Coalbed Methane System, Exploitable Control Factors, Coalbed Methane Fields Characteristics, and Reserves in Bowen Basin

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Abstract. Coalbed Methane system is a natural system that encompasses coal seams and Coalbed Methane in them including all the geologic elements and processes. In Bowen Basin, Permian-Permian Coalbed Methane system is developed, it mainly contains Bandanna, Baralaba, Mantuan, Moranbah and Reids Dome Coalbed Methane plays. The Bandanna play was substantial resource, it accounted for 69% of Bowen Basin Coalbed Methane 2P reserves, and the Baralaba play accounted for 25% (December 2019). The controlling factors for exploitable Coalbed Methane filed are structure, permeability, deposition, coal distribution, gas content, coal rank, vitrinite content, and field geological characteristics. The characteristics of Coalbed Methane fields in Bowen Basin vary widely. At Dawson Valley, there are up to 10 seams in Baralaba Coal Measures with an aggregate coal thickness of up to 30 m at depths ranging from 300 to 1,000 m. At Fairview, the high gas content Bandanna Formation are characterised by having low structural stress along the crest of the Comet Ridge anticline. Average depth range from 550 to 950 mGL. Permeabilities are generally in excess of 50 mD. At Spring Gully, the coals targeted are Bandanna Formation. Aggregate coal thickness is between 5 and 9 m with the seams having both good gas contents and permeabilities. Average gas content is 12.5 m^3/t. Average permeability is 100 mD.

Keywords: Coalbed Methane · Coalbed Methane System · Bowen Basin · Reserves · Exploitable · Moranbah · MCM · Spring Gully · Fairview · Baralaba · Bandanna

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1 Bowen Basin Overview

The Bowen Basin is situated in Queensland, eastern Australia. It has an elongate form orientated predominantly north-south. It is approximately 1,100 km long and a maximum of 300 km wide and covers an area of about 160,000 km^2 [1].

Bowen Basin is divided into 6 tectonic units. 4 of them are negative units, namely, the Denison trough, the Taroom trough, the Nebo synclinorium, and the Springsuer shelf; 2 are positive units, namely Comet Ridge and Roma Shelf. It contains much of the known Permian coal resources in Queensland. Deposits of economic importance range from Early Permian to Late Permian in age. The coals deposited in terrestrial and shallow marine environments. Thick, widespread coal seams are present at several horizons throughout the sequence.

2 Bowen Basin Coalbed Methane System

With the rise of unconventional oil and gas exploration and development, the proportion of Coalbed Methane in the reserves and production of natural gas in eastern Australia is increasing [2]. It is necessary to introduce the idea of oil and gas system into Coalbed Methane geology to guide the exploration and development of Coalbed Methane [3–7] and meet the growing energy demand.

Coalbed Methane system is a natural system that encompasses coal seams and Coalbed Methane in them including all the geologic elements and processes. The essential elements include coal seams and surrounding rocks, and the processes are generation, reservoir, and conservation of Coalbed Methane [8].

In Bowen Basin, Permian-Permian Coalbed Methane system is developed, it mainly contains Bandanna, Baralaba, Mantuan, Moranbah and Reids Dome Coalbed Methane plays (see Fig. 1). Coal seams are self-sourcing reservoirs that may contain gas or gas mixtures of thermogenic or biogenic origin. The methane encountered in the Permian coals of Bowen Basin is thermogenic in origin. Methane trapped in coal is adsorbed onto the natural fractures and cleats of the coal surface or in micropores and held in place by hydrostatic pressure. The coal is both the source and the reservoir for the methane. Seals are provided by the connate waters that occupy fractures and larger pore spaces within the coal beds as well as the fine-grained siliciclastic sedimentary strata that are intercalated with the coal.

The Upper Permian Bandanna and Baralaba Formation coals are substantial Coalbed Methane resources in Bowen Basin. The Lower Permian Reids Dome Beds and Moranbah Coal Measures (MCM) are also Coalbed Methane sources, but are less prolific.

