



UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

Coal Operators' Conference

Faculty of Engineering and Information Sciences

2014

Leveraging Gas Reservoir Data

Ray Williams
GeoGAS Pty Ltd

Publication Details

Ray Williams, Leveraging gas reservoir data, 14th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2014, 243-251.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library:
research-pubs@uow.edu.au

LEVERAGING GAS RESERVOIR DATA

Ray Williams

ABSTRACT: At a time when budgets are tight, it is increasingly important to maximise the use of gas reservoir information. This paper presents methods for leveraging gas content and permeability data and quantifying uncertainty. The objective is to adequately define the gas reservoir in terms relevant to how the data will be applied - for the least expenditure and risk. In the case of gas content, reduction in data noise reveals underlying trends that can then be mapped across a deposit. Essentially defining gas domains, with equations and uncertainty, it permits more targeted drilling and rationalisation of exploration plans. Permeability data are invariably sparse and yet critical in reservoir assessments. Two methods are presented to extend the range of direct well test data – the first maps inherent fracture development based on residuals of the Initial Desorption Rate (IDR30)/gas content relationship. The second provides a process for utilising observed relationships between permeability, depth and gas saturation to map permeability distribution with quantified uncertainty. The quantified relationships and uncertainty can then be used as inputs to probability modelling for gas emission, gas drainage and life of mine gas production.

INTRODUCTION

Acquisition of gas reservoir data is costly. Data quality is paramount – the higher the quality, the greater is the likelihood of quantifying underlying trends, potentially resulting in reduction of both data quantity and expenditure for the same level of risk. This paper addresses two key reservoir parameters – gas content and permeability, with a view to maximising the usefulness of the information obtained. Models that identify and describe trends are fundamental to leveraging data. The uncertainty inherent in such models determines the extent of their usefulness.

GAS CONTENT AND COMPOSITION

Gas content is the most basic and important gas reservoir property. There are standards (AS 3980-1999, ASTM D7569-10) which aid in governing their determination but none are sufficiently prescriptive to result in acceptable inter-laboratory reproducibility. This is especially so between fast and slow desorption testing in mixed CH₄ and CO₂ environments and between laboratories for fast desorption testing. The first requirement therefore is to know what influences the gas content result and how to undertake such testing in a manner that truly does reflect the gas adsorbed in the core sample being tested.

Every gas content test must report the following three parameters:

- Gas content expressed as the volume of gas desorbed per unit mass (m³/t)
- The gas composition of the component gases, primarily CO₂ and CH₄
- The corresponding material properties of the coal - proximate analysis, Relative Density (RD)

The extent to which each is accurately measured dictates the overall accuracy of the result. A highly accurate gas content and component determination can be rendered useless if the associated coal properties are not similarly well defined. Probably the worst problem arises in conflicting use of the core – coal quality washability testing and gas content testing. For washability testing, the core sample requires a minimum of disturbance and small, discrete sections are selected for Q₃ residual gas determination. The resulting lack of sub sample representation can be overcome by undertaking proximate analysis on the remaining core, but frequently this core is recombined into coal plies prior to analysis resulting in poor characterisation of the coal core properties.

Both depth and mineral matter have a profound effect on gas content and in assessing underlying trends for gas domain analysis, the effect of mineral matter needs to be removed. A good gas content dataset

over a narrow depth range (e.g. < 30 m), should always correlate well with mineral matter unless the coal properties have been changed by devolatilisation from igneous activity. Often, zero gas content does not occur at 100% Ash+Inherent Moisture (IM) due to carbonates in the coal (example Figure 1). Here, zero gas content equates to 88% Ash+IM. Corrections are commonly done in the coal bed methane industry to a dry ash free (daf) basis. These corrections assume zero gas content at 100% Ash+IM and result in increasingly large errors with increasing mineral matter. Corrections to a daf basis are unnecessary and only serve to increase error and mask underlying trends.

