Regional Jurassic sediment depositional architecture, Browse Basin: Implications for petroleum systems

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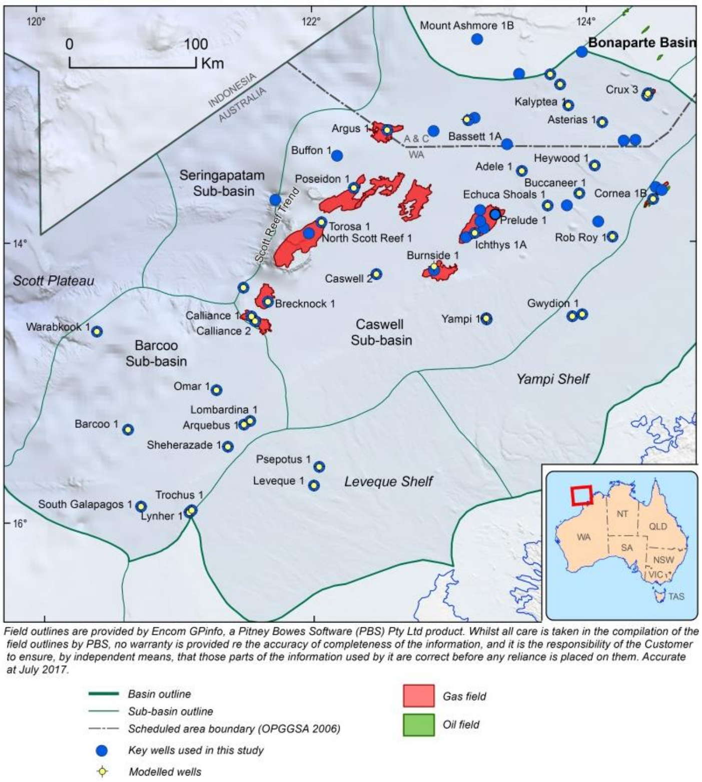
SUMMARY

The Browse Basin hosts considerable gas and condensate resources, including the Ichthys and Prelude fields that are being developed for liquefied natural gas (LNG) production. Oil discoveries are sub-economic. This multi-disciplinary study integrating sequence stratigraphy, palaeogeography and geochemical data has mapped the spatial and temporal distribution of Jurassic to earliest Cretaceous source rocks. This study allows a better understanding of the source rocks contribution to the known hydrocarbon accumulations and charge history in the basin, including in underexplored areas. The Jurassic to earliest Cretaceous source rocks have been identified as being the primary sources of the gases and condensates recovered from accumulations in the Browse Basin as follows:

- The Lower–Middle Jurassic J10–J20 (Plover Formation) organic-rich source rocks have been deposited along the northeast-southwest trending fluvial-deltaic system associated with a phase of pre-breakup extension. They have charged gas reservoired within J10–J20 accumulations on the Scott Reef Trend and in the central Caswell Sub-basin at Ichthys/Prelude, and in the Lower Cretaceous K40 supersequence on the Yampi Shelf.
- Late Jurassic–earliest Cretaceous J30–K10 source rocks are interpreted to have been deposited in a rift, north of the Scott Reef Trend and along the Heywood Fault System (e.g. Callovian–Tithonian J30–J50 supersequences, lower Vulcan Formation). The J30–K10 shales are believed to have sourced wet gas reservoired in the K10 sandstone (Brewster Member) in the Ichthys/Prelude and Burnside accumulations, and potentially similar plays in the southern Caswell Sub-basin.
- The organic-rich source rocks observed in the Heywood Graben may be associated with deeper water marine shales with higher plant input into the isolated inboard rift. They are the potential source of fluids reservoired within the Crux accumulation, which has a geochemical composition more closely resembling a petroleum system in the southern Bonaparte Basin.

Key words: Browse Basin, Jurassic, source rocks, palaeogeography, petroleum systems

INTRODUCTION



The Browse Basin contains two major depocentres, the Barcoo and Caswell sub-basins, where large gas accumulations with significant condensate volumes occur along the Scott Reef Trend (Calliance, Brecknock, Torosa), in the central and northwestern Caswell Sub-basin (Ichthys/Prelude, Crown/Proteus, Lasseter), and in the Crux field in the Heywood Graben (Figure 1). The Ichthys and Prelude fields are currently under development for liquefied natural gas (LNG) and condensate production. Initial hydrocarbon exploration in the basin focused on the Leveque Shelf, the Scott Reef Trend, where gas was discovered (Scott Reef 1), and in the central Caswell Sub-basin where a small oil discovery was made at Caswell 1. Further small oil and gas discoveries were found in shallow reservoirs (<1000 m) on the Yampi Shelf (Cornea 1, Gwydion 1). Continued exploration resulted in successes across the Caswell Sub-basin, the Heywood Graben and along the Scott Reef Trend; these discoveries emphasise the gas-prone nature of the basin. To date, no hydrocarbon accumulations have been discovered in the Barcoo Sub-basin. The Browse Basin is largely underexplored by global standards.

