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Paleozoic Petroleum Systems of the Canning Basin, Western Australia: A review

Extended Abstract

Productivity of Paleozoic petroleum systems depends on timing (Paleozoic–Cenozoic) and preservation (sub–suprasalt) of charge, as exemplified by super-giant, giant and small oil and gas fields within the Paleozoic basins of North America, North Africa, North Caspian, and the Canning Basin. Like other Paleozoic basins, one of the major exploration risks in the underexplored Paleozoic succession of the Canning Basin is the timing of charge and its preservation during a complex tectonic history. This review covers Paleozoic petroleum systems of the Canning Basin and reconstructs petroleum charge history at Acacia 1 and 2 on the Barbwire Terrace, Kidson 1 within the Kidson Sub-basin, Willara 1 within the Willara Sub-basin, and Yulleroo 1 within the Fitzroy Trough. We estimate the timing of charge based on new data (Ghori and Haines, 2006) generated to supplement published and unpublished open-file information.

Figure 1 shows the geographic distribution of oil and gas within the Canning Basin. Subsalt Ordovician sourced oil has been recovered in Cudalgarra 1, Dodonea 1, Edgar Range 1, Great Sandy 1, Leo 1, Percival 1, Pictor 1 and 2, and Solanum 1. Suprasalt Upper Devonian sourced oil is producing from the Blina field, and oil shows are present in Boronia 1, Ellendale 1, and Janpam 1. Suprasalt Lower Carboniferous sourced oil is producing at the Boundary, Lloyd, Sundown, West Kora, and West Terrace fields and a gas accumulation is present at Point Torment 1. These petroleum systems are part of the Australia-wide Larapintine 2 (Ordovician), 3 (Devonian), and 4 (Early Carboniferous) and Larapintine–Gondwanan Transition petroleum supersystems (Bradshaw et al., 1994). Figure 2 summarizes preserved stratigraphy, oil and gas distribution, major tectonic events, rock units intersected in the four modelled wells, petroleum supersystems, timing of paleothermal episodes, and source rock characteristics.

The depositional and erosional history of the Canning Basin commenced with extension and rapid subsidence in the Early Ordovician, followed by four major and several minor phases of deposition and erosion that were responsible for evolution and preservation of at least three petroleum systems: Ordovician, Devonian, and Permian. Major tectonic events responsible for the depositional and erosional histories of the basin include the Samphire Marsh extension preceding Ordovician to Silurian deposition, Devonian Prices Creek Compression prior to Devonian to Lower Carboniferous deposition, Carboniferous Meda transpression before Lower Carboniferous to Lower Triassic deposition, Triassic–Jurassic Fitzroy transpression preceding Jurassic to Lower Cretaceous deposition, and finally Jurassic–Cretaceous extension.

Figure 2b summarizes source rock generating potential and measured maturity from new and open-file data. These indicate the presence of organic-rich, oil-prone source rock intervals within the Ordovician, Devonian, Carboniferous, and Permian, with source rock richness and oil-proneness generally decreases from Ordovician to Permian. The interpretation of over 5968 open-file total organic carbon content (TOC)

from 138 wells and 1762 Rock-Eval pyrolysis analyses from 109 wells indicate that most of the analyses are either not from source rock intervals, or were contaminated by migrating oil or during drilling operations. Of these TOC and Rock-Eval data, only 106 samples from 37 wells are interpreted as reliable and most of these are from the Ordovician Goldwyer and Bongabinni Formations. These formations contain the richest oil-prone source rocks in the basin, with the richest analyses in each unit from wells on the Barbwire Terrace and Admiral Bay Fault Zone, respectively. Our new spot check analyses include 73 TOC, 26 Rock-Eval pyrolysis, 8 extract analyses for source rock potential, and 30 organic petrological analyses for source maturity.

Figure 3 displays geothermal history and time of charge as a function of petroleum generation rate at Acacia 1 and 2, Kidson 1, Willara 1, and Yulleroo 1 well locations. The geothermal history as a function of maximum paleotemperature and the timing of cooling within these wells are constrained by 14 new apatite fission track analysis (AFTA) and 30 new vitrinite reflectance (VR) analyses undertaken (Duddy et al., 2006). These data identify, characterize and quantify heating and cooling episodes that affected the preserved stratigraphy in the four modelled wells and provided key constraints on the heat flow, burial and source rock maturation histories at these locations.

