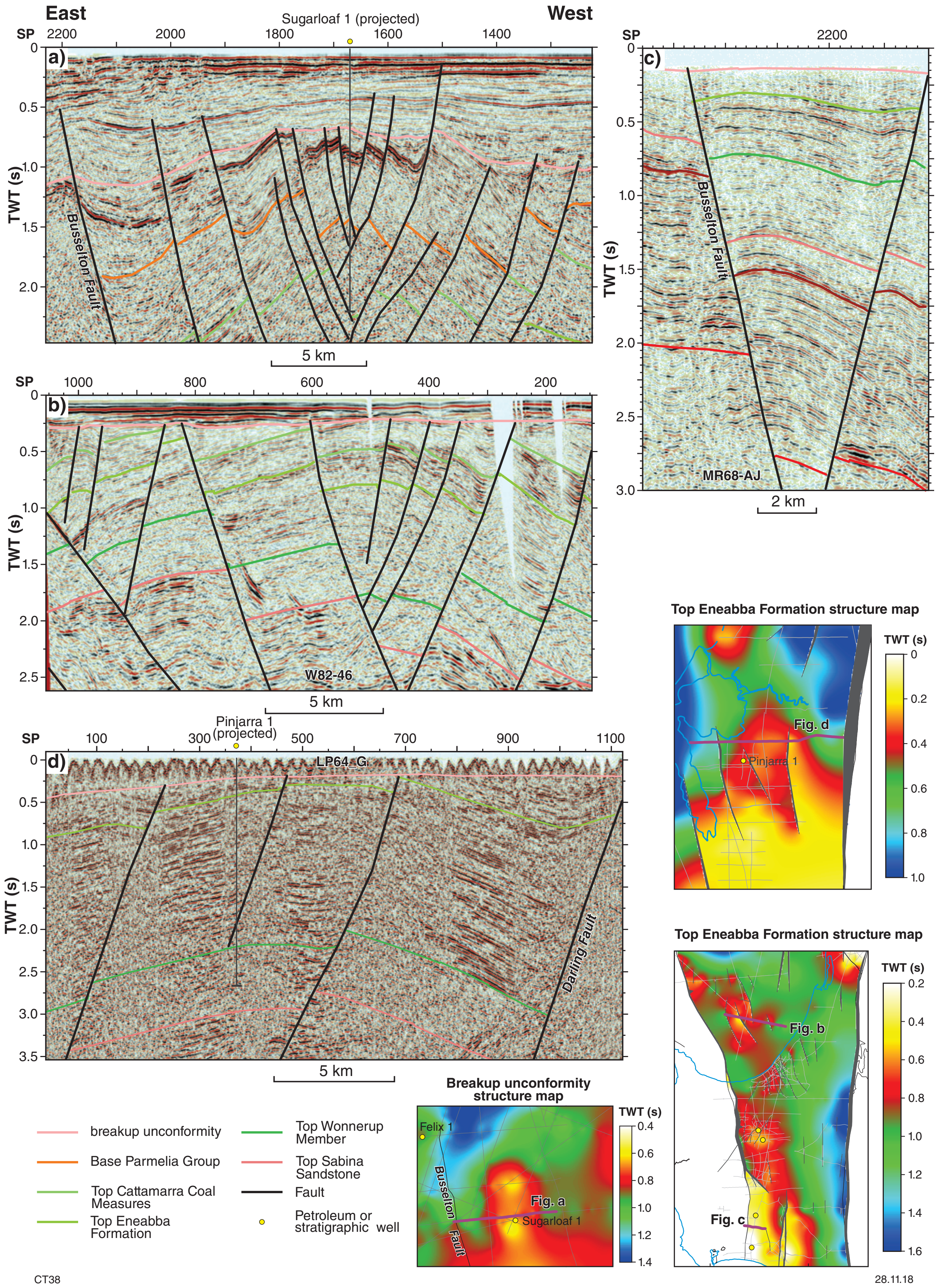

Figure 24. Contrasting styles of anticlines in the southern Perth Basin. Anticlines in the Perth Basin were previously interpreted to have formed from localized compression of hangingwall strata along major faults during oblique rifting. Locations of sections a)–d) shown in Figure 5a,b

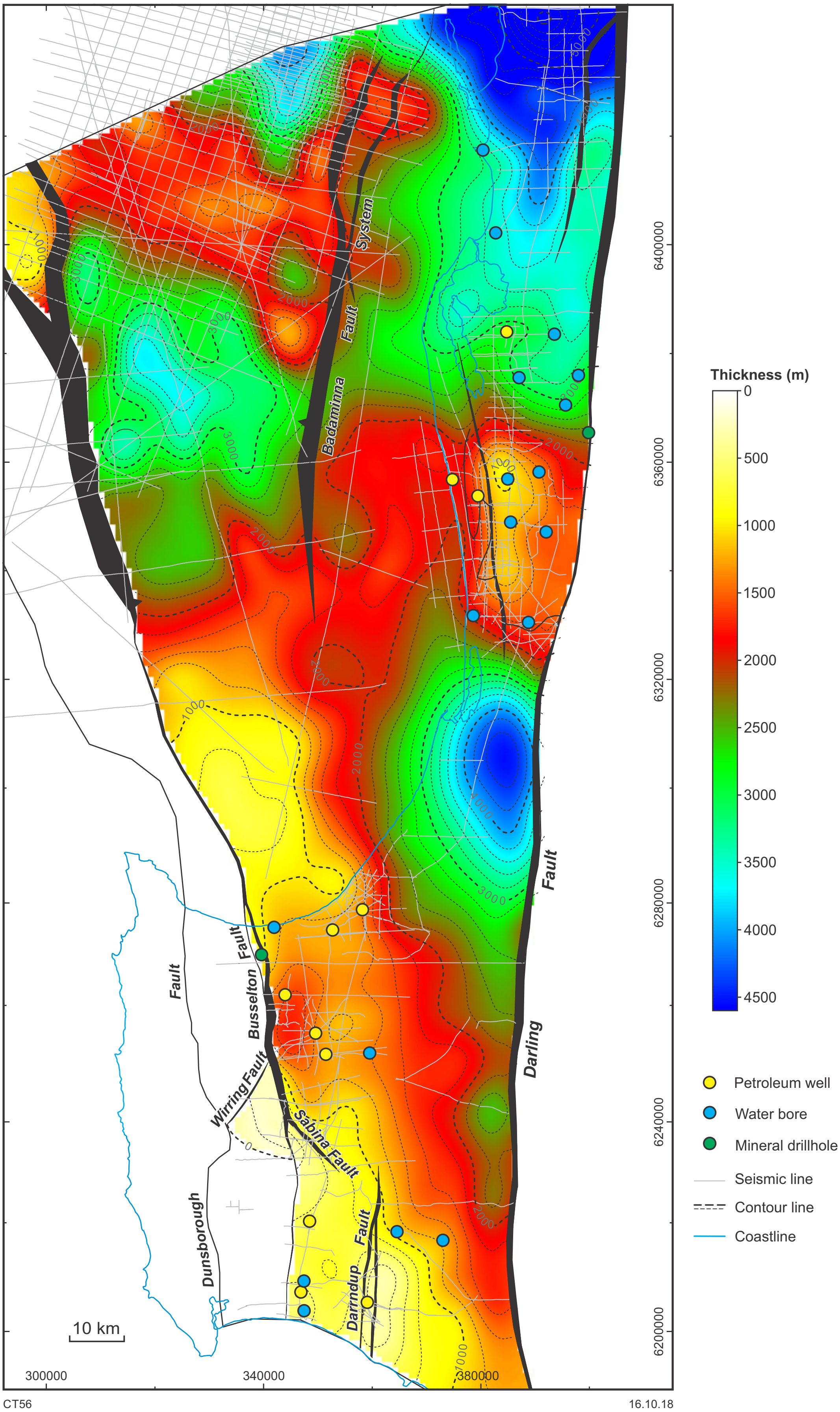

Figure 25. Isopach map of the Yalgorup Member – Eneabba Formation interval, which, in the southern Perth Basin, is difficult to differentiate lithologically

Vasse Shelf

The fault network within the Vasse Shelf could not be confidently defined due to sparse seismic coverage; only the Busselton Fault at the eastern boundary could be accurately mapped. Three seismic lines traverse the linear, high-amplitude magnetic anomaly that trends north–south in the south of the sub-basin (Fig. 4). An easterly dipping fault zone coincides with the anomaly on all three lines, but the sparse seismic coverage cannot be used to confirm if the fault is one continuous structure. Only one seismic line traverses the boundary with the Treeton Terrace, and this shows an easterly dipping normal fault at the boundary. A northwesterly strike is inferred based on the magnetic anomaly that coincides with the fault, but more seismic data are needed to confirm this.

Mandurah Terrace

All pre-breakup mapped formation surfaces in the Mandurah Terrace show a deepening trend northwards and eastwards towards the Darling Fault (Plates 1–5). The Badaminna Fault system, which forms the western boundary of the Mandurah Terrace, is interpreted here to be composed of several hard-linked faults, but is assumed to be much more complex than currently mapped. The low-confidence interpretation of horizons in the footwall of the fault is due to a gap in seismic coverage at the coast. The Darling Fault also likely comprises hard-linked faults, but very few seismic lines cross the fault. Faults with large throws splay off the Darling Fault; for example, in the Harvey Ridge area and the large fault near Rockingham 1.

As observed in the Bunbury Trough, most faults in the Mandurah Terrace formed some time after deposition of the Yarragadee Formation but before breakup. The Harvey 3D seismic survey indicates that the Yalgorup Member thickens towards the northerly striking fault near DMP Harvey 2, indicating minor movement in the Late Triassic. The dominant strike for major faults is north (also as in the Bunbury Trough), with subordinate faults striking northwest. Northwesterly striking faults are most pervasive in the Harvey Ridge.

Pinjarra 1 was drilled to investigate the petroleum potential of a large hangingwall anticline adjacent to the Darling Fault (Fig. 24d), but failed to find hydrocarbons. This anticline formed after deposition of the Cattamarra Coal Measures (which is folded) but before the breakup unconformity. It is probably the same age as the anticlines present in the Bunbury Trough, but because the Yarragadee Formation is absent (either due to erosion or nondeposition) the age of deformation is unknown. The Harvey Ridge, located at the southern margin of the Mandurah Terrace, is a large-scale, faulted anticline in the hangingwall of the Darling Fault, and is discussed in more detail below.

Harvey Ridge

Mapping from this study suggests the Harvey Ridge is a broadly northwesterly trending anticline that began to form during the Late Jurassic – Early Cretaceous. The Yarragadee Formation was either deposited thinly or not at all over the Harvey Ridge compared to adjacent areas. This is based on the low thermal maturity of the Eneabba Formation just below the breakup unconformity, as shown by the low maximum vitrinite reflectance measurements (~0.28% at 322 m in Harvey 2; Energy Resources Consulting, 2015), suggesting the Harvey Ridge had begun to uplift shortly after the deposition of this formation. The Yalgorup Member – Eneabba Formation isopach map (Fig. 25) and the north–south composite seismic section in Figure 16 indicate depositional thickening of this interval south of the Harvey Ridge; however, this likely does not reflect syndepositional thickening against an emergent Harvey Ridge. Rather, this reflects greater accommodation space generation due to greater dip-slip movement on the adjacent section of Darling Fault compared to slip on the fault adjacent to the Harvey Ridge, rather than thinning onto a topographic high. Better quality seismic, especially leading north and south off the structure, is needed to rule this out. The suggestion by Iasky (1993) that the Harvey Ridge had formed just after the Permian is rejected here because there is no evidence of thinning of the Wonnerup Member or the Sabina Sandstone onto the Harvey Ridge. The deflection of drainage during extrusion of the Basalt Basalt (Fig. 4b) suggests the Harvey Ridge remained a topographic high around the time of breakup.

The Top Sue Group to Basement isopach map shows thickening of this interval beneath the Harvey Ridge (Fig. 23). The seismic quality degrades and becomes very poor with depth north of the Harvey Ridge where the Permian section and basement are deep, so the thickness of the interval has not been mapped. East–west sections from the Harvey 3D seismic survey (Fig. 26) show easterly dipping reflectors down to at least 10 km close to the Darling Fault. Figure 26 also shows a slight steepening of dip below 6000 m. The age of these deep reflectors is unknown, and may be either a pre-Permian succession, or a thickened lower Permian succession.

Vlaming Sub-basin

The structural complexity of the Vlaming Sub-basin is not resolved by the current seismic line coverage. The northern half of the Vlaming Sub-basin (north of Sugarloaf 1) is more intensely faulted compared to the rest of the study area, and the faults have larger throws compared to faults within other sub-basins. This high-density faulting may be the result of this part of the Vlaming Sub-basin being closer to the site of lithospheric necking and an incipient tear in the continental crust. The fault linkages and intersections were deduced from changes in throws observed along the faults. Most of these faults formed prior to the breakup unconformity, and are coeval with deposition of the uppermost Parmelia Group.

The sparse distribution of seismic lines in the southern Vlaming Sub-basin precludes a definitive assessment of the geometry of the Busselton Fault at the boundary with the Bunbury Trough. More seismic data are required to understand if it is a single, continuous fault similar to the present-day Darling Fault, or is a soft-linked or hard-linked series of faults. The nature of the Busselton Fault around Felix 1 is also uncertain, as it cannot be resolved by the available 2D seismic coverage.

Whereas most faults within the Vlaming Sub-basin were initiated in the Early Cretaceous, some of the faults with larger throw show earlier movement. For example, the north-striking fault to the east of Bouvard 1 shows thickening of the Upper Jurassic Yarragadee Formation as well as the Parmelia Group, with footwall erosion of the Yarragadee Formation and possibly the top of the Cattamarra Coal Measures, indicating these faults initiated at those times (Fig. 18). The Badaminna Fault system may also have been initiated during deposition of the Yarragadee Formation, as is suggested by the isopach map (Fig. 28). Although the Yalgorup Member – Eneabba Formation unit thickens towards the Badaminna Fault system in the south (Figs 17, 25), it is uncertain if this implies fault-controlled deposition or if there was a general thickening of this interval eastwards that the Badaminna Fault system later crosscut. The uncertainly arises because there are no well penetrations in the footwall of this fault offshore; therefore, it is difficult to constrain picks on this side of the fault, making it difficult to compare thicknesses across the Badaminna Fault system. Faults comprising the Badaminna Fault system show varied geometry; faults adjacent to the Peel 1 anticline have a lower dip angle and listric geometry after depth conversion compared to the steeper and more planar geometries of faults in the south. In the footwall of the Badaminna Fault system adjacent to the Peel 1 anticline, a strongly faulted, easterly dipping shallow stratigraphic section overlies a deeper westerly dipping section (Fig. 27). This juxtaposition is inferred to be due to a shallowly dipping detachment fault, which the higher angle faults sole into. However, the shallower section could otherwise have onlapped the westerly dipping older section, with the higher angle faults being initiated afterwards and causing rotation of hangingwall blocks. Connection of seismic lines to the onshore datasets as well as better imaging are needed to clarify this structure in detail.

As in the Bunbury Trough, anticlines developed in close proximity to the major faults of the sub-basin, including the Busselton Fault and Badaminna Fault systems. Sugarloaf 1 and Peel 1 have tested these anticlines for hydrocarbons but were unsuccessful. These anticlines formed during deposition of the upper parts of the Berriasian Parmelia Group, with localized normal faults initiating as crestal collapse structures. The anticlines intersected by Sugarloaf 1 and Peel 1 continued to grow after breakup (Figs 24a and 27, respectively), causing further movement on the crestal collapse faults. Previously, these anticlines were interpreted to represent flower structures (Marshall et al., 1993), or to have resulted from localized compression during oblique extension (Nicholson et al., 2008). Aside from the Peel 1 anticline, there is no evidence to suggest that these anticlines developed from pure dip-slip movement on normal faults (i.e. rollovers) because adjacent normal faults do not display listric or ramp–flat geometries, although deeper imaging is required to ascertain if fault geometries change at depth. The preferred interpretation is folding from localized compression during oblique extension, possibly either at constraining bends or step-overs. An oblique extensional regime would have been set up during the final Late Jurassic to earliest Cretaceous rifting event that was directed northwest–southeast (as inferred from interpreted sea-floor magnetic isochrons in the Perth abyssal plain), and that was accommodated on faults that strike north. A small component of dextral strike-slip movement (in addition to normal dip-slip movement) can be expected on north-striking faults during this rifting phase, which could result in contraction at favourably oriented bends along these faults. The Peel 1 anticline possibly formed as a rollover along a low-angle easterly dipping fault (with initiation of the northern section of the Badaminna Fault system later), but clearer and deeper imaging will aid future interpretation of this structure.

Discussion

The tectonostratigraphic history of the southern Perth Basin can be determined using isopach maps derived from depth maps. Isopachs were computed for each mapped interval to determine timing and location of subsidence and uplift, which helped identify possible periods of syntectonic deposition (Plate 7). From this, a revised tectonostratigraphic scheme has been devised for the southern Perth Basin.

Tectonostratigraphic history

Pre-Permian or earliest Permian extension

The thick sedimentary package below the interpreted base of the Permian in the Harvey Ridge, as interpreted in the Harvey 3D seismic survey (Fig. 26) and some of the better quality 2D seismic lines, implies movement on the Darling Fault prior to the Permian or during the earliest Permian. The preservation of the package only in the hangingwall of the Darling Fault, a normal fault, and its erosion or nondeposition on the footwall before the Stockton Group was deposited, indicates this tectonic event was extensional. This tectonic event appears to be expressed only as normal movement on the Darling Fault.

Three factors suggest differential timing of movement on the Darling Fault: 1. pre-Permian or thickened lower Permian sedimentary package only on the Harvey Ridge (Fig. 26); 2. absence of this sedimentary package in the Bunbury Trough; 3. a distinct kink in the Darling Fault at latitude 33°21’ (MGA 6320000N). South of the bend the fault strikes approximately north, and north of it the strike changes to north-northeast (cf. Dentith et al., 1994).The presence of a pre-Permian or thickened Permian succession suggests the northern section of the fault formed first before or early in the Permian, and extension was initiated later on the southern section of the fault, before the two segments were linked.

Permian extension

The isopach map between Top basement and Top Sue Group horizons (Fig. 23) shows a slightly thickened succession in the Bunbury Trough compared to the Vasse Shelf; however, this thickening is considered tentative. Sue 1 on the Vasse Shelf penetrated 1800 m of complete Permian section through to gneissic basement, and the average full thickness elsewhere on the onshore portion of the shelf is ~2000 m. Given the vintage of the seismic data on the Vasse Shelf, the mapped thickness of this succession away from Sue 1 is tentative. By comparison, the thickness in the adjacent Bunbury Trough is tentatively estimated at ~2200–3000 m. However, the confidence in the interpretation is low because of the difficulty in interpreting the top of the basement due to the poor seismic quality at depth, and the reliance on stacking velocities only at this depth. Nevertheless, this thickening suggests the Bunbury Trough was subsiding more than the Vasse Shelf, and that the Busselton Fault may have been active at this time. An extensional event during the Permian is consistent with the northern Perth Basin rifting history (Harris, 1994; Song and Cawood, 2000); however, better quality seismic data across the Vasse Shelf and the Bunbury Trough are needed to confirm this interpretation.

