Reserve estimation and the influence of coal seams on coal seam gas productivity

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Introduction

SRK has undertaken coal seam gas (CSG) reserve and resource estimations for many companies and has consistently found that the influence of the coal seam setting and coal quality is commonly underestimated. This can significantly impact production risks and can result in the failure to achieve mean outcomes for the most commonly assessed proved and probable (2P) reserves and contingent resources.

The nature of the peat forming environment and the genesis of the contained methane in shallow CSG reservoirs often results in highly variable gas saturations. By understanding these processes and identifying the geological features responsible for high-frequency variations in gas contents, exploration can be better targeted, reserves can be reported more accurately and production variations better understood and predicted.

In comparison to most traditional gas reservoirs, the peat forming environment produces thinner and less laterally continuous reservoirs. Not only do individual seams split and coalesce within hundreds of metres but seam characteristics such as ash content can also vary over similar distances. The thin nature of the CSG reservoir also provides the potential for relatively small faults (<5 metres) to fully displace the coal seam and effectively compartmentalise the reservoir.

In shallow CSG reservoirs there are numerous instances where methane distribution in a CSG reservoir appears to oppose the traditional oil and gas scenario of upward migration and trapping. For instance gas contents appear higher in synforms rather than antiforms and higher on the upside of faults rather than the downside. This is true of the San Juan Basin in the USA (Scott *et al*, 1994) as well as the Surat Basin (Figure 1). During exploration, reserve estimation and production it is important to have a good understanding of the origin of the methane and how it has been stored in the reservoir.

By considering the geological environment and accounting for the inherent variability – including sweet spot analysis and definition – reserve determinations should not impact long-term outcomes. Rather, the prospectivity should be based on the available data combined with robust geological models that enable capture of the available upside without undue or overly optimistic reporting.

Methane generation in coal reservoirs

Coal reservoir history can be divided into three stages:

1. Burial – where thermogenic gases are generated. Gas contents in the reservoir are more a case of gas retention as large quantities of gases are generated (about 100 m3/t of CH4 and 150 m3/t of CO_2) that are subsequently lost. Subsequent to maximum burial there are not many instances where it can be shown that methane has migrated within the coal reservoir.

2. Uplift – where faulting and folding and temperature and pressure reduce. The reduction in temperature results in the coal being able to adsorb more gas and consequently gas saturation significantly falls (typically to 30-60 per cent).

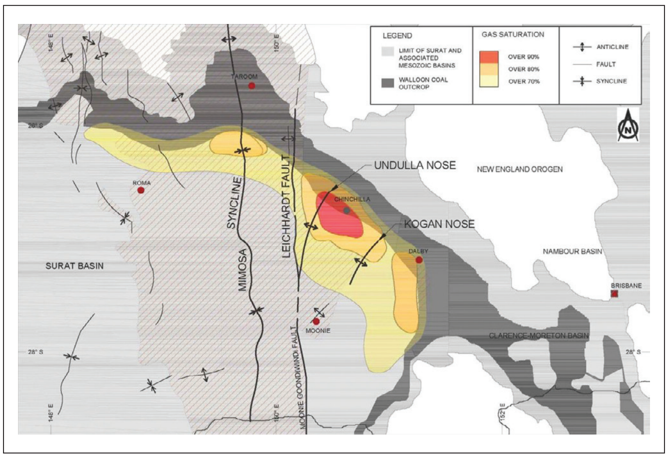

Figure 1. Surat Basin methane saturation trend (modified after Hamilton et al*, 2012).*

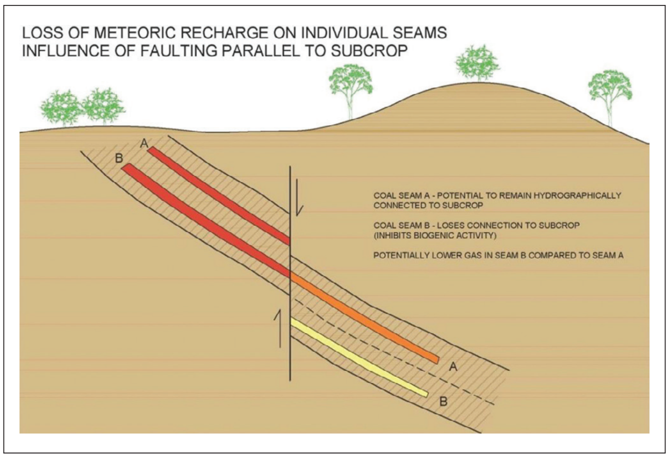

Figure 2. Potential impact of a fault on biogenic recharge.

3. Post uplift – where a secondary biogenic recharge occurs at basin margins and can result in re-saturation of coals (>70 per cent) at shallow depths. This process consumes C2+ compounds, carbon dioxide and the coal substrate itself to form isotopically lighter and dry methane compared to conventional natural gas.