The Bandanna Coalbed Methane play was substantial Coalbed Methane resource and accounted for 69% of Bowen Basin Coalbed Methane 2P reserves (December 2019). The coal seams in the Dawson River, Moura and Peat fields produce methane from the Bandanna Formation coal measure. The Bandanna formation contains low ash and low moisture. These Late Permian coals are at the right maturity for thermogenic methane generation. The coal rank of the Bandanna formation is approximately 0.9% Rv with up to 70% of vitrinite content. Gas content varies from 10 to 15 m^3/t. The typical depth of the developed Bandanna formation varies from 420 to 1000 mGL [9].

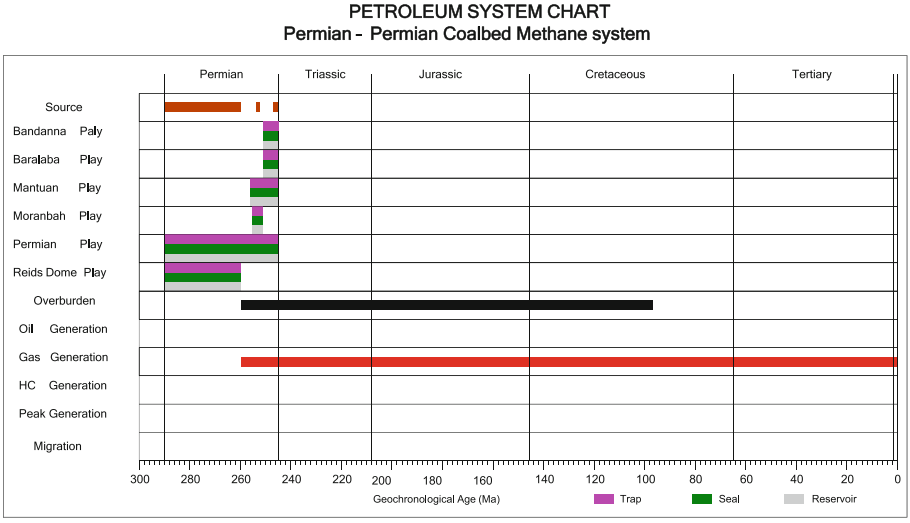

Fig. 1. Permian-Permian Coalbed Methane System Chart.

The Baralaba Coalbed Methane play was substantial Coalbed Methane resource and accounted for 25% of Bowen Basins Coalbed Methane 2P reserves (December 2019). The play contains thickly developed coal, with seams up to 6 m thick. The Baralaba coals is characterised by very thick coal with generally high gas contents, ranging from 9 to 25 m^3/t combined with low permeabilities. Generally, the Baralaba coals have acceptable permeabilities, good lateral continuity and appropriate maturity and are gas-saturated. The coal seams in the Fairview and Durham Ranch fields which produce methane from the Baralaba Coal Measures are generally about 500 to 1,000 m below the surface. The coals in these fields are clean and highly permeable, producing commercial quantities of high quality methane.

The MCM play accounts for 3% of Bowen Basin Coalbed Methane 2P reserves (December 2019). MCM is mainly deposited in the fluvial and lacustrine sedimentary system, transitioning to delta facies towards the south. Coal seams are thin in thickness and numerous in number, often accompanied by branching, merging, and pinching out[10]. The depth of the coal seams is mostly between 100 and 650 m. The cumulative net thickness of coal seams ranges from 10 to 30m, with an average value of 20 m. The coal rank is mainly medium and fat coal. Gas content varies from 7.4 to 13.2 m^3/t. The vitrinite reflectance ranges from 0.55 to 1.4%, with an average value of 1.0%. Due to the high content of clastic matter in coal seams and the development of mineralization, the permeability is relatively small and is concentrated in 0.1–100 mD [11].

