An Integrated Approach Of Uncertainty Assessment For Coalbed Methane Model

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Abstract

This study deals with quantitative detection of parameters uncertainty in coalbed methane(CBM) modelling and a systematic and integrated workflow is developed to analyze the uncertainty of CBM model. In structure modelling, the uncertainty of measure depth (MD) and coal thickness were analyzed by disturbing the structure surfaces or thickness surfaces while fixed at the well locations. In property modelling, an analysis of the residual distribution between each correlation and its measurements was used to characterize the uncertainty of each parameter. Sensitivity analysis was performed for the parameters, such as gas content, structure surfaces, coal thickness, density, ash content, etc., to evaluate the uncertainty of original gas in place (OGIP). The critical sensitive attributes were used to build multiple realizations to determine the P90, P50 and P10 of OGIP. The low, middle and high probabilistic geological models were achieved corresponding to the probabilistic OGIP, and used for the following reservoir simulation and development plan design.

Introduction

Limited amount of hard data, lack of well control and scarcity of geology studies are the great challenges in the exploration and development phase of a CBM field. Most of the risks are related to the uncertainty in the static reservoir characterization, which also affects the dynamic response (Shirazi et al. 2010; Mohsen et al. 2007; Sharma et al. 2008). The inability to properly manage subsurface uncertainty is often a key reason for the CBM projects failing to meet their objectives. Thus, quantification of the significant uncertainty exiting in the geologic CBM model is critical in the field development.

The uncertainties mainly come from structure modelling and property modelling procedures when building a CBM model. In the structure modelling, the uncertainties are the picking and interpretation of coalbed surface, geometry distribution of the coalbed geological heterogeneities. In the property modelling, the uncertainties are mainly from modelling the petrophysical parameters, such as gas content, density, ash content, etc. In this paper an integrated workflow was developed to quantify these uncertainties of CBM geologic modelling.

3D Modelling for CBM

Three dimensional, geocellular static models was built to model CBM reservoirs with all the available information from wells, seismic data, outcrop, sample data, etc. A typical 3D modelling workflow for the CBM reservoir is as follows (Zhang et al. 2014):

1) Structure modelling. Build the coal seam structural formations, including the horizons and faults, truncation, erosion, etc.
2) Coalbed thickness modelling. Build the top and bottom surfaces of the coal surfaces based on the high resolution coal ply picking and correlation, and depict the swelling, pinching out, merging or

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erosion of the coal plies.

3) Property modelling. Build the 3D distribution of the parameters, such as gas content, density, ash, moisture, permeability, Langmuir volume, saturation, etc.
   a) Log density (SSD) model: built with well density log using Kriging or move average method.
   b) Relative density (RD) model: built with formula from the correlation analysis between the sample density data and density log data.
   c) Ash model: built with the correlation formula between the relative density (RD) and ash sample data.
   d) Moisture model: usually regarded as a constant value.
   e) Gas content dry ash free (GC_DAF) model: calculated with using the correlation with the measure depth.
   f) Permeability model: calculated with using the correlation with the measure depth.

Based on the above models, the original gas in place (OGIP) is calculated with the formula,

$$\mathrm{OGIP} = \sum(V_{bulk} * \mathrm{GC\_DAF} * (1 - \mathrm{Ash} - \mathrm{Moisture}) * \mathrm{RD}), \quad (1)$$

where V_{bulk} is the cell volume of the model.

Uncertainty Analysis

Uncertainty of Structure Modelling. The uncertainties in structure model generally relate to the well picks and surface interpolation, time-depth conversion, etc. (Leahy and Skorstad 2013; Piquet et al. 2013). To assess the horizon uncertainty, an alternative surface is created by perturbing the base surface while honoring the well picks at the well locations (**Figure 1**). The detailed procedure consists the following steps:

Step 1: A measure depth surface of the base horizon is calculated, and the uncertainty surface which has the value of 10% of the measure depth is created. Here the value of 10% can be changed based on experience.

Step 2: A random surface is created by the sequential Gaussian simulation (SGS) method, with a minimum value of -1 and a maximum value of +1, and mean value of zero, and zero at well locations.

Step 3: The uncertainty surface and the random surface are multiplied, and then the result is added to the base horizon to obtain an alternative surface.

