



Government of **Western Australia**
Department of **Mines, Industry Regulation**
and **Safety**

RECORD 2019/10

COAL RESOURCES OF THE CANNING BASIN, WESTERN AUSTRALIA: EXPLORATION AND EVALUATION HISTORY

by

SL Simons



Geological Survey of Western Australia



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PERTH 2019



**Geological Survey of
Western Australia**

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Coal resources of the Canning Basin, Western Australia: exploration and evaluation history

by

SL Simons

Abstract

This Record collates the exploration and evaluation history of coal resources in the Canning Basin, Western Australia. Permian coal occurs within the Lightjack Formation that is mostly limited to the northwestern part of the basin, primarily in the Fitzroy Trough. The coal is generally in two laterally extensive and consistent coal seams about 2 m thick, separated by several metres of sandstone, siltstone and mudstone. The seams locally converge to form a single coaly sequence up to 15 m thick. The depth of the coal varies from essentially surficial (5–15 m of cover) to depths exceeding 1 km. Due to the need for coal to smelt the Pilbara iron ores, combined with the demand for coal from overseas, extensive exploration in the region took place during the 1960s to 1980s. Targeted exploration recommenced in the late 2000s and one deposit, Duchess–Paradise, has resource estimates reported according to the JORC code (2012). The Canning Basin coal is classified as sub-bituminous with high sulfur, due to the presence of pyrite and marcasite, and moderate to high ash, and is a low to moderate energy coal.

KEYWORDS: Canning Basin, coal deposits, coal exploration, coal resources, Permian

Introduction

Some of the first coal discovered in the Canning Basin was in the early 1900s. Additional minor coal occurrences were noted in petroleum wells from the mid-1950s onwards. The most active period of coal exploration occurred in the late 1960s and early 1980s, which led to several discoveries of Permian sub-bituminous coal in the Fitzroy Trough.

This Record collates the exploration and evaluation history of coal resources in the Canning Basin in Western Australia (Fig. 1). Information sources include both published and unpublished data. Published information was derived from Geological Survey of Western Australia (GSWA) publications, scientific journals and conference proceedings. Geological descriptions of the deposits and reported coal intersections have, in most cases, been taken directly from the explorer's original reporting.

Unpublished information comes from statutory exploration reports held by the Department of Mines, Industry Regulation and Safety (DMIRS) within the Western Australian mineral exploration database (WAMEX) and the Western Australian petroleum and geothermal information management system (WAPIMS). This information has been supplemented by reports and media releases to the Australian Securities Exchange (ASX), including company annual and quarterly reporting, and university theses.

Due to changes in prospective areas and their perceived extent over time, and name changes applied by different companies, names allocated by the original explorers are maintained in this report to avoid confusion. Drillhole details were extracted from open-file reports where

available, and where necessary, coordinates converted to GDA94 using the GDAit transformation software or by georeferenced maps (in GDA94) in ArcGIS. The scale and quality of the original maps varies greatly, both over time and between companies, and consequently the accuracy of the collar locations is highly variable. Drillhole locations and details are available from the DMIRS Data and Software Centre at <www.dmp.wa.gov.au/datacentre> as a data package associated with this Record.

Unless otherwise specifically stated, resource figures do not comply with reporting requirements of the Joint Ore Reserves Committee Australian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code), most recently revised in 2012. If resources were originally reported as complying with an earlier version of the JORC Code, then that particular JORC Code version is referenced.

Regional geological setting

The Canning Basin is an intracratonic rift basin covering approximately 700 000 km² of northern Western Australia, of which 165 000 km² occurs offshore (Mory and Hocking, 2011). Structurally, the basin comprises two major northwest–southeast trending depocentres, separated by mid-basinal platforms and flanked by a series of shelves and terraces (Fig. 2). These flanking regions extend to the Mesozoic Bight and Cenozoic Eucla Basins. Basin formation began in the early Ordovician and development proceeded as the result of a series of major tectonic events (Fig. 3) (Shaw et al., 1994; Parra-Garcia et al., 2014). Basin

subdivisions are commonly fault-bounded (Figs 2, 4), and are covered in more detail by Hocking (1994). Much of the structure and stratigraphy of the basin has been interpreted from subsurface data, because of the extensive Cenozoic sedimentary cover.

Basin fill from the Lower Ordovician to Lower Cretaceous (Forman and Wales, 1981; Towner and Gibson, 1983; Yeates et al., 1984), was deposited in four major depositional cycles, the details of which are presented in Kennard et al. (1994). In the northern part of the basin, the Fitzroy Trough contains up to 15 km of sedimentary rocks. Devonian to Middle Triassic strata comprise the thickest deposits in this section, although the exact thickness of pre-Devonian strata is unknown, as it has not yet been intersected by drilling. In the southern part of the basin, in the Willara and Kidson Sub-basins, the fill is dominated by Ordovician to Silurian strata that are up to 5 km thick and overlain by Devonian to Jurassic rocks. Southwest of the Willara Sub-basin, the Devonian to Lower Cretaceous section is thin, generally less than 1 km thick, but subsurface control is poor (Zhan, 2018).

Known coal deposits in the Canning Basin are most significant in the Fitzroy Trough. Post-Permian uplift resulting from Late Triassic to Early Jurassic tectonism has strongly influenced coal exploration in this area. Four main anticlines are present in the Fitzroy Trough: The Sisters, Grant Range – Mount Wynne, Deep Well and Nerrima

Anticlines (Fig. 2). Significant coal is present at the Grant Range – Mount Wynne Anticline and the nearby St George Range Anticline. Exploration drilling shows that the coal-bearing sequence continues along the northern limb of the Quanbun Syncline, east of the Mount Wynne Anticline. The southern limb of the St George Range Anticline and deeper sections of the Deep Well Anticline also contain minor coal, and petroleum wells have recorded coal in the Sisters Anticline (Cornelius, 2010).

Stratigraphic distribution of coal

Coal has been recorded in several stratigraphic units within the Canning Basin of which the most significant are in the Lightjack Formation, Condren Sandstone and Hardman Formation of the Middle to Upper Permian Liveringa Group (Fig. 3). Minor occurrences are also present in the Lower Carboniferous Fairfield Group and Laurel and Anderson Formations; the Lower Permian Grant Group, Poole Sandstone and Noonkanbah Formation; and the Upper Jurassic to Lower Cretaceous Jarlemai Siltstone, as well as possible lignite in the middle Jurassic Wallal Sandstone (Galloway and Howell, 1975; Yeates et al., 1975b; Gibson et al., 1980; Towner 1981; Cornelius et al., 2011; Ringrose, 2012).

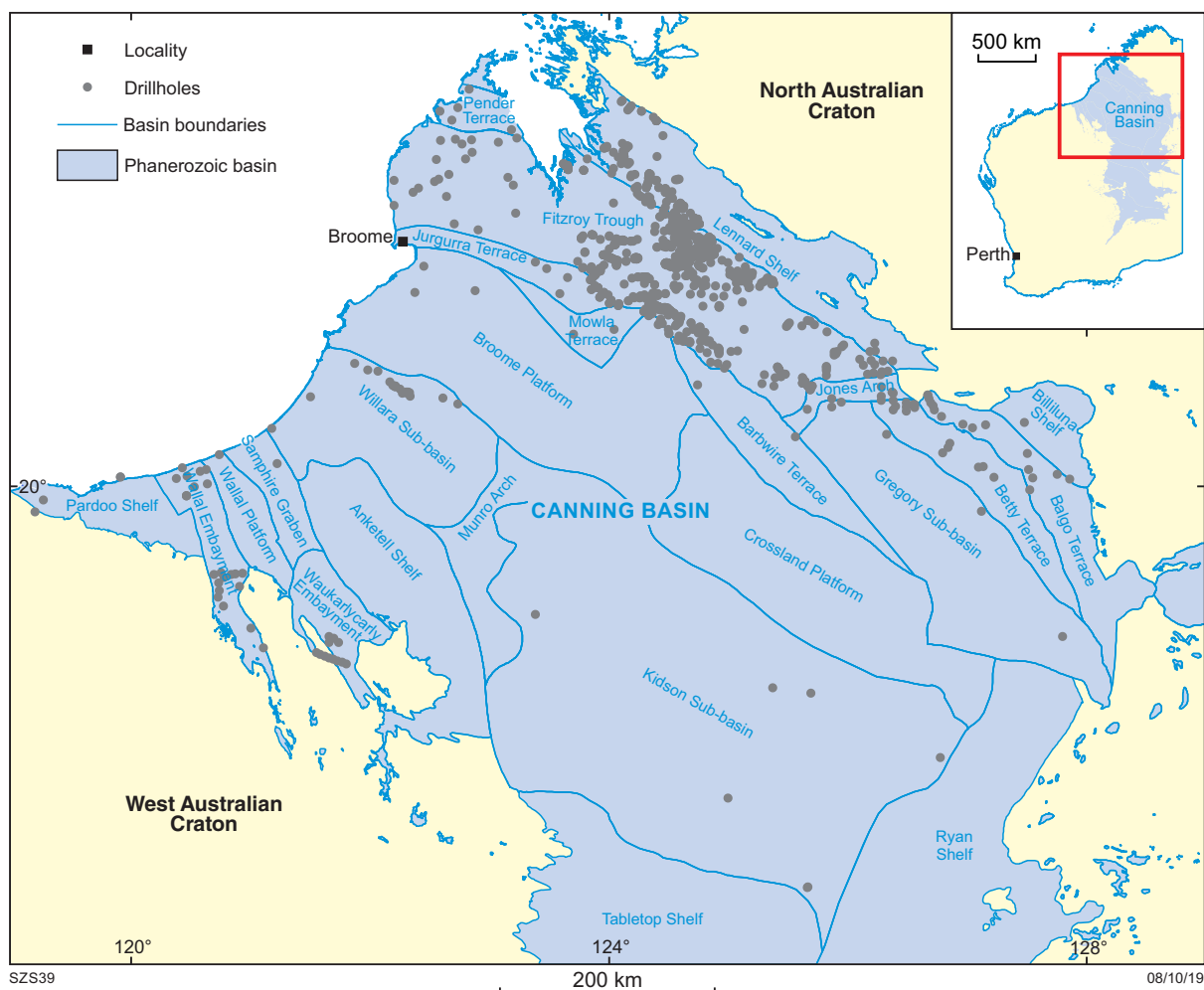


Figure 1. Location of coal exploration drillholes in the Canning Basin

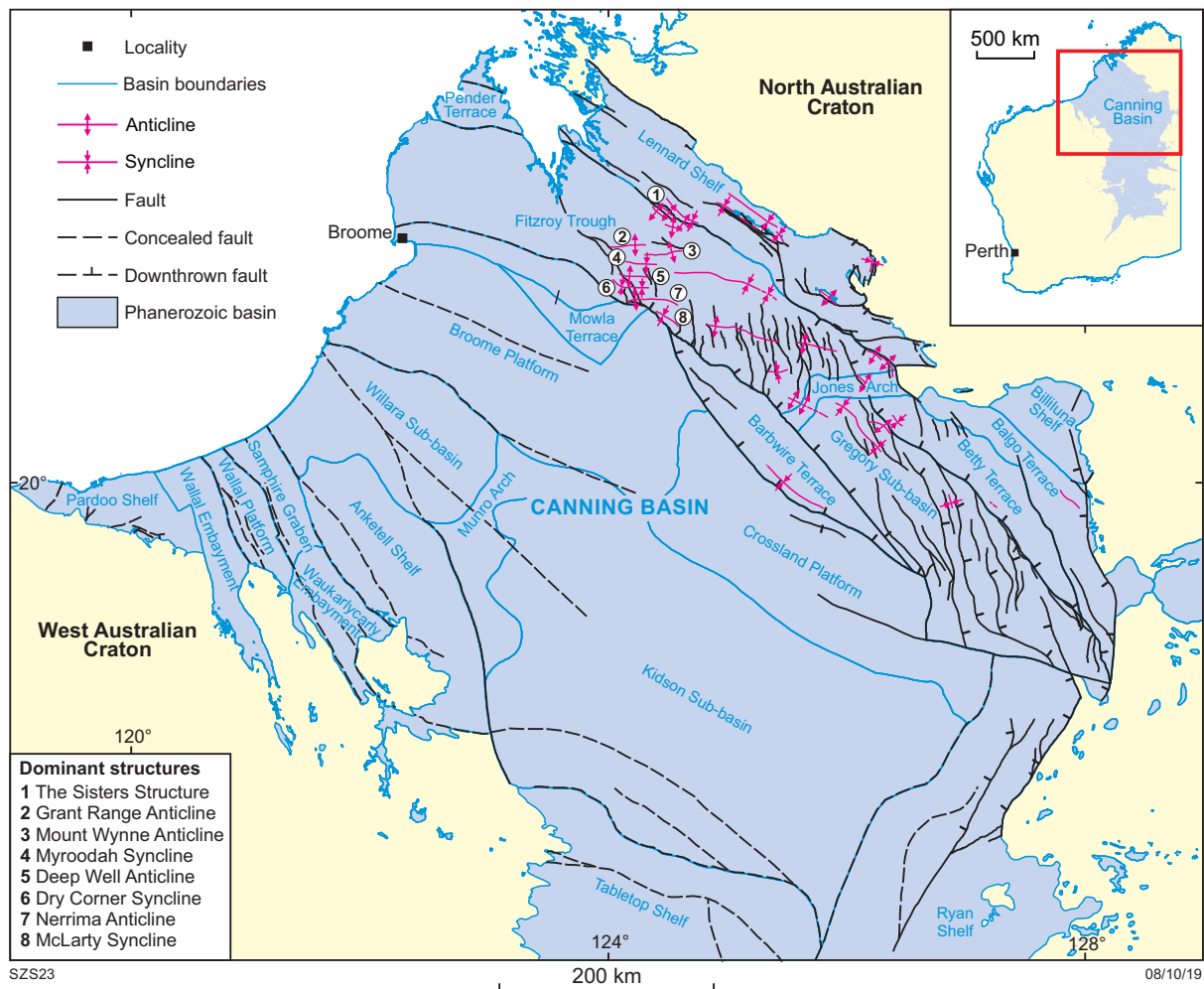


Figure 2. Canning Basin location map of onshore tectonic subdivisions and major structures after Hocking (1994)

Significant coal intersections are limited to the northwestern part of the basin, primarily in the Fitzroy Trough within the Lightjack Formation, which contains seams up to 4 m thick. The formation (and the entire Liveringa Group), and its equivalents in the south of the basin (Triwhite Sandstone), are absent in the central sub-basins including the Broome–Crossland Platform, Jurgurra–Mowla Terrace and Willara Sub-basin (Mory, 2010). Pre-Jurassic strata, including the Lightjack Formation, are folded and preserved at various depths in the northwestern part of the Fitzroy Trough; however, the formation has been removed by Mesozoic erosion across the crests of the large anticlines (Fig. 5).