3 Control Factors on Exploitable Coalbed Methane Field in Bowen Basin

3.1 Structure and Permeability

The Australian continental crust is in a compressional setting with the principal stress direction in Bowen Basin being east-northeast. This is important as this minimises the permeability of the coals so the search for Coalbed Methane field needs to focus on areas that have a tensional component where the cleats and fractures are at least partly open. Exploration should focus in areas where the geological environment has led to relief of any tectonic stress component.

The Comet Ridge containing the Fairview and Spring Gully fields is a large anticlinal structure (see Fig. 2). The axes of anticlines and synclines are obvious sites for enhanced permeability as they are tensional settings. Anticlines have an added advantage that free gas can migrate into the structures. A value of 100 mD is given for Fairview and Spring Gully fields.

The Peat and Scotia fields are located on the Burunga anticline (see Fig. 2). These fields contain structurally trapped free gas. Although the anticline favours enhanced permeability, there is a diminution of permeability with depth, such that seams below 900 m are considered subeconomic.

The Moranbah project is in a broad syncline, it produces gas from seams in the MCM. Data from Thomson and MacDonald indicate coal permeabilities of 30 mD at Moranbah North. Values at North Goonyella are 3–9 mD. The low permeabilities in the coals in this area have been dealt with in-seam drilling to enhance production. Coal seams in the area generally strike NNW-SSE and dip generally to the east at between 3 and 5, although localised areas of steeper dip may occur in association with structural features. Seismic surveys in conjunction with borehole data identified a series of NE-SW trending faults. Additionally, a large NW-SE trending fault has been extrapolated with throws of up to 100m in the eastern portion. The Moranbah area is in a hinge area associated with a major change in the direction of faulting (see Fig. 3). Folds or low amplitude microstructures formed by tectonic movements can induce the development of structural fractures in coal seams [13–16], improve the permeability of coal seams, and significantly increase gas production.

In the Moura area exploration focusses on seams at about 300 m depth. Permeabilities are quite low (<10 mD). At the Moura Mine gas is produced from within seam wells. The Moura area is partly monoclinal (see Fig. 2) and faulted. There are anticlines associated with the thrust faults.

Coalbed Methane field accumulations are not necessarily related to the presence of anticlinal closures. Many Coalbed Methane field project areas are located on anticlinal trends, however, although not all these anticlines may form valid structural closures. Anticlinal trends are attractive targets for Coalbed Methane field exploration, because the depth to a coal seam is often less on an anticline than on its flanks, and also because fracture development is often more intensive along the anticlinal axis.

3.2 Deposition and Coal Distribution

The depositional setting has a significant impact on the distribution of coal. Continuous, laterally persistent coals are easier to exploit than coals that thicken and thin over short distances or are subject to regular splitting.

Reids Dome beds coal measures formed in a series of grabens and half grabens. Coal seams formed mainly in overbank swamps in a meandering fluvial environment. Thicker seams, up to 12 m, formed in deltaic settings at the top of the unit; these are probably associated with the sag phase. Although the coals are locally thick, they tend to be discontinuous.

The MCM and the German Creek Formation represent a transition from fluvial to delta plain deposition in the north to paralic and marginal marine deposition. Laterally continuous coal seams split and coalesce for some 250 km along the strike of the basin. The Moranbah project produces gas from the MCM.

The Bandanna Formation and Baralaba Coal Measures contain a number of producing fields (Fairview, Spring Gully, Peat, Scotia, Moura, Dawson Valley). They represent the most widespread and continuous of all the coal groups being present throughout the basin. Although there are variations in seam thickness (maximum thickness $>$ 10 m) across the basin, many seams have a high degree of lateral continuity. The Baralaba Coal Measures are largely of fluvial origin whilst the Bandanna Formation in the Denison Trough was deposited in a large fresh water delta system passing upwards into a fluvial environment.

3.3 Gas Content

Bowen Basin shows a broad range of gas content including some high values. The wide spread indicates a complex set of factors control the actual gas content. The factors are gas generation, coal properties and reservoir conditions.