The alternative surface is considered as an uncertainty realization of the base horizon. It disturbs around the base horizon within the upper and lower boundary and match with the picks at well locations. Multiple realizations of the alternative surface can be achieved by the difference random surface created with difference seed in Step 2.

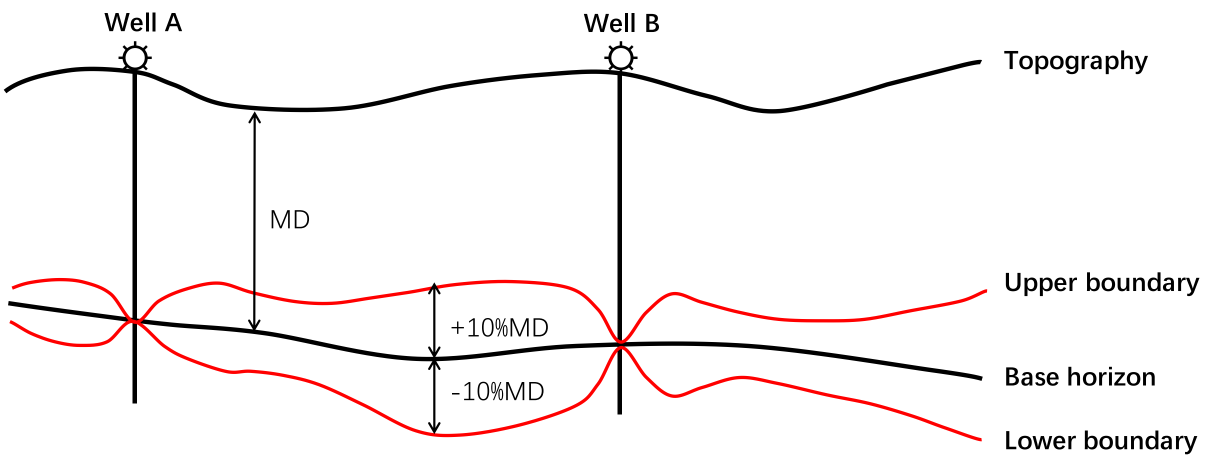

Figure 1—Structure uncertainty analysis.

Uncertainty of Coal Thickness. This refers to the uncertainty of the coal ply isochore thickness interpolated in the zonation process. The procedure is as follows (**Figure 2**):

1) Surfaces of 10th and 90th percentile values of the coal ply thickness are generated and named as "Min" and "Max" surfaces while maintaining zero thickness at well locations.
2) The "High_residual" and the "Low_residual" surfaces are created by calculating the difference between the "Base Case" isochore thickness and the "Max" and the "Min" surfaces, respectively.
3) A random surface is created by the SGS method, with a minimum value of -1 and a maximum value of +1, mean value of zero, and zero at well locations.
4) A residual surface is generated by multiplying the random surface from step 3) with the "High_residual" or the "Low_residual" surfaces from step 2) according to the positive or negative value of the random surface. A one third is introduced to the residual surface considering the experience.
5) The uncertainty thickness surface is then calculated by adding the "Base Case" isochore surface and the residual surface from step 4).

Multiple realizations of the thickness surface can be achieved by different random surface created with difference seed in step 3). The uncertain thickness surface disturbs around the "Base Case" isochore surface and match with the picks at well locations, and the uncertainty of the coal ply thickness ranges within one third of the "Min" and the "Max" surfaces.