Within the 100–300 m thick Lightjack Formation, the coal-bearing succession is up to 40 m thick about 50 m above the underlying Noonkanbah Formation. Previous work has shown that the coal has a consistent stratigraphic position within the Lightjack Formation. Where present, the coal-bearing succession usually contains either one thick seam, or an upper ‘A’ (or ‘P1’) seam and a lower ‘B’ (or ‘P2’) seam, up to 25 m apart (Sheppard, 2014). The A seam is up to 4 m thick on Liveringa Station and contains few, if any, interbeds, whereas the B seam is up to 10 m thick in the McLarty Syncline but contains numerous siliciclastic

and tuffaceous bands (Familiar and Bradbury, 2013). The seam thicknesses however, are variable (Sheppard, 2014), especially within the lower interval, which is better referred to as ‘coal measures’ than a seam.

Depositional environment

The Liveringa Group was deposited in fluvial to shallow-marine environments, including lagoonal and deltaic settings, and records the regression of a shallow sea across the basin during the Early Permian (Dent, 2017). The Lightjack Formation is generally interpreted as a regressive shallow-marine facies within a shallowing-up sequence conformable with the underlying Noonkanbah Formation (Veevers and Wells, 1961; Yeates et al., 1975a; Forman and Wales, 1981; Towner and Gibson, 1983). Foraminifera, brachiopods, goniatites and conodonts in the Lightjack and Hardman Formations indicate shallow-marine conditions for some intervals, but the general lack of macrofossils suggests that seasonally variable brackish to non-marine conditions dominated during deposition of the group (Mory and Hocking, 2011).

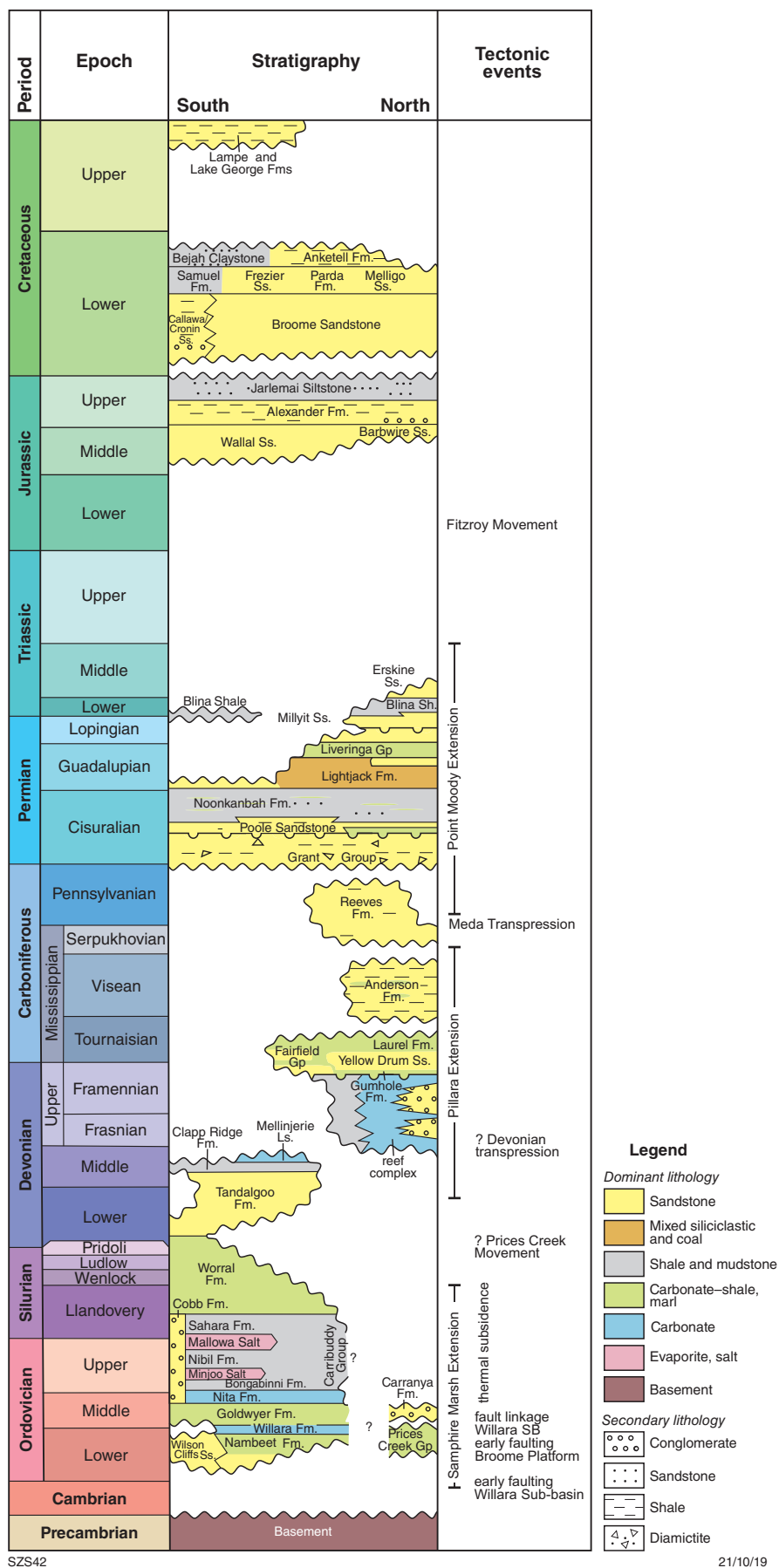
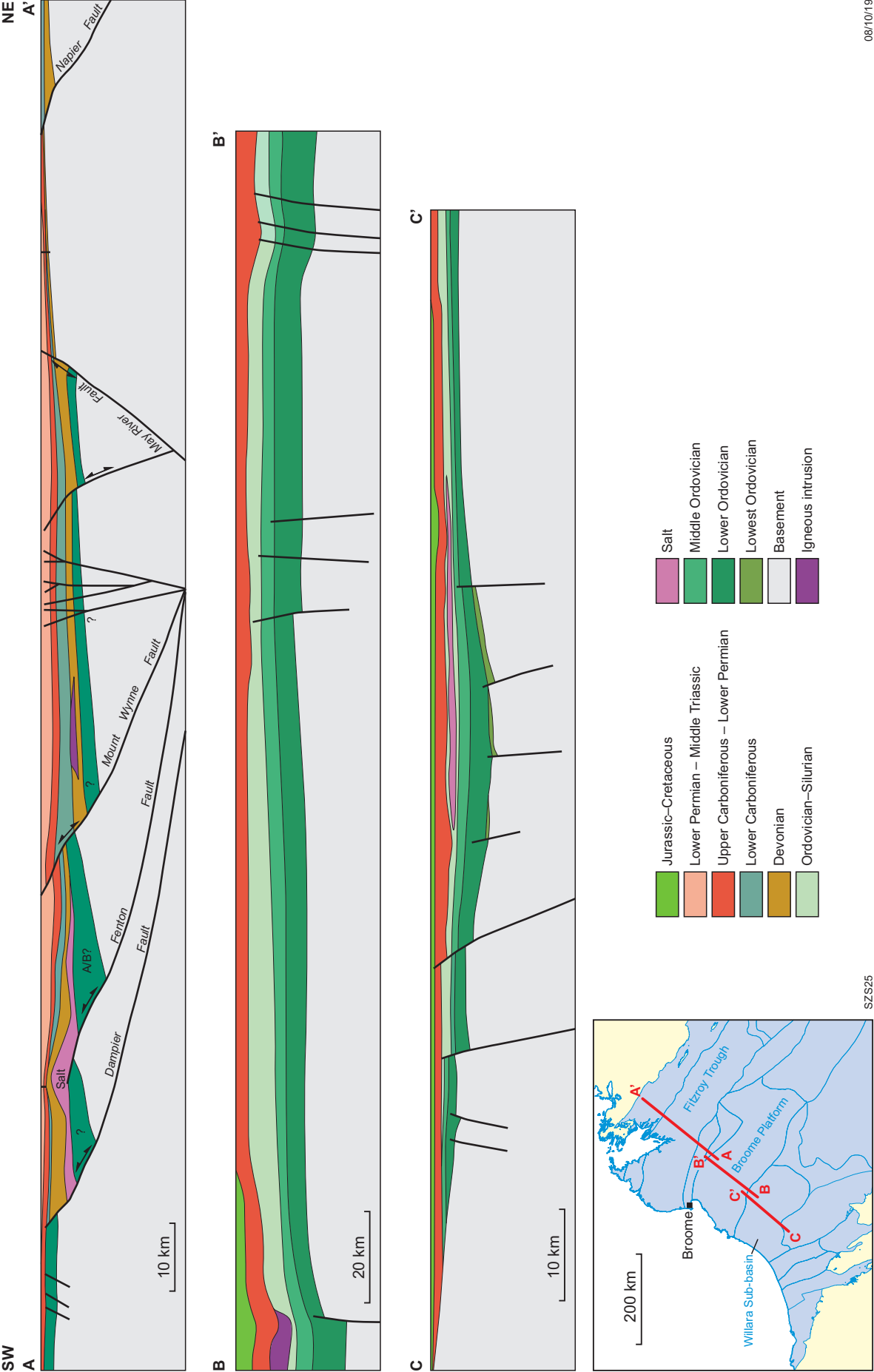


Figure 3. Summary of Ordovician–Cretaceous stratigraphy of the Canning Basin, adapted from Mory and Hocking (2011) and tectonic events after Parra-Garcia et al. (2014)



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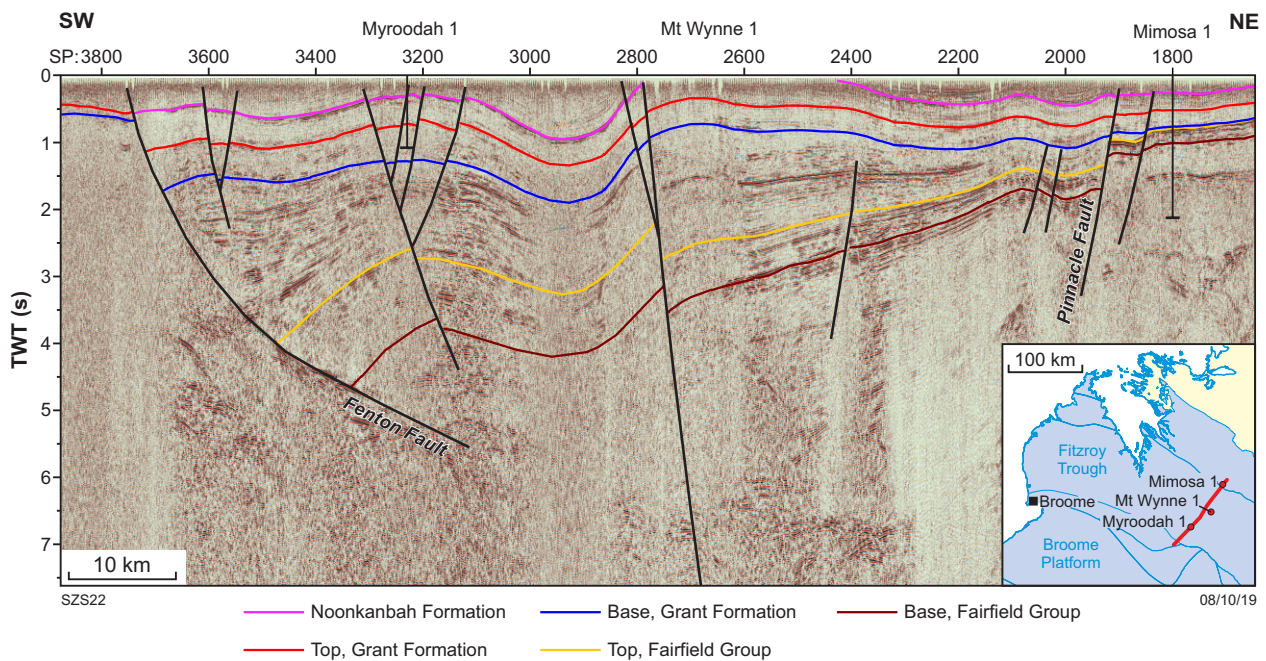


Figure 5. Regional seismic interpretation across the Fitzroy Trough after Zhan and Mory (2013). Abbreviation: TWT, two-way time, in seconds

Biostratigraphy

In a summary of marine faunas, including ammonoids, brachiopods and bivalves, Archbold (2002) indicated a Guadalupian (Middle Permian) age for the Lightjack Formation. By comparison, Backhouse (2007, in Mory, 2010) records Middle to Late Permian palynofloral assemblages of the *Dulhuntyispora granulate* to *Dulhuntyispora parvithola* Zones from the formation. The upper age limit of the formation is poorly constrained as the *D. parvithola* Zone also extends into the overlying Condren Sandstone and Hardman Formation (Dent, 2017).

Coal quality and utilization

Historic data relating to coal quality can be unreliable as the quality of sampling varies. Nevertheless, previous exploration shows that in its raw state, the coal is low to medium rank (Galloway and Howell, 1975; Ringrose, 2012), sub-bituminous (Sheppard, 2014) with high sulfur due to the presence of pyrite and marcasite, and moderate to high ash, that is, it is a low to moderate energy coal (Cornelius, 2010). Vitrinite reflectance values range from 0.27% to 0.58%, indicating that it is unsuitable for use as a coking coal. Wash test results suggest that the coal could be used as a thermal product such as feedstock for power generation (Blackfin Pty Ltd, 2005; Cornelius et al., 2011; Ringrose, 2012).

Resources

In the Canning Basin, the only deposit for which JORC-compliant resource estimates are available is Duchess–Paradise. There, in accordance with the 2012 edition of the

JORC Code, Rey Resources Limited calculated that the P1 seam contains 305.8 Mt in situ, with Reserves of 26.3 Mt (run-of-mine, as received [ar]), which, after beneficiation, represents a marketable Reserve (ar) of 17.8 Mt (Table 1) (Rey Resources Limited, 2014).