Of the coal properties, ash content is significant as methane is adsorbed on the organic matter, so the ash acts to lower the volume of gas that can be stored in a set amount of coal.

Vitrinite has a greater adsorptive capacity than inertinite and bright coals have a higher diffusivity than dull coals. Within a particular fairway or play, coal properties will be reasonable consistent, so wide variations in gas content are due to other factors.

Reservoir conditions exert a major influence. Reservoir pressure and temperature influence gas content including the impacts of uplift and cooling. The presence of free gas from conventional trapping will provide higher than expected gas contents.

3.4 Coal Rank and Vitrinite Content

Rank is an indicator of gas generation. The maximum rate of methane generation is between vitrinite reflectance of 1.3% and 1.8% Rv.

Reids Dome beds coals are perhydrous coals with liptinite contents between 6% and 11%. Vitrinite content ranges from 34% to 68%. Ash contents are generally low ($<$10%). Vitrinite reflectance ranges from 0.6% to 2.93% Rv, but the bulk of the coals are in the range 0.7% to 0.9% Rv. Ranks around Moura vary along strike from 0.7% Rv

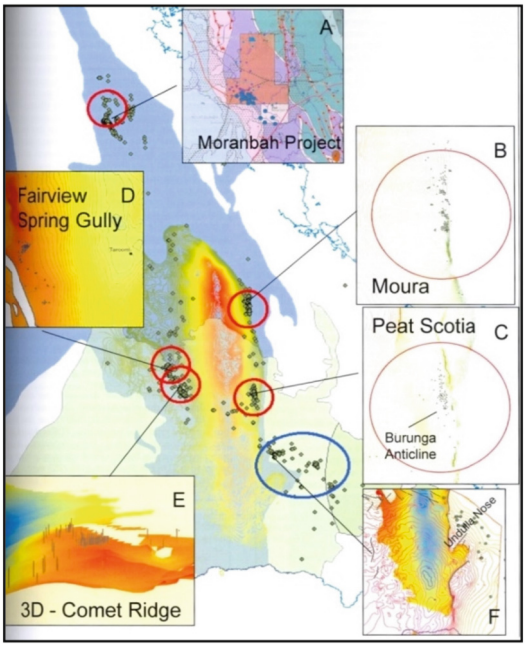

Fig. 2. Structural setting of Coalbed Methane fields. Contours represent depth to top of Bandanna Formation and isochronous stratum coals (red deepest, green shallowest). a. Moranbah Project: note change of trends of faults and flattening of dips; b. Moura area: note broad monoclinal structure. c. Peat and Scotia: note Burunga Anticline; d. Fairview and Spring Gully: large anticlinal ridge is called the Comet Ridge; e. 3D view of Comet Ridge looking south; f. Contours at top of Walloon Subgroup at Undulla Nose, draping over Permian structures can be seen clearly [12].

at Theodore to about 2.1% Rv at Baralaba and is about 1% Rv in the Moura area. At Peat and Scotia, south of Theodore, the rank values are of the order 0.55% to 0.7% Rv and vitrinite content is about 60%.

The coals from MCM have a wide range of ranks, from 0.6% to 3.5% Rv. The western outcrop areas have a narrower range of vitrinite reflectances from 0.98% to 1.63% Rv. Vitrinite content ranges_from 55% to 75%. Ash contents range between 5% and 15%. The ranks indicate the potential for optimal gas generation during burial. The Moranbah project produces in an area where rank is greater than 1.1% Rv with vitrinite contents of the order of 60%.

The rank of Bandanna Formation and Baralaba Coal Measures coals varies from 0.6% to 2.6% Rv. Vitrinite contents are highly variable ranging between 30% and 70%. Ash content ranges from 7% to 16%. The Bandanna Formation at Fairview and Spring Gully has a rank about 0.9% Rv with vitrinite contents of up to 70%.