Research undertaken in the late 1990s determined that the Lower Cretaceous Echuca Shoals Formation was a source of oil in the basin, based on geological and geochemical evidence (Spry and Ward, 1997; Blevin et al., 1998a).

Figure.1 Structural elements of the Browse Basin and

location of the key wells used for this study.

Subsequent studies, including modelling (Kennard et al., 2004) and the detailed mapping of the Cretaceous supersequences (Abbott et al., 2016; Rollet et al., 2016a), led to a good understanding of the Lower Cretaceous petroleum system. Although Jurassic sedimentary successions are known to contain some of the most effective source rocks in the Westralian basins on the North West Shelf (Bradshaw et al., 1998; Longley et al., 2002), there is much less published information available for the Jurassic source rocks and their hydrocarbon-generating potential in the Browse Basin.

This study has focused on understanding the palaeogeography of the Jurassic successions and the distribution of potential Jurassic to earliest Cretaceous source rocks in the Browse Basin; it complements, at a basin scale, work undertaken by Tovaglieri et al. (2013) and Tovaglieri and George (2014). Palaeogeographic maps of the Lower–Middle Jurassic J10–J20 supersequences (Plover Formation) and Upper Jurassic–Lower Cretaceous J40–K10 supersequences (Vulcan Formation) are derived from seismic and well log data. Integration of the palaeogeography with geochemical analyses has enabled a better understanding of the spatial and temporal distribution of the source rocks. The role of these Jurassic to earliest Cretaceous source rock pods is demonstrated in a petroleum systems model that aims to clarify the charge history of the basin and determine which active source kitchens may have generated the fluids in the known hydrocarbon accumulations (Palu et al., 2017).

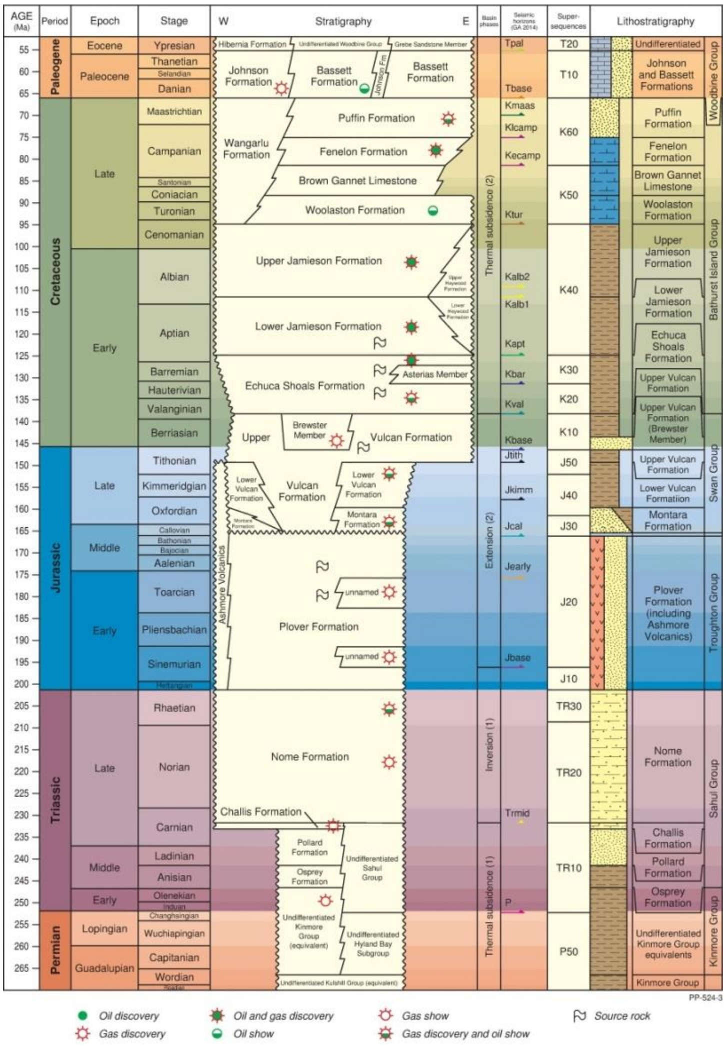


Figure 2. Schematic stratigraphy, hydrocarbon discoveries and sequence stratigraphy of the Browse Basin based on a revised tectonostratigraphic nomenclature (after Marshall and Lang, 2013), the Geologic Timescale 2016 (Ogg et al., 2016) and Browse Basin biozonation and stratigraphy chart (after Kelman et al., 2016).

