8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-108

Prediction of CBM Reservoir Parameters, Jharia CoalField, India

Rima Chatterjee, P. K. Pal, Ujjwal Nandi and Suman Paul*

Summary

An attempt has been taken to compute cleat volume (i.e. porosity) and permeability in a part of CBM reservoir around three wells in Jharia Coalfield. Short Normal resistivity log has been used to calculate cleat volume/porosity for coal seams, lying at more than 1000m depth. Temperature gradient, recorded in the wells, varies from 2.22^{0}C per 100m to 3.44^0 C per 100m. Characterization of coal in term of its physical properties like porosity and permeability has generally been performed on limited sample volumes as available from borehole cores. Cleat volume/porosity varies from 0.3 to 1.45% whereas permeability varies from 0.01 to 1.02 md in these three wells. Cleat volume/porosity and permeability generally decreases with depth. Permeability is correlated with the overburben stress (i.e. vertical stress).

Introduction

Coalbed Methane (CBM) has been explored and produced in many basins worldwide. In India, CBM is also being produced from Gondwana coalfields of Raniganj , Jharia and Sohagpur. CBM content, adsorbed in coal seams, is mainly controlled by temperature, pressure and organo-chemical properties of the coal seams. As reservoir pressure is lowered, gas molecules are desorbed from the coal matrix and travel to the cleat network which acts as the passageway for the gas to the producing wells. Fluid movement is controlled by diffusion co-efficient of coal matrix and governed by the Darcy flow through the cleat network (Robertson et al., 2005). Gas storage capacity generally increases with coal rank, depth of burial of the coalbed and reservoir pressure. Fractures or cleat network, that permeate coalbeds, are responsible for the permeability of coal and are thus important for CBM production. Direct measurement of in-situ coal permeability is practically impossible to obtain. However, it has been observed that fracture permeability in coal ranges from microdarcys to darcys (Scott, 1999 and Scott, 2002). In general coal beds of Gondwana coalfields are considered to have low permeability. As the coal matrix is effectively impermeable, cleats, slips and other fractures provide the primary transmission pathways in a coal seam. Previous studies in coal basins of USA, Australia and Canada indicated that permeability of coal seams correlates strongly with stress magnitude (Bell and Bachu, 2003). This provided an index parameter for easier estimation of coalbed permeability and CBM producibility.

The coal bearing Barakar formation of the Jharia basin of India will have a major role in CBM production to meet the future energy requirement of the country. Temperature gradient, recorded in three wells under study, varies from 2.22^0 C per 100m to 3.44^0 C per 100m. Measurements of cleats and natural fractures are made from both outcrops and well cores. Present study involves well log evaluation for computing the following CBM reservoir parameters using data of three CBM wells, drilled in Jharia coalfield such as: (a) in-situ vertical stress magnitude, (b) cleat volume or coal seam porosity (c) coal seam permeability and (d) correlation between coal seam permeability and effective vertical stress.

Department of Applied Geophysics, Indian School of Mines, Dhanbad, Jharkhand-826004
email: rima_c_99@yahoo.com

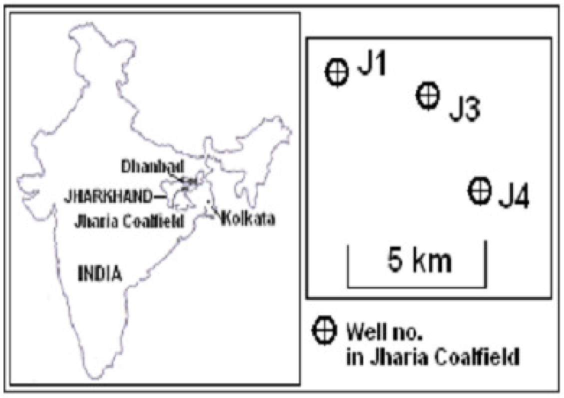

Figure 1: Illustrating location of three wells in Jharia Coalfield, Jharkhand, India.