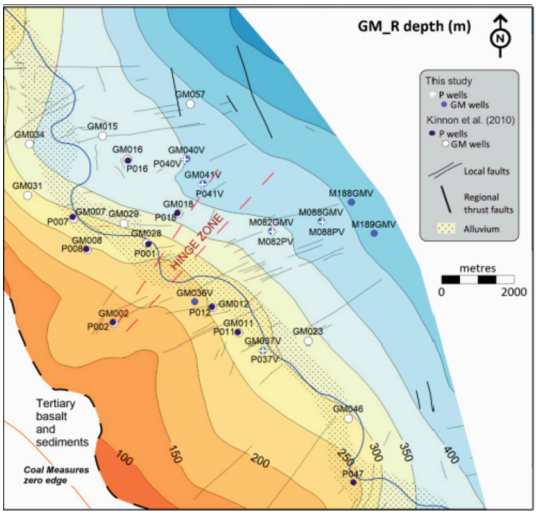

Fig. 3. Depth to top of the MCM GML seam below ground level [17].

3.5 Geological Characteristics

The producing fields in Bowen Basin have thick widespread seams. The advantage of continuous thick seams is that they provide a large target area, and increases the chance that some of the coals will be subject to stress reduction due to their structural setting.

Table 1. Comparison of geological factors for Coalbed Methane production.

Coalbed Methane plays	Coalbed Methane field	Tectonic setting	Structural setting	Depositional	Rank Rv (%)	Vitrinite content (%)	Gas content	Permeability
Bandanna Formation	Fairview,Spring Gully	Foreland basin	Comet Ridge anticline	Delta top, Fluvial	0.9	70	high	good
Baralaba Coal Measures	Peat,Scotia	Foreland basin	Burunga anticline	Fluvial	0.6–2.6	60	High	moderate
	Moura area	Foreland basin	Monocline, fracturing	Fluvial	1.0	60	high	poor
MCM	Moranbah Project	Foreland basin	Syncline, stress shadow	Delta plain, Delta	0.6–3.5	90	high	moderate

Anticlines offer a favourable target, but the permeability can be reduced by mineralisation in the cleats. Stress shadows such as round the Moranbah area also provide suitable targets.

The rank ranges from about 0.5% to 3.5% Rv in Bowen Basin. Gas contents broadly parallel rank, but are affected by local factors.

Permeabilities range from low in Permian coals near Moura to high in Permian coals in the Fairview and Spring Gully area.

The geological characteristics of the producing Coalbed Methane fields are summarised in Table 1.

4 Characteristics of Coalbed Methane Fields

4.1 Dawson Valley

The Dawson Valley Coalbed Methane operations comprise Moura, Mungi and Nipan project. The operations are based on recovering Coalbed Methane from the thick, gassy coals of the Baralaba Coal Measures. There are up to 10 seams in these coal measures with an aggregate coal thickness of up to 30 m at depths ranging from 300 to 1,000 m. Production was approximately 20 TJ per day or 7.3 PJ in 2006.

The thickness of the coal seams in Mungi field is generally 3–4 m, with a depth of 200–700 m. The gas content ranges from 7.9 to 26.9 m^3/t, with an average of 15.58 m^3/t. Ash content variation range: 5.9–94.2%, average 25%. Permeability variation range: 0.006–6.04 mD, average 0.5 mD. The coal seam presents a monoclinic structure with high in the east and low in the west, with a series of NNW trending thrust faults and folds developed inside. Coal seams are formed in the sedimentary environment of alluvial fans, with lateral discontinuities, large variations in the number of layers, and large differences in thickness. The gas production of 15 vertical wells varies greatly, with the cumulative gas production of 5 vertical wells accounting for 70% of the total cumulative production. Peak gas production ranges from 50 to 1000 mcfd, with an average of 430 mcfd. Peak water production ranges from 20 to 70 bwpd, with an average of 45 bwpd (see Fig. 4).