Geophysics

Numerous regional-scale geophysical datasets across the Canning Basin include radiometric, magnetic, gravity and seismic reflection profiles. Although seismic reflection profiles can provide an approximation of the depth to the coal, the majority of 2D seismic surveys were for petroleum exploration and therefore either inadequately imaged shallow, coal-bearing formations or did not include shallow data. Wireline logs have been acquired in many of the exploratory holes across the region.

Previous exploration

Some of the first coal seams discovered in the Canning Basin were from a water well drilled on Lower Liveringa Station, north of Mount Anderson in 1909 (GSWA, 1910; Woodward, 1915; Blatchford, 1927). The seam was estimated to be 12 feet thick at a depth of 50 feet, and was described by Woodward (1915) as ‘a seam of hydrous bituminous non-coking coal’. Analysis of the clean coal is presented in Table 2.

In 1921, coal was reported from the Jarlemai Siltstone near Babrongan Tower (Department of Industry and Resources historical tenement register; Hassan, 2004 and references therein). Additional minor coal occurrences from this unit have been noted in petroleum wells from the mid-1950s onwards.

Table 1. Duchess–Paradise P1 seam resources (in place, with in situ moisture) from 28 October 2014 (JORC, 2012) (Rey Resources Limited, 2014). Some values do not sum due to rounding

Measured (Mt)	Indicated (Mt)	Inferred (interpolated) (Mt)	Inferred (extrapolated) (Mt)	Total Inferred (Mt)	Total (Mt)
60.2	78.5	51.3	115.7	167.1	305.8

Table 2. Analysis of coal from water well drilled on Lower Liveringa Station (Woodward, 1915)

Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)
11.71	37.81	36.92	13.56

From 1965 to the early 1980s, exploration for coal peaked due to the desire to smelt Pilbara iron ores locally, and the demand for coal from overseas (Lord, 1975). Exploration accelerated following increased demand for thermal coal during the 1970s energy crisis. In the Canning Basin, this activity largely focused on the Fitzroy Trough, followed by the Anketell and Lennard Shelves and Betty Terrace, where coal had been recorded in numerous petroleum wells. By comparison, the Broome Platform and Willara and Kidson Sub-Basins were overlooked by coal explorers. Extensive low-grade deposits were drilled at Audreys Bore by Premier Mining Company Co. Pty Ltd (Baarda, 1966), at Myroodah by Thiess Brothers Pty Ltd (Pickering, 1968), at Liveringa Ridge by Australian Inland Exploration Company Co. Ltd (AIE) and Texasgulf Australia Ltd (Gair, 1972; Lee et al., 1980), and at Mount Fenton (The Broken Hill Proprietary Company Limited Australia, 1978). This exploration delineated a few small low-rank deposits; however, none were large enough to progress to a mineable stage. The poor results, and the worldwide downturn in demand for coal in the 1980s, discouraged further work in the region.

Since the early 2000s, there has been a resurgence in coal exploration in the Fitzroy Trough, with Rey Resources, Blackfin and Rio Tinto Exploration Pty Limited conducting extensive drilling campaigns. Despite these campaigns and exploration by several other companies, only Rey Resources produced a JORC resource statement (Rey Resources Limited, 2014).

Premier Mining Co. Pty Ltd (1965–66)

Tenements held by Premier over both the Fitzroy Trough and the Lennard Shelf originally relied on coal recorded at Lower Liveringa Well, in the Myroodah 1, Meda 1 and Langoora 1 petroleum wells, and in drillers logs of water bores. In 1965, the company drilled eight holes around the Lower Liveringa Well, with only one hole (Liveringa 3) intersecting coal to a maximum thickness of 8 inches between layers of bituminous shale (Baarda, 1966) (Fig. 6). Proximate analysis of this coal is presented in Table 3.

In 1966, Premier drilled 104 boreholes within the Lightjack Formation. Several of the boreholes were too shallow to test for the coal horizons, particularly northwest of the

Meda River although some of the drilling was scouting in nature as the geology of the region was not well understood at the time. The thickest coal seam intersected was 0.8 – 2.25 m thick on the Paradise temporary reserve (TR 3431H) and 1.32 – 1.93 m thick on the Duchess temporary reserve (TR 3432H) (Baarda, 1966). The seam at Paradise was described by Premier Mining as persistent and sub-bituminous, at depths of approximately 20 m, and extending 6.5 km along strike and weathered to clay above the water table (Baarda, 1966). A second coal seam identified approximately 9 m below the first seam contained 60 cm of impure coal (Baarda, 1966). Premier Mining concluded that the coal measures were widespread and persistent within the Lower Liveringa Group. Nevertheless, the company recognized that seam thickness varied and distinguished three types of coal occurrences (Baarda, 1966):

- Trace coal (laminae) and carbonized black and lignitic brown plant fragments.
- A ‘coal zone’ consisting of interbedded and interlaminated coal and clay with occasional, relatively uninterrupted seams of coal up to 0.9 m thick. This coal is mainly black, finely laminated and the thickness of this zone varies; however, the thickest occurrence is 7 m.
- A seam 0.9 – 2 m thick with only minor clay. This coal is mostly black, hard, sub-bituminous and high ash with a conchoidal fracture and a well-developed cleat (Baarda, 1966).

Premier reported dips of up to 6° and a relative density of 1.45 for the Paradise core samples (Baarda, 1966). The high sulfur is due to the presence of pyrite and marcasite (Piggot, 2009). Within the tenement containing the Paradise deposit, Premier Mining reported a coal reserve of 10 Mt to a depth of 45.7 m; however, at this depth, the ratio of overburden to coal (34:1) is very high (Baarda, 1966). Reserves of around 46 Mt are estimated at a vertical depth of 152 m, assuming a continued down-dip extension of the seam (Baarda, 1966).

Thiess Bros Pty Ltd (1966–67)

Thiess Bros began a test drilling exploration program in 1966 (Lowry, 1967; Ward, 1968), with the Liveringa Group and the Poole Sandstone as the main targets (Fig. 7). Although nine holes were drilled into the Poole Sandstone (Lukins 1–4 and Invasion 1–5), no coal was intersected (Ward, 1968). Of the ten holes drilled in the Liveringa Group (Myroodah 1–9, including 5 and 5A), six intersected about 15 m of coal measures (Ward, 1968) at depths between 21 and 41.4 m. The maximum thickness of coal recovered in a single hole was approximately 55 cm (Ward, 1968). Their coal analyses (table b) included a sample from Myroodah 2 noted as being contaminated.

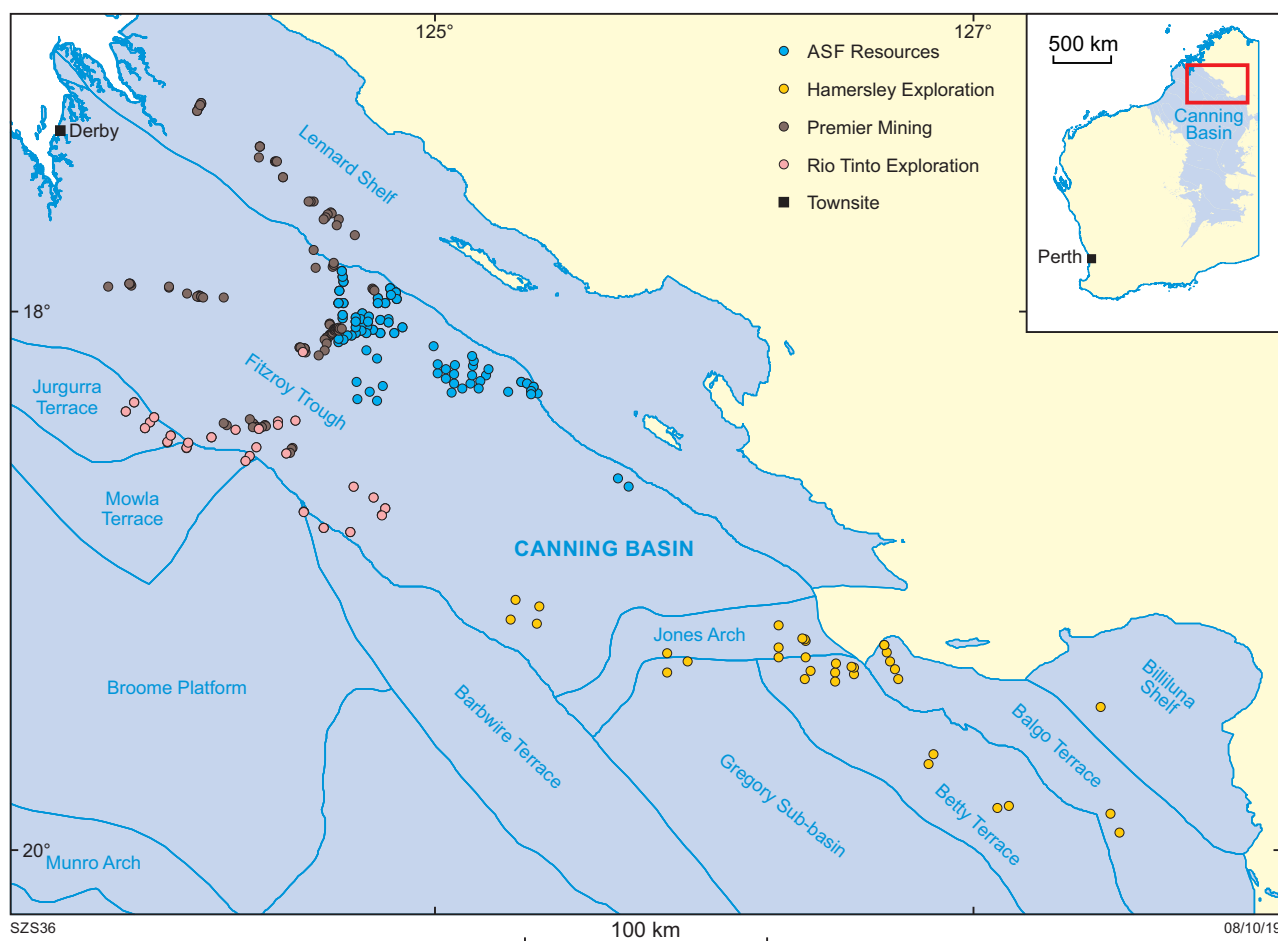


Figure 6. Location of holes drilled by companies: ASF Resources, Hamersley Exploration, Premier Mining and Rio Tinto Exploration

Table 3. Proximate analysis of coal from Liveringa 3 drilled by Premier Mining Company (Baarda, 1966). Abbreviation: BTU, British thermal units

Moisture (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)	Calculated value, moist (BTU)	Calculated value, dry (BTU)
20.00	27.40	16.00	36.30	8780	13 400

In 1967, the company drilled a further 18 holes in the Myroodah area to determine the extent and variation in grade of the coal measures. The thickness of the coal-bearing interval was generally constant at approximately 15 m, although thinner seams had a higher ash content than the thicker seams (Pickering, 1968). The thickest seam intersected was 70 cm and contained 20% moisture, 20.8% volatile matter, 27.6% fixed carbon, and 31.6% ash as calculated on a 20% moisture basis (Pickering, 1968). The interpreted extent of the coal from the drilling was 2.13 km strike length, and 914 m down dip (Pickering, 1968), from which approximately 1.1 million m³ of coal was calculated, assuming 50% coal within the coal measures (Pickering, 1968).

Australian Inland Exploration Co. Ltd (1970–72)

Australian Inland Exploration drilled for coal in the Fitzroy Trough of the Canning Basin between 1971 and 1972

(Fig. 8) (Gair, 1972). The company initially drilled down dip from previous occurrences reported by Premier Mining at Paradise in order to test the entire thickness of the Liveringa Group. Six stratigraphic diamond drillcore holes were drilled at Paradise in 1971, establishing the presence of a single seam of coal between 0.7 and 1.3 m thick within a gross coal measures interval of about 15 m (Gair, 1972). Further drilling of the Liveringa Group in nearly 100 holes in 17 locations showed the coal seam thickness ranges from less than 1 m in the east to 30 m approximately 190 km west at Liveringa Ridge on the south side of the Grant Range (Gair, 1972). From Liveringa Ridge, the coal measures thin rapidly to the west (Gair, 1972). The coal seam is generally at the top of the coal measures and at Liveringa Ridge shows a maximum thickness of 3 m, and can be traced for about 8 km along strike and for about 0.8 km down dip (20–25°), to a depth of nearly 400 m (Gair, 1972).