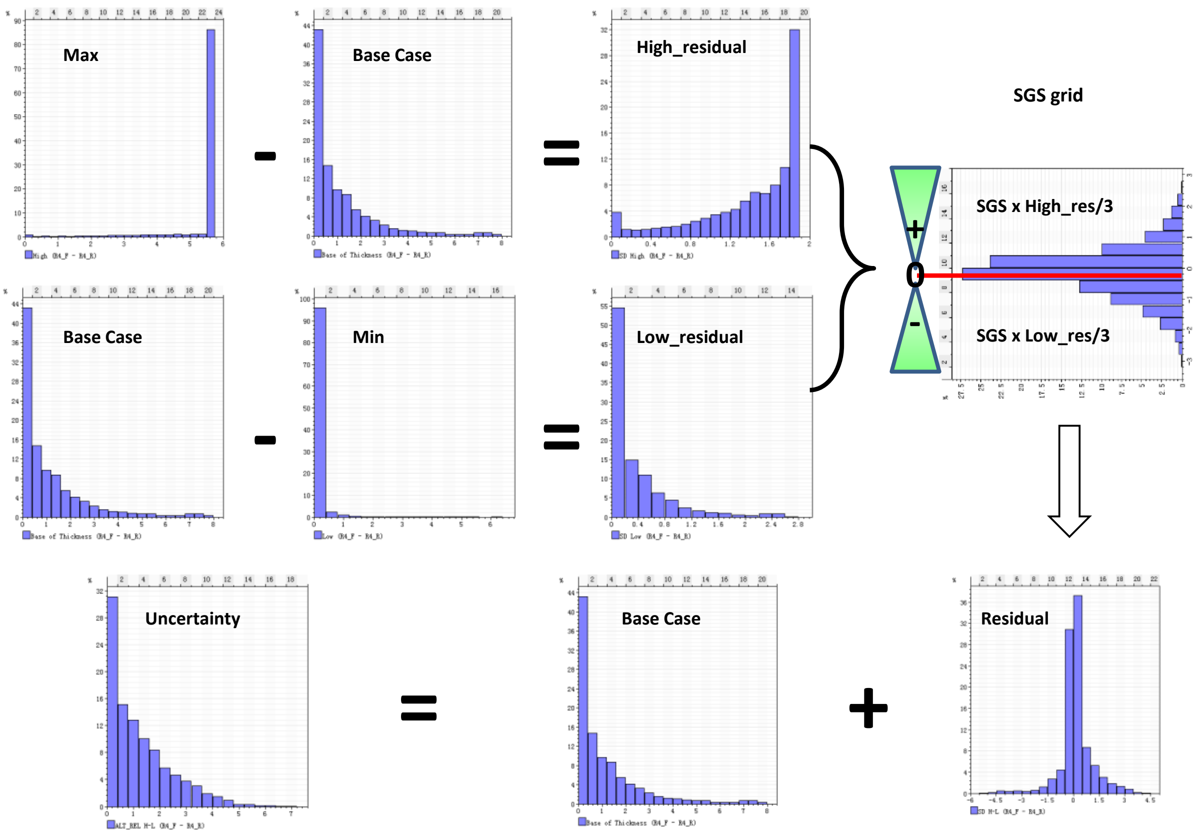

Figure 2—Procedure to quantify the uncertainty of coal thickness.

Property Uncertainty. Different uncertainty assessment methods are used for different parameters. For the log density (SSD), the assessment uses the same method as that used for the coal thickness uncertainty, in which the "Base Case" is the log density surface, and the "Min" and the "Max" surfaces are the 10th and 90th percentile values of the coal ply log density.

For the RD, ash, gas content data, as can be seen from the CBM modelling workflow, several correlations are involved (**Figure 3**). Significant uncertainty exists around each fitted trend, which is shown by the scatter points observed in Figure 3. The uncertainties for these parameters are considered as the result of the heterogeneity of the coal and quantifying the range related to their specific locations.

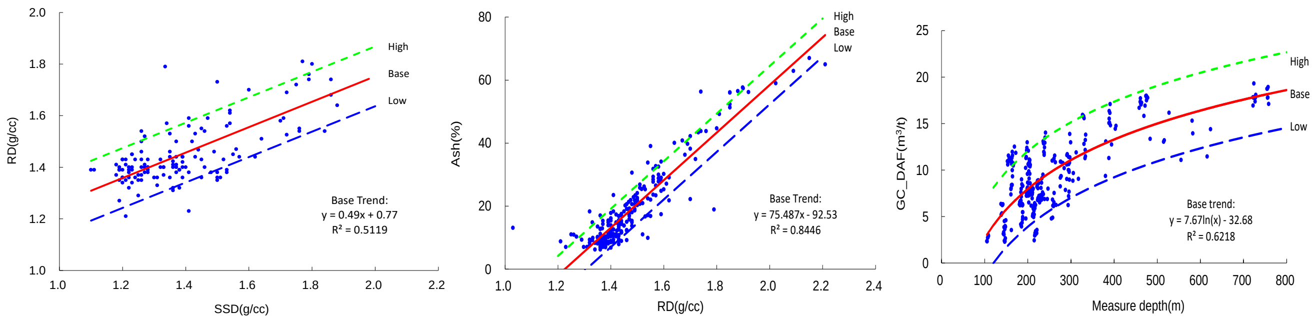

Figure 3—Parameters uncertainty analysis.