The source maturation history at Acacia 1 and 2 on the Barbwire Terrace is constrained by two paleothermal episodes of cooling from the maximum temperature, recognised from the AFTA and VR data, indicating maximum generation rate during the Triassic. However, the Goldwyer Formation is immature to marginally mature in these wells (Figure 3a), as it is elsewhere on the Barbwire Terrace due to comparatively shallow depth of burial when compared to adjacent basinal areas of the Fitzroy Trough and Gregory sub-basin to the north and Kidson, and Willara sub-basins to the south.

At Kidson 1 within the Kidson Sub-basin, three paleothermal cooling episodes from maximum temperatures are recognised and the geothermal history indicates that maximum generation rate from Ordovician source rocks occurred during the Permian. However, the Goldwyer and Bongabinni Formations are overmature in this well. In contrast, the maximum generation rate from Devonian source rocks occurred during the Jurassic, and the Devonian Mellingerie Formation is mature for oil generation in Kidson 1 (Figure 3b). Source rock evaluation data available from Kidson 1 are unreliable due to contamination, most probably during the drilling operation.

For Willara 1 within the Willara Sub-basin, only one paleothermal episode is recognised for cooling from maximum temperatures, and its source maturation history indicates that maximum generation rate for Ordovician source rocks occurred first during the Permian, then during the Cenozoic. The Goldwyer and Bongabinni Formations are marginally mature to mature in this well (Figure 3c). Although 223 TOC and Rock-Eval pyrolysis analyses are available for Willara 1, none is characterised as a source rock, except one highly organic-rich sample within the immature Permian.

At Yulleroo 1 within the Fitzroy Trough, three paleothermal episodes involving cooling from maximum temperatures are recognised, with maximum generation rate for Upper Devonian source rocks occurring during the Carboniferous, and for Lower

Carboniferous source rocks, during the Permian. The Upper Devonian succession is overmature and Lower Carboniferous succession (Unit B) is mature at this location (Figure 3d). However, good oil-prone source rocks are not recognised in this well from the available TOC and Rock-Eval data.

To evaluate the oil occurrences within reservoir lithologies, 100 potential reservoir rock samples from Acacia 1, Dodonea 1 and 2, Looma 1, White Hills 1, and Yulleroo 1 were analysed using new techniques that measure Quantitative Grain Fluorescence (QGF) and Quantitative Grain Fluorescence-Extract (QGF-E). These are extremely sensitive in determining the presence of microscopic amounts of oil in reservoir rocks and migration pathways. From QGF-E intensity, depth profiles, and spectral characteristics, Liu and Fenton (2005) recognised several intervals representing either residual reservoir oil or migration pathways in all of these wells. This initial reservoir evaluation, though tentative at this stage, indicates generation and migration of petroleum in these areas and provides incentives for further studies.

This review concludes that oil and gas is geographically and stratigraphically widespread, the timing of petroleum charge varies greatly across the basin, and the quantity and quality of existing source-rock evaluation data for the Willara and Kidson Sub-basins are limited for determining source-rock distribution and charge volume risks. The timing of charge for Ordovician source rocks varies from Early Permian in Kidson 1 to Early Jurassic in Acacia 1 and 2. For Devonian source rocks, it varies from Early Carboniferous in Yulleroo 1, where gas was recovered, to Early Jurassic in Kidson 1.

The exploration history of the underexplored Canning Basin shows a direct correlation between drilling activity and discoveries, with peak exploration drilling and discoveries made during the 1980s (Figure 4). The low level of exploration and wide geographic and stratigraphic distribution of oil and gas, demonstrate the high potential for significant new oil discoveries. However, this requires further systematic studies of key risk factors in different tectonic units, including source (Gregory, Kidson, and Willara sub-basins), reservoir (subsalt plays) and seal (suprasalt plays) distribution and quality, timing of trap formation versus generation – accumulation (Gregory Sub-basin), and its preservation (Fitzroy Trough).

KEYWORDS: petroleum system, source rock, petroleum generation, Paleozoic, Ordovician, Devonian, Carboniferous, Canning Basin, Western Australia.