Australian Inland Exploration commented that the quality of the coal is poor and is classed as non-coking, sub-

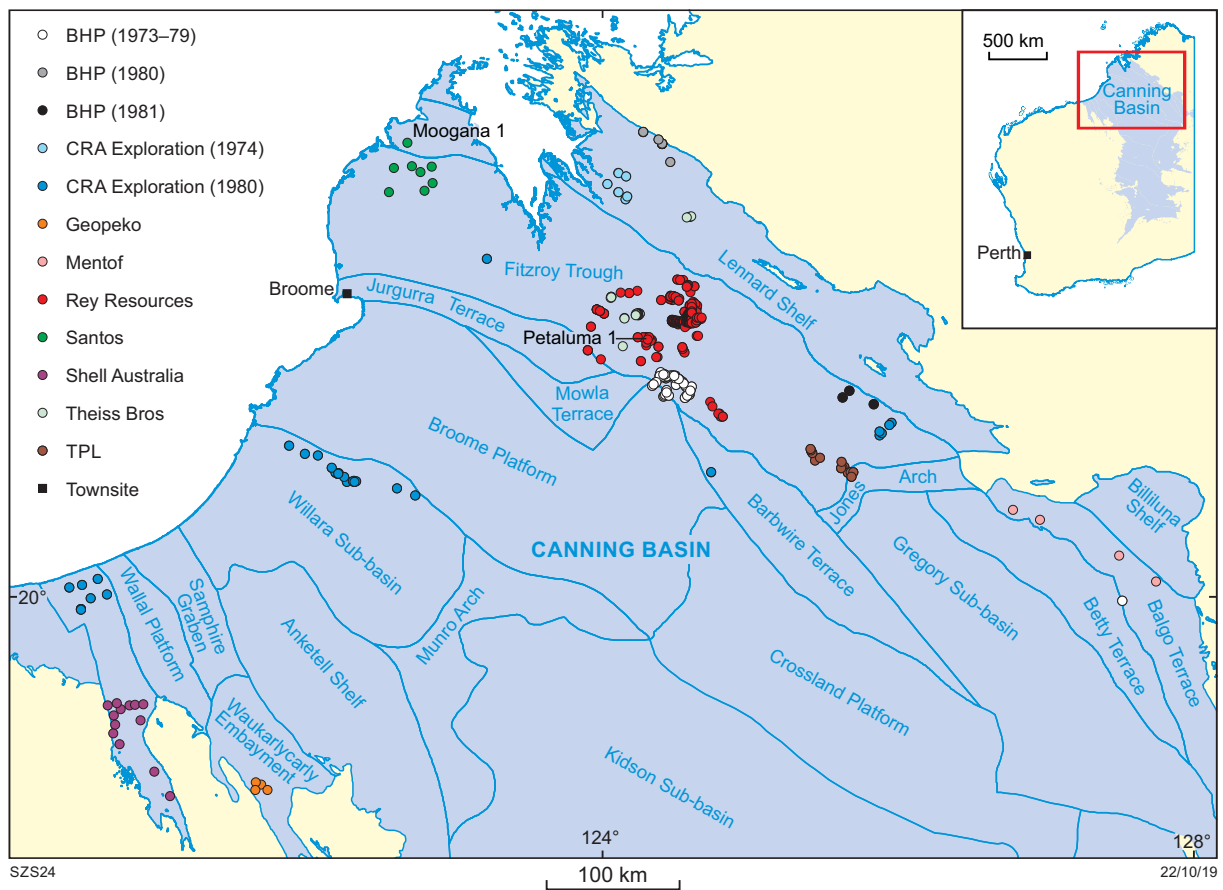


Figure 7. Location of holes drilled by companies: BHP, CRA Exploration, Geopeko, Mentof, Rey Resources, Santos, Shell Australia, Thiess Bros and TPL

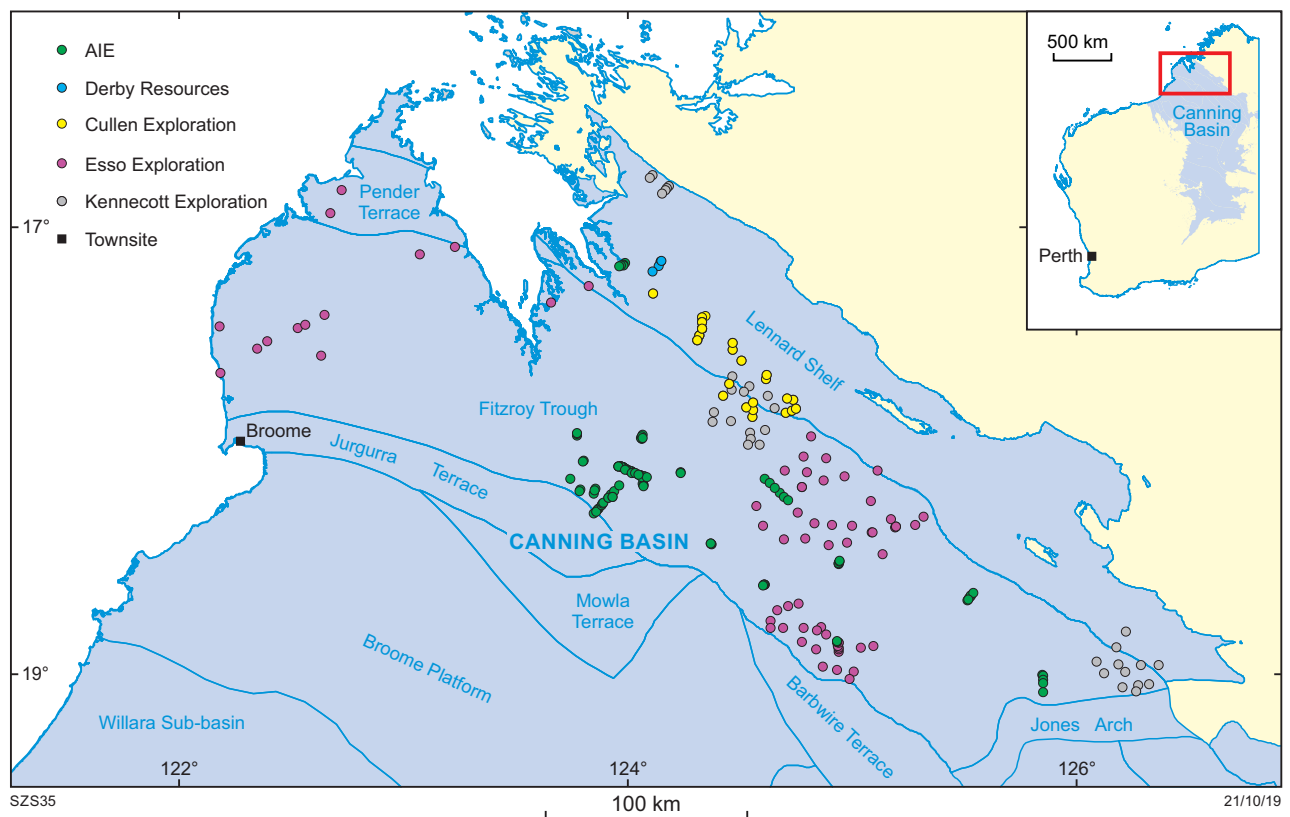


Figure 8. Location of holes drilled by companies: AIE, Derby Resources, Cullen Resources, Esso Exploration and Kennecott Exploration

bituminous coal with a high ash content (24–35%). It has a calorific value of 13 500 (no units given in original report) and is low in moisture at 8% (air dried [ad]) (Gair, 1972). Volatile matter ranges from 31–33%, sulfur is considered high (>0.7%) and crucible swelling numbers (CSN) of up to 2 were observed in three holes (Gair, 1972). Australian Inland Exploration estimated a reserve of 50 Mt of coal, but this estimate is based on eight drillholes (Gair, 1972). Robertson Research (Australia) Pty Ltd conducted a preliminary feasibility study of the Liveringa Ridge area in 1980 for Texasgulf based on data from AIE at Liveringa Ridge and revised the estimated reserve to 35 Mt (Lee et al., 1980).

Australian Inland Exploration used two geophysical devices in their exploration program — a mercury analyser and downhole gamma ray logging. Neither these logs, nor subsequent infrared photography, produced useful results (Gair, 1972).

CRA Exploration Pty Limited (1974)

CRA explored for coal in 1973, drilling six diamond drillcore holes in the Alexander Creek and Meda River areas (Fig. 7) (Quinton, 1974). Trace coal was intersected in four of the drillholes, including DD73AC1, which intersected a 0.28 m-thick seam at a depth of about 53 m, consisting of coal, carbonaceous shale and pyrite. CRA determined that the coal is a low rank and sub-bituminous with a vitrinite mean maximum reflectance ($R_{o\ max}$) in oil of 0.40 – 0.41% (Quinton, 1974).

Esso Exploration and Production Australia Inc. (1974–75)

Esso explored in two main areas at Ellendale, north of the Fitzroy River and south of the St George Ranges Anticline as a joint venture with Dampier Mining Company (Galloway and Howell, 1975). An extensive drilling program was carried out in 1974, consisting of 55 drillholes including 5 redrills (Fig. 8). Wireline logs were obtained in all holes (Galloway and Howell, 1975). Borehole depths ranged from 165 to 365.8 m. The drilling was designed to intersect the entire Liveringa Group, from the base of the Triassic to the Noonkanbah Formation, with the target coal horizon being at the top of the Lightjack Formation. The report noted that the interpretation of the coal distribution relied heavily on the electronic logs due to contamination rendering the lithological logs unreliable (Galloway and Howell, 1975). Based on core descriptions and geophysical logging, Esso–Dampier were able to correlate the Liveringa Group between holes and subdivide the group into four units, named A (further subdivided into A1 and A2), B, C and D (Galloway and Howell, 1975), where unit A was interpreted to be equivalent to the Lightjack Formation. Although coal was recorded in cuttings throughout the group (within informal units A, B, C and D) it was commonly described as only a trace of coal interpreted to be thin and discontinuous lenses. The thickest and most extensive coal seam is at the top of unit A1 (Galloway and Howell, 1975), although it is of poor quality. The drilling results revealed the coal-bearing sequence consists of two distinctive coal seams in the upper Lightjack Formation.

The thickness of coal intersected in the A1 unit by Esso–Dampier ranges from 0.05 to 2.13 m, with an average cumulative coal thickness of 0.76 m. Coal was also reported in the Condren Sandstone and Hardman Formation by Galloway and Howell (1975) and Crowe and Towner (1981); however, later work suggests that the presence of coal in these formations is unlikely (Dent, 2017).

Vitrinite reflectance was measured for 36 samples, five from the Poole Sandstone and 31 from the Liveringa Group. The data did not show a significant variation or trend in vitrinite reflectance laterally or with depth (Galloway and Howell, 1975). Esso reported a mean maximum reflectance range of vitrinite from within the Poole Sandstone of R_o 0.27 – 0.28 % and from within the Liveringa Group of R_o 0.35 – 0.55 % (Galloway and Howell, 1975). Core from hole 41R was analysed for relative density and ash content. The analytical results were 1.7 and 15.5 – 34.8%, respectively (Galloway and Howell, 1975). Trace amounts of pyrite were also detected.

Shell Australia Ltd (1975)

Shell explored an area near the Oakover River at the southern margin of the Canning Basin, drilling 13 rotary chip and core holes (Fig. 7). Traces of brown lignite were encountered in three holes at depths of about 50 m (Kempton, 1976; Harrison, 1981c).

Broken Hill Pty Co. Ltd (1973–79)

BHP began exploring in the Fitzroy Trough in 1973–74 after an assessment of previous exploration in the area indicated the presence of low-grade coal (Fig. 7). Their drilling program focused on the centre of the McLarty Syncline and progressed north until the base of the Liveringa Group was intersected (The Broken Hill Proprietary Company Limited Australia, 1973). Twenty-one boreholes were drilled and two thin coal seams were identified, with the thickest measuring 90 cm and consisting of coal and carbonaceous shale with numerous dirt bands (The Broken Hill Proprietary Company Limited Australia, 1973).

In 1977, BHP drilled 50 holes on the northern and southern limbs of the McLarty Syncline and only minor intersections were obtained across the southern limb adjacent to the Fenton Fault (The Broken Hill Proprietary Company Limited Australia, 1978). Two coal seams were intersected on the northern limb of the syncline over about a 20 km strike length: seam A is 0.46 – 1.67 m thick with the shallowest intersection at 14.5 m deep; seam B was reported as being ‘very poor quality’ and consisted of interbedded claystone, coal and carbonaceous shale, ranging from 0.9 to 8.2 m thick (The Broken Hill Proprietary Company Limited Australia, 1978). Seam A was reported as good quality coal with raw ash contents ranging from 21 to 27% (dry basis [db]) and moisture content ranging from 8.7 – 13.7% (ad). The CSN of 0 indicates that the coal has no coking potential (The Broken Hill Proprietary Company Limited Australia, 1978). On the northern limb of the syncline, the company interpreted a possible rapid lateral facies change west of Mount Fenton hole no. 39, resulting in the disappearance of the two coal horizons.

In 1979, BHP explored for coal in the currently named Balgo Terrace, although virtually no prior drilling had been done in this area. A single hole was drilled (Lake Gregory Rotary 1) to 364 m and one thin seam (40 cm) of sub-bituminous, high-ash coal was intersected in the interval from 158 to 160 m (Table 4; Lemon, 1980). The coal is a dull black, friable, sub-bituminous, high ash steaming coal.

Geopeko Limited (1978)

In 1978, Geopeko investigated coal potential within the Permian and younger section of the Waukarlycarly Embayment, calling the project the Barnicarndy Coal project (Fig. 7). This work resulted in the drilling of four holes, with the deepest hole terminating at 150 m (Kitto, 1978). Three carbonaceous horizons were intersected in the drillholes; however, Geopeko concluded that there was little possibility of coal lithotypes being produced and little likelihood of the presence of a viable coal (Kitto, 1978).

CRA Exploration Pty Limited (1980)

In 1980, five holes were drilled to test for coal in the Permian Poole Sandstone and Lightjack Formation near the Talbot Syncline (Fig. 7) (Mason, 1980). Traces and specks of coal and root horizons were detected in holes PH80PR1 and AC80PR3. No coal was detected in the other holes (Gunther, 2011). Three of the five holes were drilled at Poole Range to test a possible coal intersection in the Poole Sandstone reported in the Billabong Bore water bore on Christmas Creek Station (Baarda, 1966), even though the position of the bore could not be identified. Minor traces of coal and root zones were detected, as was black carbonaceous and pyritic shale; this 6 m-thick interval was possibly interpreted as coal by Guppy et al. (1958).

Between 1980 and 1981, CRA Exploration drilled eight holes for coal in the Wallal Embayment based on intersections of coal within the Upper Permian in the Chirup 1 petroleum exploration well. However, the coal intersected was poor and thin, the carbonaceous material present was soft and woody and, in some cases, the holes did not reach their target depth (Morgan, 1981; Tighe, 1981).

In the late 1980s, CRA Exploration drilled about 20 holes targeting Pb–Zn mineralization in the Admiral Bay Fault Zone area. Coal was intersected in numerous drillholes at depths between 350 and 650 m and was described as occurring within the Jurassic Wallal Sandstone and occasionally in the Alexander Formation (Lennox and Harvey, 1988; Williams and Harvey, 1989; Williams and Haederle, 1990). The coal has been described as thin beds that become more prominent with depth, dull brown to black, vitreous and moderately hard, and occasionally tending towards lignite (Lennox and Harvey, 1988).

BHP Minerals Ltd (Dampier Mining Company) (1980)

In 1980, the then Dampier Mining Company (subsequently BHP) drilled seven holes in the Alexander Creek area after a shallow, thick seam of lignite was intersected while drilling for diamonds on the Lennard Shelf in 1979 by Carr Boyd Minerals (Fig. 7). The lignite was restricted to a sinkhole within limestone of the Devonian to Carboniferous Fairfield Group (Harrison, 1981a). Lignite was only intersected in two drillholes at a depth of 12.2 – 31.8 m (AX1) and 14.3 – 26.2 m (AX5) over a lateral extent of 200 m (Westblade, 1981). Analysis reported high moisture and sulfur content and a low specific energy (db; Table 5).