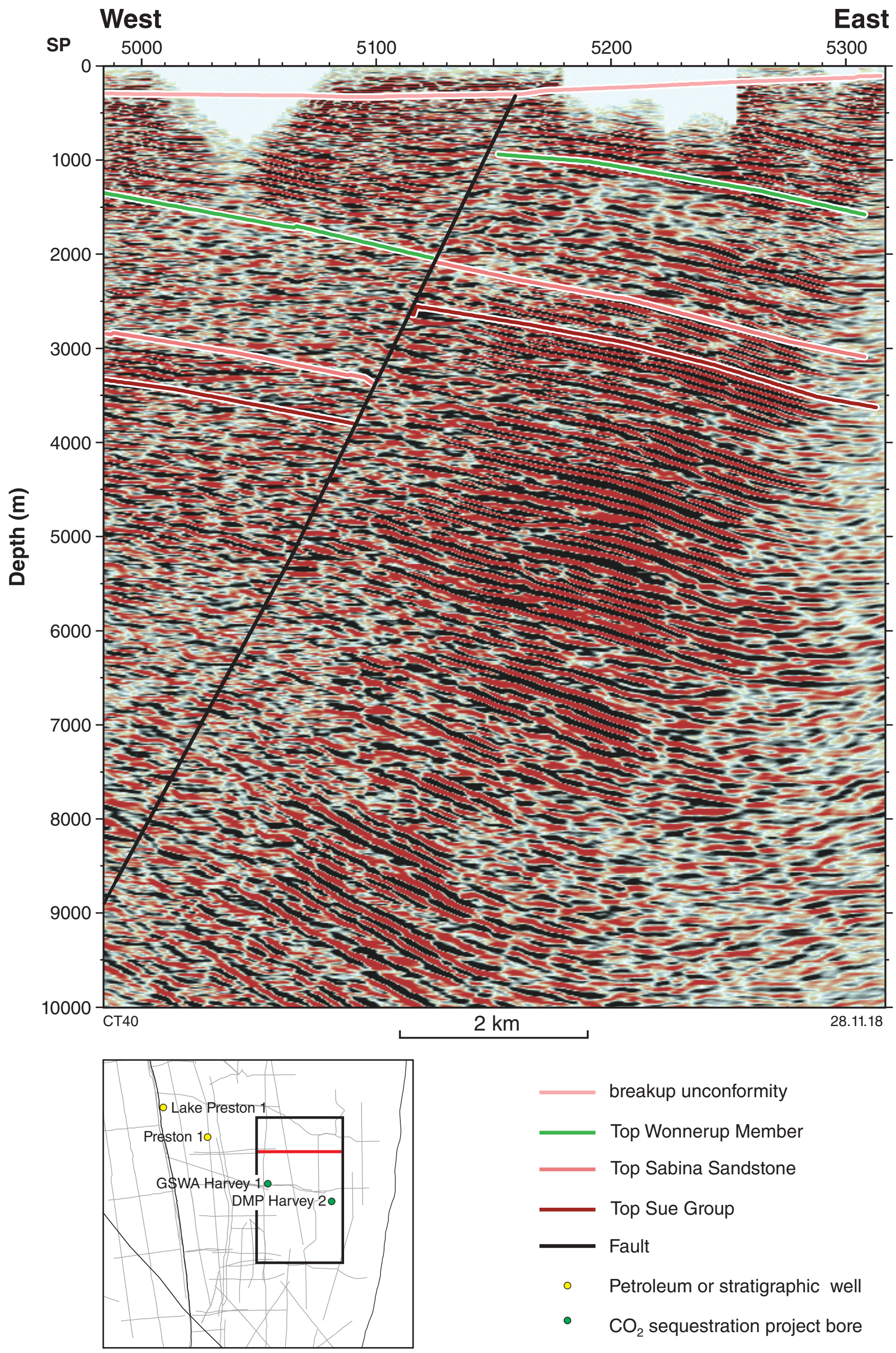

Figure 26. Interpreted west–east section through the 3D Harvey post-stack depth-migrated volume, with no vertical exaggeration. Parallel reflectors down to at least 10 km depth are interpreted as sedimentary layers, and may represent either a thickened Permian section or a pre-Permian section

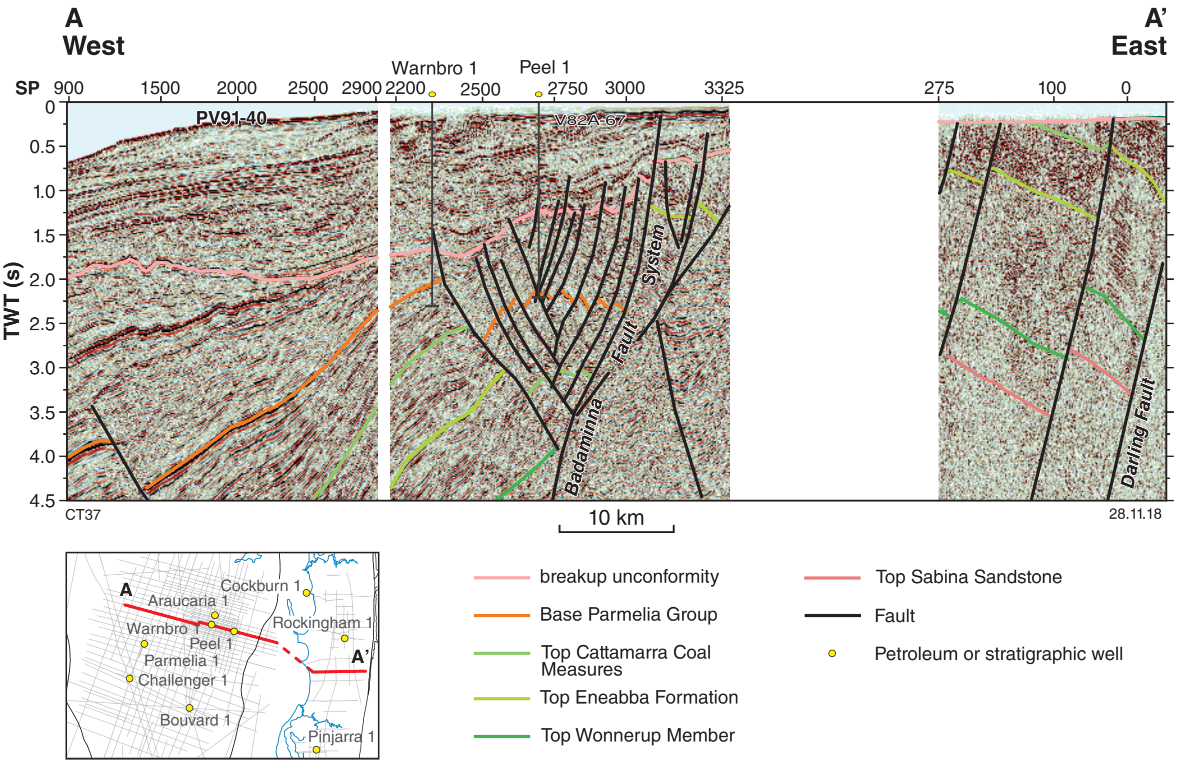

Figure 27. **West–east composite seismic section across the Vlaming Sub-basin and the western edge of the Mandurah Terrace in the north of the study area. The horizon interpretation in the footwall of the Badaminna Fault system is uncertain due to gaps in seismic coverage at the coast. The anticline intersected by Peel 1 is possibly a rollover on the easterly dipping fault and/or the westerly dipping Badaminna Fault system, or it is related to localized compression during oblique rifting, but better imaging is required to resolve this complex structure**

Late Triassic – Early Jurassic extension

The combined Yalgorup Member – Eneabba Formation has the greatest variation in thickness across the area (Fig. 25). There is significant thickening of this interval northwards and eastwards towards the Darling Fault (Figs 20, 22), but there is no evidence of these units on the Darling Fault footwall block (Yilgarn Craton and western Albany–Fraser Orogen). Unfortunately, the data quality of seismic lines abutting the Darling Fault precludes a more accurate assessment of stratigraphic and structural relationships in the hangingwall, therefore evidence for syntectonic deposition is only based on the wedge-shaped geometry of this stratigraphic interval against the Darling Fault and the isopach map.

This interval is thickest between Rockingham 1 and Pinjarra 1, but the depth conversion is uncertain in this area because there are no full intersections north of Pinjarra 1, and only seismic stacking velocities were used as the main constraint on the interpretation. Strata in the Bunbury Trough thicken towards the Darling Fault (Figs 21, 22, 26), but any depositional thickening of this interval towards the Darling Fault in the Harvey Ridge is obscured due to significant erosion of the top of the Eneabba Formation. The Harvey 3D seismic survey, constrained by four holes with a Top Yalgorup Member pick, shows subtle thickening of the Yalgorup Member into larger faults synthetic to the Darling Fault (the seismic survey itself did not reach the Darling Fault; Odin Reservoir Consultants, 2017). Although not as pronounced as the thickening against the Darling Fault, thickening into the Busselton Fault is also evident on seismic profiles (Fig. 22), implying this fault was also active during this time.

In the southern Perth Basin, this rift event was relatively subdued, given the long period of time the Yalgorup Member and Eneabba Formation interval represents (at least 40 Ma). Overall deposition rates were low but steady, as evidenced by the frequent and, in some places, very thick paleosol intervals. If movement at this time occurred on the northerly striking Darling Fault, Busselton Fault, and possibly the Badaminna Fault system, rifting is inferred to have been east–west oriented. A similar rifting azimuth at this time was inferred for the northern Perth Basin (Song and Cawood, 2000). However, the Darling Fault was probably influenced by pre-existing underlying Proterozoic structures of similar orientation (Dentith et al., 1994), so the Busselton and Badaminna Fault systems might also have been influenced by similar basement fabrics. Therefore, the orientation of the rift axes during Late Triassic – Early Jurassic rifting is uncertain.

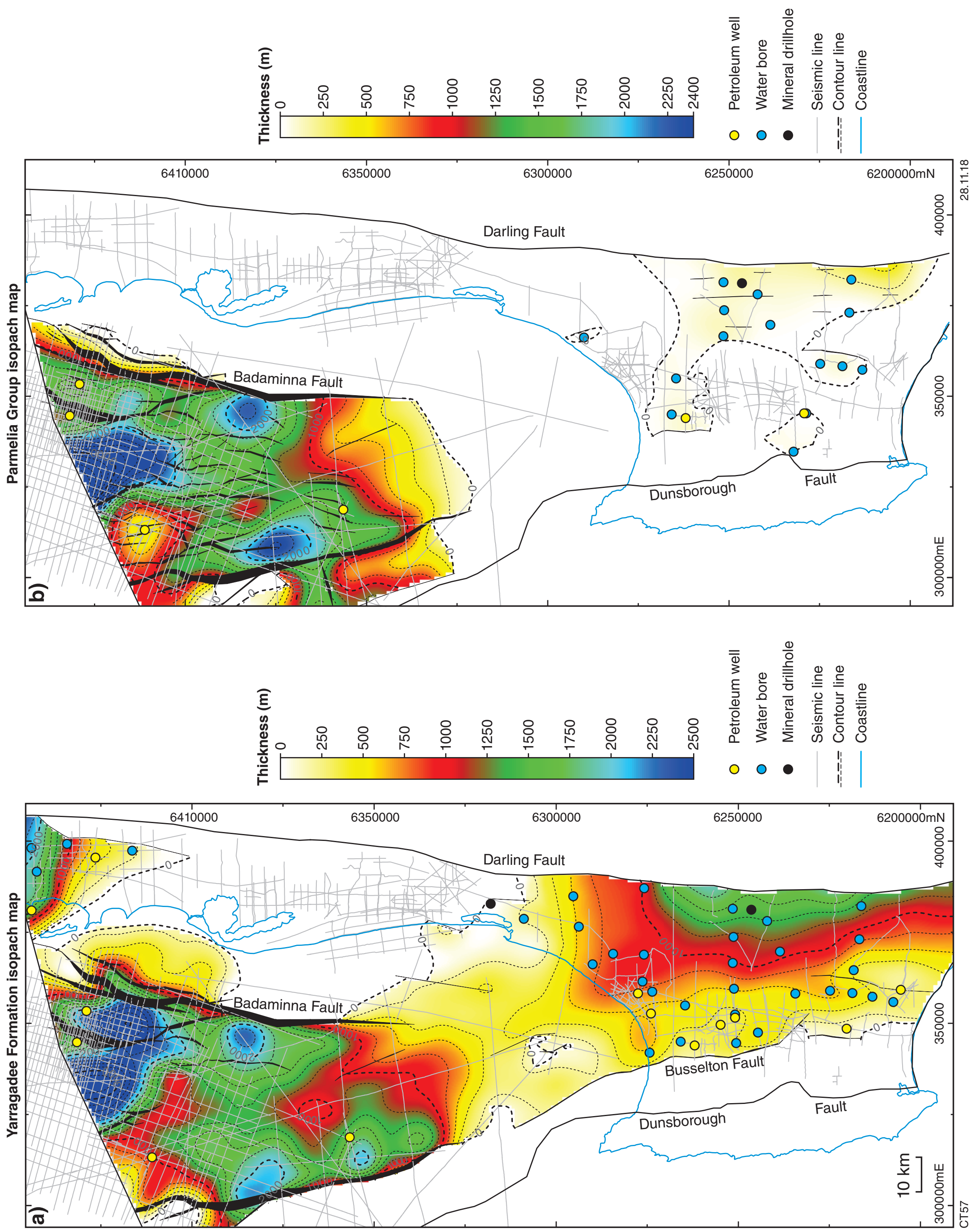

Figure 28. **Isopach maps: a) Yarragadee Formation; b) Parmelia Group. The Yarragadee Formation shows thickening against the Darling Fault in the Bunbury Trough and against a northwest-striking fault in the northern Vlaming Sub-basin**

Middle Jurassic to earliest Cretaceous oblique rifting and breakup

The Yarragadee Formation and Parmelia Group both thicken towards the Darling Fault in the Bunbury Trough (Fig. 27), but thickening of the Parmelia Group is most pronounced in the Vlaming Sub-basin, in which the total thickness of ~3400 m was deposited in a relatively short time. This rifting event was subdivided into two phases by Jones et al. (2011) for the offshore northern Perth Basin; a two-phase rifting event is also suggested here in the southern Perth Basin to account for: 1) an unconformity at the base of the Parmelia Group in some places; and 2) the disparate rates of sediment accumulation between the Yarragadee Formation and the Parmelia Group. Two-phase rifting is common for rifts that lead to breakup, whereby there is initial slow rifting, followed by high-velocity rifting (Brune et al., 2016).

The southern Perth Basin is unique during this time because it is placed between two developing rifts — the rift between Greater India and Australia, and the rift between Australia and Antarctica. Greater India is inferred to have moved away from Australia in a northwesterly direction based on the orientation of magnetic isochrons interpreted within the Perth abyssal plain sea floor (Gibbons et al., 2012). Rifting between Australia and Antarctica commenced in the Late Jurassic, and is inferred by Norvick and Smith (2001), Blevin and Cathro (2008), and White et al. (2013) to have also initially been northwest–southeast oriented, and that in the earliest Cretaceous the motion of Australia relative to Antarctica changed to a more northerly direction. Others have argued for a continual north–south direction of motion since the onset of rifting between the two continents (Williams et al., 2011). It is not clear what the implications of plate motion azimuths were for the principal extension direction in the southern Perth Basin, but any azimuth of extension from northwest–southeast to north–south would have initiated an oblique rifting regime in the southern Perth Basin. Northerly striking faults would have incurred a component of dextral strike-slip displacement which, especially at bends of favourable orientation, resulted in localized compression (i.e. restraining bends or step-overs) forming anticlines in the hangingwall. The Harvey Ridge is interpreted to be an example of this.

Uplift and formation of the Harvey Ridge

During Middle Jurassic to Early Cretaceous rifting, the Harvey Ridge was positioned in a relay zone between the southern section of the Darling Fault and the Badaminna Fault system. This interpretation is based on the isopach maps of the Yarragadee Formation and the Parmelia Group (Fig. 28), which show that the section of the Darling Fault adjacent to the Bunbury Trough was active during deposition of these units and its throw was transferred onto the Badaminna Fault system. This caused the section of the Darling Fault adjacent to the Harvey Ridge and northwards to about Rockingham 1 to become less active or inactive. There is no evidence from the current seismic mapping that the southern section of the Darling Fault and the Badaminna Fault system became hard linked, but it is possible that at depth there is a pre-existing northwest-trending structure in the basement that hard links the two faults — it has long been speculated that northwest-trending lineaments in the Yilgarn Craton extend into basement beneath the Harvey Ridge (e.g. Dentith et al., 1994; Crostella and Backhouse, 2000). Oblique northwest–southeast rifting is interpreted to have induced a component of dextral strike-slip motion on the active Darling and Badaminna Fault systems, resulting in localized compression and the formation of a restraining step-over (Fig. 29). This same mechanism was similarly invoked by Morley et al. (2004) to explain anticlines in relay zones between en echelon soft-linked faults during highly oblique rifting in the Phitsanulok Basin, Thailand.

Cretaceous post-rift thermal subsidence and minor tectonism

Many of the larger normal faults in the study area, including the Darling Fault and the Busselton Fault (Fig. 22), show minor displacement of the Breakup Unconformity horizon and overlying post-rift strata. The anticline intersected by Sugarloaf 1 appears to have continued forming after breakup until the Aptian–Albian. However, it is unclear whether these reflect minor adjustments to the crust during the post-breakup thermal sag phase or are due to far-field effects of the rifting between Australia and Antarctica.

Implications for hydrocarbon exploration

Re-evaluation of petroleum well postmortems

This seismic interpretation project has shed new light on the structure of the southern Perth Basin, and the reason two wells, Lake Preston 1 and Canebreak 1, may have failed to find hydrocarbons.