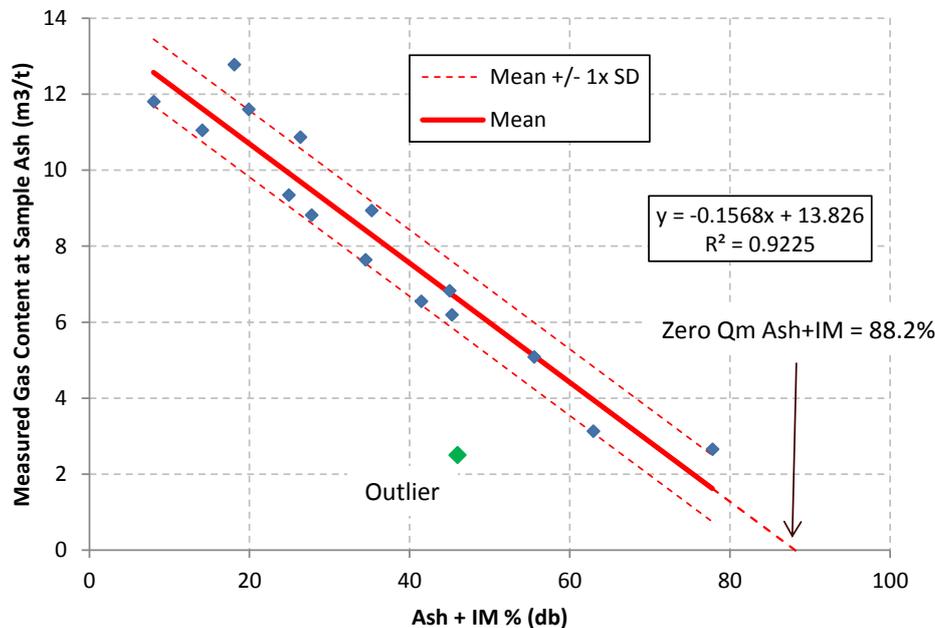


Figure 1 - Example of relationship between gas content and mineral matter

An anomalous value such as the outlier in Figure 1 could be the result of an error in gas volume determination or an error in assignment of coal properties. An outlier on its own should never be discounted unless there is corroborating evidence to that effect. A range of tests can be applied to rule on such outliers, such as relationship to initial desorption rate (Williams, *et al.*, 2002) and mismatches between calculated core density and measured RD.

Once the gas content data are validated and corrected to a common ash, underlying trends against depth can be discerned (Figure 2). Data may be affected by lesser quality results, ultimately expressed in the standard deviation about the mean (e.g. 1.46 m³/t in Figure 2). Good data sets normally have standard deviations less than 1 m³/t.

Resolution of these groupings (where data overlap) is made on the basis of spatial mapping of the gas domains as described in Williams *et al.* (2002, example Figure 2).

While probably the majority of gas domains can be defined by mappable depth/gas content relationships, many are more complex as indicated for Mount Arthur North/Saddlers Creek and Goonyella Riverside in Esterle *et al.*, (2006).

The gas domain boundaries are often quite sharp, although frequently difficult to relate to geological features. On a mine scale, they give direction for further drilling in defining boundaries, and enable rationalisation of drilling within boundaries.

PERMEABILITY

Factors affecting

Permeability is a measure of the ease with which a fluid can pass through a material. Coal itself (i.e. the coal matrix), is essentially impermeable and it is the cleat system that primarily determines the

permeability of a coal seam. How well it is developed is a reflection of the coals burial and tectonic history but it is also sensitive to material properties.

Bright coal contrasts with dull coal in containing a higher frequency of cleats and the reduced permeability of dull coal is well documented. Cleat development is also affected by mineral matter and is retarded as mineral matter content increases. The cleat system can be in-filled by secondary mineralisation such as calcite, significantly reducing the permeability of a well cleated coal.