Table 4. Proximate analysis of washed coal chips from Lake Gregory Rotary 1 from a 40 cm seam between 158 and 160 m (Lemon, 1980)

Sample number	Moisture (% [ad])	Ash (% [db])	Volatile matter (% [db])	Total sulfur (% [db])	Specific energy (MJ/kg, [db])*
D382	19.9	19.5	31.3 (includes CO ₂)	0.41	23.71

NOTE: * Originally reported as MK/kg, which is assumed to be a typographical error

Table 5. Analytical results for coal in drillholes AX1 and AX5 (Westblade, 1981)

Drillhole	AX1			AX5		
Depth	12–22 m	22–24 m	24–318 m	14.3 – 15.3 m	15.3 – 20 m	20–23 m
Moisture (%)	43.95	42.66	40.79	49.4	39.74	43.55
Volatiles (% [db])	43.4	39.9	39.51	42.13	36.53	39.25
Ash (% [db])	10.23	11.13	16.1	17.34	30.77	19.37
Fixed carbon (% [db])	46.37	48.97	44.39	40.53	32.7	41.38
Sulfur (% [db])	0.74	1.09	1.09	1.84	1.44	1.17
Specific energy (MJ/kg [db])	24	23	22.5	19.7	16.5	20
Si, ash (%)	17	17	20.3	16	19.8	16.1
Na, ash (%)	0.07	0.24	0.15	0.1	0.03	0.04

Kennecott Exploration (Australia) Ltd (1981)

In 1981, Kennecott Exploration investigated the synclines on either side of the Pinnacle Fault system based on possible fault-controlled thickening of the Liveringa Group producing thicker coal seams (Fig. 8). The company drilled 14 holes (BS1–14) from 33.18 to 152.02 m deep. In the southern syncline, 1.0 m-thick seams described as comprising bands of coal (70%) and claystone (30%) were intersected in two boreholes, at depths of 105 m in BS 3 and at 68 m in BS 8 (Harrison, 1981b). No coal was intersected in the northern syncline (Harrison, 1981b). In the same year, Kennecott Exploration drilled 12 holes in the Christmas Creek – Bohemia Downs area and six holes 90 km northeast of Derby; however, no coal was intersected (Harrison, 1981d).

Broken Hill Pty Co Ltd (1981)

During 1981, BHP drilled and wireline logged three boreholes within the Talbot Syncline at Christmas Creek following a report of thick carbonaceous sequences in drillers logs for water bores (Fig. 7). Although thick carbonaceous sequences were intersected at similar depths and thicknesses within the Lightjack Formation, only traces of coal were present in one hole at 63.6 and 66.8 m (Venning, 1982; Westblade, 1982).

Hamersley Exploration Pty Ltd (1981)

In 1981, Hamersley Exploration committed to exploring for coal in the northern Canning Basin, near Lake Betty (Fig. 6) (Hamersley Exploration Pty Limited, 1982). About 30 holes were drilled and Hamersley Exploration reported that the carbonaceous horizons intersected in the drilling were indicative of coal lithofacies, but no coal or coaly horizons were intersected.

Santos Ltd (1981)

Santos noted that drillhole Moogana 1 intersected Mesozoic coal or lignite in the upper 500 m and thought that this interval would be closer to the surface south of the well (Fig. 7). Although the company drilled seven holes 23 km to the southeast in the Lake Louisa area, none intersected coal (Santos Ltd et al., 1981).

Mentof Pty Ltd (1982)

Mentof explored for coal in the Poole Formation and Grant Group in the northeast Canning Basin (Fig. 7), drilling four diamond drillholes over a strike length of 120 km in the Balgo Terrace, but did not intersect any coal. Detailed stratigraphic analysis of the core indicated shallow-marine environments unsuitable for coal accumulation (Mentof Pty Ltd, 1982).

Rio Tinto Exploration Pty Limited (2003)

In 2003, Rio Tinto acquired several tenements within the Fitzroy Trough for shallow, export-quality, Permian coal (Millar, 2004). The project largely depended on the presence of seam B within the Lightjack Formation across the Fenton Fault and in other untested areas (Millar, 2004). In late 2003, Rio Tinto drilled 27 holes consisting of three diamond holes and 24 reverse circulation (RC) drillholes (Fig. 6). Only two RC holes, GEG001 and MCL006, and two diamond core holes, MCL008 and PAR001, intersected coal, which Rio Tinto classified as sub-bituminous. GEG001 intersected 7 m of very shaley coal from 43–50 m that appeared to be a westerly extension of coal along the Nerrima Ridge. Analytical results show the typical ash value being in the order of 35–55% (ad). Based on the intersected thickness and the extremely shaley nature of the coal, Rio Tinto interpreted this as seam B. MCL006, on the eastern limb of the McLarty Syncline, intersected two thin shaley seams at 31.5–32.5 m and 52.8–54.5 m. Both seams are very high in ash (Millar, 2004).

In an attempt to obtain reliable samples of both seams A and B, MCL008 was drilled near historical BHP hole MF23, which had intersected seam A at 34.3–35.2 m and seam B at 50.3–51.5 m. The new hole intersected a single, shaley, banded seam at 34.8–39.8 m, which Rio Tinto interpreted as seam B (Fig. 9). The intersected seam was analysed as eight separate plies (proximate analysis, sulfur and calorific value) with the interval being recombined with a float/sink analysis completed at F1.6 density fraction and a proximate analysis on the floats and sinks (Millar, 2004). Ash values for the raw individual plies range from 39% (ad) for the cleaner intervals to 62% (ad) for the shaley units. Raw calorific values range from 4 to 14.5 MJ/kg (ad), and total sulfur ranges from 1.5 to 3.2% (ad). For the 5.05 m composite sample of this seam, only 15.5% was recovered by floating at F1.6 (Table 6).

Rio Tinto attempted to drillhole PAR001 down dip of Premier Mining's hole D3 (Baarda, 1966) that had intersected seam A at approximately 27 m in the Duchess Ridge – Paradise area. Unfortunately, the locations of all Premier Mining's drillholes are poorly documented, so PAR001 intersected coal at 17.18 m indicating it was up dip of D3 and closer to hole D4. PAR001 intersected relatively clean coal from 17.18 to 19.48 m (2.3 m) (Fig. 10) and a shaley banded seam from 28.60 to 35.39 m (6.79 m) (Millar, 2004). Analysis of three individual raw plies from the upper seam, plus a float 1.6 composite analysis (Table 7), indicated 19–28% ash (ad), a calorific value range of 18–21 MJ/kg (ad) and 1.0–3.8% total sulfur (ad). Analysis of seven individual raw plies plus a float 1.6 composite analysis from the lower seam were more variable, with 30–60% ash (ad), a calorific value range of 4–19 MJ/kg (ad) and 0.45–3.0% total sulfur (ad).

Ultimate analysis and vitrinite reflectance were also completed on the F1.60 density fraction from Seam A of PAR001, with the latter analysis yielding an $R_{o\ max}$ of 0.43%.



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Figure 9. Rio Tinto drillhole MCL008 showing a single, shaley, banded seam that was intersected between 34.8 – 39.8 m and interpreted as seam B (Millar, 2004)

Table 6. Analysis of seam B composite (F1.6 ad) from drillhole MCL008 (Millar, 2004)

Yield (%)	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Total sulfur (%)	Calorific value (MJ/kg)
15.5	14.7	16.6	28.7	40	2.1	21.04 (5025 kcal/kg)



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Figure 10. Rio Tinto drillhole PAR001 showing the coal upper (A) seam intersection between 18.6 and 19.5 m (Millar, 2004)

Table 7. Seam A and B composite analysis of drillhole PAR001 (Millar, 2004)

	Yield (%)	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Total sulfur (%)	Calorific value (MJ/kg)
Seam A composite (F1.6 ad)	76.9	14.9	10.3	31.7	43.1	1.2	23.85 (5700 kcal/kg)
Seam B composite (F1.6 ad)	16.2	12.9	17.1	26.7	43.3	1.62	21.72 (5190 kcal/kg)

Rio Tinto concluded that:

- no coal was intersected in holes drilled southwest of the interpreted Fenton Fault and that the potential for significant shallow coal in these areas is very low
- the upper seam (A) in the Duchess–Paradise area contains 2.3 m of relatively clean coal with moderate ash and energy but relatively high in total sulfur
- the lower seam (B) is banded, high in ash and sulfur, and relatively low in energy in a raw state
- none of the samples tested show any coking properties.

ASF Resources Pty Ltd (2008–12)

In 2007, following an in-house review of the coal potential of the Canning Basin, ASF purchased the South Ellendale tenement package in the Fitzroy Trough. The area has been the subject of intensive diamond exploration from the mid-1970s to the present, and ASF believed that the coal potential had not been fully evaluated (Derriman and Lee, 2008). In 2009, ASF Resources engaged MBA Petroleum Consultants to interpret all existing ground seismic lines to produce a ‘depth to seismic-interpreted coal map’ (Fig. 11) (Derriman, 2010).

In 2009, ASF drilled 31 mud rotary holes targeting coal seams within the Lightjack Formation (Fig. 6) (Derriman, 2010); downhole geophysical logs were acquired in all holes. Nine holes intersected coal but most were trace amounts. The thickest seam intersected was about 1 m thick at a depth of 60 m. The downhole geophysical data indicates coal thickness is mainly less than 0.5 m (Derriman, 2010; Luketina and Ray, 2011). In September 2010, a palynological study on samples from three holes was initiated to determine whether the target coal-bearing interval of the Lightjack Formation had been fully intersected. The results suggest that the targeted interval was fully intersected in ARCMR-21, whereas ARCMR-9 and ARCMR-29 were not drilled deeply enough (Luketina and Ray, 2011; Reel and Ray, 2012).

In 2010, geophysical logs from five additional mud rotary drillholes at the Verity Bore prospect area confirmed the absence of coal in these holes (Ray, 2011). However, there are several discrepancies in the total depth and differences in drillhole names and locations in the report. Palynological studies suggest that some of these holes did not penetrate the target interval (Ray, 2011; Reel, 2012).

In 2011, nine mud rotary holes (ARCMR-37–45) were drilled to assess the coal resource potential of the P1 and P2 seams in the Lightjack Formation that had previously been identified as Resources in the adjacent Duchess–Paradise project (Reel and Ray, 2012). Six of these holes were drilled close to the western margin of that deposit. ASF Resources reported that the P1 Seam was intersected in all but two holes, ARCMR-43 (in which the seam appears to have graded into a carbonaceous mudstone) and ARCMR-45 (in which the total depth of the hole was interpreted around 3 m above the P1 seam). In the remaining holes, the P1 seam thickens westwards from 0.5 m in ARCMR-39 to 1.15 m in ARCMR-42, whereas the depth of cover generally increases towards the northeast, east and southeast, ranging from 186 to 252 m (Reel and

Ray, 2012; Radford and Familiar, 2013). The thicker P2 seam lies about 8 m below the floor of the P1 seam, and contains tuffaceous siltstone, sandstone and carbonaceous mudstone with thin coal bands up to 0.3 m thick. The P2 seam is interpreted to be 2–8 m thick based on geophysical logs, and also has a very high ash content. In ARCMR-42, for example, the unit appears to contain just a few thin coal bands (Radford and Familiar, 2013). Analysis of a coal chip sample reports an $R_{o\max}$ value of 0.53% and sub-bituminous coal rank as indicated by the high volatile matter content (Table 8) (Reel and Ray, 2012).

In July 2011, palynology was undertaken on 19 samples from a range of ASF’s tenements. Results from two samples from ARCMR305 indicated the top of the Hardman or upper Lightjack Formation was penetrated at about 75 m, and the depth to the top of the Noonkanbah Formation is around 175 m. ASF concluded that the Lightjack Formation could reasonably be expected in other parts of the tenement between these depths (Familiar, 2013).

Twenty mud rotary chip holes (ARCMR046–65) were drilled at the Verity Bore tenement, one of ASF’s most eastern tenements, during mid-2012. Total depth ranged from 133 to 355 m, and all holes reportedly intersected the Noonkanbah Formation (Familiar, 2013). Coal was absent in all but four of the 20 holes (ARCMR056, 060, 061 and 063) and the depth to the top of the P1 seam ranged from around 92 to 118 m. Coal thickness ranged from 0.2 to 0.7 m. The P2 seam is absent in all of these holes (Familiar, 2013).

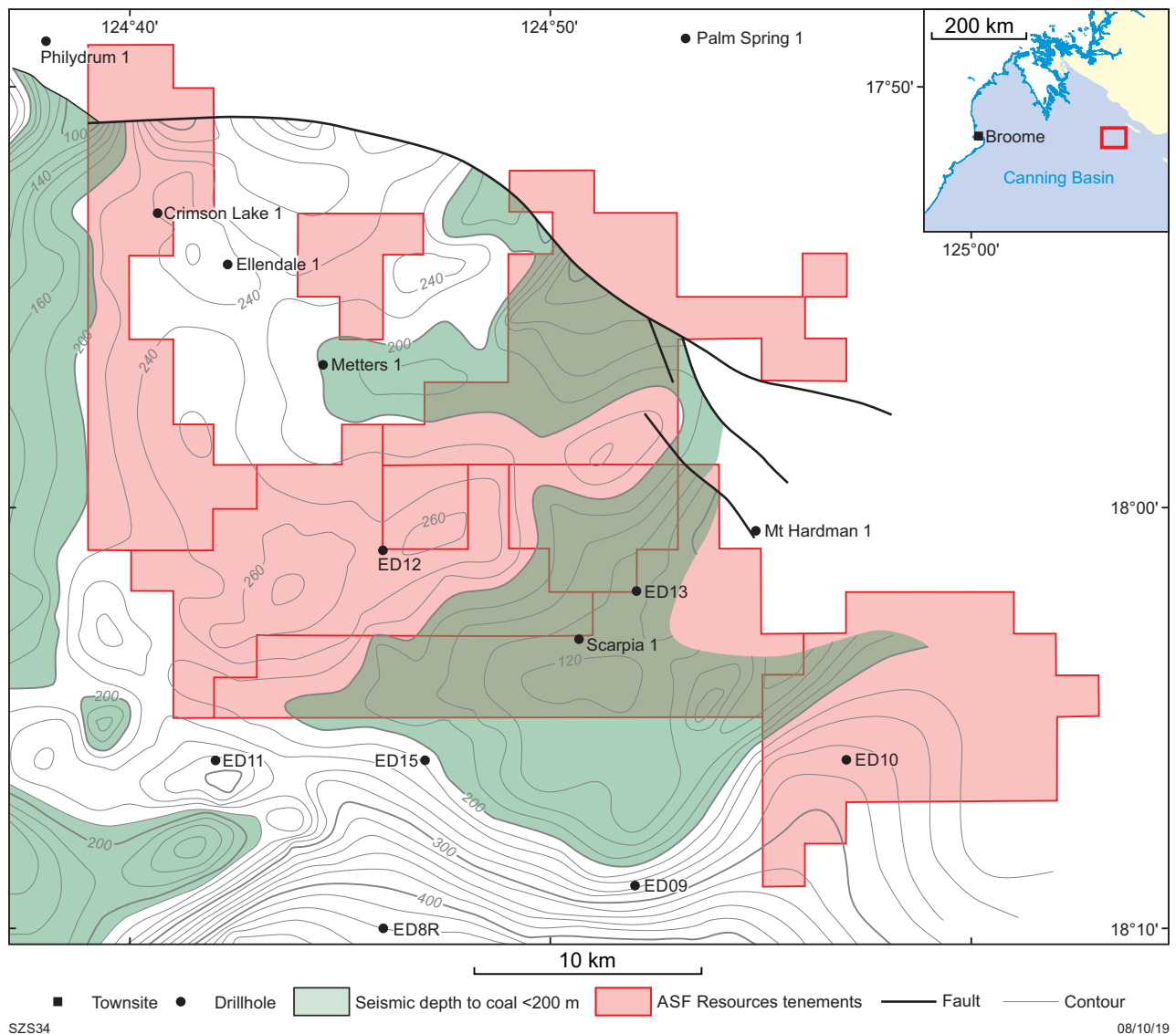
Exploration drilling in 2012 was designed to assess the coal potential in the untested southerly parts of the Ellendale South tenements. Seven holes (ARCMR066–072) drilled in September 2012, to total depths ranging from 211 to 355 m, all terminated in the Noonkanbah Formation with no coal present except at ARCMR070, in which there was 0.17 m of coal at a depth of 125.97 m (Derriman, 2013a). In October 2012, two mud rotary open holes (ARCMR073 and 074) at Nipper Creek on Christmas Creek Station reportedly intersected the Noonkanbah Formation at relatively shallow depths (111.2 and 118.5 m, respectively) without finding coal (Familiar, 2012; Derriman, 2013b).