METHOD AND RESULTS

Seismic mapping based on regional 2D and some 3D seismic survey data was tied to 60 key wells (Figure 1) using a revised tectonostratigraphic framework (Figure 2) for the basin. Recent seismic and well interpretations (Rollet et al., 2016a) are used to produce palaeogeographic maps (Figure 3) and develop a regional 3D geological model of the Browse Basin (Palu et al., 2017). The model is used to map the gross thickness of each set of supersequences containing source rock facies; i.e. J10–J20 and J30–K10 supersequences across the entire basin, and the J10–J50 supersequences in the Heywood Graben (Figure 4). The source rock pod extents (Figure 4) within each of the three supersequences are mapped using well control, total thickness maps and palaeogeographic interpretation. Integration of downhole geochemical, lithological and biostratigraphic data has allowed the identification of the stratigraphic position and depositional environment of the organic-rich samples. Indicative source rock characteristics are assigned based on an updated compilation of quality controlled total organic carbon (TOC), Rock-Eval pyrolysis and vitrinite reflectance data.

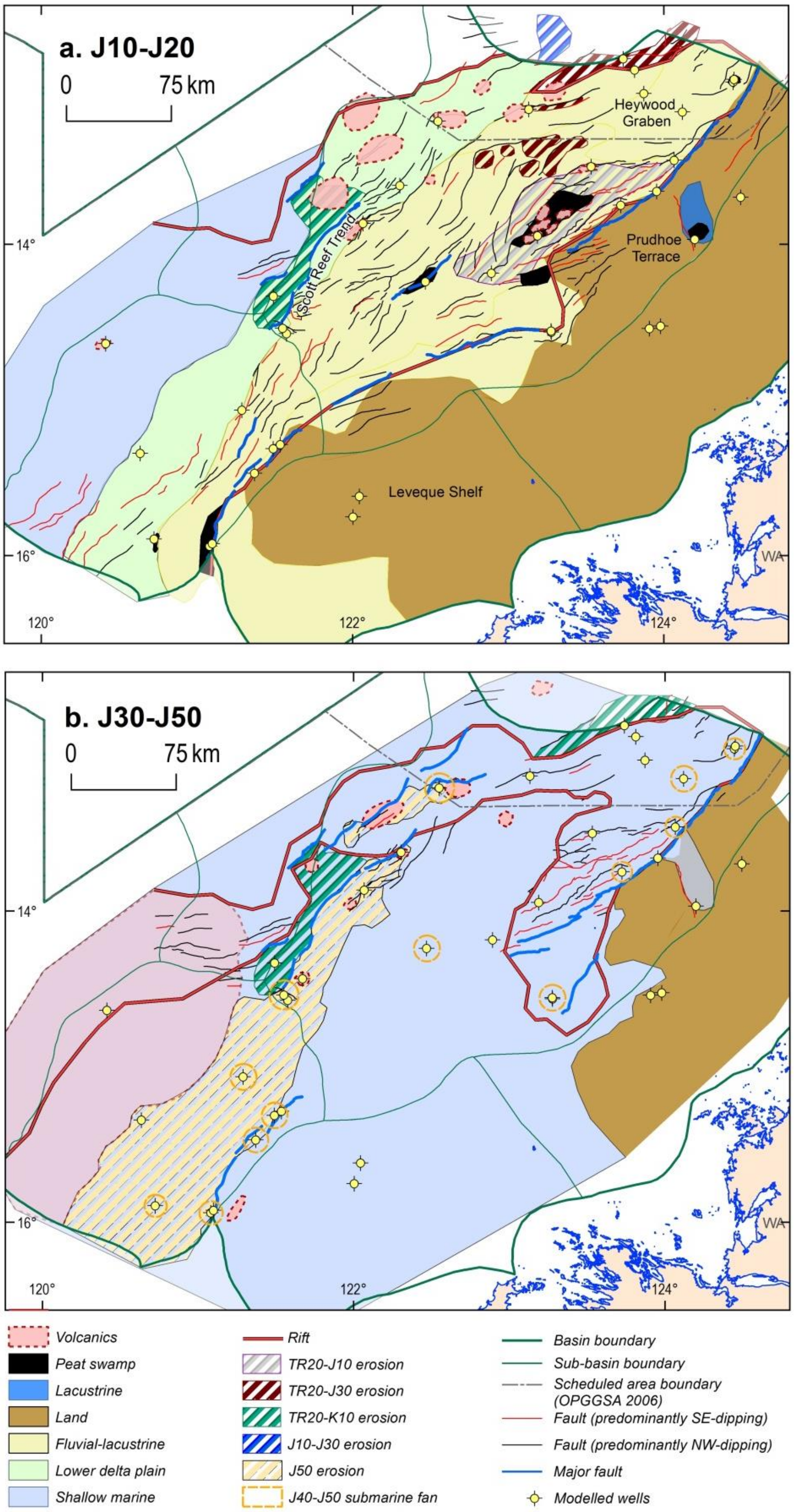
Integrating the source rock property data into a pseudo-3D petroleum systems model is on-going to predict transformation ratio, maturity and charge history. The superimposition of modelled hydrocarbons expelled from each source rock and known hydrocarbon accumulations will provide a better understanding of migration pathways from the main depocentres to the reservoirs. These results will refine the spatial extent of proven Jurassic petroleum systems and predict their potential extent.