Canebreak 1

Canebreak 1 targeted the Willepsie Formation — the same formation which forms the reservoir at the Whicher Range gas accumulation — in a tilted fault block bounded by the westerly dipping Darradup Fault (Fig. 21). In the well completion report, Lowry (1982) contended that Canebreak 1 failed to find hydrocarbons because it missed the targeted footwall trap, and was drilled completely within the hangingwall of the Darradup Fault. New mapping in this study suggests that the well did intersect the Darradup Fault and underlying footwall stratigraphy. Two indications that a fault zone was penetrated by the well are: sandstones from ~1625 to 1770 m are cemented with quartz; and during drilling of the well, penetration rates were slow from ~1700 to 1900 m due to pyritized stringers. This study places the fault intersection in Canebreak 1 at ~1700 m, which also explains the absence of ‘typical’ Sabina Sandstone lithologies (noted in the well completion report and evident in its gamma ray log signature and cuttings descriptions). Whereas Crostella and Backhouse (2000) identified the Sabina Sandstone in Canebreak 1 (presumably because cuttings from 1282 m are described as having a minor component of green, micaceous

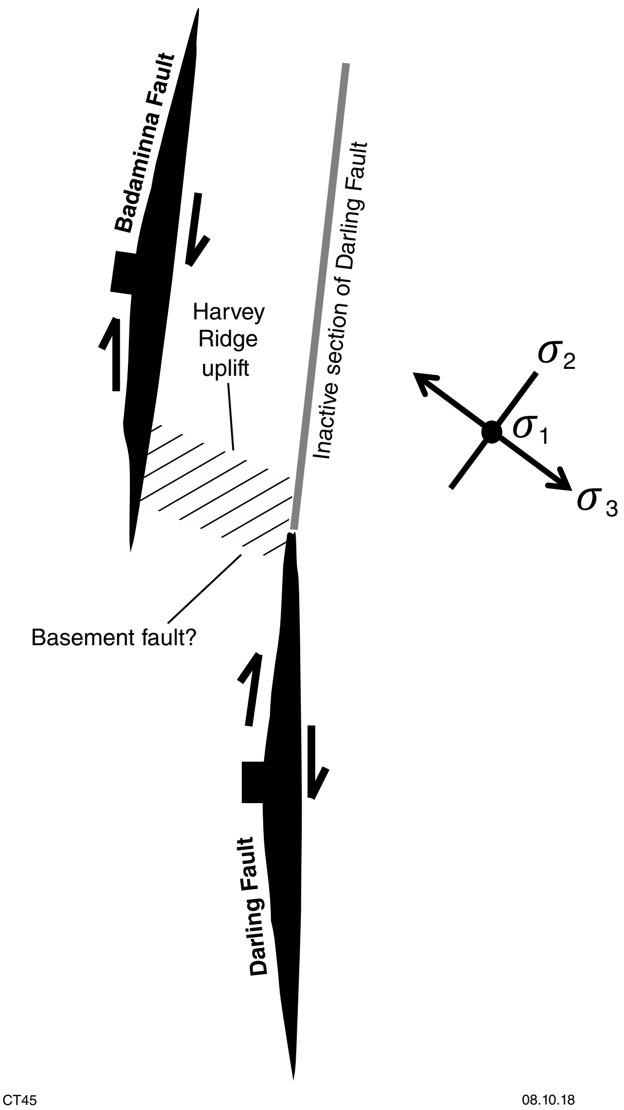

Figure 29. Schematic diagram of the proposed structural mechanism that led to the uplift that formed the Harvey Ridge. Oblique northwest–southwest extension during the final Middle Jurassic to earliest Cretaceous rifting phase set up a component of dextral strike-slip motion on the northerly trending Darling Fault and Badaminna Fault system. Left-stepping of the active section of the oblique-slip Darling Fault and the Badaminna Fault system resulted in a restraining relay between the two faults

sandstone, but in an otherwise predominantly 'clear' quartz sandstone), it is more likely that the section assigned to the Sabina Sandstone is part of the Wonnerup Member, with the Sabina Sandstone mostly or completely faulted out. The Wonnerup Member in Sue 1 and Blackwood 1 also contains horizons of green sandstone towards its base, and so a minor component of green sandstone at the base of the Wonnerup Member can be similarly expected in Canebreak 1.

Based on this new interpretation, an alternative explanation for the failure of the well to find hydrocarbons is that the bounding Darradup Fault is not sealing, because the targeted reservoir rocks are juxtaposed against the Wonnerup Member of the Lesueur Sandstone — a clean sandstone with very high porosities and permeability.

Lake Preston 1

Lake Preston 1 is a dry well that aimed to test the Willespie Formation on the Harvey Ridge. It was sited using extremely poor-quality seismic data of the time, and was assumed to be on the crest of a structure, given its location within a gravity anomaly. However, from this new seismic mapping it is evident that Lake Preston 1 penetrated the downthrown side of a large fault. This model is also supported by later drilling — GSWA Harvey 1 is in the footwall and penetrated the Sabina Sandstone at 2895 m, and Lake Preston 1 intersected the same rocks at ~3500 m.

The anomalous gravity signature may be due to differences in the density characteristics of basement either side of the fault, or there may be an intrusion at depth on the west side of the fault.

New plays and prospects

This Report has identified new plays and possible prospects in the basin. A structural high at the southern tip of the Vlaming Sub-basin just offshore from the town of Busselton is an untested possible trap, and is situated on-trend from the Whicher Range and possible Wonnerup accumulations. However, in the two seismic lines crossing this high (one shown in Fig. 24b), the Permian section is highly faulted and is juxtaposed against the Wonnerup Member, introducing a risk of leakage. There is very poor seismic coverage over this structural high, so more acquisition is required to assess its potential. Another untested structural high at the Permian level is the crest of the Harvey Ridge, because Lake Preston 1, the only petroleum well in the Harvey Ridge to have intersected the Willespie Formation, was drilled in the hangingwall of a large fault.

Trapping geometries could be present along the Badaminna Fault system footwall, charged from deeper source rocks either to the west in the hangingwall, such as the Otorowiri Formation of the Parmelia Group, the Yarragadee Formation and possibly the Cattamarra Coal Measures equivalent, or from Permian coal measures directly underneath. Cockburn 1 has a marine signature in the Middle Jurassic (Western Palynoservices, 1991) introducing the possibility of mature oil-prone source rocks offshore. The Cattamarra Coal Measures, the Yarragadee Formation, possibly the Eneabba Formation, and possibly the thin Parmelia Group, are all interpreted to subcrop beneath the breakup unconformity in the footwall. The Badaminna Fault system is structurally complex and more seismic acquisition, in particular long lines that connect to onshore lines, is needed to clarify its structure. The footwall offers an attractive target for exploration because it is well positioned to receive charge from the Otorowiri Siltstone member of the Parmelia Group to the west, as well as possible source horizons within the Cattamarra Coal Measures below.

The eastern Bunbury Trough directly adjacent to the Darling Fault has very sparse seismic coverage, and it is possible there are more anticlines that have been missed. Stratigraphic traps may be present in the thick Upper Triassic – Lower Jurassic synextensional section in the Darling Fault hangingwall. Therefore, this part of the sub-basin still holds potential.

Conclusions and further work

The seismic and well interpretations presented in this Report update the work by Iasky (1993), and incorporate new and reprocessed seismic data, and new well, mineral and water bore data, which have allowed further subdivision of the Upper Triassic – Lower Jurassic section. The maps presented here show the areas of greatest basin subsidence and uplift through time, which has allowed an assessment of the tectonic history of the basin.

Tectonic events proposed to have driven basin subsidence in the northern Perth Basin can also be recognized in the southern Perth Basin. In seismic lines that extend to the Darling Fault, strata interpreted as the Upper Triassic Yalgorup Member of the Lesueur Sandstone and the Lower Jurassic Eneabba Formation thicken towards the fault, possibly indicating a rifting event. This assumption is consistent with an Early Jurassic rifting event interpreted in the northern Perth Basin (Song and Cawood, 2000; Jones et al., 2011). Seismic mapping has also identified a significantly thickened lower Permian section or a thick older Paleozoic section beneath the Harvey Ridge. This may indicate an early Permian synrift section, which is consistent with a Permian rifting phase proposed previously in the northern Perth Basin, or it may indicate an earlier extensional phase. The final Middle Jurassic to earliest Cretaceous rifting phase that led to continental breakup in the Valanginian–Hauterivian allowed deposition of the Yarragadee Formation and the Parmelia Group, which attained greatest thickness offshore in the Vlaming Sub-basin.

Broadly, the major faults, the Busselton, Badaminna and Darling Faults, are today continuous linear faults. However, changes in throw or kinks along them hint that they were initially a series of smaller faults that have linked up as rifting persisted. The continuity of the Busselton Fault from onshore to offshore, as indicated in the current tectonic element maps, cannot be confirmed by seismic data because coverage in the nearshore area is too sparse. However, the TMI aeromagnetic data suggest it is continuous.

Anticlines have been targeted for their petroleum trapping potential. Whereas all folds were previously interpreted to have formed in local zones of compression during oblique rifting, the mapping from this project raises the possibility that alternative mechanisms, such as ramp–flat or rollover folding, could instead be responsible for some structures. Forward kinematic modelling could shed light on this problem. The sparse distribution of seismic data in some areas raises the possibility of more anticlines in the basin.

Poor seismic imaging due to the Bunbury Basalt, Pleistocene limestone, and laterite in the shallow subsurface of the southern Perth Basin could be improved with more modern processing and acquisition techniques. More and deeper seismic coverage is needed to assess the complex structure of the basin, and determine the extent to which pre-existing discontinuities in the basement controlled the structural history of the basin. The maps created from this project will provide a starting point for targeting future exploration activity for hydrocarbons or groundwater.

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Appendix 1

Well and drillhole inventory and formation tops

									Formation top (m MD)								
Well name	Hole type	Latitude	Longitude	Easting (MGA Zone 50)	Northing (MGA Zone 50)	Elevation reference	Elevation (m AHD)	Total depth (m)	breakup unconformity	Top Parmelia Group	Top Yarragadee Formation	Top Cattamarra Coal Measures	Top Eneabba Formation	Top Wonnerup Member	Top Sabina Sandstone	Top Sue Group	Top basement
Mandurah Aquatic & Recreation Centre 01	Geothermal bore	32° 32' 11.45"S	115° 44' 12.4"E	381378	6399390	GL	~ 3	1502	195–420	–	–	195–420	195–420	ni	ni	ni	ni
84 ACH 1	Coal exploration drillhole	33° 57' 14.38"S	115° 12' 5.46"E	333814	6241488	KB	86.3	289	180	–	–	–	–	180	ni	ni	ni
Alcoa E2	Groundwater bore	32° 39' 47.3"S	115° 56' 52.81"E	401353	6385568	GL	~ 43	304	30	–	–	–	30	ni	ni	ni	ni
Alcoa O-10	Groundwater bore	32° 41' 31.21"S	115° 54' 3.29"E	396970	6382323	TOC	19.2	274	135	–	–	135	ni	ni	ni	ni	ni
Alcoa O9	Groundwater bore	32° 38' 58.62"S	115° 53' 50.83"E	396597	6387019	TOC	13.1	215	95	–	–	95	ni	ni	ni	ni	ni
Alexandra Bridge 1	Petroleum well	34° 9' 22.7"S	115° 15' 41.6"E	339744	6219148	KB	39.0	766	70	–	–	–	–	70	278	407	ni
AM47	Groundwater bore	32° 8' 6.86"S	115° 55' 11.06"E	398111	6444063	GL	27.3	742	405	–	405	ni	ni	ni	ni	ni	ni
AM50	Groundwater bore	32° 13' 24.66"S	115° 55' 49.64"E	399219	6434287	TOC	15.5	343	243	–	243	ni	ni	ni	ni	ni	ni
AM50Y	Groundwater bore	32° 14' 25.67"S	115° 58' 37.05"E	403619	6432451	GL	30.8	306	101	–	–	101	ni	ni	ni	ni	ni
AM50Z (Byford 2)	Groundwater bore	32° 12' 55.55"S	115° 57' 8.82"E	401283	6435204	TOC	21.2	183	166	–	–	166	ni	ni	ni	ni	ni
AM51	Groundwater bore	32° 10' 52.68"S	115° 58' 42.03"E	403687	6439011	GL	27.2	421	129	–	–	129	ni	ni	ni	ni	ni
AM52Y (Garden Island North Bore)	Groundwater bore	32° 9' 30.97"S	115° 40' 2.07"E	374326	6441206	TOC	6.8	450	369	–	–	369	ni	ni	ni	ni	ni
AM54	Groundwater bore	32° 17' 15.8"S	115° 44' 47.58"E	381972	6426982	TOC	5.8	449	392	–	–	392	ni	ni	ni	ni	ni
AM56	Groundwater bore	32° 17' 58.31"S	115° 58' 55.96"E	404176	6425908	TOC	34.7	351	117	–	–	117	ni	ni	ni	ni	ni
AM62	Groundwater bore	32° 26' 1.34"S	115° 48' 20.68"E	387727	6410862	GL	7.7	386	276	–	–	276	ni	ni	ni	ni	ni
AM64	Groundwater bore	32° 26' 34.66"S	115° 58' 36.72"E	403825	6410003	GL	54.7	358	13	–	–	13	ni	ni	ni	ni	ni
AM65	Groundwater bore	32° 29' 54.66"S	115° 48' 9.79"E	387523	6403674	GL	2.1	363	209	–	–	209	ni	ni	ni	ni	ni
AM66	Groundwater bore	32° 29' 54.92"S	115° 54' 26.84"E	397363	6403772	GL	20.9	384	215	–	–	215	ni	ni	ni	ni	ni
AM67	Groundwater bore	32° 30' 41.36"S	115° 45' 9.5"E	382835	6402182	TOC	12.2	376	253	–	–	–	281	ni	ni	ni	ni
AM68	Groundwater bore	32° 32' 46.65"S	115° 50' 12.45"E	390782	6398413	TOC	9.8	327	199	–	–	199	ni	ni	ni	ni	ni
Araucaria 1	Petroleum well	32° 12' 27.87"S	115° 21' 49.35"E	345784	6435363	KB	18.0	2218	1886	1886	ni	ni	ni	ni	ni	ni	ni
Becher Point 1 (AM57)	Groundwater bore	32° 22' 25.82"S	115° 43' 42.57"E	380385	6417415	GL	2.3	806	333	–	–	–	333	ni	ni	ni	ni
Becher Point 2 (AM58)	Groundwater bore	32° 23' 29.26"S	115° 48' 2.52"E	387200	6415540	GL	9.1	742	288	–	–	288	ni	ni	ni	ni	ni
Becher Point 3 (AM59)	Groundwater bore	32° 22' 22.57"S	115° 51' 18.93"E	392310	6417650	GL	9.0	796	263	–	263	?	ni	ni	ni	ni	ni
Becher Point 4 (AM60)	Groundwater bore	32° 23' 5.07"S	115° 54' 31.63"E	397359	6416394	GL	16.6	810	187	–	187	ni	ni	ni	ni	ni	ni
Becher Point 5 (AM61)	Groundwater bore	32° 22' 51.49"S	115° 57' 38.74"E	402244	6416861	GL	37.0	806	57	–	–	57	ni	ni	ni	ni	ni
BHP SC22	Mineral sand exploration	34° 17' 0.29"S	115° 16' 10.91"E	340734	6205064	GL	~10	18	18	–	–	–	–	–	–	18	ni
Blackwood 1	Petroleum well	34° 8' 50.7"S	115° 21' 25.47"E	348534	6220279	KB	70.6	3338	186	–	186	276	462	1059	2061	2448	ni
BN20Y	Groundwater bore	33° 40' 4.57"S	115° 28' 31.61"E	358659	6273619	GL	18.3	354	70	–	70	ni	ni	ni	ni	ni	ni
BN32Y	Groundwater bore	33° 44' 10.69"S	115° 19' 35.34"E	344970	6265824	TOC	22.7	353	159	159	257	ni	ni	ni	ni	ni	ni
BN34Y	Groundwater bore	33° 44' 55.39"S	115° 26' 0.69"E	354908	6264603	TOC	46.8	353	102	102	146	ni	ni	ni	ni	ni	ni
BN6Y	Groundwater bore	33° 34' 19.52"S	115° 35' 21.71"E	369076	6284397	GL	29.2	377	70	–	70	ni	ni	ni	ni	ni	ni
Bouvard 1	Petroleum well	32° 31' 31.98"S	115° 15' 16.87"E	336082	6399966	KB	12.0	1986	1117	1117	ni	ni	ni	ni	ni	ni	ni
Boyanup 3A	Groundwater bore	33° 29' 18"S	115° 40' 15"E	376519	6293784	GL	31.8	1200	35	–	35	741	ni	ni	ni	ni	ni
Boyanup 4A	Groundwater bore	33° 28' 31.67"S	115° 45' 38.4"E	384848	6295314	TOC	76.2	998	360	–	360	ni	ni	ni	ni	ni	ni
BP22A	Groundwater bore	34° 0' 41.57"S	115° 21' 1.53"E	347678	6235337	GL	86.7	408	170	–	–	170	ni	ni	ni	ni	ni
BP28	Groundwater bore	33° 57' 16.44"S	115° 40' 49.77"E	378077	6242097	GL	96.5	347	52	52	120	ni	ni	ni	ni	ni	ni