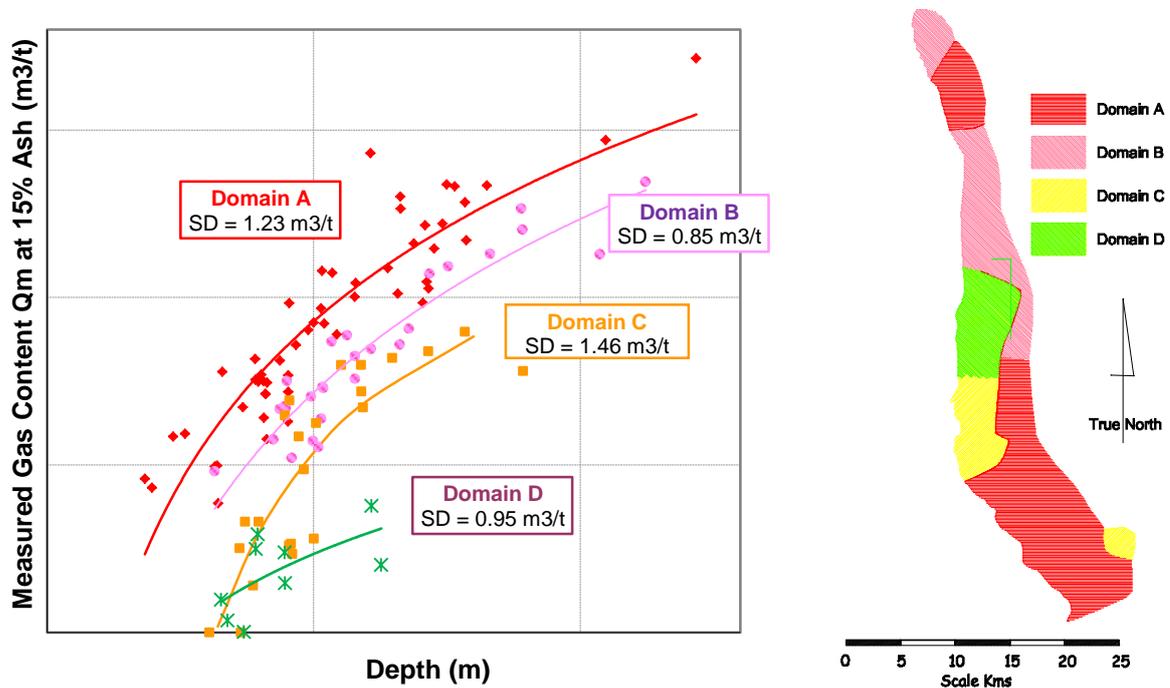


Figure 2 - Gas domain defined by gas content depth gradients

Coal has a low Young's Modulus and is especially sensitive to stress. Increased stress squeezes the cleat system, usually resulting in a marked reduction of permeability with depth of cover. For example, the Goonyella Middle seam of the Moranbah Coal Measures is particularly stress sensitive exhibiting a 12 fold decrease in permeability for every MPa increase in stress. Because of the sensitivity of permeability to stress, permeability values should always be accompanied by at least depth measurements but also pore pressure.

Simply plotted against depth, variations can be large, reflecting the combined effects of cleat development (burial/tectonic history, coal properties of mineral matter and coal type, mineral in-filling) and stress (depth of cover and local perturbations). In Figure 3 the response of decreasing permeability with depth is clearly seen in Seam C. Even so, the scatter is quite large (around two orders of magnitude) presumably reflecting smaller scale changes in coal properties, stress and cleat development. Seam A and to a large extent, Seam B show the effect of lower cleat development, which happens to be due to relatively high ash coal.

The higher ash coal with its higher Young's Modulus attracts more stress. For Seam A, this results in lower permeability, but this reduction is also influenced by a lack of cleating in the high ash coal (right side diagram, Figure 3).

A proxy for cleat development

Gas content determinations using the direct method initially involve the field measurement of gas desorption rate for calculation of gas lost between taking the core and sealing in a canister (as described in AS3980-1999). From these initial desorption measurements, the calculation of the IDR30 desorption rate is reported as the quantity of gas desorbed in the first 30 minutes after time t_0 per unit mass (IDR30 = v/m m³/t where v = l volume in ml, m is coal mass in g, Figure 4).

IDR30 is strongly related to:

- Gas content
- Gas composition
- Core diameter, and less clearly related to
- Degree of fracturing of the intact core – drilling induced and geological