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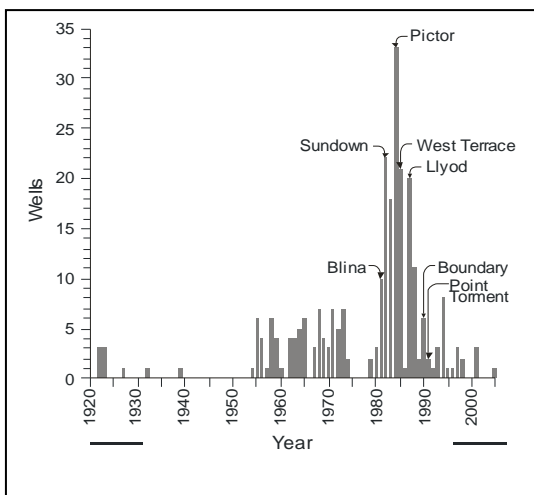
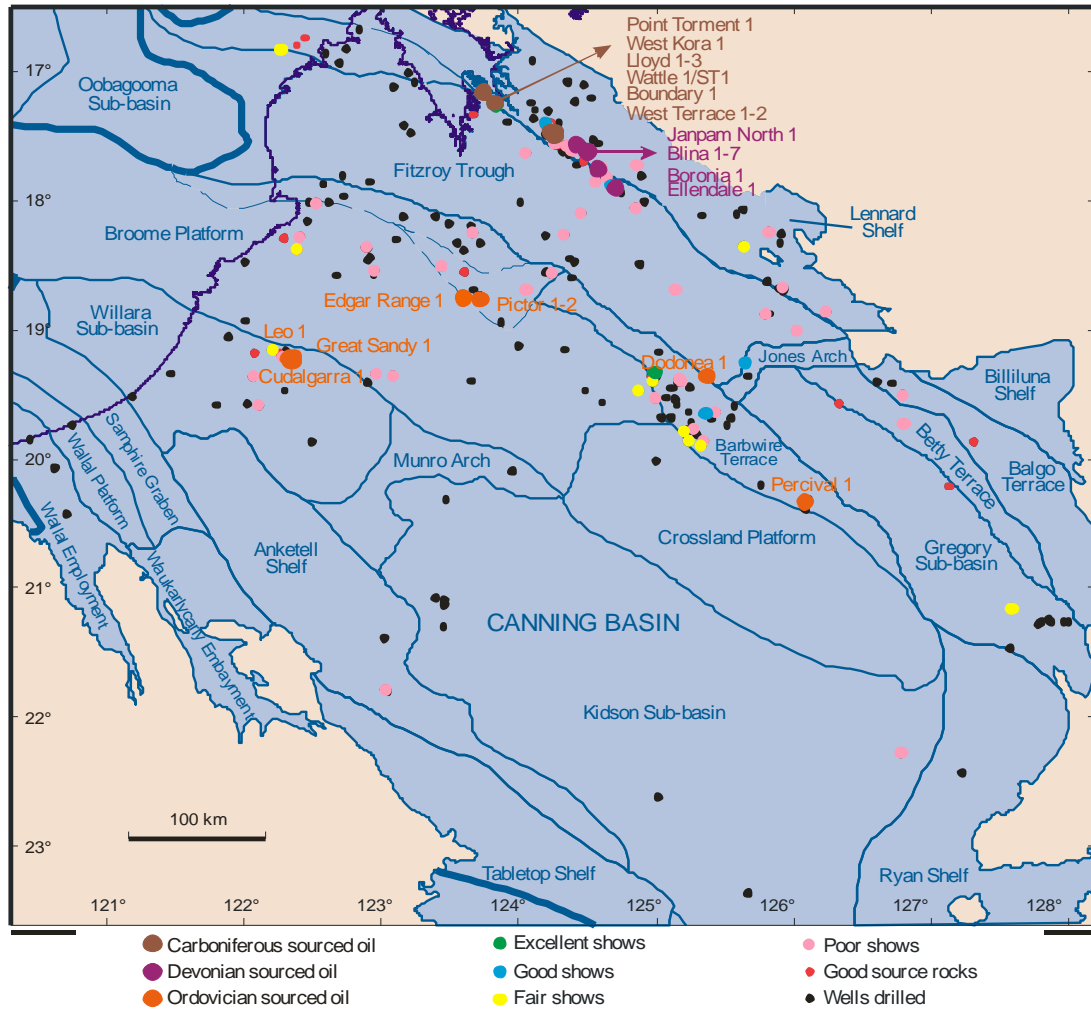


Figure 1. Ordovician, Devonian, and Carboniferous sourced petroleum systems, poor to excellent oil and gas shows, and wells drilled within the onshore Canning Basin.