PALAEOGEOGRAPHIC MAPS AND SOURCE ROCK FACIES DISTRIBUTION

From the Late Triassic to Cretaceous, the Browse Basin transitioned from being an intracratonic rift basin to a passive margin. The location of the source rock pods is influenced by the regional basin architecture and the drainage patterns set up from the late Triassic–early Jurassic Fitzroy Movement, forming a complex network of sedimentary input to the basin. Consequently, the source rocks are not evenly distributed throughout the Jurassic succession.

Early–Middle Jurassic

Widespread Early–Middle Jurassic extension led to the deposition of the J10–J20 supersequences, which comprise interbedded shales and sandstones deposited in fluvial-deltaic settings in the Caswell and inboard Barcoo sub-basins (Figure 3a). J10–J20 fluvial sediments extend across most of the basin and peat swamps and lakes developed on the eastern side of the rift valley (Figure 3a). Tectonic subsidence curves from 38 modelled wells (location on Figure 1) confirm that extensional faulting was concentrated along the Scott Reef Trend, in the Caswell Sub-basin basinward of the Prudhoe Terrace, in the Heywood Graben and in the Barcoo Sub-basin, basinward of the Leveque Shelf (Figure 3a). The patterns of faulting suggest that the extension direction was approximately NW–SE (Figure 3a, Rollet et al., 2016a).



Palaeogeographic mapping (Figure 3a) and total sequence thickness maps (Figure 4a) provide a better understanding of the distribution of the Lower–Middle Jurassic source rock pods (Figure 4c). The fluvial-deltaic dominated J10–J20 supersequences show an axial NE-SW trending drainage system associated with the syn-rift extension and reactivation that extends from the Heywood Graben in the northeast, across the central Caswell Sub-basin, and into the inboard Barcoo Sub-basin in the southwest. Source rocks were deposited along this fluvial-deltaic system in three main depositional environments (Figure 3a):

1) fluvial-lacustrine environments bounded by major faults on the eastern side (basinward of the Prudhoe Terrace and Leveque Shelf) and by structural highs (e.g. Scott Reef Trend) on the western side,
2) brackish to marginal marine lower delta plain environments (e.g. Calliance 1, Omar 1, Torosa 1; see location on Figure 1),
3) shallow marine environments in the outboard Barcoo Sub-basin.

During the Early–Middle Jurassic, high sediment influx is observed from the north, east and west (Blevin et al., 1998b) into the fluvial-channel complex axis and flood plain where reservoirs, seals and source rocks are juxtaposed and vary in thickness. Good quality reservoirs are found within the Lower–Middle Jurassic *C. torosa* to *D. complex* spore and pollen zone along the Scott Reef Trend, with variable porosity in the Ichthys field, whereas reservoir quality is poor or absent in the northern part of the Caswell Sub-basin (Le Poidevin et al., 2015).

The Heywood Graben was isolated in the south from the central Caswell Sub-basin by a structural high that experienced a long period of erosion during the Late Triassic to Middle Jurassic (non-deposition of TR20–J30 supersequences). An opening of the graben towards the south along the Heywood Fault System connected the Heywood Graben with a broader extensional depocenter (e.g Ichthys field area) during the upper J20 supersequence (Figure 3a).

Figure 3. Palaeogeographic maps for a) J10-J20 supersequences (Plover

Formation) and b) J30-J50 supersequences (lower Vulcan Formation).