Rey Resources Limited, Blackfin Pty Ltd (2000–14)

Rey Resources and its subsidiaries (Blackfin Resources Pty Ltd, Rey Kimberley Pty Ltd) held numerous exploration tenements and applications over approximately 8000 km² within the Fitzroy Trough. The tenement holdings are located ~100 km southeast of the township of Derby.

The fold axes of the Grant Range and Mount Wynne Anticlines can be traced across the Rey Resources tenements along a combined strike length of ~335 km, providing numerous, shallow thermal coal targets as proven by coal discoveries by Premier, AIE and Thiess on the fold limbs (Reddicliffe, 2012a).

Drilling conducted by Rey Resources was concentrated in the Duchess–Paradise area on the premise that that area held the best option for open cut coal (Fig. 7). The coal seams vary in thickness and quality across the tenements. In places, the coal beds are shallow and gently dipping at



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Figure 11. Depth to coal map for the South Ellendale project after Derriman (2010), highlighting areas where the depth to coal interpreted from seismic data is less than 200 m

about 2–5° east, as observed at Paradise in the east, but those at Liveringa to the west are steeper at up to 35° south (Rey Resources Limited, 2009a). Postdepositional folding and faulting have locally influenced the seam geometry, and lensing of the coal seam along strike was noted in some parts of the basin (from previous exploration data) with localized seam splitting and feathering out of the seams (Fig. 12) (Fowers, 2009; Bryans, 2010c).

The coal is hosted within the Lightjack Formation as two laterally extensive and consistent seams separated by approximately 10 m of sandstone, siltstone and mudstone, but can be locally contiguous to form one thick, coaly sequence (Preston, 2009a). The P1 (upper) seam thickness averages 2.2 m (range 0.2 – 3.2 m) from Duchess Ridge to Paradise outstation, whereas the P2 (lower) seam averages 6.8 m at Duchess but thins to the north to an average of 2.3 m in the Paradise area (Preston, 2009a; Rey Resources Limited, 2009c). In areas where only one seam can be

differentiated, such as at Myroodah where it is about 200 m deep, the seam tends to be thicker (up to 15 m) but is banded with abundant shale partings (Rey Resources Limited, 2009e). The seams dip 7–10° south along Duchess Ridge and 2–5° east in the Paradise area (Rey Resources Limited, 2009f).

The higher quality P1 seam consists of relatively clean coal compared to the deeper P2 seam, which contains interbedded dull coal and parting units (Fowers, 2010b). Washed coal quality analyses for the two seams indicate that the P1 seam could be characterized as a moderate ash, moderate energy coal (Rey Resources Limited, 2009f). Three core samples from 2005 drilling at Myroodah tested for in situ density returned average densities of 1.37 for the raw coal (Fowers, 2009). Density analyses on raw coal samples of the P1 and P2 seams at Duchess–Paradise yielded average relative densities of 1.56 and 2.0, respectively (Fowers, 2009).

Table 8. Analysis of a coal chip sample of the P1 seam from approximately 187 m deep in ARCMR-38 (Reel and Ray, 2012)

Moisture (% [ad])	Ash (% [ad])	Volatile matter (% [ad])	Fixed carbon (% [ad])	Calorific value (kcal/kg)	Net calorific value (kcal/kg)	Carbon (% [ad])	Hydrogen (% [ad])	Nitrogen (% [ad])
8.9	13.2	44.7	33.2	6036	5092 (at 7.0% total moisture)	60.1	4.42	1.78

The depth of the coal varies from essentially surficial (below 5–15 m of cover) to over 1 km. Coal depth estimated from regional mapping and structural modelling of the Lightjack Formation (Bryans, 2010a), combined with seismic survey data available over most of the project area, was used to delineate the geometry of the deposit at depth (Fig. 12). This data, in conjunction with mapping and drillhole information, illustrates the coal trends and continuity at the project scale (Bryans, 2011a). Even so, depth estimates for the +350 m contour are approximate, especially where dip measurements from regional mapping had to be extrapolated across areas where such measurements could not be made (Bryans, 2010b, 2011a; Reddicliffe, 2012c).

Drilling history

Blackfin and BHP Billiton Minerals Pty Ltd entered into an agreement to review the whole Canning Basin for coal prospectivity in the early 2000s (Blackfin Pty Ltd, 2005). Basic coal analyses (proximate analysis and specific energy) were conducted on cuttings from Petaluma 1 petroleum well; however, these analyses (Table 9) are considered to show some degree of contamination (Blackfin Pty Ltd, 2005).

In 2005, five holes were drilled at the Deep Well Anticline near Myroodah/Nerrima, approximately 40 km southwest of the Duchess–Paradise resource close to Petaluma 1 (International Coal Consulting Pty Ltd, 2006; Reddicliffe, 2012b). A single coal seam consisting of approximately 15 m of interbedded coal and tuffaceous mudstone and siltstone was intersected in three of the drillholes (International Coal Consulting Pty Ltd, 2006), which was informally named the ‘Liveringa seam’. The coal was intersected at approximately 200–210 m in two holes (P01, P01C) and at 285–298 m in P10 (International Coal Consulting Pty Ltd, 2006). Tests on core from one of these drillholes indicated coal seam gas content was very low (International Coal Consulting Pty Ltd, 2006). From available downhole geophysical logs and comprehensive analysis of the coal (Table 10, Quinn, 2007), the company concluded that the raw ‘Liveringa seam’ at Myroodah/Nerrima is a high-ash, high-sulfur, sub-bituminous non-coking coal. Further tests for product quality and utilization were also undertaken (International Coal Consulting Pty Ltd, 2006).

In 2007–08, Blackfin Resources commissioned a photogeological study of their tenements to assist in designing the drilling program and to identify possible stratigraphic and structural controls of potential coal measures in the Lightjack Formation (Preston, 2009b). During 2008, three open holes were drilled at Myroodah to evaluate the deeper underground coal gasification potential

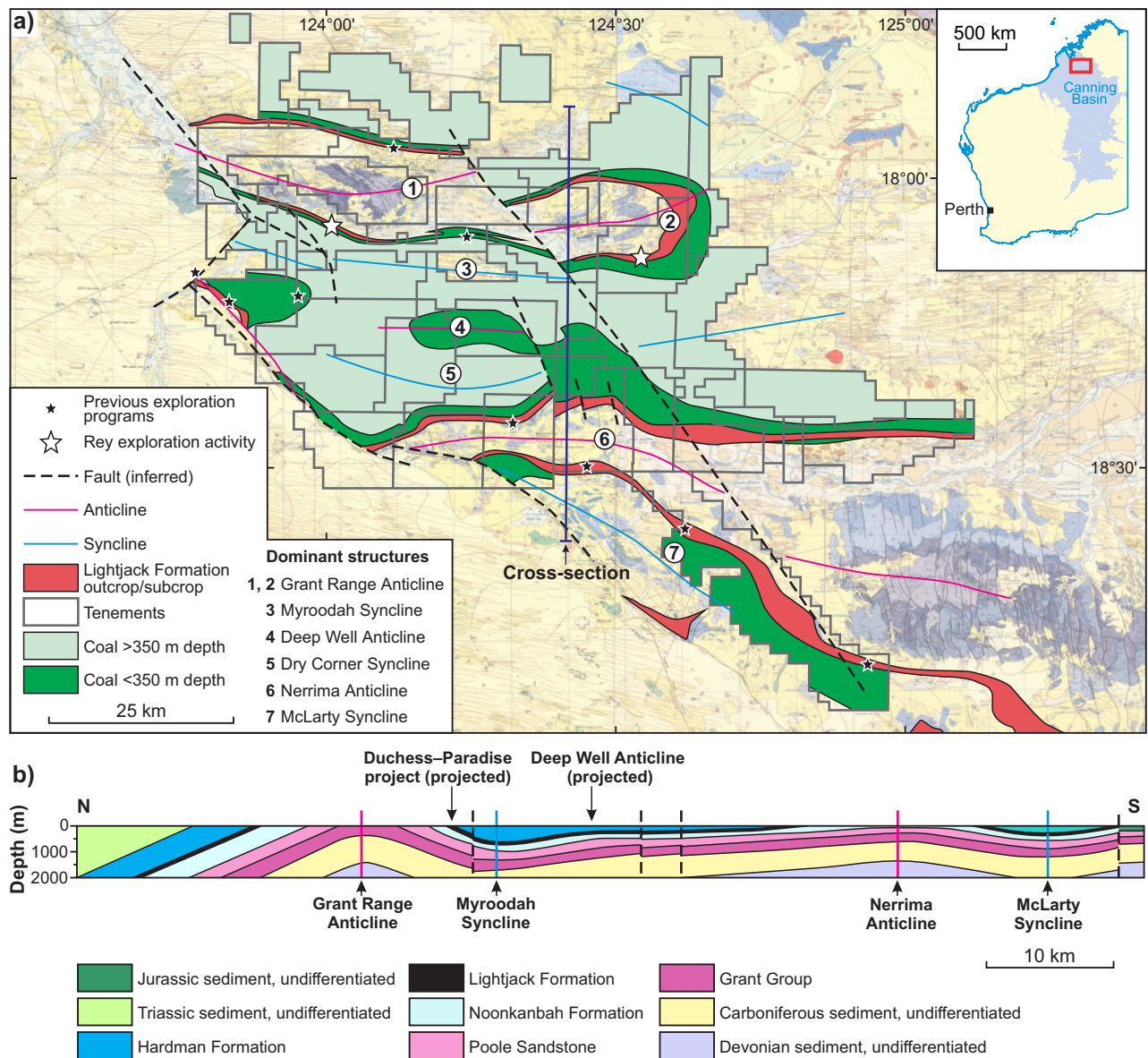
(Reddicliffe, 2012b), of which one intersected 16 m of coal (Preston, 2009b). In May 2008, drilling of 220 mud rotary holes and 37 diamond drillcore holes commenced across the Duchess–Paradise project area. This drilling revealed that the coal ranges in depth from 5 to 10 m below the surface at the weathered subcrop, to over 300 m down dip (Preston, 2009a). In July 2008, nine exploration holes drilled in the Liveringa Ridge area showed that the P1 coal was about 3.5 m thick and the P2 thickness varied from 6 to 30 m (Preston, 2009b).

Rey Resources produced a comparison of historical coal quality washability tests (Rey Resources Limited, 2008) and data from drillhole D12C indicated similar coal properties (ad), such as an energy content of 5500–6000 kcal/kg and 10–15% ash. Likewise, data for raw and washed coal analyses presented in the March 2009 Quarterly Report (Rey Resources Limited, 2009f; Table 11) showed that the raw coal analyses of the P1 seam were comparable to those reported from previous drilling. However, in a presentation made on 28 May 2009 (Rey Resources Limited, 2009b), Rey Resources reported on the properties of the export-quality thermal coal product target (Table 12), stating that washing would be required to produce a coal product with similar properties to their previous coal quality data.

In April 2009, a JORC (2004) Resource of 498 Mt was reported for an area of approximately 50 km², which was calculated using 29 cored holes that were drilled in 2008 (Fig. 13, Table 13); however, the resource is open to the west, dips south at Duchess and dips east at Paradise. Nearly all of the Measured and Indicated Resources occur above 250 m depth and the majority of the Inferred Resource occurs above 300 m depth (Rey Resources Limited, 2009c).

In June 2009, a geostatistical analysis of data from the coreholes and 180 open holes drilled in 2008 yielded a revised JORC (2004) volume estimate of 510.5 Mt for the Duchess–Paradise project (Table 14; Rey Resources Limited, 2009d). This estimate was based on three assumptions: coal density was estimated as an average of 1.5; the P1 seam comprised entirely coal; the P2 seam comprised 40% coal (Rey Resources Limited, 2009a).

In August 2009, Rey Resources announced an estimate of the coal potential within their leases of 30–36 Gt, divided into three categories: above 350 m from the surface, 350–1000 m from the surface; below 1000 m from the surface. This provided a rough estimate of openpit/underground extractable coal vs deeper tonnage targets (Table 15; Rey Resources Limited, 2009a). These estimates were based on assumed coal thickness constrained by existing drillhole information (Rey Resources Limited, 2009a).