									Formation top (m MD)								
Well name	*Hole type*	*Latitude*	*Longitude*	*Easting (MGA Zone 50)*	*Northing (MGA Zone 50)*	*Elevation reference*	*Elevation (m AHD)*	*Total depth (m)*	*breakup unconformity*	*Top Parmelia Group*	*Top Yarragadee Formation*	*Top Cattamarra Coal Measures*	*Top Eneabba Formation*	*Top Wonnerup Member*	*Top Sabina Sandstone*	*Top Sue Group*	*Top basement*
BP44B	Groundwater bore	33° 59' 7.12"S	115° 35' 20.9"E	369683	6238576	TOC	103.8	207	66	66	157	ni	ni	ni	ni	ni	ni
BP67A	Groundwater bore	34° 4' 16.04"S	115° 19' 23.25"E	345265	6228689	GL	77.2	350	46	46	–	–	–	168	ni	ni	ni
BPL1	Groundwater bore	33° 8' 47"S	115° 41' 54.01"E	378601	6331730	GL	2.0	810	195	–	–	195	744	ni	ni	ni	ni
BPL2	Groundwater bore	33° 8' 54"S	115° 44' 34.01"E	382749	6331565	TOC	16.1	780	160	–	–	160	ni	ni	ni	ni	ni
BPL3	Groundwater bore	33° 9' 32.99"S	115° 48' 27.01"E	388799	6330435	TOC	13.5	801	139	–	–	–	139	ni	ni	ni	ni
BPL4	Groundwater bore	33° 9' 39"S	115° 51' 14.01"E	393127	6330298	GL	14.9	803	98	–	–	98	284	ni	ni	ni	ni
Canebreak 1	Petroleum well	34° 16' 57.44"S	115° 28' 11.15"E	359150	6205447	KB	30.7	2098	118	–	118	220	360	842	f.o.	1709	ni
Challenger 1	Petroleum well	32° 25' 14.89"S	115° 0' 46.41"E	313153	6411182	KB	10.0	2248	1429	1429	1907	ni	ni	ni	ni	ni	ni
Chapman Hill 1	Petroleum well	33° 46' 15.97"S	115° 18' 54.1"E	343972	6261948	KB	36.5	1354	147	147	239	438	952	ni	ni	ni	ni
CL1	Groundwater bore	33° 52' 5.01"S	115° 12' 30.01"E	334278	6251029	GL	93.7	501	190	–	–	–	–	–	–	190	ni
CL2	Groundwater bore	33° 51' 44.99"S	115° 15' 36.01"E	339047	6251728	GL	144.6	763	250	–	–	–	–	–	–	250	ni
CL4	Groundwater bore	33° 52' 18.89"S	115° 24' 14.99"E	352400	6250900	GL	134.3	1075	156	–	156	~385	868	ni	ni	ni	ni
CL5	Groundwater bore	33° 52' 12.65"S	115° 28' 51.43"E	359500	6251200	GL	178.1	1504	191	–	191	802	1304	ni	ni	ni	ni
CL6	Groundwater bore	33° 52' 5"S	115° 33' 26.02"E	366552	6251537	GL	116.0	1497	120	120	250	1215	ni	ni	ni	ni	ni
CL7	Groundwater bore	33° 52' 14.99"S	115° 38' 4.01"E	373699	6251327	GL	110.5	1671	97	97	180	1306	ni	ni	ni	ni	ni
CL8	Groundwater bore	33° 52' 11.66"S	115° 43' 4.41"E	381416	6251529	GL	155.3	1448	192	192	237	ni	ni	ni	ni	ni	ni
Cockburn 1	Petroleum well	32° 8' 1.62"S	115° 44' 17.34"E	380981	6444038	KB	7.3	3054	304	–	304	1919	ni	ni	ni	ni	ni
CRCH1	Coal exploration drillhole	33° 45' 45.7"S	115° 11' 0.45"E	331770	6262673	GL	43.0	567	201	–	–	–	–	–	–	201	568
CRCH3	Coal exploration drillhole	33° 42' 37.2"S	115° 11' 56.03"E	333099	6268505	KB	29.5	848	118	–	–	–	–	–	–	118	ni
CYCH1	Coal exploration drillhole	33° 54' 57"S	115° 42' 51.49"E	381148	6246432	GL	152.3	357	227	227	300	ni	ni	ni	ni	ni	ni
DDH-2	Coal exploration drillhole	33° 52' 13.21"S	115° 15' 11.75"E	338438	6250848	GL	133.0	198	200	–	–	–	–	–	–	–	200
Delroys Bore	Groundwater bore	33° 31' 16.36"S	115° 33' 33.2"E	366200	6290000	GL	0.0	159	51	51	90	ni	ni	ni	ni	ni	ni
Donnelly River DR2	Coal exploration drillhole	34° 27' 36.19"S	115° 44' 38.31"E	384634	6186117	GL	22.0	150	28	–	28	ni	ni	ni	ni	ni	ni
Eaton No 3	Groundwater bore	33° 18' 52.42"S	115° 42' 26.09"E	379663	6313094	GL	2.6	518	179	–	179	ni	ni	ni	ni	ni	ni
Felix 1	Petroleum well	32° 44' 45.25"S	114° 50' 44.7"E	298164	6374829	KB	25.9	1020	927	–	927?	–	–	–	–	955	ni
Harvey 1	CO^2 sequestration project bore	32° 59' 30.73"S	115° 46' 28.09"E	385502	6348948	KB	24.0	3000	250	–	–	–	250	1378	2897	ni	ni
Harvey 2	CO^2 sequestration project bore	33° 0' 31.77"S	115° 50' 39.7"E	392053	6347142	KB	16.0	1351	133	–	–	–	133	1242	ni	ni	ni
HL1B	Groundwater bore	32° 54' 52"S	115° 42' 9.01"E	378672	6357451	KB	2.3	605	194	–	–	–	194	ni	ni	ni	ni
HL2A	Groundwater bore	32° 55' 13"S	115° 46' 10"E	384940	6356879	KB	13.7	810	256	–	–	–	256	ni	ni	ni	ni
HL3A	Groundwater bore	32° 54' 33.01"S	115° 49' 52.99"E	390718	6358177	GL	12.8	603	204	–	–	–	204	ni	ni	ni	ni
HL4A	Groundwater bore	32° 53' 57"S	115° 54' 26.01"E	397799	6359362	KB	33.5	600	57	–	–	–	57	ni	ni	ni	ni
JE7A	Groundwater bore	32° 8' 52.28"S	115° 51' 2.3"E	391608	6442597	KB	26.4	855	467	–	467	ni	ni	ni	ni	ni	ni
KE1D	Groundwater bore	33° 14' 31.01"S	115° 47' 54.99"E	388075	6321247	KB	17.5	474	158	–	–	158	ni	ni	ni	ni	ni
KE2D	Groundwater bore	33° 12' 38.64"S	115° 42' 44.62"E	380000	6324612	GL	2.9	501	138	–	–	138	ni	ni	ni	ni	ni
KEMC1	Groundwater bore	33° 13' 20.46"S	115° 45' 50.09"E	384817	6323382	GL	11.8	209	136.5	–	–	136.5	ni	ni	ni	ni	ni
KEMC2	Groundwater bore	33° 11' 16.23"S	115° 45' 55.93"E	384923	6327210	GL	14.2	223	107	–	–	107	ni	ni	ni	ni	ni

Well name	Hole type	Latitude	Longitude	Easting (MGA Zone 50)	Northing (MGA Zone 50)	Elevation reference	Elevation (m AHD)	Total depth (m)	Formation top (m MD)								
									breakup unconformity	Top Parmelia Group	Top Yarragadee Formation	Top Cattamarra Coal Measures	Top Eneabba Formation	Top Wonnerup Member	Top Sabina Sandstone	Top Sue Group	Top basement
KL1A	Groundwater bore	34° 9' 55.99"S	115° 11' 7.99"E	332755	6218000	KB	13.8	656	86	–	–	–	–	86	139	200	ni
KL4A	Groundwater bore	34° 9' 47.16"S	115° 27' 45"E	358281	6218692	KB	85.1	1207	137	137	235	835	ni	ni	ni	ni	ni
KL5A	Groundwater bore	34° 10' 1.94"S	115° 31' 50.16"E	364565	6218329	KB	61.0	1165	45	–	45	390	667	ni	ni	ni	ni
KL6A	Groundwater bore	34° 10' 55.79"S	115° 37' 20.2"E	373038	6216788	GL	111.8	1605	63	63	127	977	1423	ni	ni	ni	ni
KL7A	Groundwater bore	34° 11' 17.88"S	115° 43' 15.96"E	382154	6216226	GL	121.5	1682	263	263	384	ni	ni	ni	ni	ni	ni
Lake Preston 1	Petroleum well	32° 55' 12.46"S	115° 39' 38.85"E	374779	6356772	KB	10.2	4572	112	–	–	112	450	2046	3315	4035	ni
Laporte No 3	Groundwater bore	33° 16' 14.99"S	115° 44' 29.98"E	382808	6317982	KB	13.0	322	~175	–	~175	ni	ni	ni	ni	ni	ni
MPL1A	Groundwater bore	32° 41' 46.8"S	115° 38' 19.39"E	372396	6381558	TOC	7.5	354	ni	ni	ni	ni	ni	ni	ni	ni	ni
MPL2A	Groundwater bore	32° 41' 5.73"S	115° 44' 52.93"E	382629	6382949	GL	4.1	366	193.5	–	–	193.5	ni	ni	ni	ni	ni
MPL3A	Groundwater bore	32° 40' 52.96"S	115° 51' 48.98"E	393460	6383464	GL	14.9	192	137	–	–	–	137	ni	ni	ni	ni
MPL4A	Groundwater bore	32° 45' 7.95"S	115° 47' 39.74"E	387058	6375540	KB	13.3	253	101	–	–	–	101	ni	ni	ni	ni
MPL5A	Groundwater bore	32° 44' 57.59"S	115° 54' 38.84"E	397961	6375977	KB	26.3	300	70	–	–	70	195	ni	ni	ni	ni
MPL6A	Groundwater bore	32° 48' 51.45"S	115° 41' 16.11"E	377160	6368538	GL	7.3	288	245–288	–	–	245–288	ni	ni	ni	ni	ni
MPL7A	Groundwater bore	32° 47' 54.95"S	115° 53' 5.78"E	395597	6370490	KB	23.2	210	90	–	–	–	90	ni	ni	ni	ni
MR1/10	Groundwater bore	33° 55' 39.68"S	115° 20' 58.21"E	347443	6244635	GL	139.2	849	329	–	329	ni	ni	ni	ni	ni	ni
Parmelia 1	Petroleum well	32° 18' 5.09"S	115° 4' 37.84"E	318961	6424530	KB	21.0	1770	1469	1469	ni	ni	ni	ni	ni	ni	ni
Peel 1	Petroleum well	32° 15' 52.85"S	115° 26' 33.67"E	353320	6429162	KB	30.0	3714	1625	1625	3551	ni	ni	ni	ni	ni	ni
Pinjarra 1	Petroleum well	32° 40' 33.6"S	115° 46' 15.6"E	384770	6383964	KB	5.5	4574	148	–	–	148	354	3185	ni	ni	ni
PL1A	Groundwater bore	33° 21' 9.01"S	115° 41' 45.01"E	378653	6308874	GL	7.6	1200	280	–	280	540	ni	ni	ni	ni	ni
PL3A	Groundwater bore	33° 21' 5"S	115° 45' 25"E	384338	6309067	GL	18.0	794	200	–	–	200	ni	ni	ni	ni	ni
Preston 1	Petroleum well	32° 56' 53"S	115° 42' 33"E	379341	6353732	KB	7.6	767	190	–	–	–	190	ni	ni	ni	ni
Quindalup 1	Groundwater bore	33° 39' 32.07"S	115° 17' 42.96"E	341936	6274359	GL	3.1	588	83	–	–	83 or eroded	83?	ni	ni	ni	ni
Quindalup 2	Groundwater bore	33° 39' 25.03"S	115° 14' 3.29"E	336274	6274481	GL	3.7	551	110	–	–	–	–	–	–	110	ni
Quindalup 3	Groundwater bore	33° 38' 37.48"S	115° 10' 29.85"E	330750	6275850	GL	3.7	453	216	–	–	–	–	–	–	216	ni
Quindalup 4	Groundwater bore	33° 38' 13.56"S	115° 25' 59.91"E	354700	6276980	GL	5.0	585	81	–	81	ni	ni	ni	ni	ni	ni
Quindalup 5	Groundwater bore	33° 38' 38.55"S	115° 30' 21.86"E	361460	6276310	GL	20.0	613	72	–	72	ni	ni	ni	ni	ni	ni
Quindalup 6	Groundwater bore	33° 38' 54.99"S	115° 35' 7.01"E	368813	6275907	GL	42.4	1118	104	–	104	1083	ni	ni	ni	ni	ni
Quindalup 7	Groundwater bore	33° 39' 6.29"S	115° 38' 37.6"E	374380	6275766	GL	100.8	1049	144	–	144	ni	ni	ni	ni	ni	ni
Quindalup 8	Groundwater bore	33° 39' 16.17"S	115° 42' 10.44"E	379870	6275528	GL	59.0	1160	255	–	255	ni	ni	ni	ni	ni	ni
Quindalup 9	Groundwater bore	33° 39' 4.28"S	115° 46' 53.74"E	387022	6275853	GL	96.1	1469	354	–	354	ni	ni	ni	ni	ni	ni
Rockingham 1	Petroleum well	32° 17' 33.62"S	115° 53' 26.65"E	395556	6426583	KB	15.8	1565	270	–	270	855	ni	ni	ni	ni	ni
RS1A	Groundwater bore	34° 4' 21.62"S	115° 10' 13.8"E	331183	6228276	KB	62.3	331	163	–	–	–	–	–	163	ni	ni
RS2A	Groundwater bore	34° 2' 17"S	115° 12' 34.79"E	334730	6232179	KB	45.5	353	47	47	–	–	–	214	ni	ni	ni
Sabina River 1	Petroleum well	33° 39' 53.38"S	115° 24' 40.34"E	352697	6273874	KB	13.2	4297	150	–	150	648	1004	2230	3432	3914	ni
SC1A	Groundwater bore	34° 5' 41.86"S	115° 12' 59.31"E	335469	6225879	GL	13.0	301	97	–	–	–	–	97	156	179	ni
SC2A	Groundwater bore	34° 13' 26.01"S	115° 10' 58.99"E	332640	6211526	KB	13.0	152	110	–	–	–	–	–	110?	ni	ni
SC5A	Groundwater bore	34° 14' 59.43"S	115° 16' 8.23"E	340602	6208786	GL	18.5	262	36	–	–	–	–	36	197	258	ni
SC9A	Groundwater bore	34° 14' 46.62"S	115° 20' 36.53"E	347459	6209295	KB	21.4	504	87	–	–	–	87	ni	ni	ni	ni

Well name	Hole type	Latitude	Longitude	Easting (MGA Zone 50)	Northing (MGA Zone 50)	Elevation reference	Elevation (m AHD)	Total depth (m)	Formation top (m MD)								
									breakup unconformity	Top Parmelia Group	Top Yarragadee Formation	Top Cattamarra Coal Measures	Top Eneabba Formation	Top Wonnerup Member	Top Sabina Sandstone	Top Sue Group	Top basement
SC10A	Groundwater bore	34° 17' 44.83"S	115° 20' 33.93"E	347482	6203804	KB	16.6	303	102	–	–	–	102	ni	ni	ni	ni
SC11A	Groundwater bore	34° 6' 28.45"S	115° 28' 14.17"E	358936	6224824	GL	54.5	201	99	99	130	ni	ni	ni	ni	ni	ni
SC12A	Groundwater bore	34° 12' 44.55"S	115° 27' 2.91"E	357286	6213211	KB	46.5	203	44	44	105	ni	ni	ni	ni	ni	ni
SC13A	Groundwater bore	34° 15' 54.89"SS	115° 25' 57.09"E	355700	6207300	GL	22.9	269	~105	–	~105	ni	ni	ni	ni	ni	ni
Scott River 1	Petroleum well	34° 15' 54.73"S	115° 20' 13.35"E	346900	6207187	KB	26.8	2370	~120	–	–	–	~120	403	1320	1801	ni
Sue 1	Petroleum well	34° 3' 52.82"S	115° 19' 23.88"E	345270	6229405	KB	86.9	3074	34	34	–	–	–	169	878	1216	3054
Sugarloaf 1	Petroleum well	32° 54' 53.58"S	115° 3' 38.33"E	318646	6356481	KB	30.2	3646	710	710	2143	ni	ni	ni	ni	ni	ni
South West Yarragadee 1/03	Groundwater bore	34° 1' 18.87"S	115° 27' 48.92"E	358146	6234351	GL	45.4	680	80	–	80	598	ni	ni	ni	ni	ni
VCH1	Coal exploration drillhole	33° 42' 14.69"S	115° 16' 9.98"E	339625	6269310	GL	10.1	320	85	–	–	–	85	ni	ni	ni	ni
Warnbro 1	Petroleum well	32° 14' 20.28"S	115° 21' 3.06"E	344625	6431883	KB	25.0	3660	2204	2204	2982	ni	ni	ni	ni	ni	ni
Waroona Junior High School 3	Groundwater bore	32° 50' 42.1"S	115° 55' 46.33"E	399825	6365385	KB	58.0	230	15	–	–	–	15	ni	ni	ni	ni
Whicher Range 1	Petroleum well	33° 50' 7.99"S	115° 22' 28.03"E	349588	6254889	KB	153.2	4658	191	–	191	458	939	2246	3486	3916	ni
Whicher Range 3	Petroleum well	33° 52' 15.02"S	115° 23' 39.25"E	351480	6251005	KB	137.6	4500	140	–	140	478	793	2208	3515	4017	ni
Wonnerup 1	Petroleum well	33° 37' 55.1"S	115° 28' 16.15"E	358202	6277601	KB	24.4	4725	~80	–	~80	850	1164	2370	3644	4104	ni
Woodmans Pt Strat No. 3	Stratigraphic hole	32° 6' 43.59"S	115° 58' 14.24"E	402886	6446674	GL	17.2	620	357	–	357	ni	ni	ni	ni	ni	ni

Water bore prefixes:

AM	Artesian monitoring
BN**Y	Busselton–Capel Yarragadee
BP	Blackwood Plateau
BPL	Binningup Line
CL	Cowaramup Line
HL	Harvey Line
KE*D	Kemerton Deep
KEML	Kemerton–Wellesley
KL	Karridale Line
MPL	Murray–Peel Leederville
MR	Molloy Road
PL	Picton Line
RS	SW Lesueur
SC	Scott Coastal

Notes:

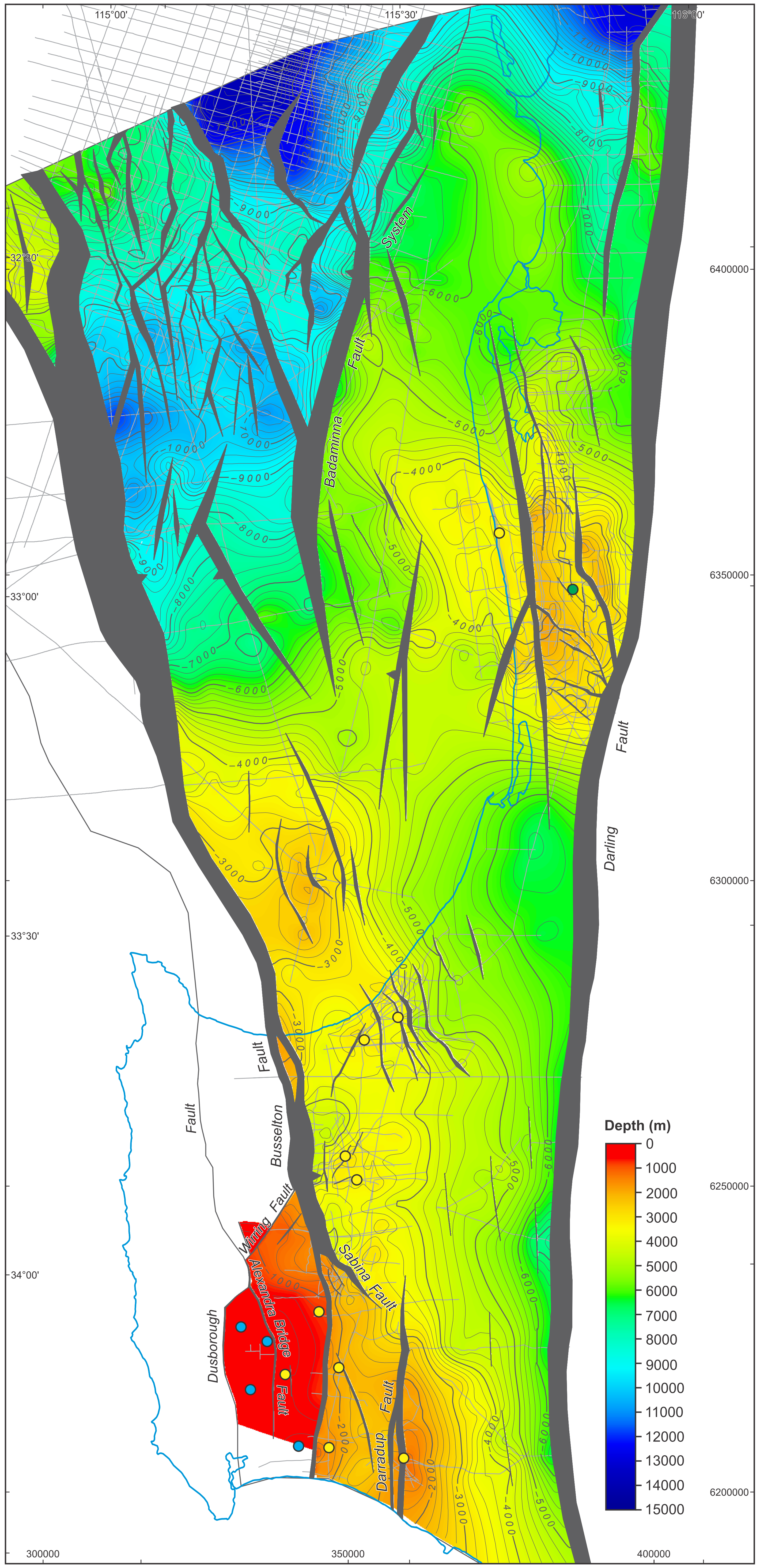
TOC	Top of casing (typically <1 m above ground level)
GL	Ground level
KB	Kelly bushing
f.o.	Faulted out
ni	Not intersected
–	Not present or not identified