This last process and the geological features that control it are most likely responsible for the high-frequency variations observed in CSG reservoirs. The following parameters are conducive for the biogenic recharge process:

- good meteoric water flow (provides nutrients and allows bacteria to migrate)
- good permeability (>0.5 mD) suggesting shallow depths (generally <600 m)
- proximity to basin margin (generally within 10-15 km – Table 1)
- good seam development (extending to subcrop)
- low acidity, low salinity, <70 degrees.

The distance from subcrop and the depth that biogenic recharge may influence gas distribution is also dependant on seam continuity and the seam's hydraulic connection to meteoric water inflows.

Faults and palaeo-channels that displace the seam are features that would conceivably be responsible for disrupting meteoric water flows and thereby impacting negatively on biogenic recharge (Figures 2 and 3).

The features that would have the strongest impact on meteoric water flows are logically those that strike parallel with the basin margin.

The greater the distance from subcrop the more likely the seam in question loses hydraulic contact with the subcrop. The combination of these geological features and a gradual reduction of permeability with depth results in a 'goldilocks zone' or fairway being formed as a band within the basin margin as occurs in the Powder River Basin (Montgomery, 1999) and the Surat Basin (Figure 1).

If the dominant strike of regional faults or palaeochannel systems is known for a given basin then one can further rate the prospectivity of various parts of the basin margin (Figure 4).

The distance/depth limit of the 'goldilocks' zone or fairway may be inferred by several means:

- a fall in the moving average of total gas contents against depth or relative level
- reduction in permeability below 0.5 mD
- trends in gas composition and isotopes suggesting waning of biogenic recharge particularly when CO_2 data is separated from methane effects
- evidence of an 'ethane line'
- trends in water quality (salinity) and the potentiometric surface.

Location	Maximum distance from subcrop (km)	Maximum depth (m)	Estimate of general permeability (mD)
Surat Basin	20-30	7-800	<100
Undulla Nose	30-40	800	100s
Bowen Basin	10-15	5-600	<50
Fairview	10-15	1000 (steep dips)	<100
Sydney Basin	10-15	3-800 (variable)	<10
Newcastle Coalfield	5-10	4-500	<5
Gunnedah Basin	15-20	6-800	<10
Ordos Basin, China	5-10	6-700	<5
San Yuan Basin, USA	50	1500	100s
General	10-15	6-800	Driven by permeability

Table 1. Influence of biogenic recharge – depth and distance from subcrop.

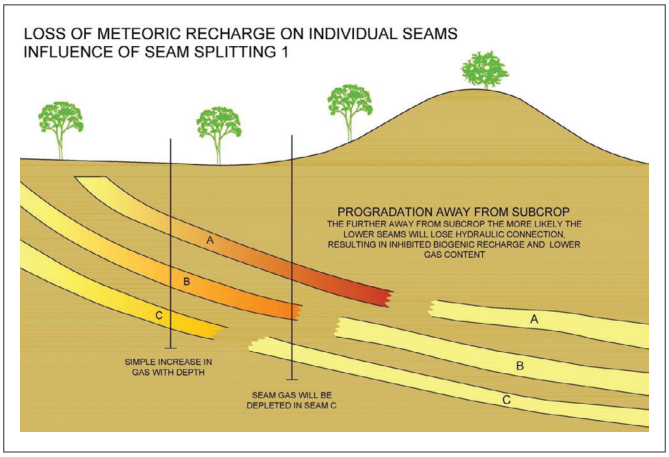

Figure 3. Potential impact of a migrating paleo-channel on biogenic recharge.

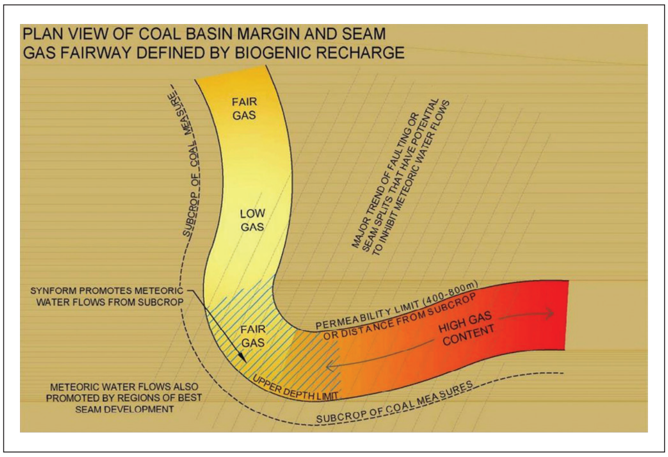

Figure 4. Proposed fairway characteristics.