Source rocks within the J10–J20 supersequences contain abundant terrestrial organic matter with significant gas potential (kerogen type D/E, Pepper and Corvi, 1995; equivalent to type III) and include pro-delta shales, coaly shales and thin coals. Some source rock samples within the J10–J20 supersequences have oil potential (TOC> 2% and HI> 300 mg hydrocarbons/g TOC). They occur in localised areas mainly associated with the shaly coals within the J25.0–J29.0 sequences (upper Plover Formation). These oil-prone source rocks are found in *C. turbatus* coals interbedded with claystones and sandstones deposited in fluvio-deltaic environments (e.g. Trochus 1 ST1), in *C. cooksoniae* coaly shales deposited in shelfal to nearshore marine environments (e.g. Calliance 1 and 2) and in *D. complex* sandstones interbedded with claystone, siltstone and coals deposited in lacustrine environments (e.g. Rob Roy 1). The oil generating potential is confirmed by pyrolysis-gas chromatography of a few samples showing generation of long-chain *n*-alkanes (e.g. Calliance 2). The subsidence on the rift flanks was favourable for the development of coal beds, which were subsequently buried by transgressive marine shales. Most of the Scott Reef Trend structural high was initially emergent and then buried during the Early to Middle Jurassic (Tovaglieri et al., 2013) when carbonaceous siltstone and claystone were deposited in a brackish restricted embayment where swamps developed (Woodside, 2008a). The warm and wet Jurassic climate was favourable to luxuriant floral growth assisting with the development of peat swamps (Bradshaw and Yeung, 1990). Peat swamps may have developed behind either sand bars that offered protection against major inundations by the sea, which developed above tilted fault blocks in the outer Caswell Sub-basin (e.g. Calliance field and along the Scott Reef Trend, Figure 3a), or natural levees against river flood-waters assisted by fault movement on the eastern edge of the fluvial system (e.g. Ichthys field, Figure 3a). In the Heywood Graben, J10–J20 source rocks are stacked in an isolated rifted graben where the J25.0–J29.0 carbonaceous sediments (e.g. Crux 3) host some good oil-prone source rocks. On the by-passed Prudhoe Terrace, potential source rocks could have been deposited in a lacustrine environment within the low depression formed by an earlier Paleozoic Graben (e.g. Rob Roy 1).

Late Jurassic–Early Cretaceous

The Callovian rifting event (J30 supersequence) coincides with breakup and seafloor spreading in the Argo Abyssal Plain. This event is associated with restricted deposition (Figure 3b) in the outer Caswell Sub-basin (e.g. Argus 1) and inboard along the Heywood Fault System (e.g. Buccaneer 1). Marine shales in the lowest part of the rift indicate occasional flooding with potential for good source rocks (J30–J50 supersequences (Lower Vulcan Formation) potential source pods on Figure 4d). Anoxic conditions may have been established in the newly formed elongated and narrow seaway. Lack of geochemical data in the J30 supersequence prevents full assessment of these potential source rocks. Elsewhere, a major time gap is observed in all key wells around the Callovian breakup unconformity, specifically between periods defined by the *C. Cooksoniae* spore and pollen zone (Callovian) and *W. spectabilis* dinocyst zone (Oxfordian). At the end of this rifting event, an Oxfordian (*W. spectabilis* dinocyst zone) marine incursion spreads across most of the basin (Figure 3b). It resulted in the deposition of claystones within the J40 supersequence (J40 potential source pod on Figure 4d). Marine sediments accumulated within the rifted areas (J30–J50 potential source pods on Figure 4d), while shelfal marine sediments with low terrestrial input are observed basinward of the Leveque Shelf (e.g. Arquebus 1). During this transgressive period, sediments with fair to good source rock quality (TOC>0.5% and S2>2.5 mg hydrocarbons/g rock) and mostly gas-generating potential (HI < 300 mg hydrocarbons/g TOC) have been deposited in the Barcoo Sub-basin. Organic-rich source rocks are localised in areas associated with the J40 maximum flooding event (e.g. Barcoo 1) and the deposition of coals (e.g. Lynher 1). Subsequent Kimmeridgian deposition of the J47.0–J49.0 sequences is restricted to the rift valley, where rapid subsidence is observed in the Heywood Graben and along the Heywood Fault System (e.g. Crux 3, Yampi 1). At the end of the Jurassic, the palaeogeographic reconstruction (Figure 3b) suggests that marine source rocks within the Tithonian *D. jurassicum* J50 supersequence could extend from the Heywood Graben to the south along the Heywood Fault System and also outboard of the Buffon to Argus trend. Elsewhere, the J50 supersequence is relatively thin (less than 50 m) with local thickening across the Leveque Shelf and Prudhoe Terrace indicating the presence of a sediment source to the east in the Kimberley Basin and King Leopold Mobile Belt (Blevin et al., 1998b). Shallow marine limestones were deposited inboard on the Leveque Shelf. Submarine fans and transgressive sandstones of the J40–J50 supersequences are present within the rift valley and along major inboard faults (Figure 3b). Subsequent deltaic progradation within the K10 supersequence (Abbott et al., 2016) led to the accumulation of pro-delta shales encasing sandstones of the Brewster Member. The K10 supersequence source rock pod is predicted to be present in the central Caswell Sub-basin deposited on a mudstone-prone basin floor adjacent to the shelf-margin delta (Figure 4d).