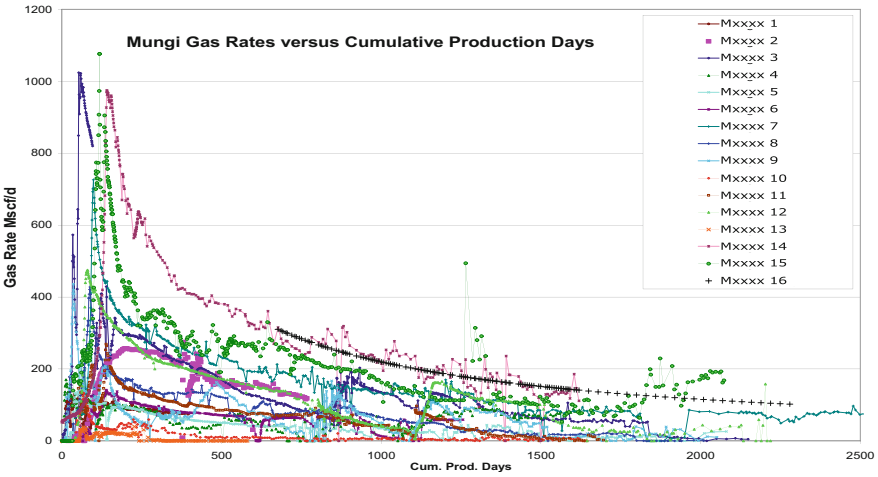

Fig. 4. Gas production curve from fractured vertical wells in Mungi field.

4.2 Fairview

The Fairview field was first identified as a potential Coalbed Methane resource in Bowen Basin in 1989. At Fairview, the high gas content Bandanna Formation coals are characterised by having low structural stress along the crest of the Comet Ridge anticline (see Fig. 5). Average depth range from 550 to 950 mGL. Permeabilities are generally in excess of 50 mD.

At 31 March 2008, Fairview was producing Coalbed Methane at a rate of 74 TJ per day or at the annualised rate of 27 PJ. Average production per well is 1 TJ per day.

4.3 Spring Gully

The Spring Gully field occupies the southern part of the Comet Ridge(see Fig. 5). The coals targeted are Bandanna Formation. Aggregate coal thickness is between 5 and 9 m with the seams having both good gas contents and permeabilities. Average gas content is 12.5 m^3/t. Average permeability is 100 mD. Permeability is related to depth with commercial levels to 1,100 mGL and possibly deeper.

Spring Gully field high yield wells and low yield wells each accounted for 50%. In high production wells, the daily production was 500–3000 GJ/d/well. In low production wells, the daily production was less than 500 GJ/d/well. Some structural closures existed providing initial free gas flow (see Fig. 6). The production ramped up and had reached 93 TJ per day (34 PJ per year) by 31 March 2008.

4.4 Moranbah

The Moranbah Project is located in the northern part of Bowen Basin. It produces Coalbed Methane from MCM using horizontal in-seam wells where two in-seam wells in a chevron configuration intersect a common vertical well. The coals at Moranbah have low to moderate permeabilities (0.1–10 mD).

Gas production was approximately 47 TJ per day (17.2 PJ per year in 2008). The wells had an average daily production rate of 0.9 TJ and relatively small amounts of water.

4.5 Peat

The Peat field is located on the Burunga Anticline. Gas is recovered from highly fractured coals of the Baralaba Coal Measures. There are four major coal seams at Peat with average aggregate thickness of 18 m. The seams occur at depths of between 500 and 900 m. Permeability is related to depth with commercial levels to at least 900 mGL. The average permeability is 10 mD. The average gas content is 9 m^3/t. At the crest of the Burunga Anticline there is free gas trapped in the cleat system. Virtually no water is co-produced with the gas at Peat.

Gas production at Peat was averaging 16 TJ per day or 5.8 PJ per year in 2008.