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Figure 12. Lightjack Formation outcrop and north-south cross-section: a) Lightjack formation outcrop is shown in red, areas of shallow coal down to 350 m deep shown in dark green and zones where coal is deeper than 350 m are shown in light green (Reddicliffe, 2012b); **b)** north-south cross-section facing east through Rey Resources lease holdings, showing the coal-bearing Lightjack Formation (black) (Fowers, 2009)

Table 9. Petaluma 1 analyses of cuttings samples (proximate analysis and specific energy) (Blackfin Pty Ltd, 2005). Abbreviation: Vro, mean vitrinite reflectance

Moisture (% [ad])	Ash (% [ad])	Volatile matter (% [ad])	Fixed carbon (% [ad] by difference)	Specific energy (kcal/kg [gross ad])	Vro
6.5	45.1	24.5	23.9	2865	0.47

Table 10. Results of raw coal analysis for drillhole P01C located on the Deep Well Anticline near Myroodah/ Nerrima (Quinn, 2007). Abbreviation: CSN, crucible swelling number

<i>Parameters</i>	<i>Basis</i>	<i>Results</i>			<i>Weighted averages</i>
		<i>P1C/01-03</i>	<i>P1C/04-07</i>	<i>P1C/08</i>	
From (m)		194.68	200.06	208.56	
To (m)		198.6	203.3	209.37	
Thickness (m)		3.92	3.24	0.81	
Initial weight (g)*	ar	9927	13 775.4	1444	
Weight after drying (g)*	ad	8848	12 545.1	1340	
Free moisture (%)	ad	12.9	8.9	76.2	10.2
Proximate analysis					
Moisture (%)	ad	9.1	10.4	9.3	10
Ash (%)	ad	41.6	50.2	39.4	47.2
Volatile matter (%)	ad	22.3	21	18.7	21.4
Fixed carbon (%)	ad	35.2	26.5	39.3	29.5
Ultimate analysis					
Hydrogen (%)	ad	2.83	2.35	2.38	2.51
Nitrogen (%)	ad	0.92	0.64	0.96	0.74
Total sulfur (%)	ad	1.6	1.4	0.73	1.46
CSN	ad	0	0	0	0
Relative density	ad	1.73	1.83	1.75	1.8
Gross calorific value (kcal/kg)	ad	3379	2463	3604	2772
Ash fusion temperatures					
Deformation (°C)	reducing	1570	1450	1550	1491
Spherical (°C)	reducing	1590	1460	1580	1504
Hemisphere (°C)	reducing	1600	1470	1590	1514
Flow (°C)	reducing	1600	1480	1600	1521
Deformation (°C)	oxidizing	1600	1520	1590	1547
Spherical (°C)	oxidizing	1600	1530	1600	1554
Hemisphere (°C)	oxidizing	1600	1540	1600	1561
Flow (°C)	oxidizing	1600	1550	1600	1567
Ash constituent analysis					
SiO ₂ (%)	db	47.6	45.9	56.5	46.5
Al ₂ O ₃ (%)	db	32.9	30.4	29.3	31.2
Fe ₂ O ₃ (%)	db	4.8	11.8	3.4	9.4
CaO (%)	db	2.1	2.3	1.8	2.2
MgO (%)	db	0.42	0.87	0.55	0.72
TiO ₂ (%)	db	9.1	5.9	6.6	6.98
Na ₂ O (%)	db	0.59	0.9	0.84	0.8
K ₂ O (%)	db	0.41	0.34	0.46	0.36
Mn ₃ O ₄ (%)	db	0.04	0.08	0.03	0.07
SO ₃ (%)	db	0.59	0.17	0.24	0.31
P ₂ O ₅ (%)	db	0.87	0.9	0.1	0.88
SrO (%)	db	0.13	0.07	0.09	0.09
BaO (%)	db	0.12	0.07	0.1	0.09
ZnO (%)	db	0.04	0.03	0.02	0.03
V ₂ O ₅ (%)	db	0.18	0.17	0.17	0.17
Basicity index (%)	db	0.093	0.197	0.076	0.161

Table 10. continued.

Parameters	Basis	Results			Weighted averages
		P1C/01-03	P1C/04-07	PIC/08	
Quick coking test					
F1.30					
Mass (%)	ad	13	1.50	0.4	5.3
Ash (%)	ad	6.1	9.40	25.1	8.4
CSN (%)	ad	0	0.00	insufficient sample	0
S1.30					
Mass (%)	ad	87	98.50	99.6	94.7
Ash (%)	ad	52.5	52.60	40.5	52.5
CSN (%)	ad	0	0.00	0	0
Size distribution (initial) (mm)					
-31.5	ad	100	100.00	100	100
-19	ad	83.1	88.10	86.5	86.4
-16	ad	78.7	83.80	84	82.1
-12.5	ad	68.7	75.10	78.9	73
-8	ad	50.6	57.70	61.8	55.4
-4	ad	29.2	36.00	36.8	33.7
-2	ad	20.3	24.80	21.5	23.3
-1.4	ad	16.1	19.00	16.2	18
-0.5ww	ad	10.4	11.50	11.4	11.1

NOTE: * Units originally reported as 'GM', which is assumed to represent grams (g)

Table 11. Raw and washed coal analysis for the Duchess–Paradise resource as reported by Rey Resources in 2009 (Rey Resources Limited, 2009c)

Raw							
Seam	Moisture (% [ad])	Volatiles (% [ad])	Ash (% [ad])	Total sulfur (% [ad])	Specific energy ^(a) (kcal/kg)	Relative density (g/cm³)	
P1	10.6	28.5	24.8	1.51	4750	1.5	
(range)	7.1 – 17.5	24–32	15.4 – 39.6	0.7 – 3.1	3784–5446	1.4 – 1.68	
P2	11.1	17.9	52.5	1.44	2206	1.86	
(range)	6.7 – 16.8	12 – 24.8	26.5 – 63.2	0.62 – 3.69	1156–3650	1.62 – 2.00	
Washed							
Seam	Float density	Yield (% [ad])	Moisture (% [ad])	Volatiles (% [ad])	Ash (% [ad])	Total sulfur (% [ad])	Specific energy ^(b) (kcal/kg)
P1	1.4	57	10	36.7	8	1.1	6029
	1.5	62	11	34	18	1.0	5221
	1.6	76	7.6	32.1	25	1.1	4956
P2	1.5	19	11	33	15	1.6	4970
	1.6	41	9.3	26	26	1.7	4509

NOTES: (a) As measured (b) As calculated from averages

Table 12. Coal quality as reported by Rey Resources Limited (2009b). Measurements are indicative coal properties on an ad basis

Energy (kcal/kg)	Ash (%)	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Sulfur (%)
5500–6000	10–15	9	34	45	0.9 – 1.3

Table 13. Duchess–Paradise JORC resources by category as at March 2009 (Rey Resources Limited, 2009c)

Seam	Measured (Mt)	Indicated (Mt)	Inferred (Mt)	Total (Mt)
P1	18.3	49.1	200.9	268.3
P2	16.9	41.7	171	229.6
Total	35.2	90.8	371.9	497.9

Table 14. Duchess–Paradise JORC resources by category as at June 2009 (Rey Resources Limited, 2009d)

Seam	Measured (Mt)	Indicated (Mt)	Inferred (Mt)	Total (Mt)
P1	18.3	101.9	160.5	280.8
P2	16.9	41.7	171	229.6
Total	35.2	143.6	331.5	510.5

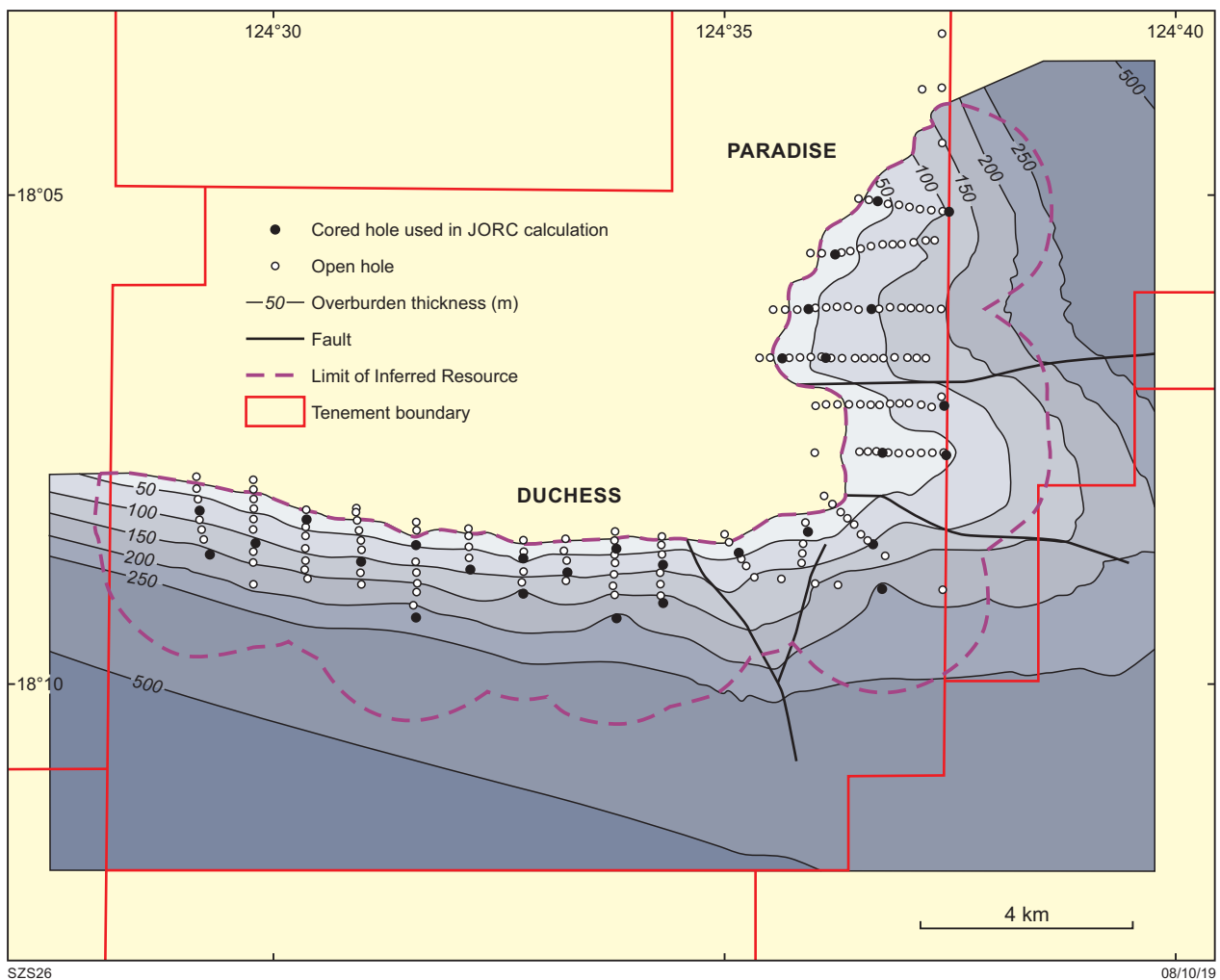


Figure 13. JORC resource outline for Duchess–Paradise P1 seam, including overburden thickness contours from Preston (2009a)

Table 15. Summary of estimated potential coal tonnages in Rey Resources tenements, August 2009 (Rey Resources Limited, 2009a). Abbreviation: SG, specific gravity

Estimate at SG = 1.5	Coal above 350 m (Gt)	Coal below 350 m (Gt)	Total coal (Gt)
Seam P1 (100%)	4–5	9–10	13–15
Seam P2 (40%)	5–6	13–15	18–21
Total	9–11	21–25	30–36

In 2009, an additional four holes (SR01–04) were drilled in the Nerrima–Moffats and Duchess–Paradise areas to test the extension of the Lightjack Formation (Fowers, 2010a,c). In 2010, contractors Geophysical Resources and Services were engaged by Rey Resources to interpret radiometric, gravity and magnetic data from the Geoscience Australia Data Archive Systems (GADDS) across the onshore Canning Basin. The primary objective of the qualitative interpretation was to define the extent of the coal-bearing Lightjack Formation within the Fitzroy Trough. A secondary objective was to identify structural and magnetic trends within the onshore part of the basin (Bryans, 2011b). Rey Resources completed a regional basin interpretation and coal study in 2010 to determine the distribution and tonnage potential of coal within their Canning Basin tenements (Reddicliffe, 2014b).

Rey Resources conducted a large drilling program within the Duchess–Paradise Resource area in 2010 (183 holes with a mixture of diamond drillcore, mud rotary and air-core drilling) to evaluate possible extensions to the known Resource (Fig. 14) (Bryans, 2011a). All holes were geologically and geotechnically logged, with downhole geophysical logs including density, natural gamma, caliper, resistivity, velocity and hole deviation (Bryans, 2011a; Rey Resources Limited, 2011a). The results of this drilling were used to update the P1 seam Resource, to 305.8 Mt (Table 16) (Rey Resources Limited, 2011b) based on the JORC 2004 guidelines. The new volumes incorporated detailed modelling of data from 381 geophysically logged holes drilled in 2008 and in 2010, of which 68 were analysed for raw coal quality. In November 2010, Rey Resources released an ASX statement highlighting that the calorific value was calculated at 5539–5666 kcal/kg (gross, ar) (Rey Resources Limited, 2010).

In 2011, a drilling program to evaluate possible extensions to the known Duchess–Paradise Resource, and to increase the density and areal extent of the Points of Observation, was completed with 52 holes totalling 6977.65 m drilled (Reddicliffe, 2013e). In June 2011, Rey Resources announced an initial coal Reserve estimate for the P1 seam of 26.3 Mt with a 10-year mine life plan (Rey Resources Limited, 2011c).

In 2012, three mud/rotary holes (totalling 417 m) were completed for the Freney and Victory projects within the Myroodah area (Reddicliffe, 2013d). The results indicated the likely continuity of the coal seam within the Freney project area over a strike length of 60 km and that the seam extended a farther 30 km along strike to the Victory project area (Reddicliffe, 2013d). One hole drilled in 2012 within the Camballin North area, 60 km west-northwest of the Duchess–Paradise project, confirmed the continuity and thickness of the coal seam (Reddicliffe, 2013c).

A mud rotary drill program of 10 holes at the Highway and Jimbalurra Ridge prospects within the Duchess–Paradise project was undertaken in 2012; however, no coal was found in the Jimbalurra Ridge prospect and the seam intersected at the Highway prospect was 0.80 m thick (Reddicliffe, 2013b).