Source rocks within the J30–K10 supersequences are predominantly gas-prone shales (kerogen type D/E), however, thin condensed mudstones—containing type B (equivalent to type II) kerogen—formed by flooding events could be a source of liquid hydrocarbons where organic richness is sufficient (Blevin et al., 1998a). Source rocks of good to excellent quality (TOC 2–33.6% and S2 5–80 mg hydrocarbons/g rock) are found across the basin around the maximum flooding surfaces in the J40 Oxfordian *W spectabilis* claystone, in the K10 Berriasian *P. iehense*, *K wisemaniae*, *C. delicata* and *E. torynum* claystones, and also locally in the J50 Tithonian *D. jurassicum* claystone within the rifted areas. Oil-prone source rocks (TOC >2% and HI>300 mg hydrocarbons/g TOC) are found within the J40 Oxfordian *W spectabilis*, J50 Tithonian *D. jurassicum* claystone, and within the K10 Berriasian claystone. The Rock-Eval pyrolysis data gap within the K10 supersequence impedes full assessment of its generation potential. Oil generation potential is likely in rifted areas such as the Heywood Graben and its southward extension along the Heywood Fault System within the J40 *W. spectabilis* shale (e.g. Gorgonichthys 1).

Limited development of source rocks in the Barcoo Sub-basin is due to the presence of a large volcanic buildup in the outer part of the basin within the J30–J50 supersequence (e.g. Warrabkook 1 and in localised areas along the rift; Figure 3b), the decrease in sedimentation rate during the J40 supersequence and erosion or non-deposition of the J50 supersequence on the eastern side of the rift shoulder along a NE-SW trending corridor (Figure 3b).

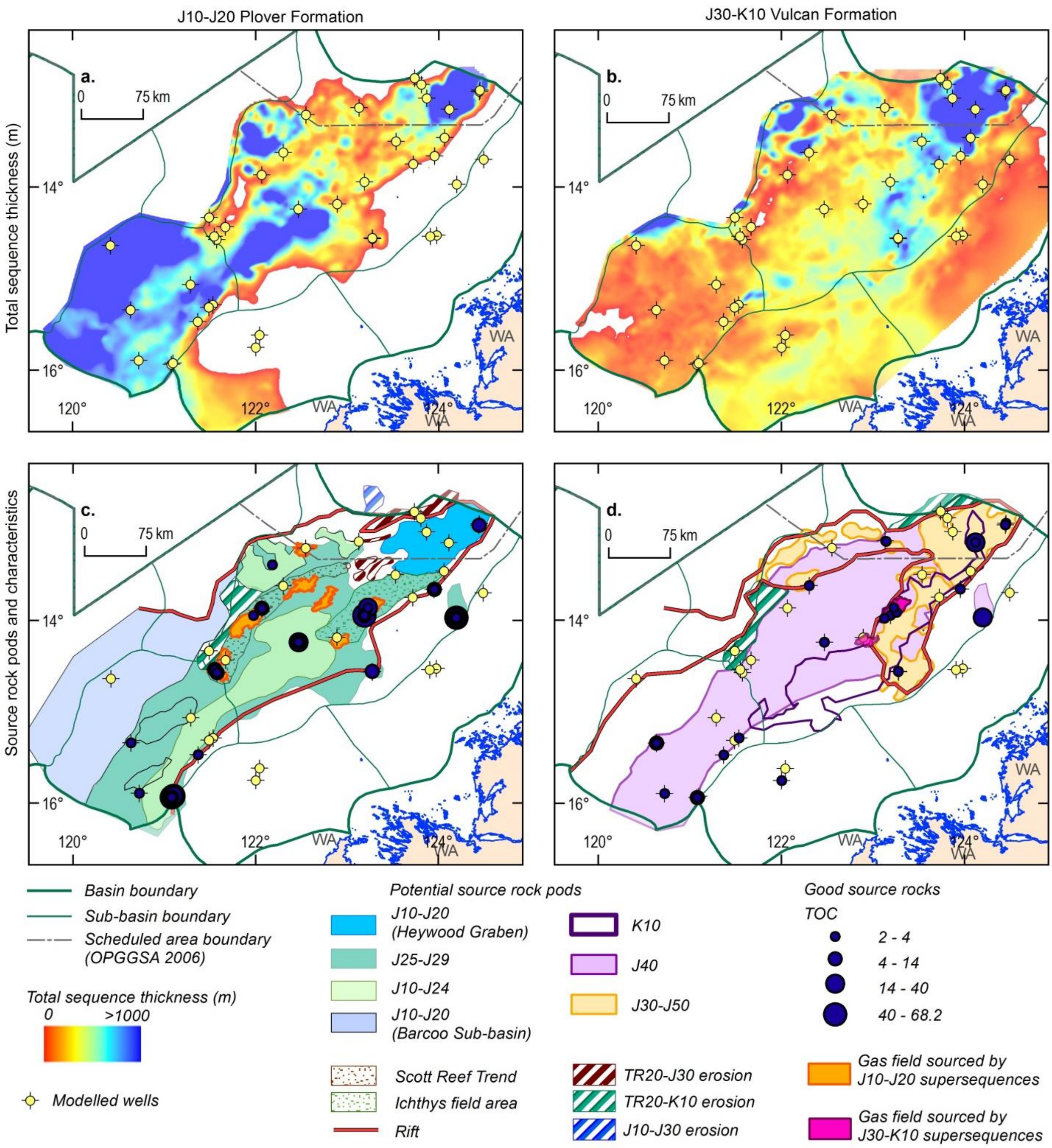


Figure 4. Total thickness of a) J10-J20 supersequences (Plover Formation) and b) J30-K10 supersequences (Vulcan Formation). Potential source rock pod distribution for c) J10-J20 supersequences (Plover Formation) and d) J30-K10 supersequences (Vulcan Formation). Gas accumulations related to the respective sources are shown.