Figure 4. Drilling and discovery histories of the Canning Basin from 1920 to 2005.

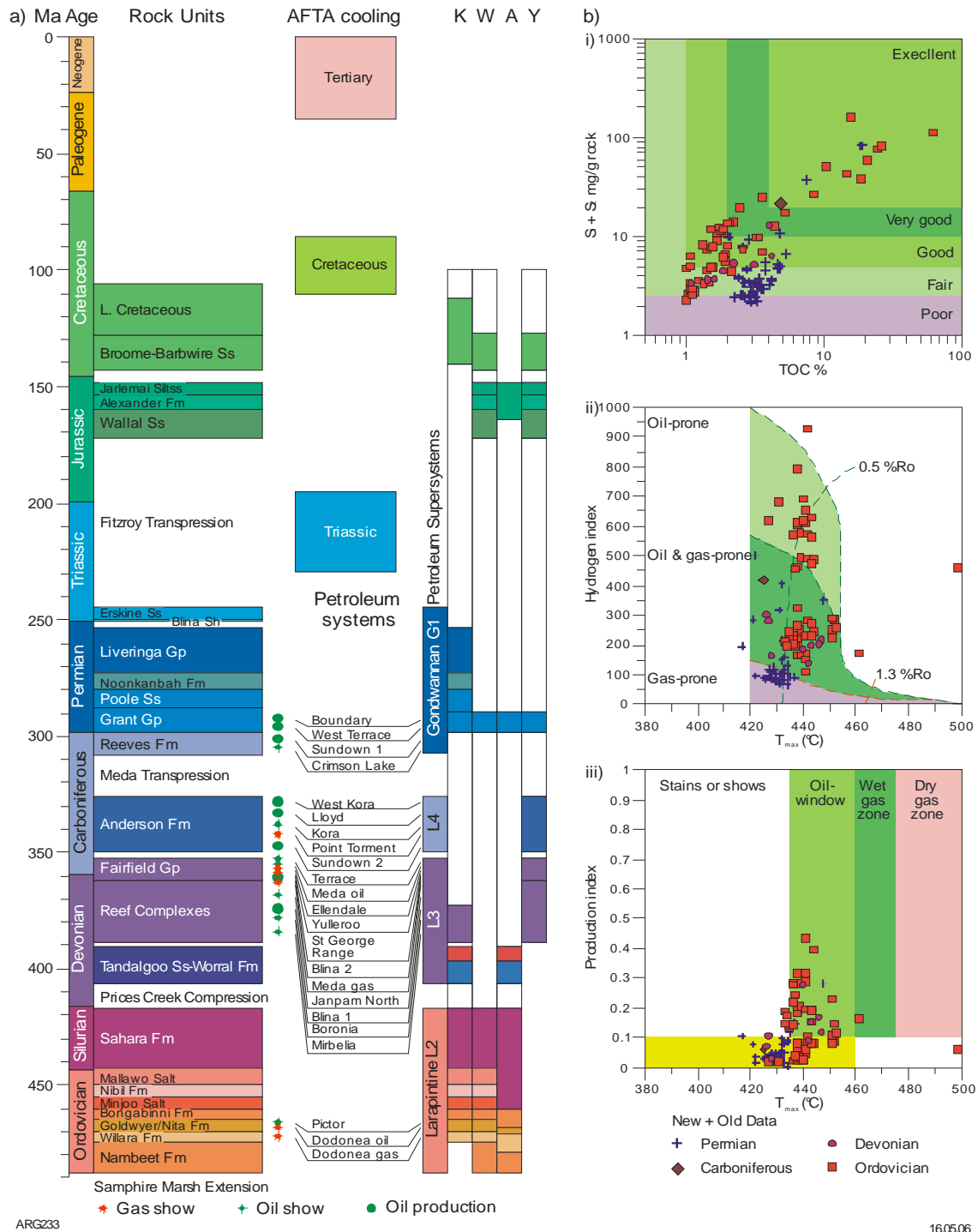


Figure 2. Canning Basin stratigraphy and source rock potential: a) generalised time-stratigraphy, rock units, oil production, oil and gas shows, and rock units present within Yulleroo 1 (Y), Acacia 1 and 2 (A), Kidson 1 (K), and Willara 1 (W) wells used for petroleum generation history reconstructions; b) organic richness, facies and maturity of Permian, Carboniferous, Devonian, and Ordovician successions within the Canning Basin, : i) generating potential, organic richness versus potential yield; ii) organic facies from RE, T_{max} versus hydrogen index; iii) thermal maturity from RE, T_{max} versus production index.