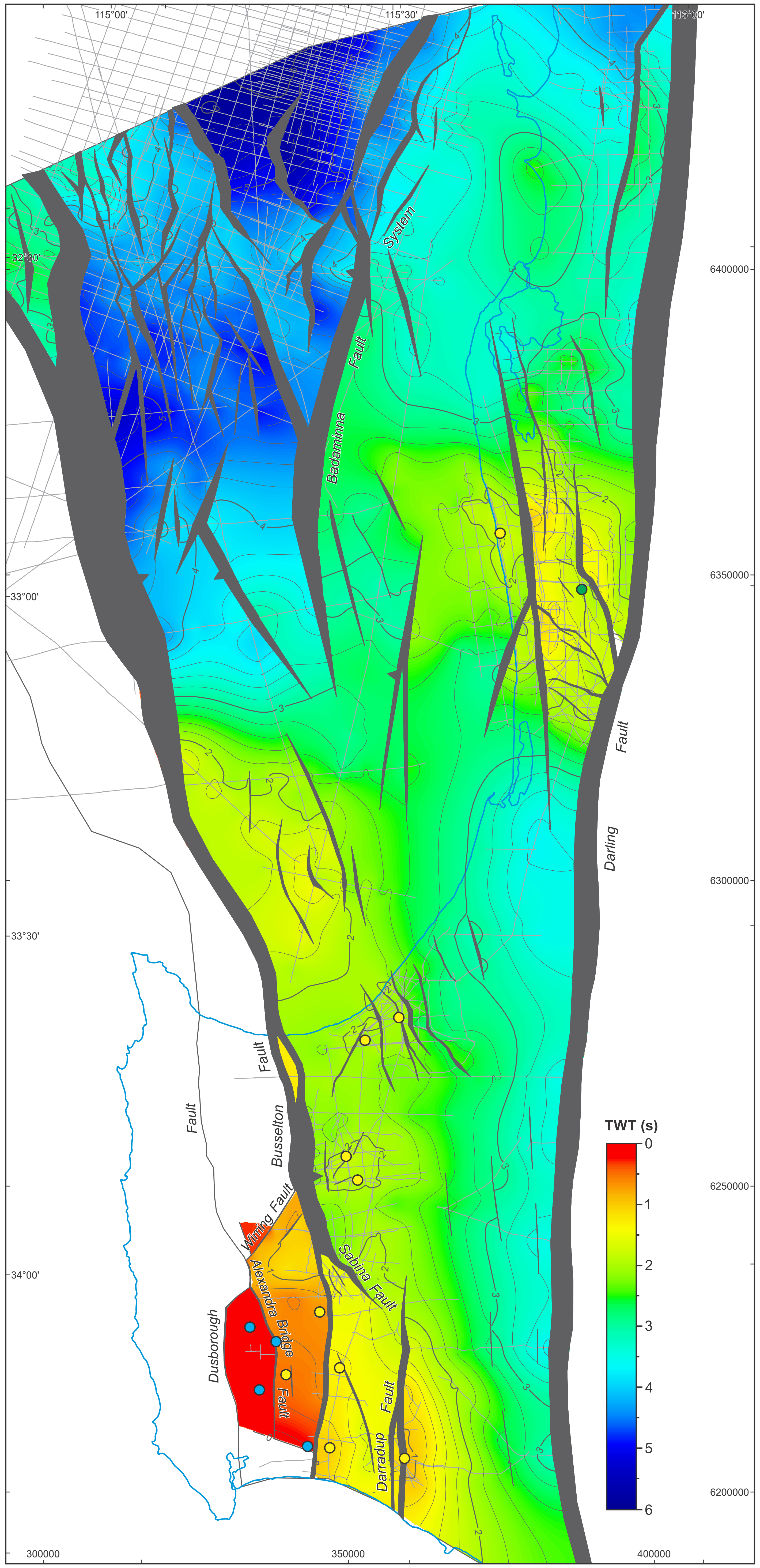
Appendix 2

Inventory of seismic data used in interpretation

Survey	*Line prefix*	*Source*	*Acquisition year*	*Acquisition*	*Available SEGY processing/reprocessing*
Blackwood SS	B65-	Dynamite	1965	GSI and UGC for WAPET	Post-trace reconstruction processing by CGGVeritas for GSWA (2011) from transcribed original scanned section
Rockingham 2 Detail SS	P75-	Vibroseis	1975	Petty-Ray Geophysical for WAPET	Trace reconstruction by CGGVeritas for GSWA (2009) from 1975 transcribed original scanned section by Chevron Oil
Ambergate SS	A81-	Vibroseis	1980	SSL	Reprocessed by Simon-Horizon Australia (1991)
Altona 2D SS	AA2K-	Vibroseis	2000	Terracorp for Amity Oil NL	Processed by Robertson Research Australia
Wonnerup–Flinders SS	WF69-	Dynamite	1969	GSI for Union Oil Development	Reprocessed by Simon-Horizon Australia for Arrow Petroleum (1991)
					Post-trace reconstruction processing by Spectrum ASB for ERM Power from transcribed original scanned section
Chapman Hill SS	D91-	Vibroseis	1991	Geo Systems for Discovery Petroleum	Processed by Digital Exploration, Digicon
Margaret River SS	MR68-	Dynamite	1968	GSI for Union Oil Development	Reprocessed by CGGVeritas for DMP (now DMIRS) (2011) from transcribed original processing
Happy Valley SS	P81-	Vibroseis	1981	Horizon	Reprocessed 1996 by Robertson Research for Amity Oil
					Post-trace reconstruction processing by CGGVeritas for GSWA (2011) from transcribed original scanned section
					Reprocessed by Simon-Horizon Australia (1990) for Petroz
Canebreak SS	P82-	Vibroseis	1982	Horizon Energy for Weaver Oil & Gas	Reprocessed 1996 by Robertson Research for Amity Oil
Tuart SS	AT97-	Vibroseis	1997	Terracorp for Amity Oil NL	Processed by Robertson Research Australia
Terrace SS	AT98-	Vibroseis	1998	Terracorp for Amity Oil NL	Processed by Robertson Research Australia
Stirling Rapids SS	80A- or 80B-	Vibroseis	1980	United Geophysical Corp	Reprocessed by Velseis for GSWA 2014
					Reprocessed 1991 by Simon-Horizon Australia for Arrow Petroleum
GSWA Lower Lesueur 2011 SS	11GA	Vibroseis	2011	Terrex for DMP/Geoscience Australia	Processed 2011 by Velseis for Geoscience Australia/DMP (now DMIRS)
Harvey SS	H69-	Dynamite	1969	GSI for WAPET	Trace reconstruction 2009 by CGGVeritas for DMP (now DMIRS) from transcribed original scanned section
Wellesley SS	EW08-	Vibroseis	2008	Terrex for Empire Oil	Processed by CGGVeritas (2008)
Korijekup SS	P91-	Vibroseis	1991	Geo Systems for Petroz NL	Processed by Simon-Horizon Australia (1991) for Petroz
Preston D1 Detail SS	PD71-	Dynamite	1971	GSI for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Preston Detail SS	PD70	Dynamite	1970	Austral for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Harvey D1 SS	HD69-	Dynamite	1969	GSI for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Karnup Reconnaissance SS	KR66	Dynamite	1966	GSI and UGC for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
					Post-trace reconstruction processing by Geoexindo for ASB
Charla SS	C66-	Dynamite	1966	GSI for WAPET	Reprocessed by Velseis for GSWA (2014)
Pinjarra Detail SS	PD65-	Dynamite	1965	GSI for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Lake Preston SS	LP64-	Dynamite	1964	GSI for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Pinjarra Reconnaissance SS	PR64-	Dynamite	1964	GSI for WAPET	Reprocessed by Simon-Horizon Australia (1990) for Petroz
Rockingham SS	P72-	Vibroseis	1972	GSI for WAPET	Trace reconstruction by CGGVeritas from GSI 1973 original processing
Medina 1981 SS	P81-	Vibroseis	1981	SSL for Phoenix Oil & Gas	Trace reconstruction by CGGVeritas from GSI 1981 original processing
Medina 1982 SS	P82-	Vibroseis	1982	Horizon Energy for Phoenix Oil & Gas	Trace reconstruction by CGGVeritas from Hosking Gephysical 1982 original processing
Coogee Detail SS	CD66-	Dynamite	1966	GSI for WAPET	Trace reconstruction by CGGVeritas from GSI 1966 original processing
Preston Detail MSS	PD71-	Aquaflex/Airgun	1971	GSI for WAPET	Reprocessed by CGGVeritas for GSWA (2013)

Survey	*Line prefix*	*Source*	*Acquisition year*	*Acquisition*	*Available SEGY processing/reprocessing*
PV91 MSS	PV91-	Airgun	1991	WesternGeCo for Petrofina Exploration	Reprocessed 2008 by Fugro Seismic for Roc Oil
Southwest Frontiers S280 (Bremer 2D) MSS	S280-	Airgun	2004	Veritas DGC for Geoscience Australia	Processed 2005 by Veritas DGC for Geoscience Australia
V82A MSS	V82A-	Airgun	1982	GSI for Esso	Reprocessed 2004 by Robertson Research for Geoscience Australia
					Reprocessed 2008 by Fugro Seismic for Roc Oil
WA-174-P 1982 MSS	W82-	Airgun	1982	Western Geophysical for BP Australia	Reprocessed 2004 by Robertson Research for Geoscience Australia
					Reprocessed 1992 by Simon-Horizon for Woodside Petroleum
					Reprocessed 1991 by Digital Exploration Ltd for Petrofina Exploration
WA-174-P 1983 MSS	W83-	Airgun	1983	GSI for BP Australia	Reprocessed 2008 by Fugro Seismic for Roc Oil
AGSO Survey 81; South Perth Basin II MSS	81R-	Airgun	1988	AGSO	Reprocessed 2004 by WesternGeco for Geoscience Australia
Naturaliste 1993 MSS	93-	Airgun	1993	WesternGeco for Woodside Offshore Petroleum	Reprocessed 2004 by Robertson Research for Geoscience Australia
V83A MSS	V83A-	Airgun	1983	GSI for Esso	Reprocessed 2008 by Fugro Seismic for Roc Oil
Geoscience Australia South West Margin 2D Geoscience Australia310 MSS	s310-	Airgun	2009	CGGVeritas for Geoscience Australia	Processed 2009 by Fugro for Geoscience Australia
2013 Harvey Waroona 3D SS		Vibroseis	2012	Geokinetics for Geoscience Australia	Processed 2014 by Velseis for DMP (now DMIRS) and Geoscience Australia





Petroleum or stratigraphic well
Water bore
CO_2 sequestration project bore
2 Contour
Coastline
Seismic line
Fault

0 25 50
Kilometres

Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
MGA Zone 50

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**
HON. BILL JOHNSTON MLA
MINISTER FOR MINES AND PETROLEUM

Geological Survey of Western Australia
JEFF HAWORTH, EXECUTIVE DIRECTOR
GEOLOGICAL SURVEY AND RESOURCE STRATEGY

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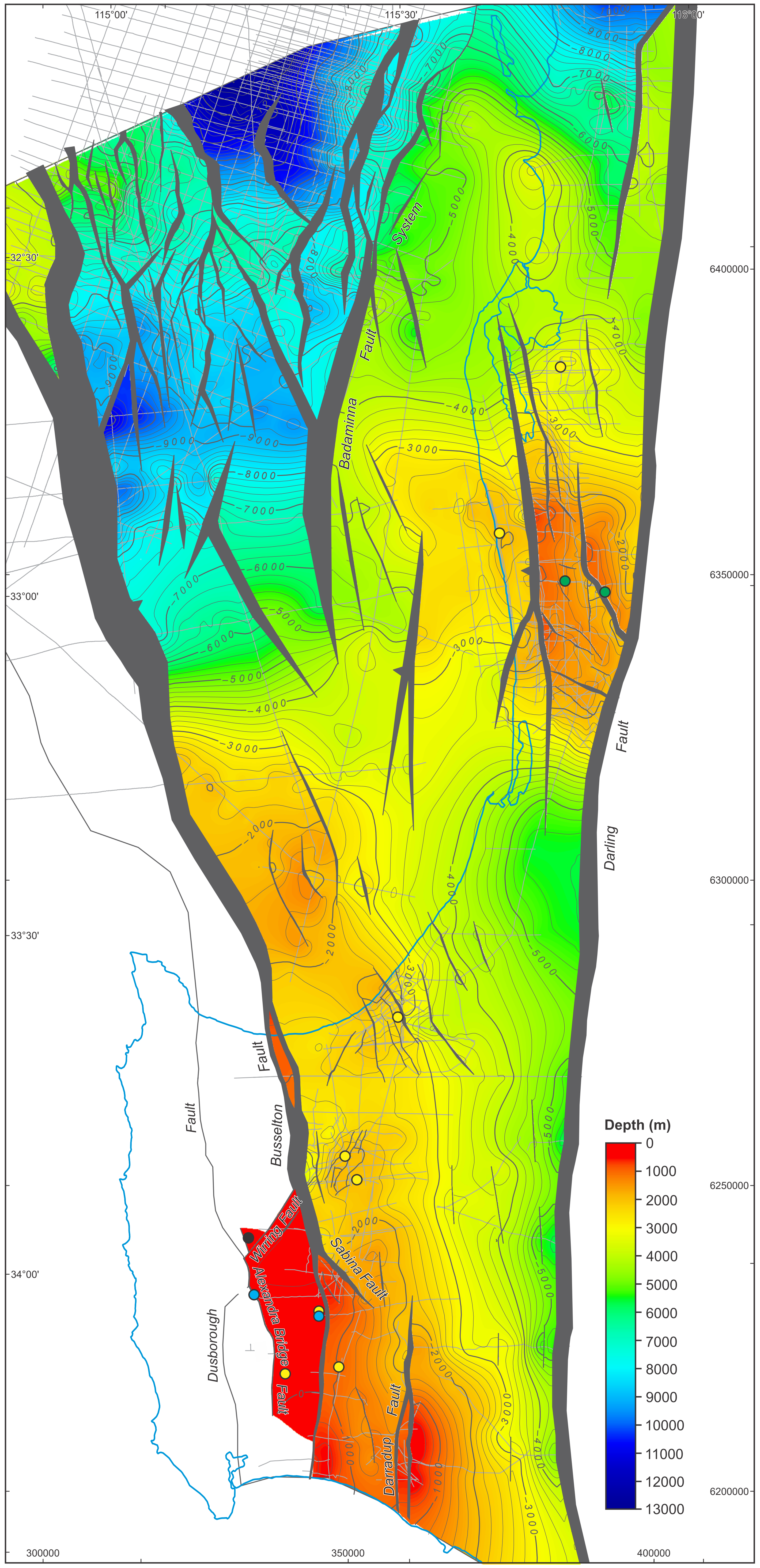
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

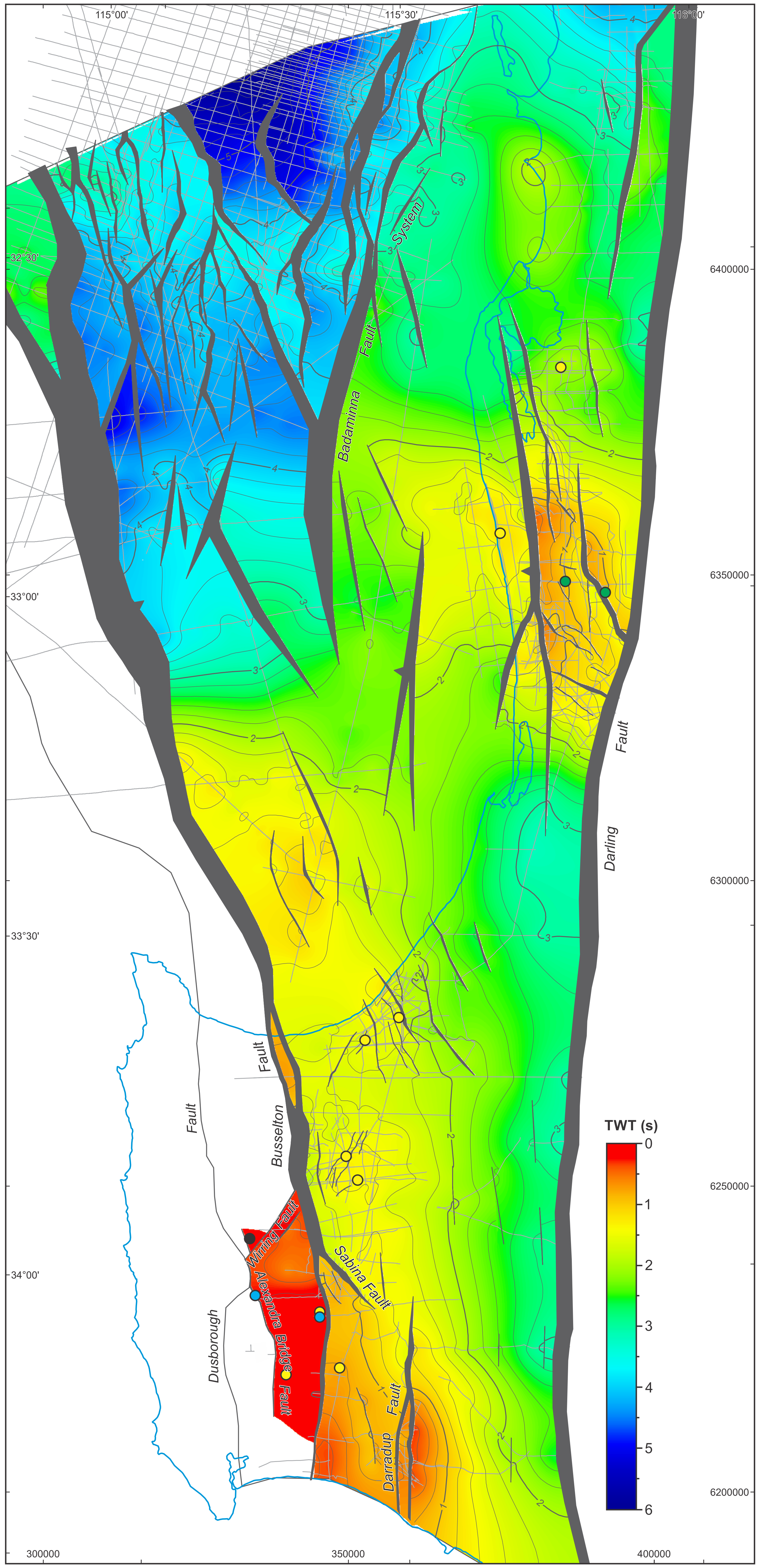
REPORT 184 PLATE 1

SOUTHERN PERTH BASIN

DEPTH AND TWO WAY TIME TO TOP OF SABINA SANDSTONE

October 2018





- Petroleum or stratigraphic well
- Water bore
- CO_2 sequestration project bore
- 2 Contour
- Coastline
- Seismic line
- Fault

0 25 50
Kilometres

Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
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Department of Mines, Industry Regulation and Safety
HON. BILL JOHNSTON MLA
MINISTER FOR MINES AND PETROLEUM

Geological Survey of Western Australia
JEFF HAWORTH, EXECUTIVE DIRECTOR
GEOLOGICAL SURVEY AND RESOURCE STRATEGY

Compiled by C Thomas, 2018
Edited by S White
Cartography by A Symonds

Published by the Geological Survey of Western Australia. A PDF of this plate can be downloaded free from the GSWA eBookshop <www.dmp.wa.gov.au/GSWApublications>.