JURASSIC PETROLEUM SYSTEMS ANALYSIS

The Jurassic to earliest Cretaceous supersequences have been identified as being the primary sources of the gases recovered from accumulations in the Browse Basin based on geochemical evidence (Edwards et al., 2014, 2015; Grosjean et al., 2015). The distribution and characteristics of the source rocks within the J10–J20 and J30–K10 supersequences show that they are predominantly gas-prone with some oil potential occurring at multiple levels within the J25.0–J29.0, J40, J50 and K10 sequences, mostly along the Scott Reef Trend, in the northern part of the Caswell Sub-basin, in the Heywood Graben, and along the Heywood and inner Barcoo fault systems. The detailed mapping of these source rocks and their variable distribution allows a better understanding of their contribution to the known hydrocarbon accumulations and charge history in the basin.

Hydrocarbon expulsion modelling (Palu et al., 2017) shows that the J10–J20 and J30–K10 source rocks within the Caswell Sub-basin have reached sufficient maturities to have transformed most of the kerogen into hydrocarbons, with the majority of expulsion occurring from the Late Cretaceous until present. Within the Barcoo Sub-basin, source rocks of the J10–J20 supersequences have reached sufficient maturity for generation, where the better-quality source rocks within this supersequence are modelled to have expelled hydrocarbons.

Source rocks within the J10–J20 supersequences (Plover Formation) have been modelled to charge the gas occurring in the J10–J20 reservoirs on the Scott Reef Trend and Ichthys/Prelude field, and in the J40 reservoir at Argus. In addition, based on the *neo*-pentane carbon isotopic data (Grosjean et al., 2016), it has been established that the gas found in the shallow Cretaceous reservoirs of the K40 supersequence on the Yampi Shelf was sourced by J10–J20 supersequence source kitchens in the depocentres further west via long distance migration pathways. Similarly, gas on the Leveque Shelf (e.g. Psepotus 1) is most likely derived from long-range migration from source rocks within the J10–J20 supersequence in the Barcoo Sub-basin and/or from a fill-spill of the Calliance accumulation on the Scott Reef Trend (Le Poidevin et al., 2015). Oil sampled from a thin shallow porous/fractured zone (~2150 mRT) in Torosa 4 is geochemically similar to the condensate recovered from the J10–J20 supersequences (Woodside Energy Ltd, 2008b), indicating a common (Plover Formation) source for these hydrocarbons. This oil may have formed by liquids dropping out of a Plover-derived gas-condensate as it migrated into a zone of reduced pressure with the associated gas not being retained (Palu et al., 2017).

The capacity of the J10–J20 supersequences (Plover Formation) source rocks to have generated oil in the past is suggested by the presence of a palaeo-oil column at Brecknock South 1 within the J10–J20 supersequences based on the identification of oil-bearing fluid inclusions using the GOI™ (Grains containing Oil Inclusions) technique (Brincat et al., 2006). A 25 to 45 m palaeo-oil column overlain by a 75 m palaeo-gas cap is interpreted in this well, indicating that an oil charge preceded the arrival of the current gas phase. In addition, GOI values of 2.4% and 1.3% detected in the reservoirs of the J10–J20 supersequences at Yampi 2 and Brecknock 1, respectively, support oil migration at this level and the possibility of a palaeo-oil column occurring in their vicinities (Brincat et al., 2004). Oil may still be generating from source rocks in the J10–J20 supersequences in areas, such as along the southern Scott Reef Trend and in the southern inboard Barcoo Sub-basin. These underexplored areas could be prospective away from reactivated faults that compromise seal integrity.

The gas accumulations reservoired within the Berriasian K10 supersequence (Brewster Member) of the Ichthys/Prelude and Burnside fields show a high liquid content (Le Poidevin et al., 2015) and have most likely been sourced locally by the Upper Jurassic to Berriasian J30–K10 supersequences (Vulcan Formation) (Grosjean et al., 2015; Edwards et al., 2016). To date, there is no other evidence of fluids related to this source elsewhere in the basin. However, the presence of oil shows within the rift area in the J30–J40 *R. aemula* and *W spectabilis* and J50 *D. jurassicum* reservoirs (e.g. Yampi 1) suggest charging from oil-prone source rocks within the J30–K10 supersequences. Palaeo-oil columns are recognised based on GOI data (Brincat et al., 2004; Volk et al., 2005) in reservoirs of the J30–K10 supersequences in the Ichthys/Prelude field (e.g. Brewster 1A, Dinichthys 1, Titanichthys 1), indicating that an initial oil system existed in the past, most likely sourced by the J30–K10 supersequences.