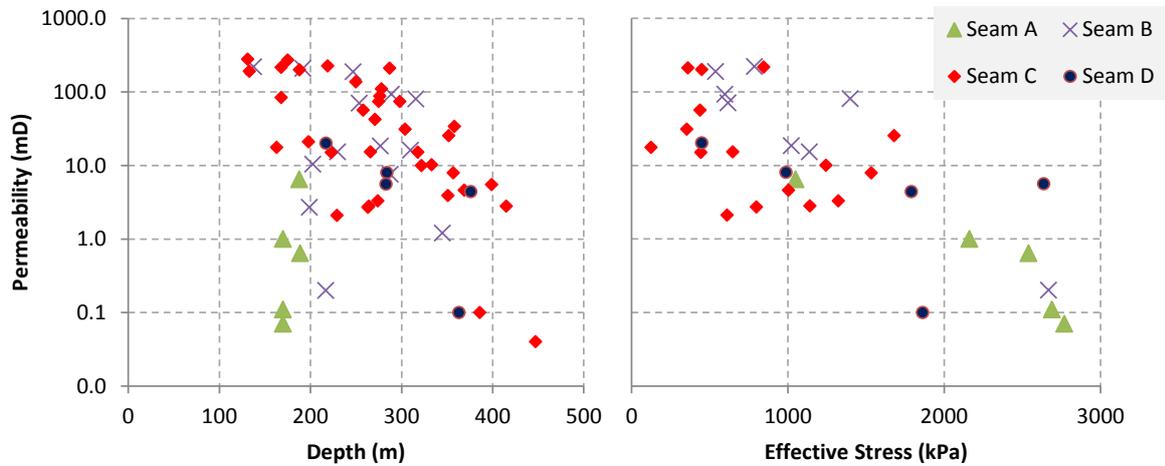


Figure 3 - Variation in permeability with depth and effective stress

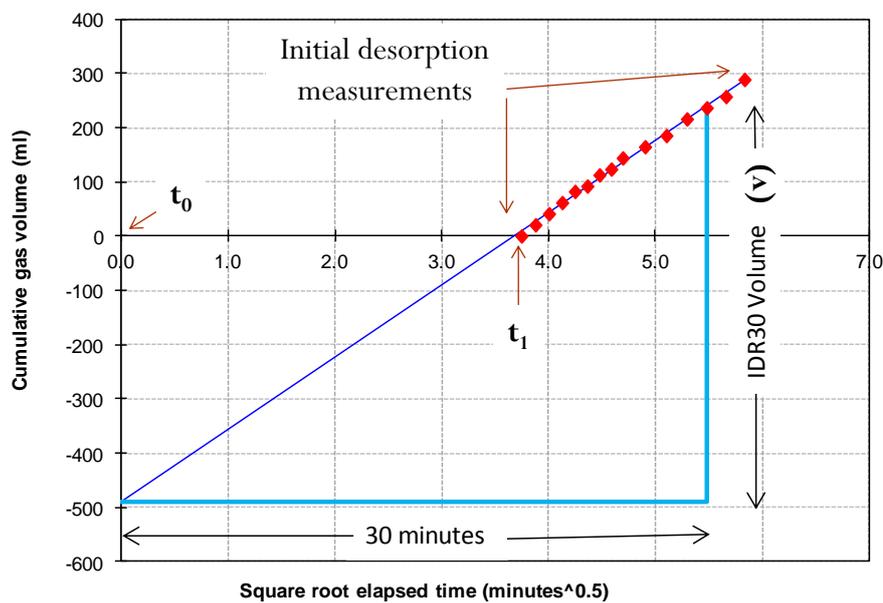


Figure 4 - Derivation of IDR30

Gas content increases with IDR30, but the relationship always shows a degree of scatter about the mean (Figure 5). For a relatively constant gas composition and consistent core size, the scatter is arguably related to variable fracturing in the core itself. In the great majority of cases the fractures are geological in nature (cleats).

The implication is that where the IDR30 is high for a given gas content, the core is more fractured and vice versa (Figure 5). Residuals about the mean can be calculated and mapped (Figure 6).

A major advantage of the method is the universality of IDR30 data, calculable from any laboratories Q1 gas content test data. But extraneous effects can affect the outcome:

- Gas content data must be validated. A high IDR30 can also be an indication of canister leakage

- The gas content/IDR30 relationship must be robustly defined and be devoid of bias from too few end data (e.g. excluded data, Figure 5)
- Where more than one laboratory has done the gas content testing, reproducibility needs to be good.
- In mixed gas (CO₂, CH₄) environments, it should only be applied for specific ranges of gas composition where a low sensitivity to gas composition can be demonstrated.