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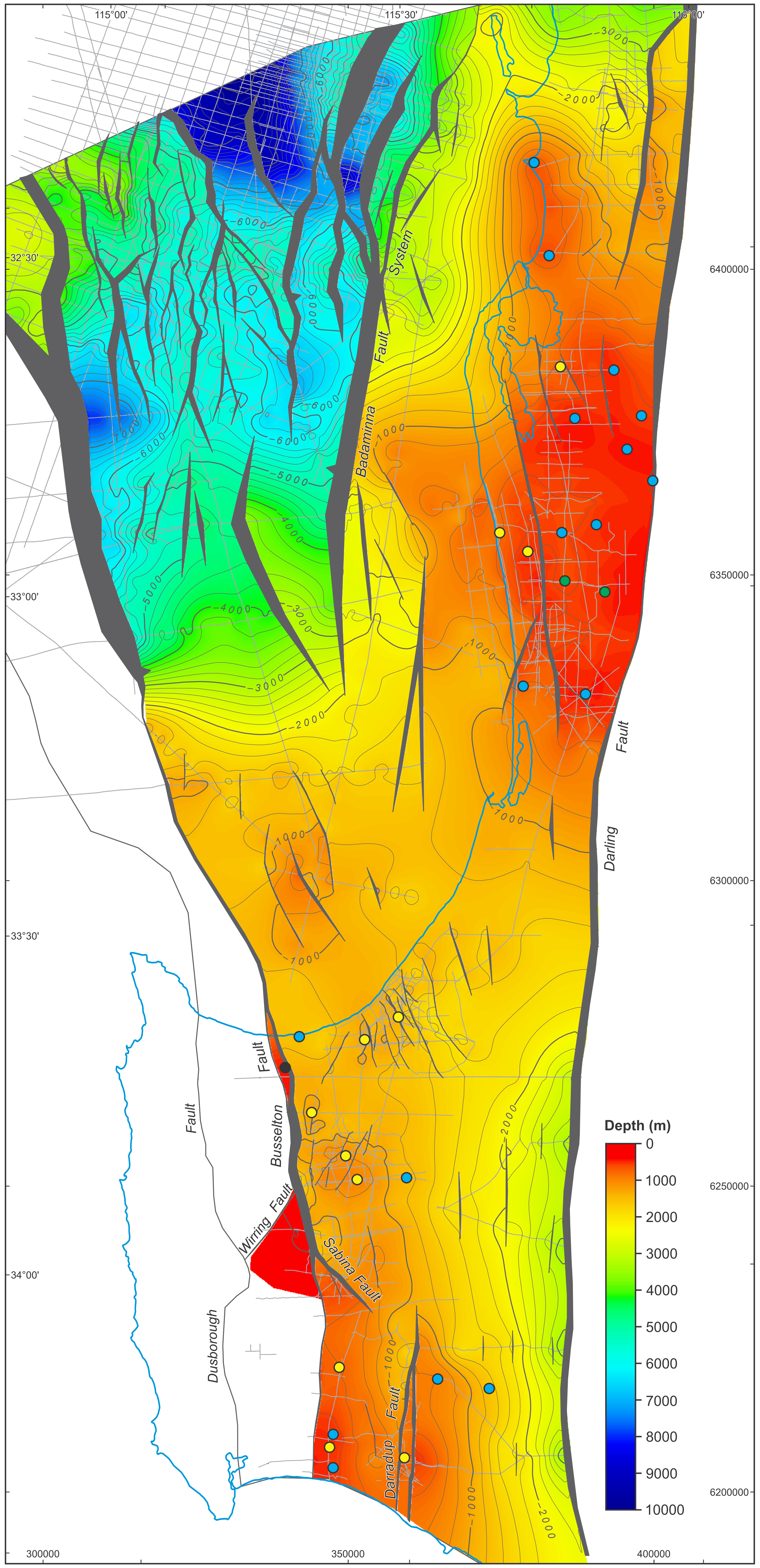
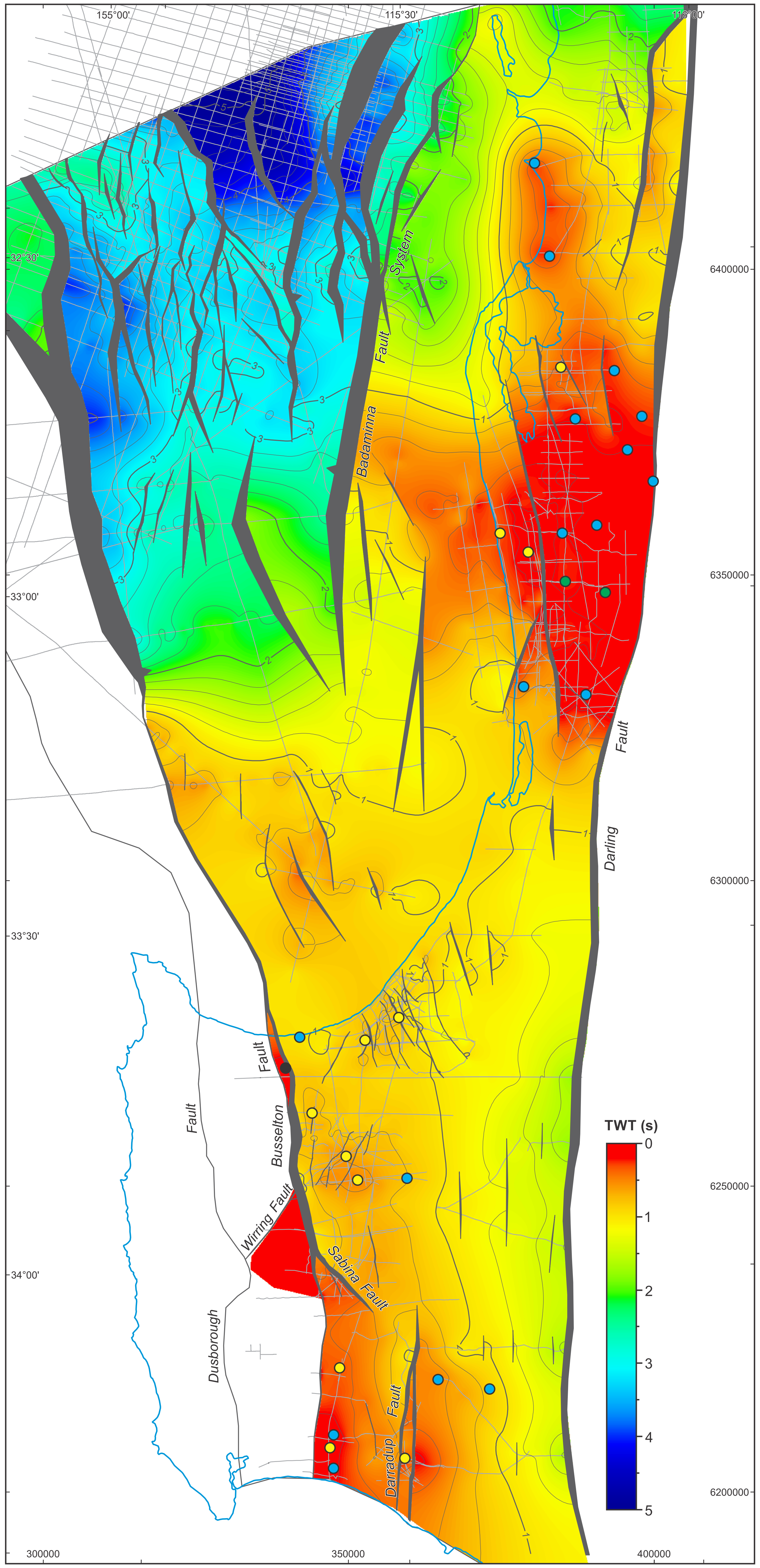
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 2

SOUTHERN PERTH BASIN
DEPTH AND TWO WAY TIME TO TOP OF WONNERUP MEMBER

October 2018





- Petroleum or stratigraphic well
- Water bore
- CO_2 sequestration project bore
- 2 Contour
- Coastline
- Seismic line
- Fault

0 25 50

Kilometres

Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
MGA Zone 50

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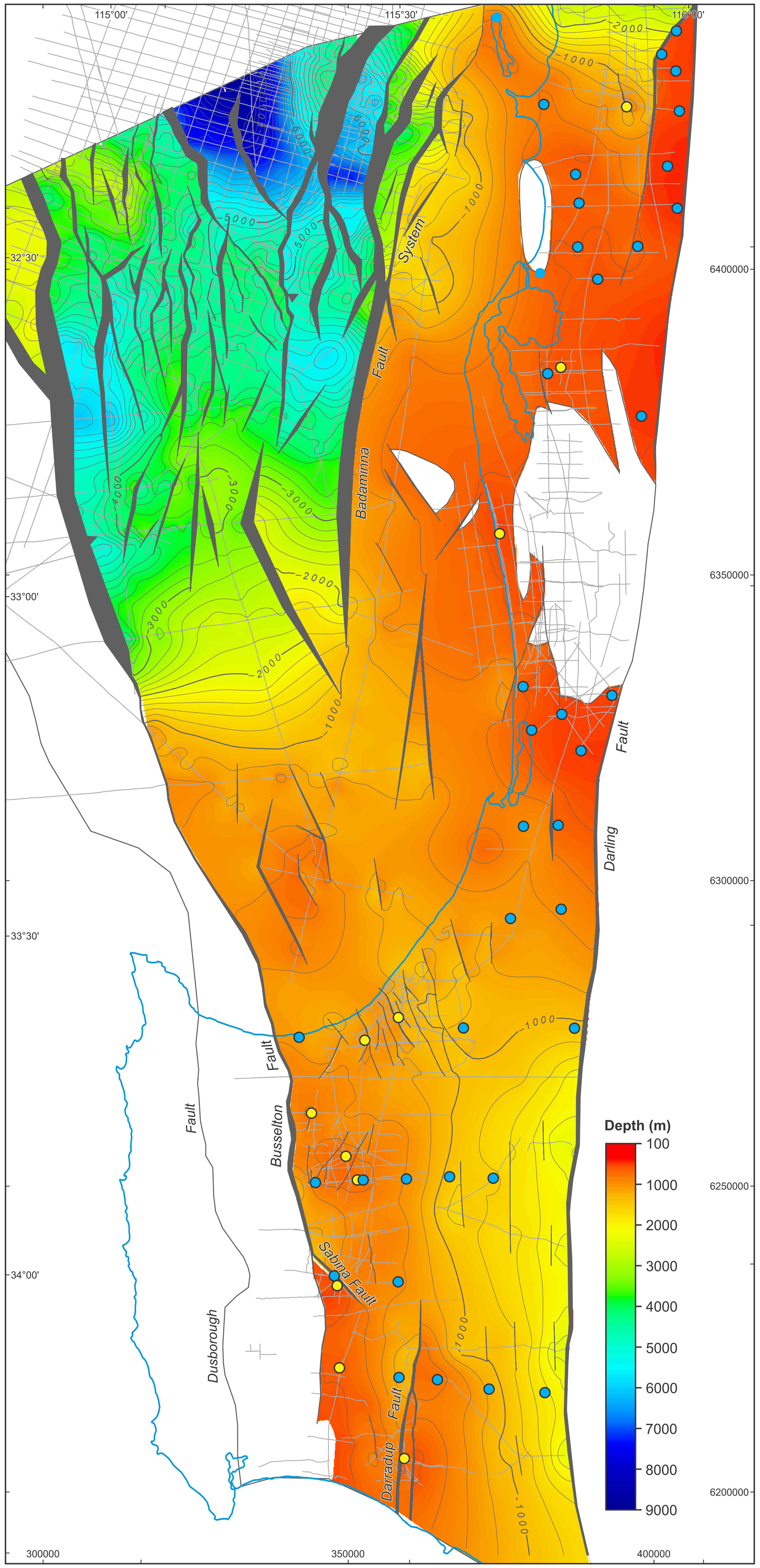
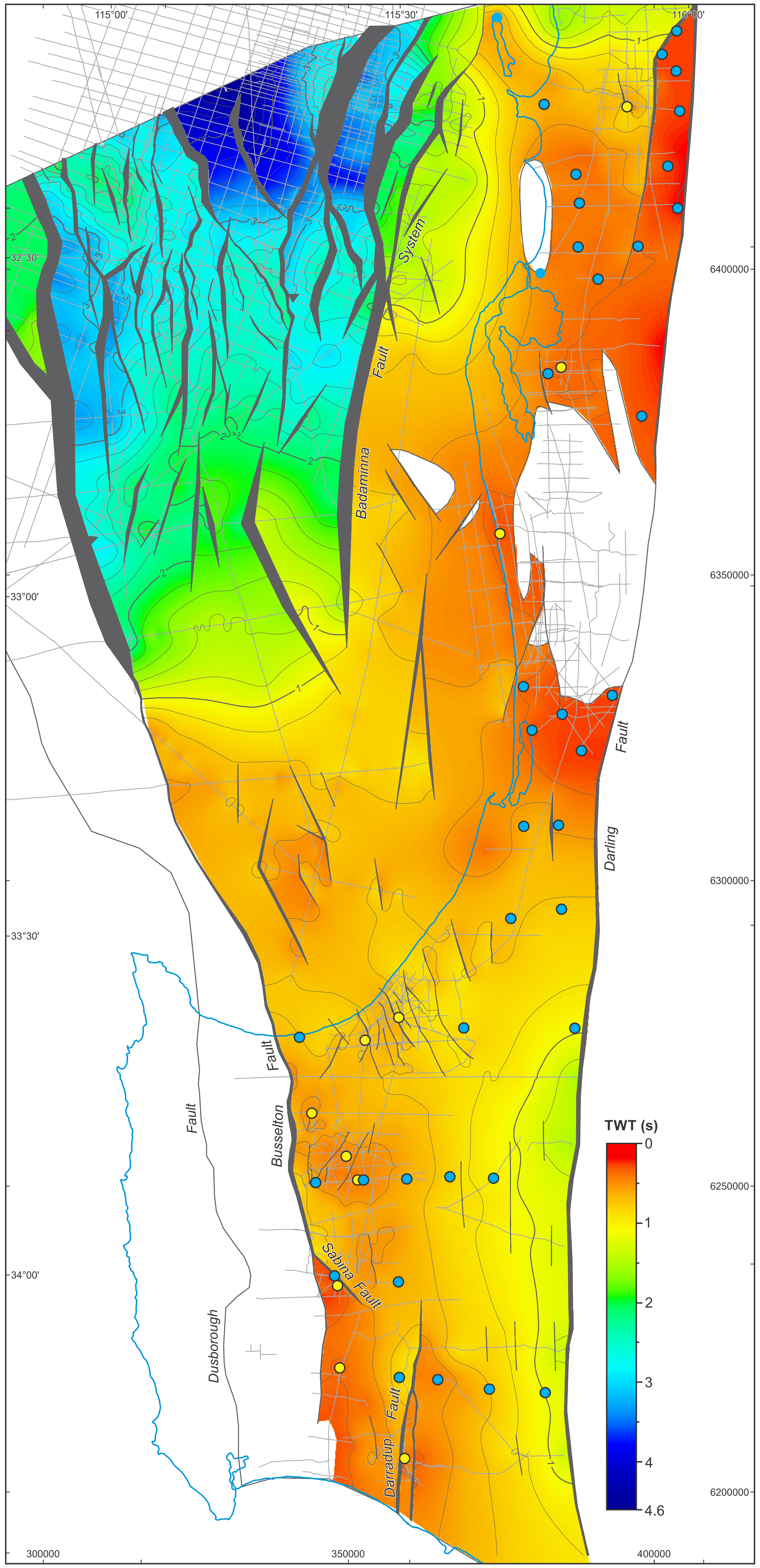
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 3

SOUTHERN PERTH BASIN
DEPTH AND TWO WAY TIME TO TOP OF ENEABBA FORMATION

October 2018





Petroleum or stratigraphic well
Water bore
CO_2 sequestration project bore
2 Contour
Coastline
Seismic line
Fault