To capture these uncertainties, the residual or error is calculated between the fitted line and each measurement, then the "Low" and the "High" limits are drawn by analyzing the residual distribution and choosing the 10^{th} and 90^{th} percentile values of the distribution as shown in Figure 3. It guarantees that most of the sample data are within the high and low limits. Other percentile values could be used if a smaller or bigger limit is required.

For the permeability data, the uncertainty is related to the limited sample data. If more data added the fitted trend from a limited sample is liable to become steeper or shallower (**Figure 4**). To capture this type of uncertainty a confidence interval approach is introduced as the following equation

$$\hat{y}|_{x=\omega} \in \left[\hat{a}+\hat{b}\omega \pm t^{*}_{n-2}\sqrt{\frac{1}{n-2}\sum \hat{\varepsilon}_i^2\left(\frac{1}{n}+\frac{(\omega-\bar{x})^2}{\sum(x_i-\bar{x})^2}\right)}\right] \quad \text{(2)}$$

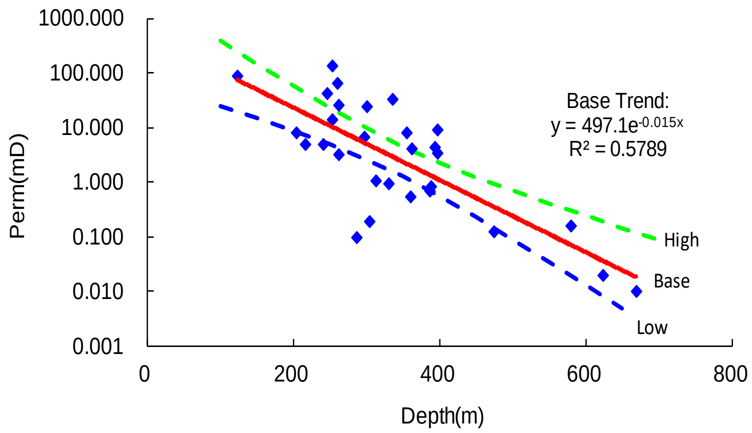

Figure 4—Permeability uncertainty analysis.

Integrating Uncertainty Models

To integrate the uncertainties from multiple sources, it is convenient to use the OGIP that aggregates the influence of the uncertainties. Therefore, an integrated workflow using the above uncertainty analysis is implemented to estimate reservoir properties. Sensitivity analysis and the probability modelling are the two main steps in this workflow.

Sensitivity Analysis. A range or distribution is estimated for each parameter, and then multiple realizations are generated to calculate the OGIP by varying one parameter at a time while keeping all other parameters as its base case value. These calculations estimate the uncertainty of OGIP due to the variables which are shown in horizontal bar in Tornado chart (**Figure 5**).

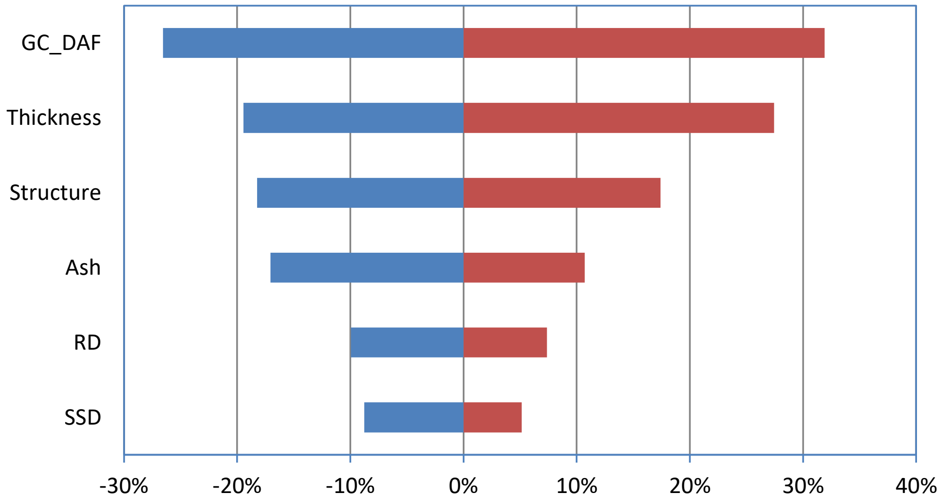

Figure 5—Sensitivity analysis.