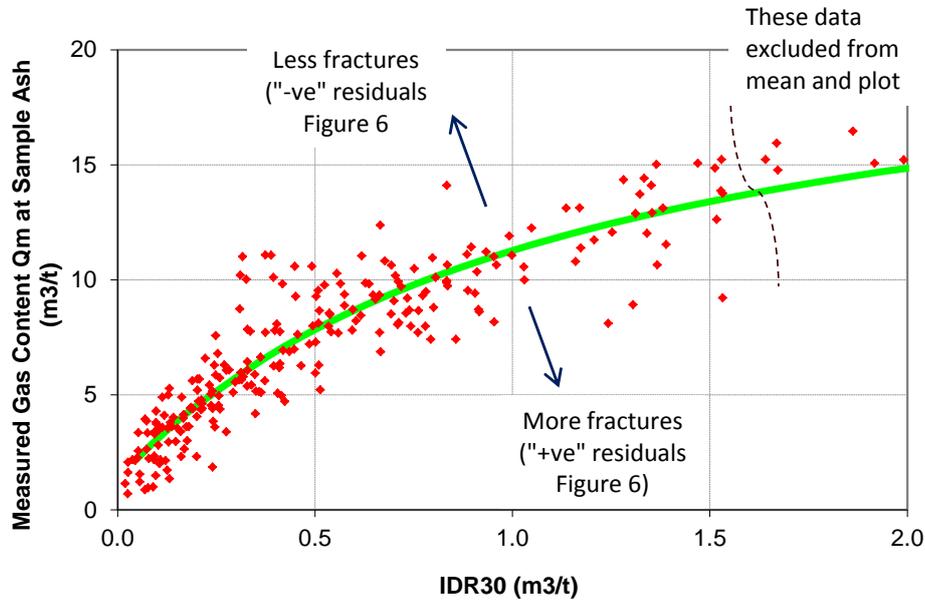


Figure 5 - Relationship between IDR30 and measured gas content

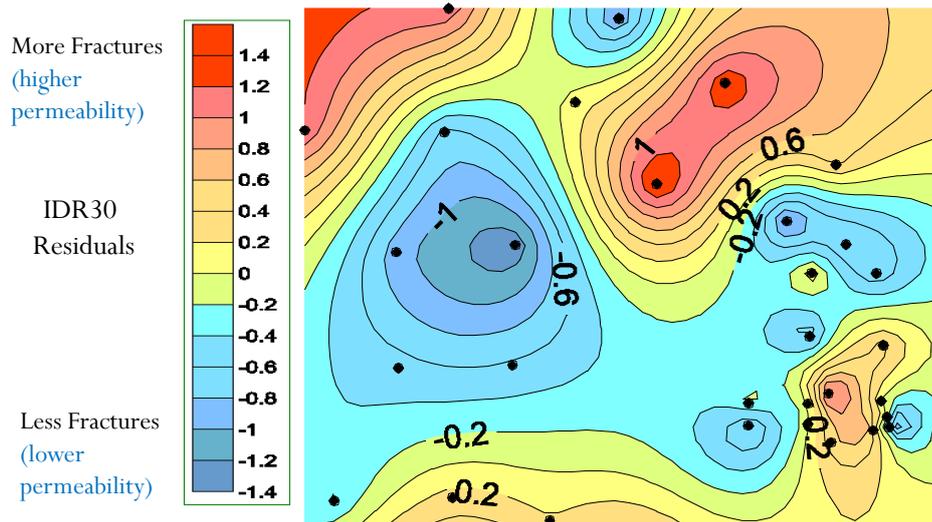


Figure 6 - Mapping implied fracture variations

This method is an adjunct, not a replacement for well test determinations of permeability. While it ignores stress effects, there are a number of potential applications:

- Combined with well test results it can improve understanding of variations in measured permeability data where those variations are due to changes in cleat frequency
- Areas of variable drainage behaviour may be better understood and predicted. Difficult to drain areas due to low cleat frequency may be identified
- More informed selection of locations for pilot well drilling and interpretation of gas production outcomes

A permeability model

The most common permeability model is simply one of plotting the trend (or lack of it) of permeability against depth. Such a model can be quite difficult to apply with a range of uncertainty usually greater than two orders of magnitude.