0 25 50
Kilometres

Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
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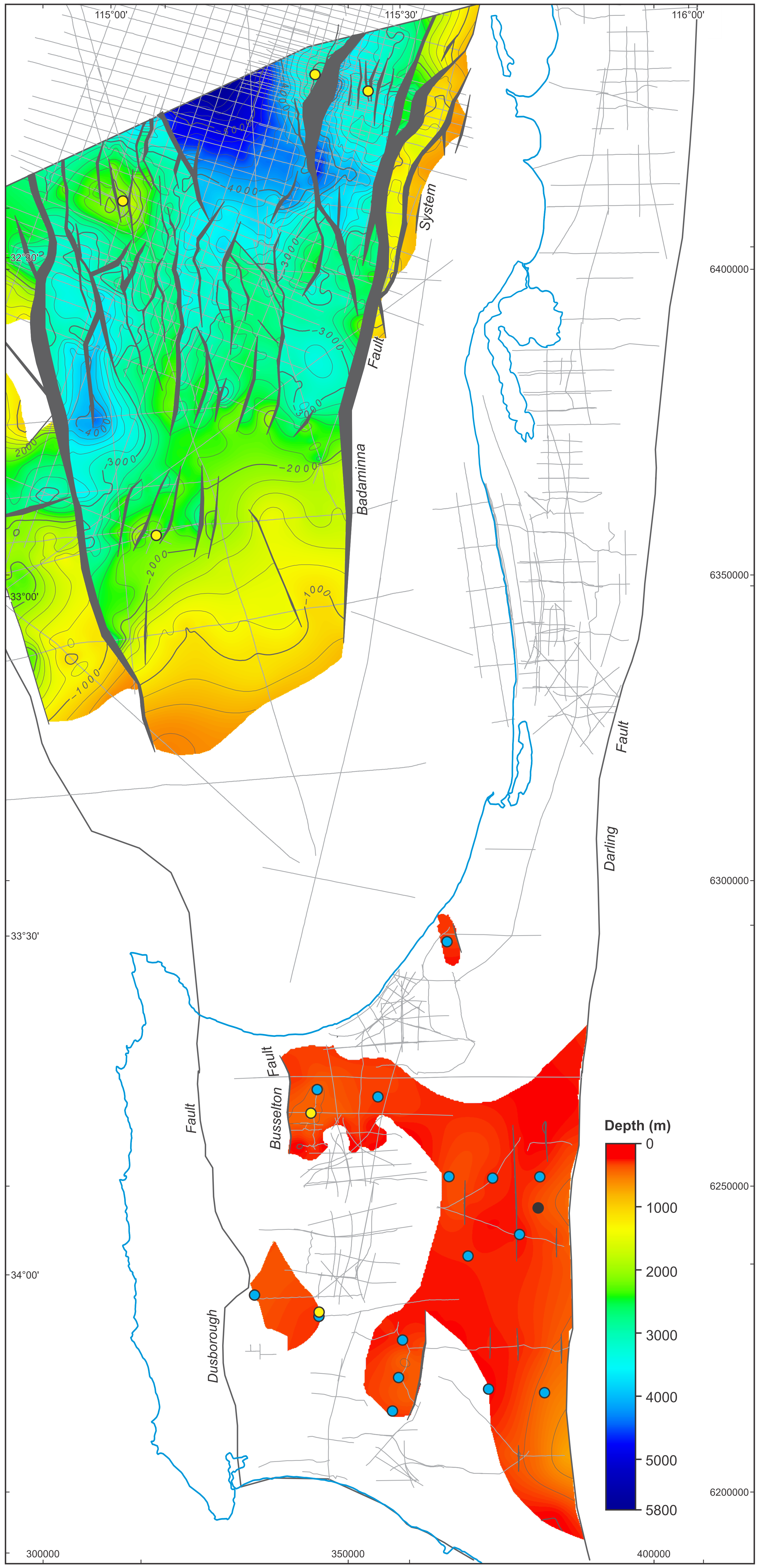
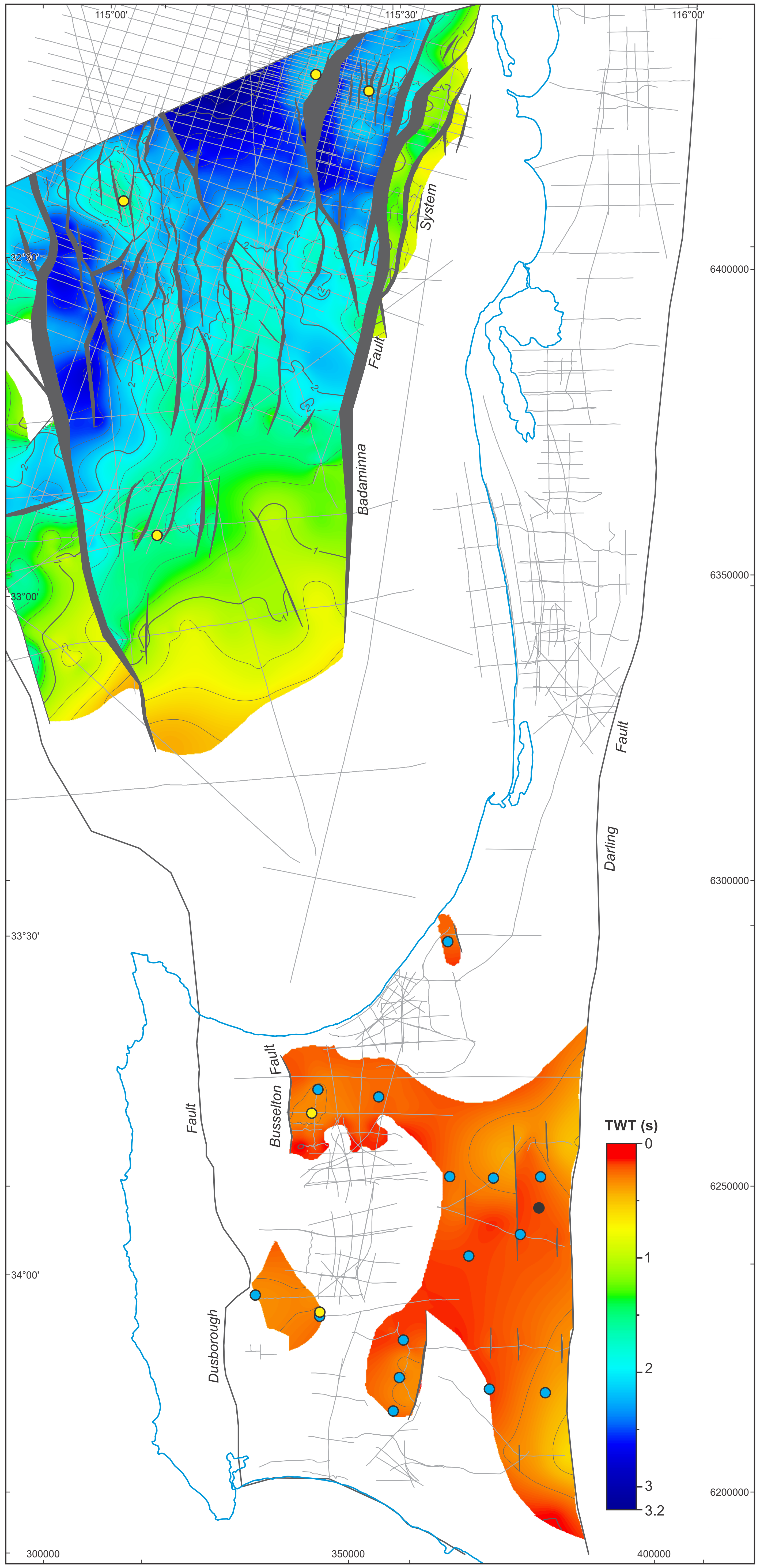
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 4

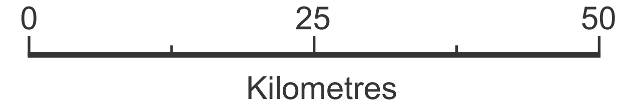
SOUTHERN PERTH BASIN
DEPTH AND TWO WAY TIME TO TOP OF CATTAMARRA COAL MEASURES

October 2018





- Petroleum or stratigraphic well
- Water bore
- CO_2 sequestration project bore
- 2 Contour
- Coastline
- Seismic line
- Fault



Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
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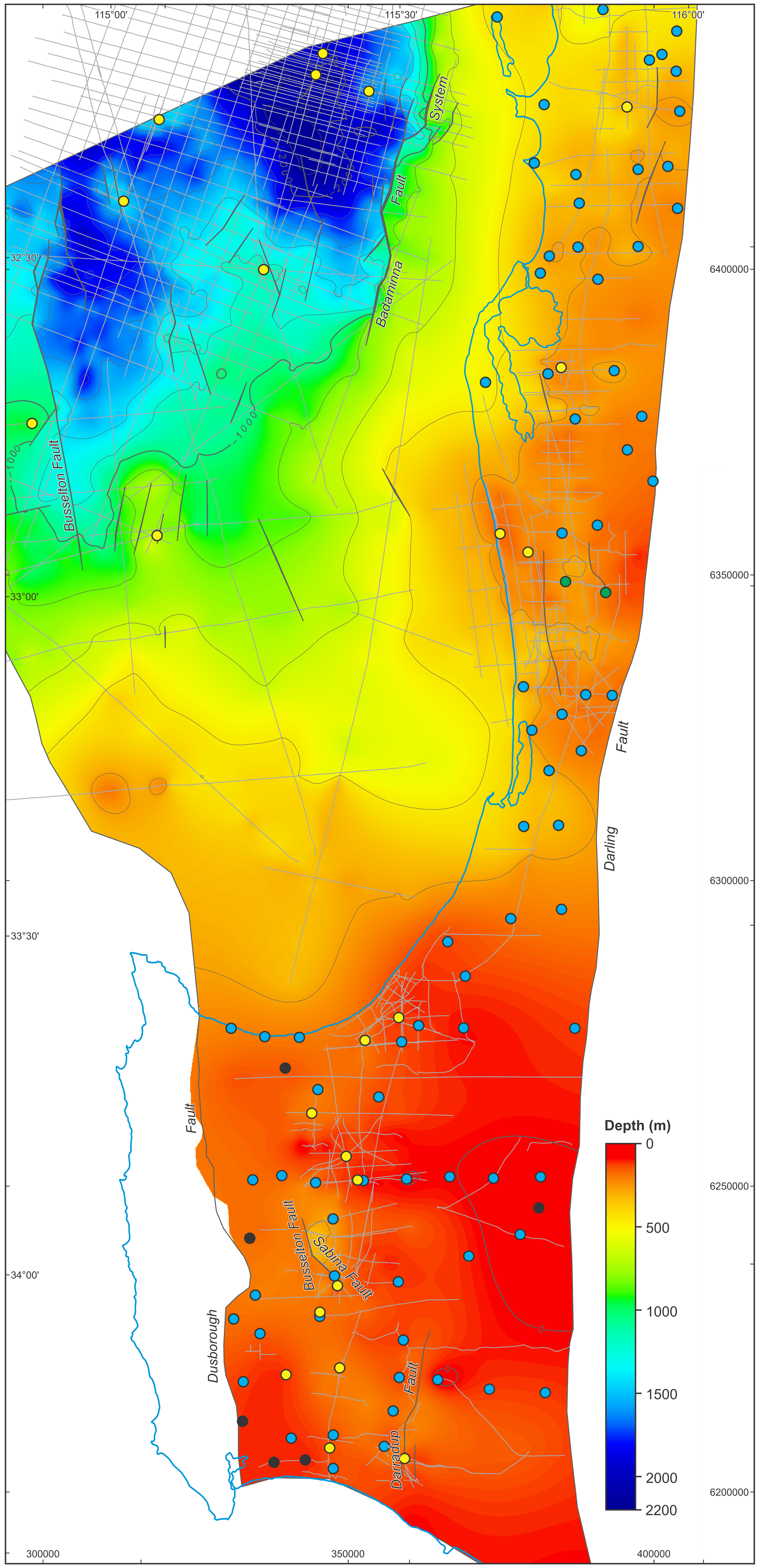
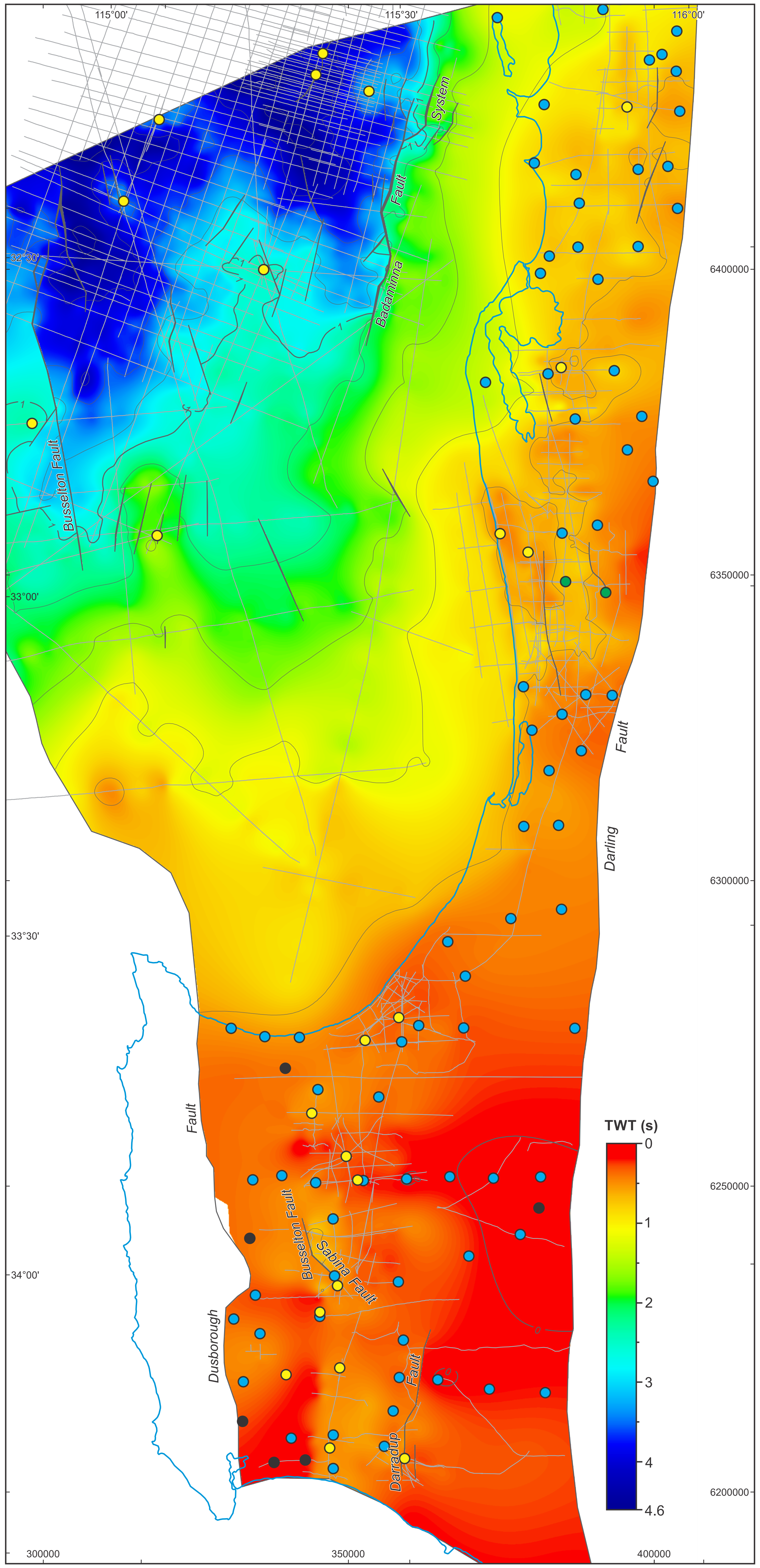
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 5

SOUTHERN PERTH BASIN
DEPTH AND TWO WAY TIME TO BASE OF PARMELIA GROUP

October 2018





- Petroleum or stratigraphic well
- Water bore
- CO_2 sequestration project bore
- Contour
- Coastline
- Seismic line
- Fault

0 25 50

Kilometres

Horizontal datum: Geocentric Datum of Australia 1994 (GDA94)
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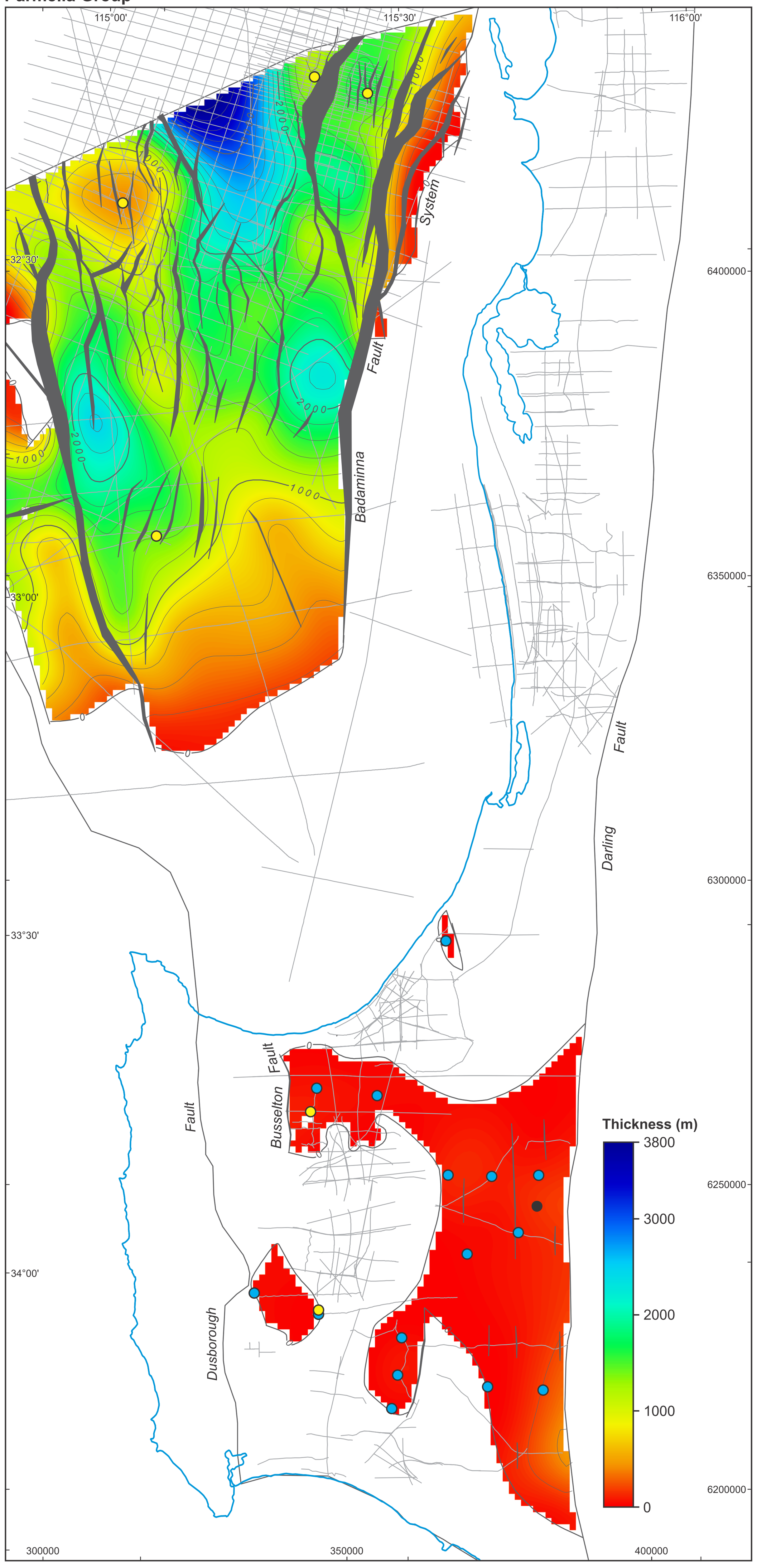
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 6