An analysis of the above data across an area may also locate sedimentary and structural features responsible for significant impacts on future field production, such as the Leichhardt Fault in the Surat Basin (Figure 1). There is also a link between biogenic recharge and permeability that can be exploited during exploration to better understand the potential production from a field.

High frequency variations in reservoir properties present a significant geological risk to exploration and field production estimates if not understood and quantified. There is a significant contrast between borehole spacing that is considered adequate for CSG Reserve estimation and coal Reserve estimation in the same coalfield:

- oil and gas – pilots up to 7 km apart, supportive boreholes at 1-2 km spacing
- coal – points of observation at 1 km to 500 m apart, supported by chip holes at half that distance to confirm seam continuity and correlations.

This contrast in data density may be interpreted to suggest that CSG operators may often be blind to high-frequency variations in gas saturation and therefore production. The pre-requisite though is to understand the mechanisms and potential geological controls responsible for these variations and use some of the investigative tools outlined in this paper.

Figure 6 illustrates a hypothetical field with two successful pilot holes (in red). Despite being in a position to assign 3P reserves the operator is unaware of:

- the location of a small fault that strikes sub-parallel to the basin margin
- gas content data from closely spaced exploration conducted by the local coal mine that identified a large area low gas contents
- the potential link between the fault and low-gas contents between the pilot holes.

Conclusion

The influence of the coal seam setting and coal quality is commonly under-estimated and can significantly impact on assessed 2P reserves and contingent resources. By considering the coal and gas composition data, known structures and the facies variability including sweet spot analysis, reserve determinations should not significantly differ from the long-term gas estimation outcomes.

Prospectivity should be soundly based on the available data combined with robust geological models that capture of the all the available upside without overly optimistic reserves estimation. A clear understanding of the genesis of the target methane and the relevant geological controls will enable cost-effective targeted exploration as well as accurate interpretations and predictions of field production potential.

In a recent article in by Matt Chambers (*The Australian*, 19 November 2013) the following statements are made with regard to a perceived failure of gas wells in Queensland to perform:

1. '… one of the main reasons for the poor well performance was that the coal was not as homogenous as expected and less permeable than expected.'
2. '… that the sweet spots were not as large as had been hoped.'
3. '… the best ground is being drilled first, meaning there is no way of knowing if the results will be replicated.'

These observations by Chambers suggest that not enough data is currently being gathered to characterise CSG reservoirs and the geological controls on gas content and permeability are not yet fully understood.

References

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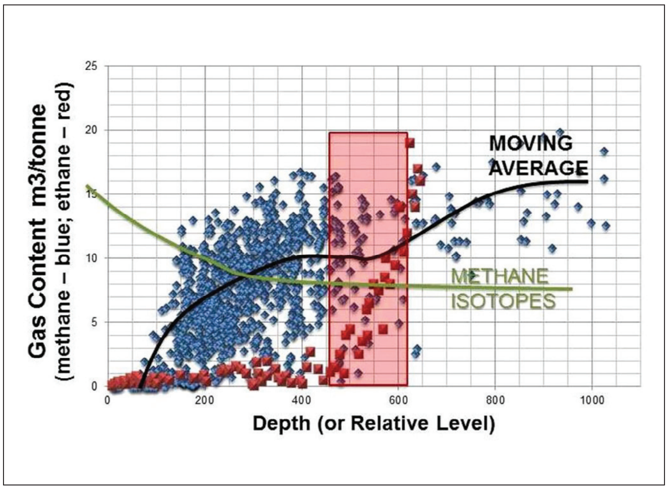

Figure 5. Changes in gas characteristics with depth.

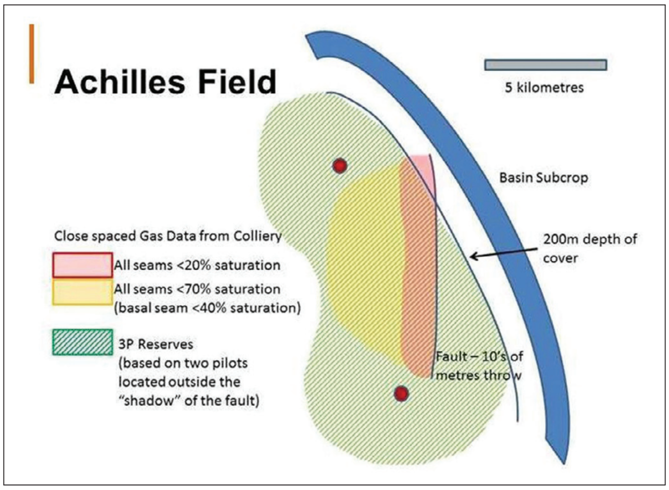

Figure 6. Impact on gas saturation of a small fault (the two red circles represent pilot test holes that are located either side of the influence of the fault).