Gases and condensates of the Heywood Graben (i.e. Crux and satellite wells) have a geochemical composition more closely resembling a petroleum system in the southern Bonaparte Basin (e.g. Maret 1, 2015) and are therefore part of a distinct petroleum system in the Browse Basin (Grosjean et al., 2015; Edwards et al., 2016). These gas accumulations are thought to be derived from terrestrial organic matter within the thick Jurassic supersequences in the Heywood Graben. Gas/condensate-source rock correlations are required to elucidate the exact source within the J10–J20 and J30–K10 supersequences in this area. The organic-rich source rocks observed in the Heywood Graben may be associated with deeper water marine shales with higher plant input into the inboard rift. This different depositional environment compared to the rest of the Caswell Sub-basin could account for the different geochemical signature observed in fluids of the Heywood Graben.

CONCLUSIONS

The integration of sequence stratigraphy aligned to the North West Shelf nomenclature with updated palaeogeography and new geochemical data has allowed the distribution and depositional environment of the Jurassic to earliest Cretaceous source rocks to be determined. The detailed mapping of these source rocks and their variable distribution allows a better understanding of their contribution to the known hydrocarbon accumulations and charge history in the basin. The Jurassic to earliest Cretaceous supersequences have been identified as being the primary sources of the gases recovered from accumulations in the Browse Basin based on geochemical evidence. The source rocks predominantly comprise gas-prone kerogen with some oil-prone potential and their deposition was localised in structurally controlled areas.

This study refines the widespread distribution of Early–Middle Jurassic J10–J20 organic-rich source rocks deposited along the NE–SW trending fluvial-deltaic system associated with a phase of pre-breakup extension and magmatism in the basin. Source rocks within the J10–J20 supersequences (Plover Formation) have charged the gas occurring in the J10–J20 reservoirs on the Scott Reef Trend and Ichthys/Prelude field, and in the J40 reservoir at Argus. Some sweet spots for wet gas generation are also identified from these predominantly gas-prone sequences. Oil-prone source rocks are concentrated in coaly facies encountered within the J25.0–J29.0 sequences (upper Plover Formation) in the central Caswell Sub-basin and inner Barcoo Sub-basin, Heywood Graben and along the Scott Reef Trend. They may have generated oil prior to the gas recovered from accumulations on the Scott Reef Trend and Ichthys field. This is reinforced by the presence of palaeo-oil columns in these areas. Oil generation may still be occurring along the Scott Reef Trend and in the southern inboard Barcoo Sub-basin. Oil may also be formed by liquids dropping out of Plover-derived gas-condensate when migrating into shallower reservoirs.

Subsequent Late Jurassic–earliest Cretaceous J30–K10 source rocks are interpreted to have been deposited in a rift, north of the Scott Reef Trend and along the Heywood Fault System, where marine shales may have been deposited under suboxic to anoxic conditions (e.g. Callovian–Tithonian J30–J50 supersequences, lower Vulcan Formation). Marine organic-rich shales with some liquid potential

are present within the J40 and J50 supersequences (Vulcan Formation) associated with flooding events. Similar shales could exist within the J30 supersequence north of the Scott Reef Trend and along the Heywood Fault System, but due to the lack of well data this is speculative. The gas-condensates with high liquid content reservoired within the Berriasian K10 supersequence (Brewster member) have most likely been sourced locally by the Upper Jurassic to Berriasian J30–K10 supersequences (Vulcan Formation). This is supported by the presence of palaeo-oil columns in J30–J50 reservoirs within the rift area indicating that an initial oil system existed and may have charged reservoirs within the J30–K10 supersequences.
The reduced subsidence rate over the structural highs may have delayed thermal maturation and hence, the most oil-prone facies are currently within the oil generation window. During the Late Jurassic rifting, the absence of liquid-prone source rocks in the Barcoo Sub-basin is due to the presence of a large volcanic buildup in the outer basin and uplift on the rift shoulder in the inner part of the sub-basin which led to the decrease in sedimentation rate and/or erosion within the J30–J50 supersequences.

The organic-rich source rocks observed in the Heywood Graben may be associated with deeper water marine shales with higher plant input into the isolated inboard rift. They are the potential source of fluids reservoired within the Crux accumulation, which has a geochemical composition more closely resembling a petroleum system in the southern Bonaparte Basin rather than those elsewhere in the Browse Basin.

This study has highlighted the tectonic and depositional control on source rock quality and distribution across the basin and suggests that underexplored areas of the basin have significant potential for undiscovered oil and gas resources.

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