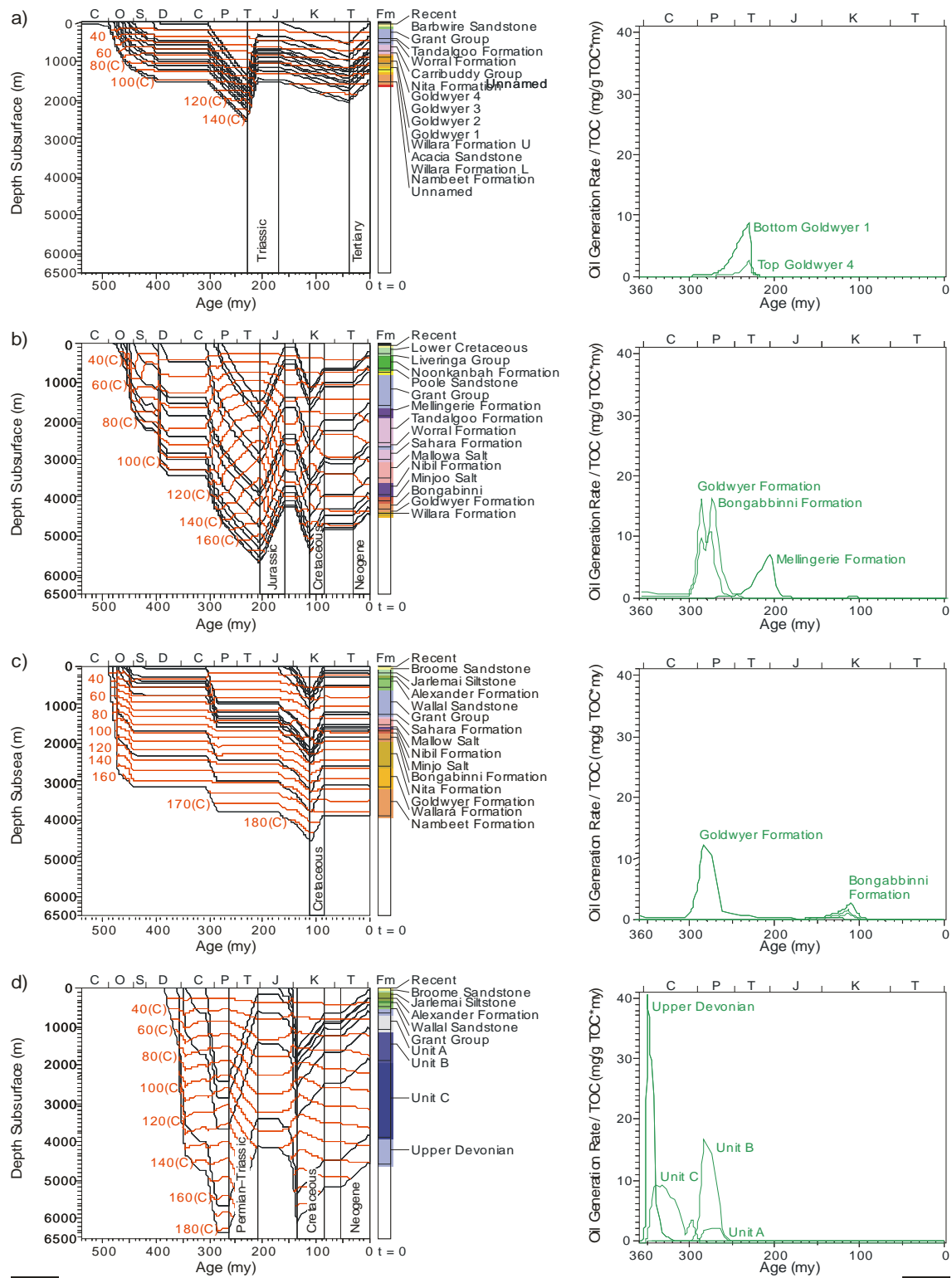


Figure 3. Deposition, erosion, and petroleum charge histories as a function of preserved stratigraphy and lithology, source rock richness and quality, magnitude and number of paleothermal episodes: a) Acacia 1 and 2 combined; b) Kidson 1; c) Willara 1; d) Yulleroo 1.