From the chart it can be seen that the most influent parameter to the OGIP is GC_DAF, followed by the coal thickness and structure, and density is the least sensitive parameter which has relative small impact on the OGIP compared to other parameters.

Probability Models. Considering the sensitive parameters which rank on the top of the tornado chart, multiple realizations were performed with all these parameters varies simultaneously in each range. The OGIP of all these models are calculated and its distribution was plotted in **Figure 6** from which the P90, P50 and P10 are obtained. Based on these probabilistic OGIPs, 3D static models with OGIPs within +/- 5% of P90, P50 and P10 are chosen as low, middle and high probability models to be used for reservoir simulation and well planning in future. (Kimber et al. 2016; Zhao et al. 2014; Philpot et al. 2013).

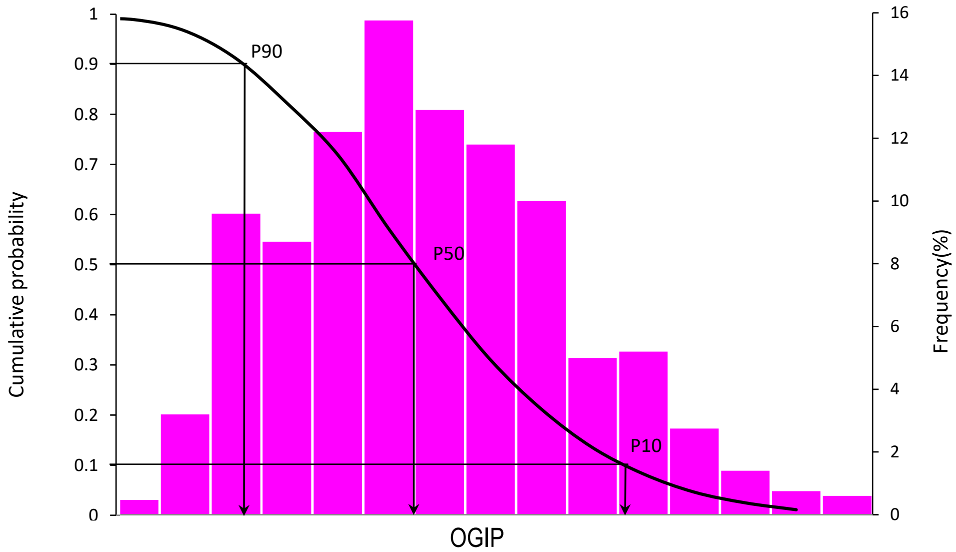

Figure 6—Probability distribution of OGIP.

Conclusions

A systematic and integrated approach to analyze the uncertainty of CBM model was proposed in the study. The workflow captures the uncertainties related to the structure and coal thickness surfaces in the structure modelling, and the uncertainties associated with various correlations developed during the property modelling. The procedure of sensitivity and uncertainty analysis ranks the impact of each parameter on OGIP, and estimates the OGIP probabilistic distribution to get the P90, P50 and P10 of OGIP, and then selects the low, middle and high probabilistic CBM models for the reservoir simulation and well plan. The workflow in this paper has been successfully carried out in several CBM projects in Australia and been confirmed to be reliable, efficient and effective for the CBM exploration and development.

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Conflicts of Interest

The author(s) declare that they have no conflicting interests.

Nomenclature

$\hat{y}\|_{x=\omega}$	=	confidence interval at x=ω
$\hat{a} + \hat{b}\omega$	=	trend fitted by linear regression
t^{*}_{n-2}	=	t-value of the Student's t-distribution
N	=	number of data points in sample
$\hat{\varepsilon}_i^2$	=	residual squared

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