For Australian coal mines it is common to see highly saturated coals with low permeability and under-saturated coals with high permeability. The inference is that the lower saturation is caused by migration of water in the geological past removing adsorbed CH₄ (this reasoning is not necessarily as applicable to CO₂).

Large areas of the Moranbah Coal Measures from North Goonyella Mine south to Saraji characteristically show decreasing gas saturation with depth of cover below a horizon that becomes increasingly shallow to the south. In the north (Grosvenor to Goonyella), gas content and saturation increase with depth to around the Goonyella Middle seam. Below this seam the gas saturation and gas content decreases primarily affecting the Goonyella Lower seam. South of Grosvenor, the zone of under-saturation/low gas content moves up the stratigraphy, ultimately affecting all seams in the sequence.

A good, but by no means atypical example for a borehole just south east of Grosvenor shows reducing gas content and saturation below the Goonyella Middle seam, where a gas content of 9 m³/t at 500 m reduces to a gas content of ~3 m³/t at 640 m depth (Figure 7). Corresponding to this change is an increase in permeability from 1 mD at 340 m to 13 mD at 637 m. The increase in permeability and decrease in gas content with depth is quite unusual and more than coincidental. It is argued the gas content is low at depth because the permeability is high, gas having been removed by migrating water. That the permeability actually increases in spite of the sensitivity to stress of these coals is quite remarkable.

For coals nearer to the subcrop, variable saturation is more easily explained from gas leakage to sub crop and removal from shallow fluids. But the relationship of increasing permeability with decreasing saturation at equivalent depths has been demonstrated. How wide spread or universal such a relationship is remains to be seen, but the cause and effect mechanism is plausible.

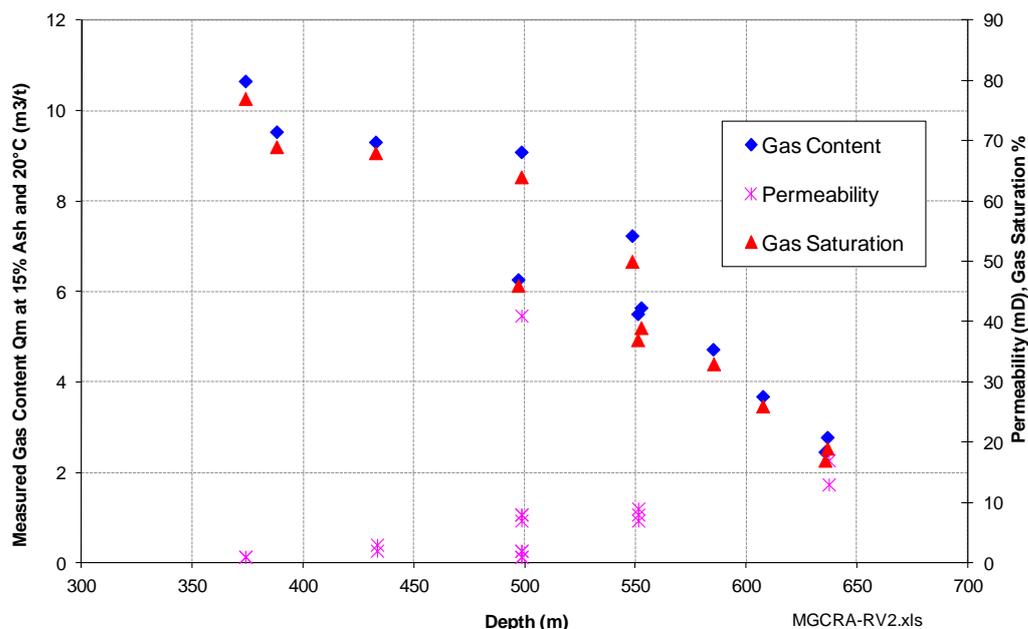


Figure 7 - Reducing gas saturation and increasing permeability with depth – River Paddock No.2 well

On this basis, permeability can be related to depth of cover (stress) and gas content (saturation) according to the equation:

$$\ln \text{ Permeability (mD)} = A * \text{Depth (m)} + B * Q_m + C$$

Where coefficients A, B and C are determined from a multivariate analysis of depth and gas content against permeability (example Figure 8).