In 2013, the Lightjack Formation within the Freney and Victory projects, on the southern margin of the Fitzroy

Trough, was tested by four holes; however, only one hole intersected 0.74 m of coal (Reddicliffe, 2013a). A drilling programme to test the coal measures in the Mount Fenton area, also undertaken in 2013, identified individual coal seams varying in thickness from 2 to 3.18 m in six of the eight holes drilled (totalling 1279 m) (Reddicliffe, 2014a).

In October 2014, Rey Resources updated the Duchess–Paradise P1 seam thermal coal Resources and Reserves Statement in accordance with the 2012 edition of the JORC Code (Table 17). For the P1 seam, the updated thermal coal Resources were 305.8 Mt in situ, with Reserves of 26.3 Mt which, after beneficiation, represented 17.8 Mt of marketable Reserves (ar) estimated in accordance with JORC 2012 (Rey Resources Limited, 2014).

Cullen Exploration Pty Ltd (2009–10)

In 2009, Cullen took up substantial holdings in the northern part of the Canning Basin over potentially coal-bearing Permian strata and commissioned a desktop study to investigate the extent and development of the Lightjack Formation, as well as previous exploration over these tenements (Dorling and Jeffress, 2010). The tenements included the edge of the Lennard Shelf in the north and limbs of dominant regional folds in the Fitzroy Trough to the south.

During 2010–11, the company conducted a small soil sampling program totalling 56 samples along a southwest-trending traverse across the Lightjack Formation. The objective was to test the use of soil gas hydrocarbon geochemistry for coal exploration. Samples submitted to Actlabs, Canada (Sutherland and Hoffman, 2010), suggested a hydrocarbon source, possibly coal, as indicated by two redox cells (Sutherland and Hoffman, 2010).

On 15 July 2010, Cullen, via its subsidiary Cullen Exploration Pty Limited, signed a Heads of Agreement with Advaita Canning Resources Pty Ltd, a subsidiary of Advaita Power Resources Pty Ltd. Advaita then operated and funded all exploration activities on Cullen's tenements (Ringrose, 2013), including drilling 25 holes (including two water bores) about 100 km southeast of Derby, in 2011 (Fig. 8). Coal was intersected in four of the holes with a maximum thickness of 0.55 m from 127.6 m in CBRM019 (Ringrose, 2012, 2013). The analysis of sample CBRM_006_61 indicated a medium-ranked thermal coal (Ringrose, 2013).

Derby Resources Pty Ltd (2010)

In 2010, Derby Resources held an exploration lease that covered a considerable strike length of prospective coal-bearing strata in the northwest of the Fitzroy Trough (Andreazza, 2011). In 2011–12 they drilled five air coreholes, to a total of 251 m, as part of a reconnaissance program to test for coal, but no coal was found (Fig. 8) (Andreazza, 2012).

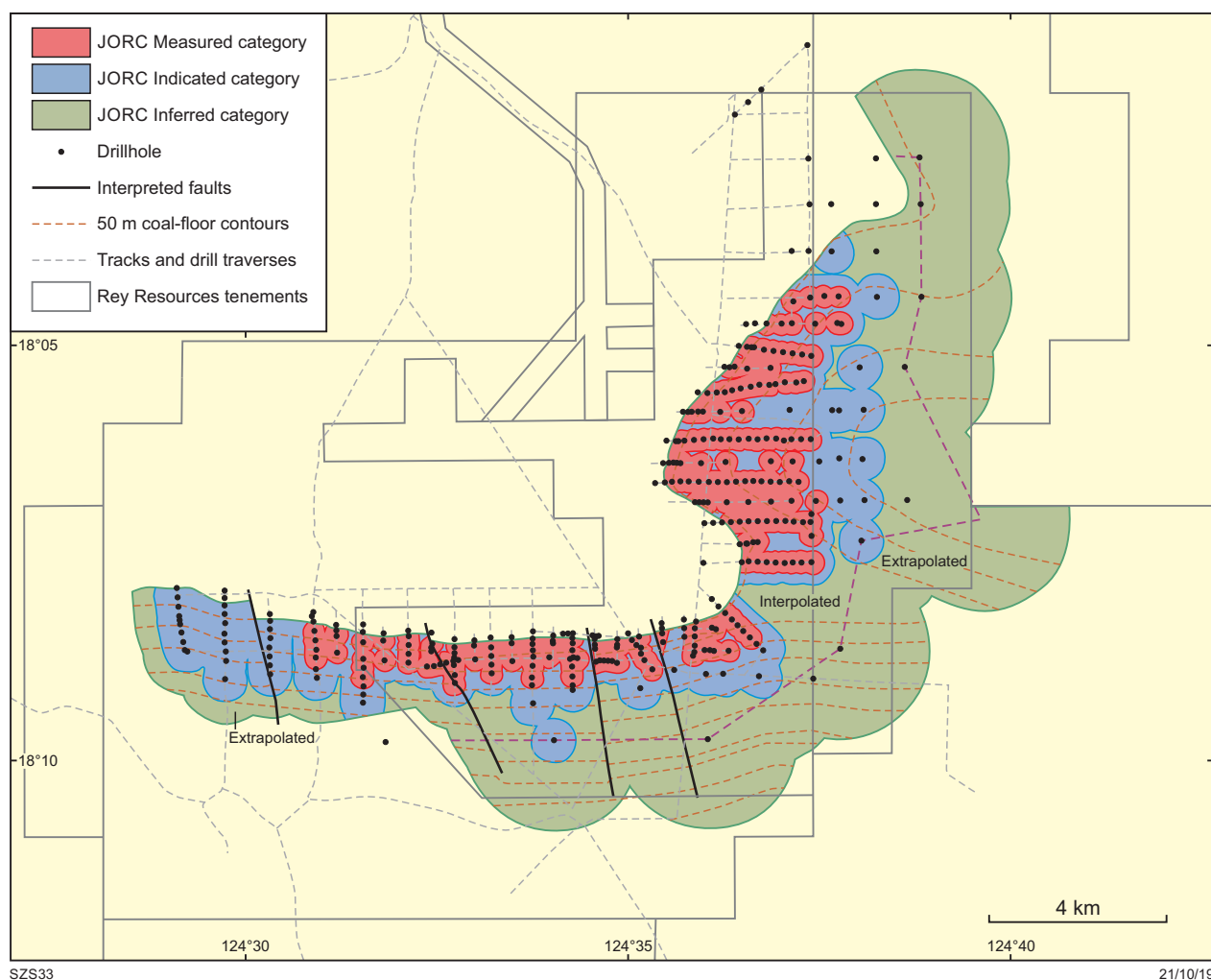


Figure 14. Rey Resources JORC 2012-compliant Duchess–Paradise resource outline (Rey Resources Limited, 2011b)

Table 16. Duchess–Paradise P1 seam JORC resource estimate at April 2011 (Rey Resources Limited, 2011b)

	<i>Measured (Mt)</i>	<i>Indicated (Mt)</i>	<i>Inferred (Mt)</i>	<i>Total (Mt)</i>
Paradise	34.6	30.3	81.9	146.8
Duchess	25.6	48.2	85.1	159
Total	60.2	78.5	167	305.8

Table 17. Duchess–Paradise resource estimate (in-place, with in situ moisture) (Rey Resources Limited, 2014) . Some values do not sum due to rounding

<i>Measured (Mt)</i>	<i>Indicated (Mt)</i>	<i>Inferred (interpolated) (Mt)</i>	<i>Inferred (extrapolated) (Mt)</i>	<i>Total Inferred (Mt)</i>	<i>Total (Mt)</i>
60.2	78.5	51.3	115.7	167.1	305.8

TPL Corporation Ltd (2011)

Tenements in the Fitzroy Trough were granted to TPL in 2010 for coal exploration (Gunther, 2011). After reviewing historic coal exploration data, including developing a geographic information systems database of drillhole locations and coal occurrences, TPL conducted a mapping program in 2010 to generate drilling targets within the Lightjack Formation (Gunther, 2011). As part of the review, GeoImage was commissioned to process Landsat 7 Enhanced Thematic Mapper+ data for the Canning Basin (Gunther, 2011).

In 2012, TPL drilled 14 holes along a 3.5 km transect at the Sisters Bore prospect, about 95 km southeast of Derby, of which four intersected coal (Figs 7, 15) (Kalal and Pratt, 2012). Analysis (ar) of coal at 84.96 – 85.76 m in hole LJM-D013 yielded a calorific value of 4499 kcal/kg, 9.2% moisture, 29.5% ash and 1.56% sulfur (Kalal and Pratt, 2012).



Figure 15. Chips from TPL drillhole LJM011, showing coal between 108–112 m (Kalal and Pratt, 2012)

Petroleum wells

Over 200 petroleum wells in the Canning Basin have been reviewed for coal occurrences; however, the accuracy of the coal recorded in the well logs is uncertain. The absence of coal in the lithological descriptions does not necessarily mean a lack of coal in the wells. It is possible that coal was not collected in the samples or that coal was not present in sufficient quantity to be recognized as a component of the sample. Cuttings are generally collected at 1.5 or 3 m intervals, and if coal is identified and logged, it is usually recorded as a percentage of the sample thereby hindering the identification of thin seams. The Upper Permian is not usually cored in the petroleum wells in the Canning Basin.

In petroleum wells, downhole geophysical logs are not commonly acquired in the near-surface section where shallow stratigraphic units are unlikely to be prospective for petroleum. Apart from the Liveringa Group, many petroleum wells have intersected minor coal in Carboniferous–Mesozoic formations (Mory, 2010). Myroodah 1, spudded in 1955 on the axial zone of the Deep Well Anticline within the Fitzroy Trough, intersected a 10.7 m thick seam of very low grade coal at 358.1 m in the Liveringa Group (Hill, 1956). Coal was intersected over a 3 m interval from 3368.9 m in the Carboniferous

Anderson Formation in Grant Range 1 (Roberts, 1956). Fraser River 1 intersected coal and plant remains in Late Carboniferous siltstone between 1892.7 and 1902.7 m and lignite between 146.3 and 149.4 m (Hunt, 1956). Early Permian coal was intersected at 548.8 m in Frome Rocks 2 (West Australian Petroleum Pty Ltd, 1962). In 1987, a seam of similar thickness (14 m) was noted at 200 m within the Liveringa Group in Petaluma 1, which was drilled 13 km to the east by Ultramar Australia Inc, (Parker, 1988). The coal interval is illustrated in the composite well log for Petaluma 1 (Fig. 16), which shows the wireline logs and interpreted lithology column (Reddicliffe, 2012b). This occurrence has been further investigated by Rey Resources and affiliated companies (Rey Resources Limited, 2014).

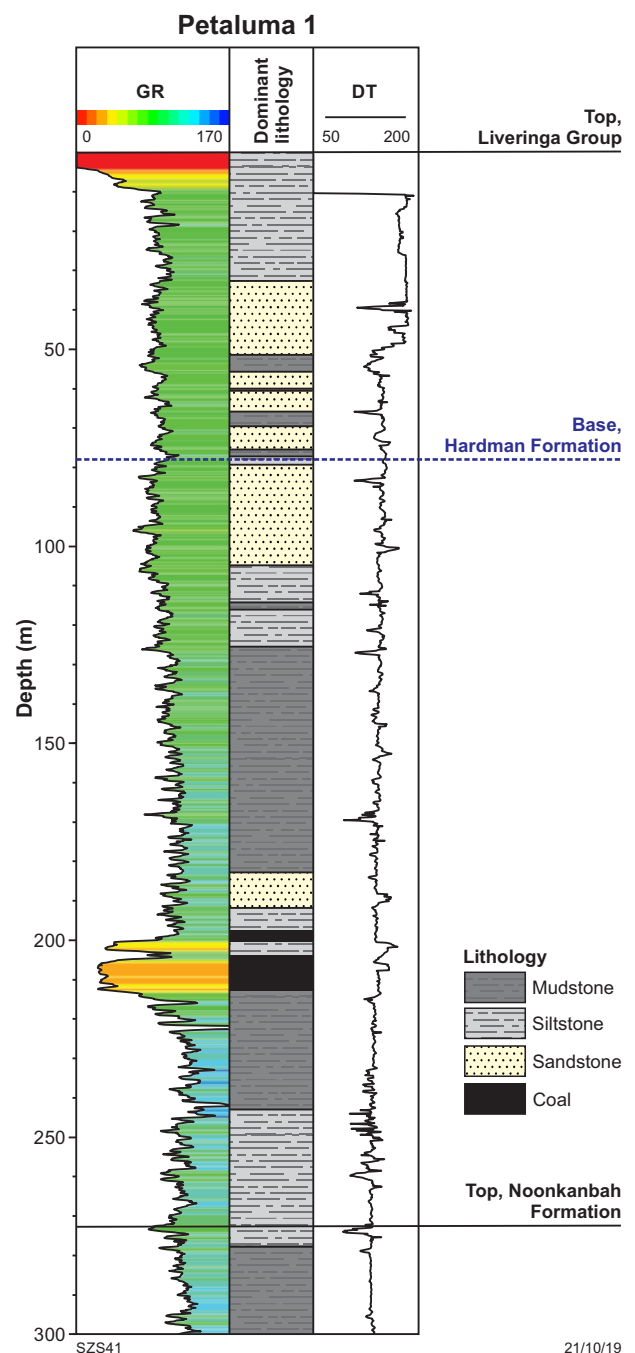


Figure 16. Geophysical logs from Petaluma 1 showing interpreted lithology and coal interval (Reddicliffe, 2012c). Abbreviations: DT, sonic; GR, gamma ray

Summary

The most active period of coal exploration in the late 1960s and early 1970s in the Canning Basin led to several discoveries of sub-bituminous coal in the Fitzroy Trough. Extensive drilling by coal exploration companies and data from petroleum wells shows that the Lightjack Formation of the Liveringa Group contains significant coal seams, particularly within the Fitzroy Trough. The coal generally occurs in two laterally extensive and consistent coal seams about 2 m thick, separated by several metres of sandstone, siltstone and mudstone. The seams locally converge to form a single coaly sequence up to 15 m thick. The depth of the coal varies from essentially surficial (5–15 m of cover) to depths exceeding 1 km. The coal is classified as sub-bituminous with moderate to high ash, high sulfur and low to moderate energy. The only JORC-compliant coal resource in the basin is 305.8 Mt, which was calculated by Rey Resources in 2014 for the Duchess–Paradise area on the south and west flanks of the Mount Wynne Anticline in the Fitzroy Trough, approximately 120 km southeast of Derby.

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