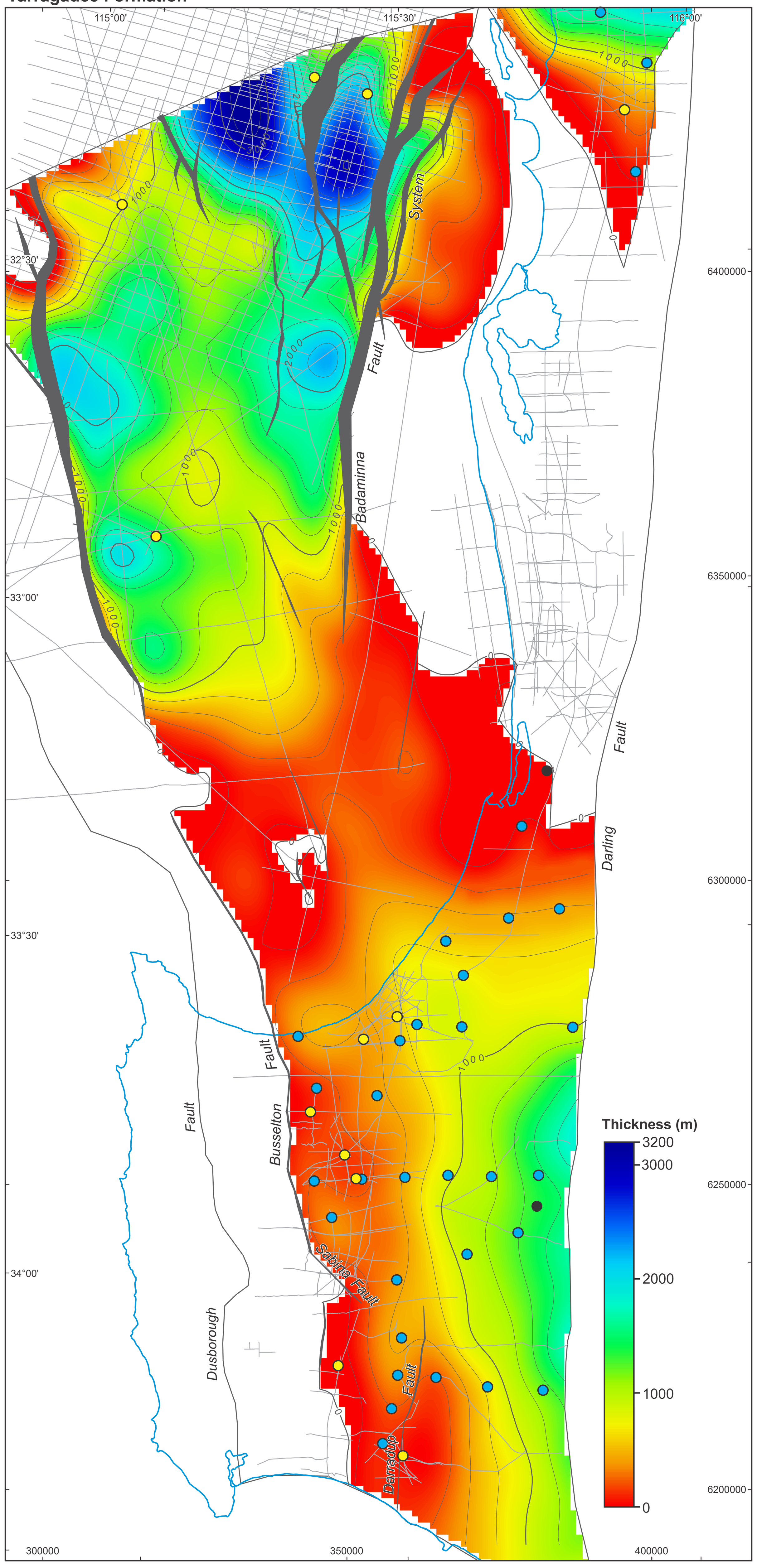
SOUTHERN PERTH BASIN
DEPTH AND TWO WAY TIME TO BREAKUP UNCONFORMITY

October 2018

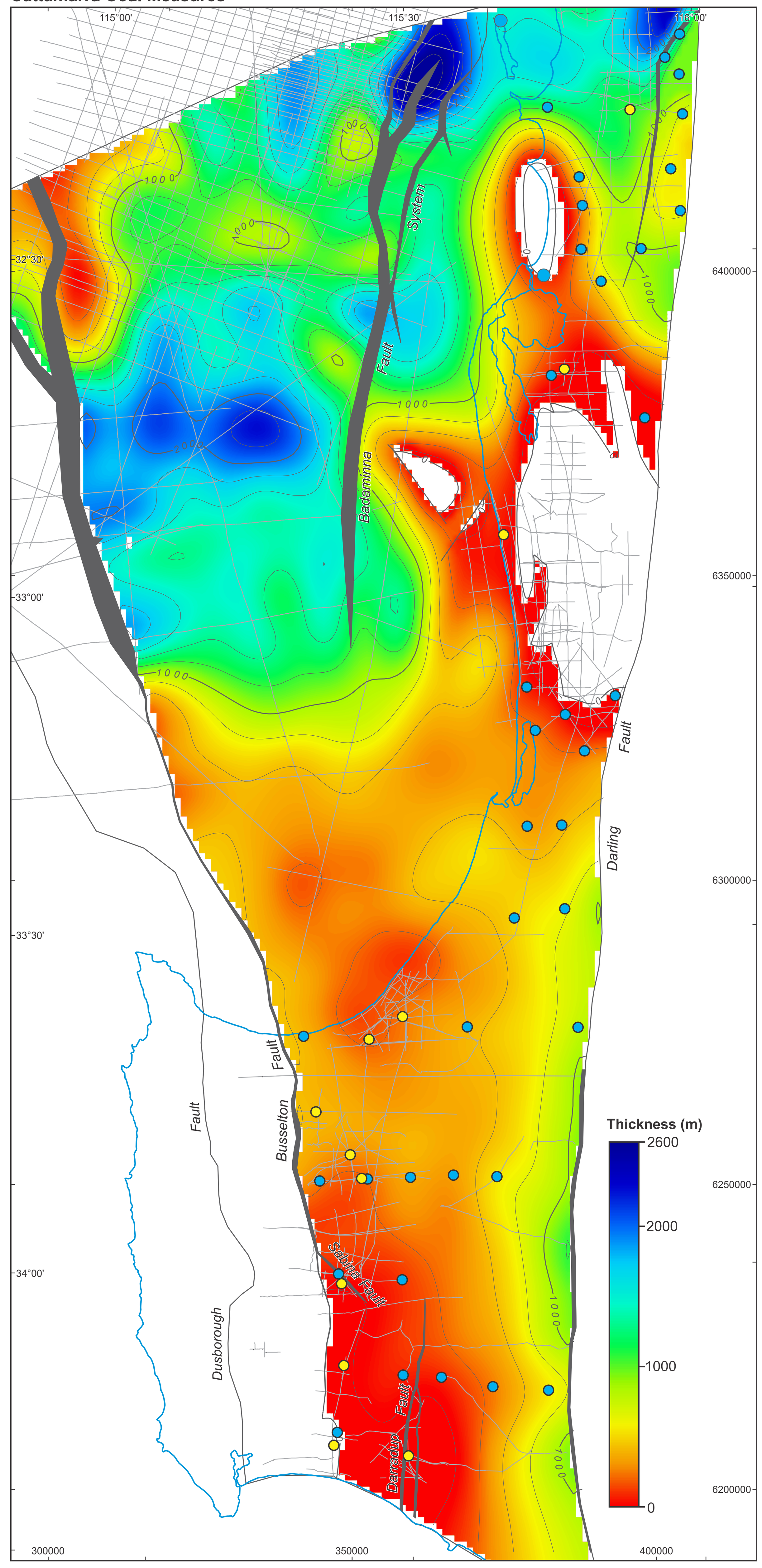
Parmelia Group



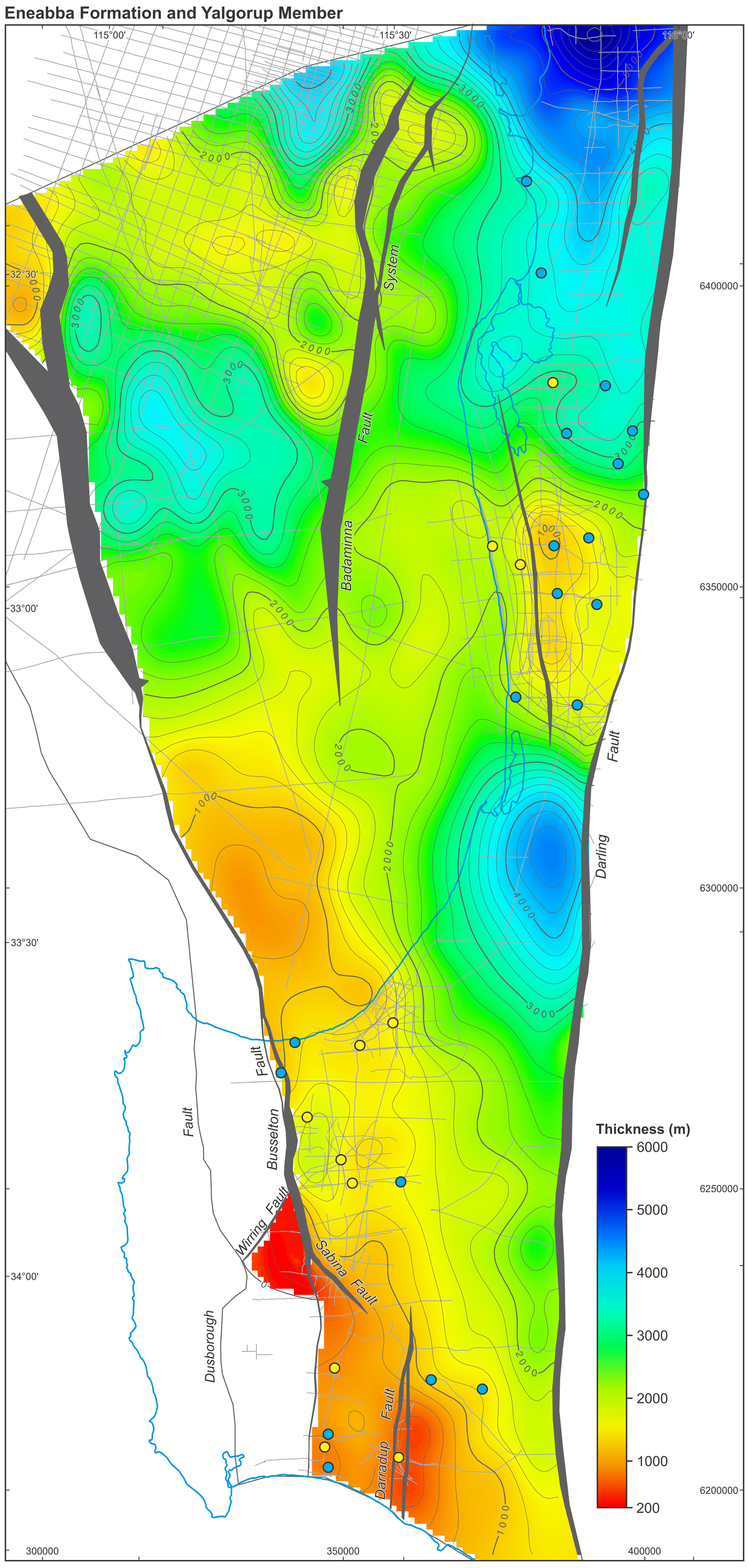
Yarragadee Formation



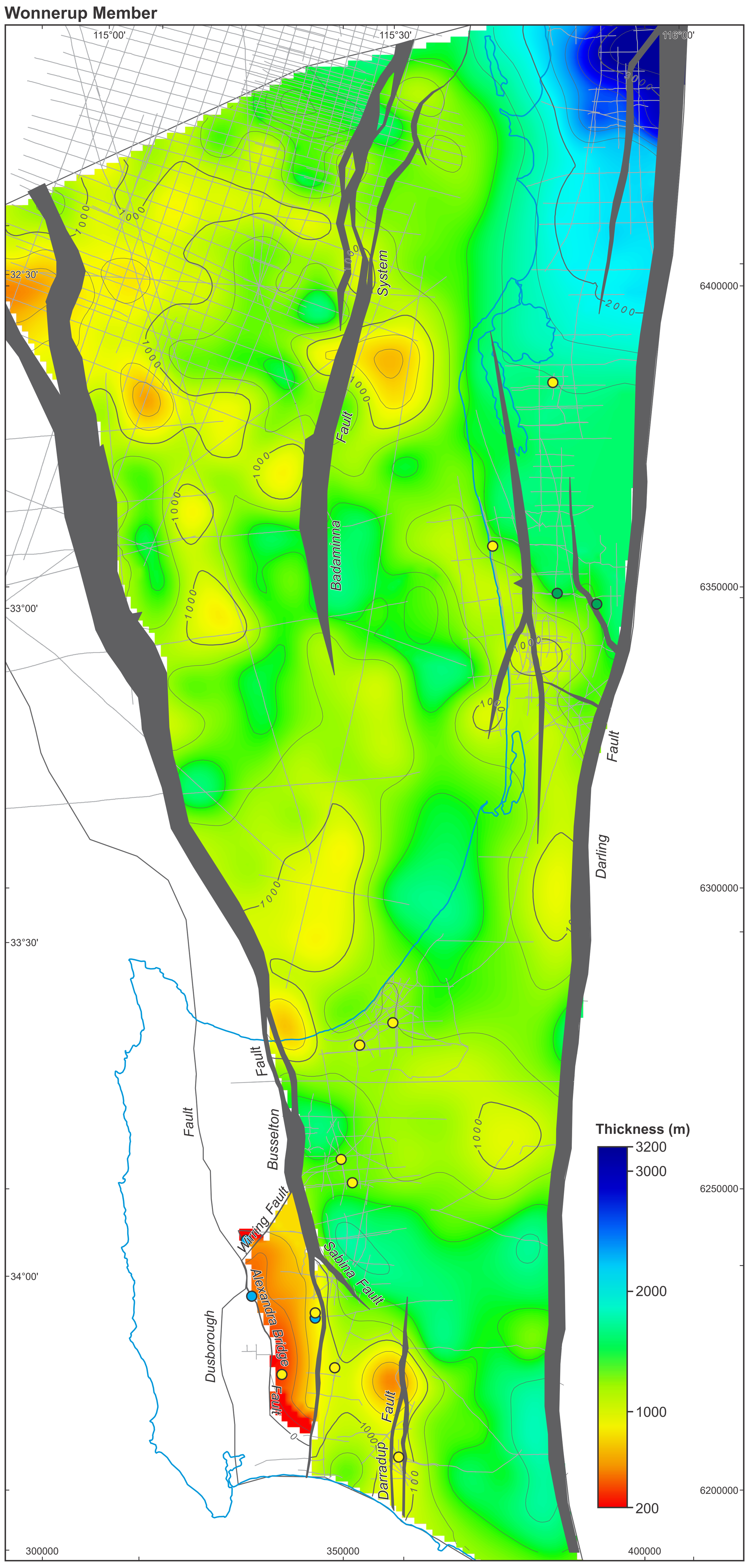
Cattamarra Coal Measures



Eneabba Formation and Yalgorup Member



Wonnerup Member



- Petroleum or stratigraphic well
- Water bore
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- Contour
- Coastline
- Seismic line
- Fault

0 25 50

Kilometres

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 184 PLATE 7

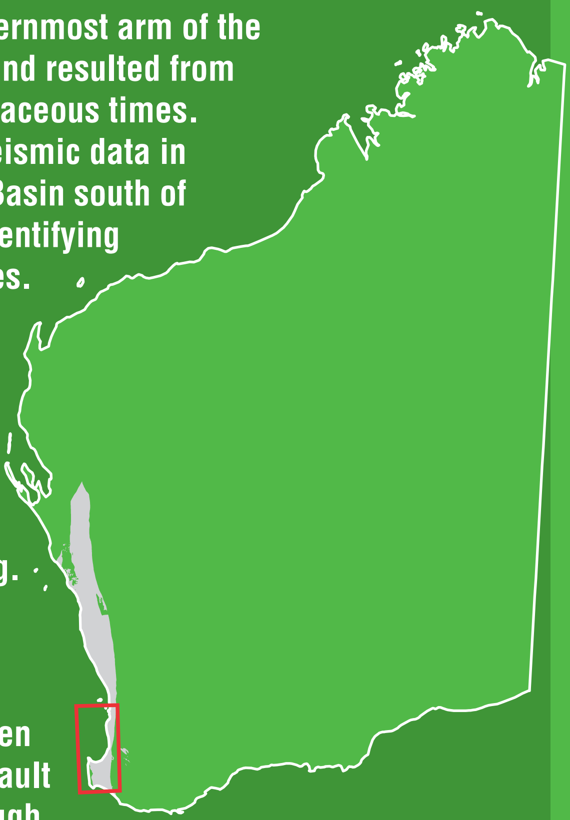
SOUTHERN PERTH BASIN
ISOPACH MAPS

October 2018

THOMAS

REGIONAL SEISMIC INTERPRETATION AND STRUCTURE OF THE SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

REPORT 184



The southern Perth Basin represents the southernmost arm of the Gondwanan interior rift in Western Australia, and resulted from multiple phases of rifting from Permian to Cretaceous times. This Report presents a new interpretation of seismic data in both the onshore and offshore southern Perth Basin south of the Perth metropolitan area, with the aim of identifying the timing and duration of basin tectonic phases. Subsurface formation boundaries have been mapped using seismic data constrained by petroleum well and drillhole data. Picks for the tops of formations in petroleum wells, and selected water bores and drillholes, have been revised using re-evaluations of historical palynological data and new sampling. Newly reprocessed legacy seismic data and recent seismic data acquisition have helped image the deepest depocentres of the basin, and at least three phases of extension have been identified. The Darling Fault, the Badaminna Fault system, the Busselton Fault and the Dunsborough Fault are recognized in this interpretation, and all played significant roles during basin tectonism. This interpretation shows that the basin potentially contains untested hydrocarbon traps.

Further details of geological products and maps are available from:

Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
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Phone: (08) 9222 3459   Fax: (08) 9222 3444

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