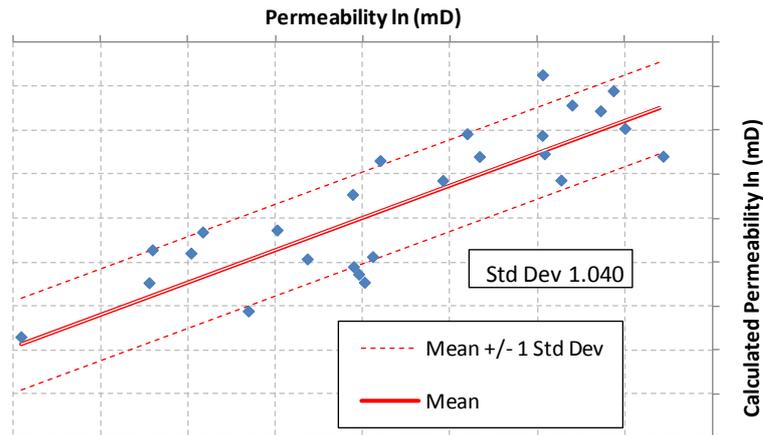


Figure 8 - Basis for indirect assignment of permeability as a function of gas content and depth

The assignment is tested and the error (uncertainty) quantified by comparing measured results against ones calculated from depth and gas content for those boreholes with well test data (Figure 9).

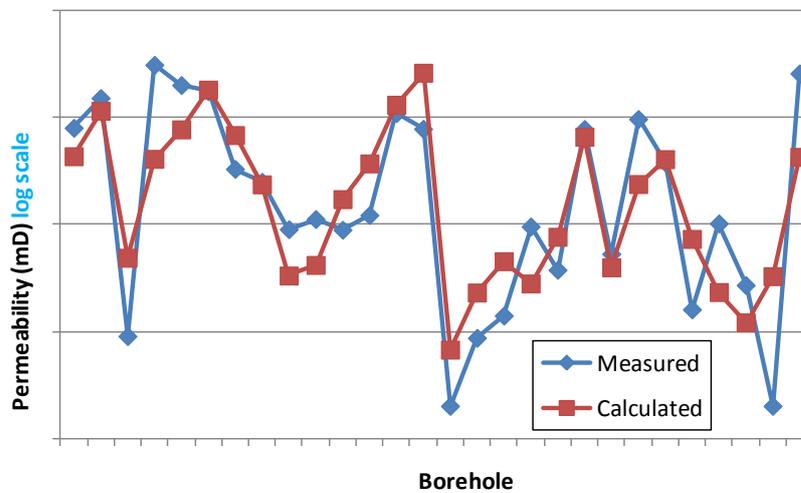


Figure 9 - Test of calculated against measured permeability

Assignment is now possible from comparatively few boreholes where permeability has been measured, to a far greater number of wells that contain depth and gas content data for the seam in question. The uncertainty in the assignment is quantified and the permeability distribution mapped (Figure 10).

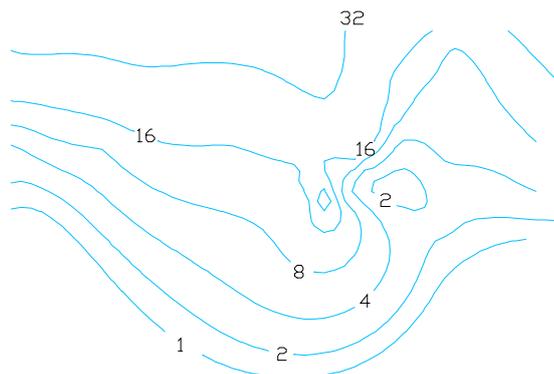


Figure 10 - Spatial distribution of permeability

Mapped variations in gas content and permeability can be applied in defining “Reservoir Regions” across a mine (Figure 11). These regions are a means of discretising for gas reservoir modelling purposes, what is a continuum of changing properties over a mining area. Quantification of uncertainty in the leveraged gas content and permeability data, together with uncertainty in gas desorption pressure enables gas drainage, emission and gas production outcomes in terms of probability distributions.