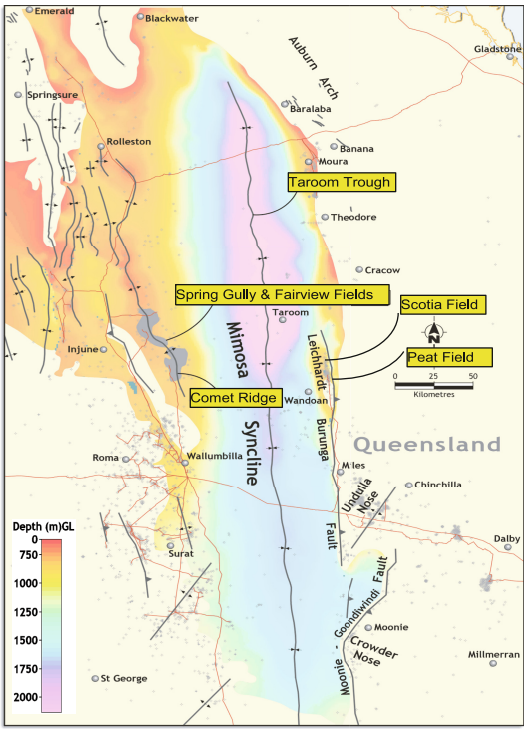

Fig. 5. Structural map of Bandanna Formation and isochronous stratum in the central Bowen Basin.

4.6 Scotia

The Scotia field occupies the northern part of the Burunga Anticline, recovering gas from coals in the same four seams in the Baralaba Coal Measures as at Peat.

Production was 27 TJ per day (9.8 PJ per year in 2008). The wells at Scotia had high productivity with average output per well being 0.9 TJ per day and produce very little water.

5 Reserves

Coalbed Methane field companies in Australia make the volume of their reserves publicly available. The independently audited and reported 2P Coalbed Methane reserves in Bowen Basin at 31 December 2019, meeting the requirements of the Petroleum Resource Management System, were 6,341.84 PJ (5,979.73 bcf).

The two Coalbed Methane fields with the largest reserves are Fairview and Spring Gully. The 2P reserves at Fairview was 1,739.83 bcf and Spring Gully was 1,624.0 bcf (see Fig. 7).

The two Coalbed Methane plays with the largest reserves are Bandanna Formation and Baralaba Coal Measures. The 2P reserves at Bandanna Formation was 4,138.08 bcf and at Baralaba Coal Measures was 1,477.07 bcf (see Fig. 8).

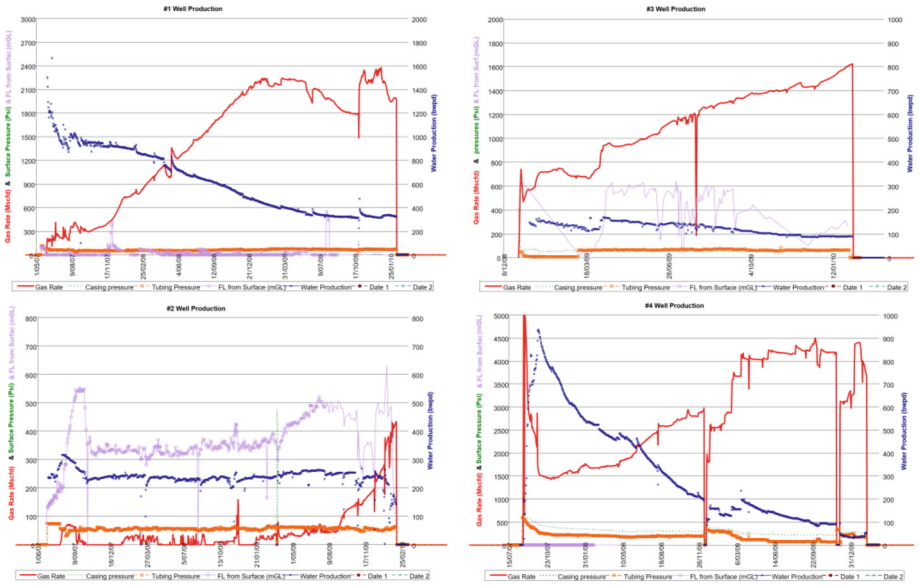

Fig. 6. Typical well production profile of Spring Gully field.

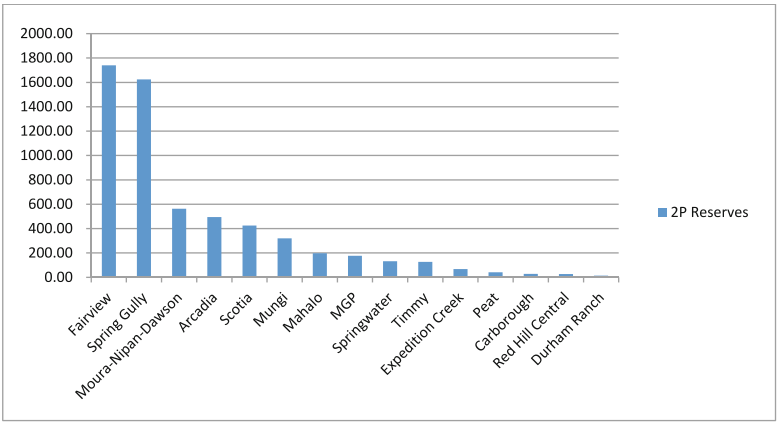

Fig. 7. 2P reserves (bcf) of Coalbed Methane fields in Bowen Basin.

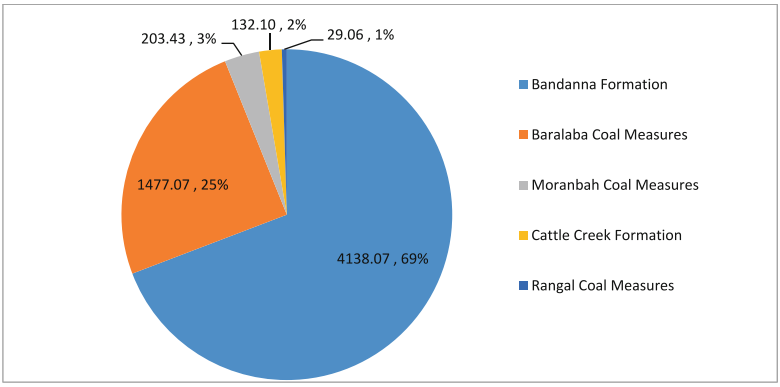

Fig. 8. 2P reserves (bcf) of Coalbed Methane plays in Bowen Basin.

6 Conclusion

Coalbed Methane system is a natural system that encompasses coal seams and Coalbed Methane in them including all the geologic elements and processes. In Bowen Basin, Permian-Permian Coalbed Methane system is developed, it mainly contains Bandanna, Baralaba, Mantuan, Moranbah and Reids Dome Coalbed Methane plays.

The Bandanna play was substantial resource, it accounted for 69% of Bowen Basin Coalbed Methane 2P reserves, and the Baralaba play accounted for 25% (December 2019).

The controlling factors of Coalbed Methane producibility are structure, permeability, deposition, coal distribution, gas content, coal rank, vitrinite content, and field geological characteristics.

The characteristics of Coalbed Methane fields in Bowen Basin vary widely. At Dawson Valley, there are up to 10 seams in Baralaba Coal Measures with an aggregate coal thickness of up to 30 m at depths ranging from 300 to 1,000 m. At Fairview, the high gas content Bandanna Formation are characterised by having low structural stress along the crest of the Comet Ridge anticline. Average depth range from 550 to 950 mGL. Permeabilities are generally in excess of 50 mD. At Spring Gully, the coals targeted are Bandanna Formation. Aggregate coal thickness is between 5 and 9 m with the seams having both good gas contents and permeabilities. Average gas content is 12.5 m^3/t. Average permeability is 100 mD.

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