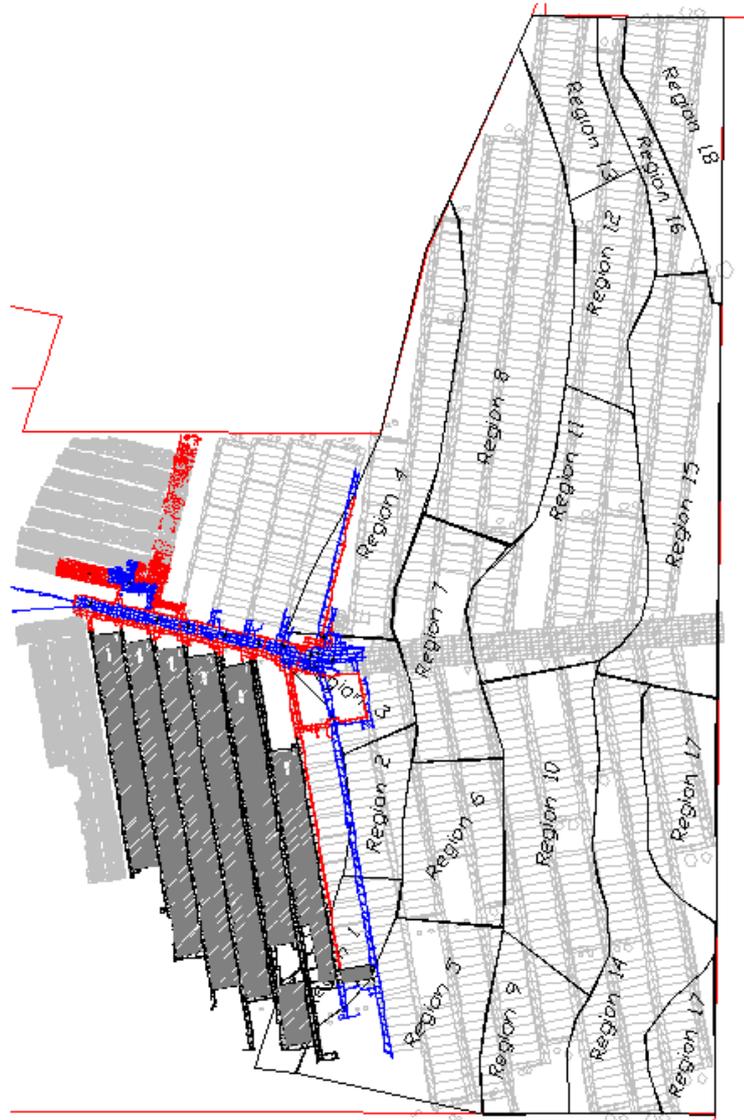


Figure 11 - Example of reservoir regions, Moranbah North Mine (Luckhurst-Smith and Williams, 2007)

CONCLUSIONS

Australian coal seam gas reservoirs display a wide range of conditions from zero gas content to as high as 20+ m³/t, gas saturation 0% to 100%, undrainable coal (<0.1 mD) to highly permeable (>1000 mD) and gas composition ranges from 100% CH₄ to 100% CO₂. Every deposit will have its own peculiarities and a “one method approach fits all” is unlikely to work.

That said, almost always, logical relationships will be found that will enable leveraging of gas reservoir data. This paper has given examples of models for leveraging gas content and permeability that should have broad application. In any event, such approaches can be tested and progressed if warranted.

The key drivers are to define the gas reservoir for the least cost and risk and provide inputs that facilitate subsequent modelling of gas drainage, emission and gas production with quantifiable uncertainty.

REFERENCES

- AS3980-1999. Guide to the determination of gas content of coal-direct desorption method. Standards Australia ISBN 0 7337 2906 1.
- ASTM D7569-10. Standard practice for determination of gas content of coal-direct desorption method. ASTM International.
- Esterle, J, Williams, R, Sliwa, R and Malone, M, 2006. Variability in gas reservoir parameters that impact on emissions estimations for Australian black coals, *ACARP project C13071*.
- Luckhurst-Smith, H and Williams, R, 2007. Moranbah North coal seam gas development – technical and statutory, *ACARP gas and outburst workshop, Mackay*.
- Williams, R.J., Casey, D.A. and Yurakov, E. 2000. Gas reservoir properties for mine gas emission assessment. *Bowen Basin Symposium 2000, Rockhampton Queensland*.