Methodology

The magnitude of vertical stress or overburden load (S_V) at any depth is produced by the pressure exerted by the rocks above that level. In order to calculate effective stress, pore pressure has been assumed equal to the hydrostatic pressure (hydrostatic pressure gradient with mud density 1.1 gm/cc).

Shallow resistivity logs of the three wells namely J1, J3 and J4 covering an approximate area of 14 sq. km of Jharia coalfield (Figure 1) have been used to estimate cleat volume (coal seam porosity), following the method of Yang et al, (2006) applied in the Uinta basin of Utah. This study indicated that the borehole fluid had replaced pore fluid in the cleats (invasion zone). Coal matrix has practically zero porosity but the mega and macro cleats present, in the coal seams, contribute to the porosity of coal seams. Archie's equation (Archie, 1942) has been used to calculate the cleat volume/porosity of clean coal seam.

$$F = 1/\Phi^m \qquad (1)$$

$$R_0 = FR_W \qquad (2)$$

$$\text{and } S_w^n = R_o/R_t \qquad (3)$$

where, F is the formation resistivity factor, R_0 =Resistivity of rock sample with 100% water, R_t = Trueresistivity of formation, R_W = Formation water resistivity S_W = water saturation (fraction), Φ = porosity (fraction) m and n are the cementation factor and saturation exponents respectively.

To calculate the cleat volume, it is assumed that (a) all porosity is confined to the cleat systems and that the coal matrix porosity is negligible, (b) the water saturation in the cleat system is 100% and all fluid in the cleat system, investigated by the short normal resistivity logging tool , has been replaced by borehole fluid (drilling mud), (c) there is no free gas in the cleats and (d) the cleats are occupied by water with mud resistivity (R_m) only. The equations (1) – (4) have been reduced to the following:

$$F = R_t/R_m = 1/\Phi^m \qquad (4)$$

In unconsolidated clastic rocks, "m" usually lies between 1.8 to 2.2. The value of 'm' should be lower than 1.8 because of the small apertures of cleat system in coal seam (Yang et al., 2006). Value of 'm' has been assumed as 1.6. Substituting R_m= 0. 65 ohm-m in equation (4) :

$$F = 1/\Phi^{1.6} = R_t/R_m$$

$$\text{and } \Phi = (R_m/R_t)^{1/1.6} = (0.65/R_t)^{0.6} \qquad (5)$$

Cleat volume (porosity) of coal seams has been computed using equation (5) by putting the value of resistivity (R_t) from short normal resistivity logs of the three wells.

Using a matchstick model of cleats, initial porosity and initial permeability of coal can be expressed as a function of cleat spacing and aperture (Harpalani and Chen, 1995).

$$\text{Porosity } (\varphi) = 2b/s$$

$$\text{and Permeability } (K) = b^3/12s \qquad (6)$$

where b and s are the 'cleat aperture' and 'cleat spacing' respectively.

Analysis of well log data

Data of short normal resistivity, density, neutron and sonic logs have been analysed from the three CBM wells namely, J1, J3 and J4 of Jharia coalfield. The well data from the depth of 945m – 1330m have been considered for estimation of vertical stress magnitude, cleat volume/porosity and coal seam permeability. Well logs of these boreholes showed occurrence of five major consistent coal seams (A, B, C, D and E) at different depths. Coal seam A is found at relatively shallower depth (950 – 976m) in well J1 whereas the same seam occurs at higher depth (1328 – 1330m) in well J3. Coal seam B (1244.6 – 1245.4) is only found in well J3. Coal seams C, D and E (Bottom and Top) are correlated at different depths in the wells; J3 and J4 respectively. In this present study, stress, cleat volume/porosity and coal seam permeability values are calculated for five coal seams from the three wells. It is observed that the resistivity log signature against coal seam C in well J4 varies erratically. Therefore, cleat volume/porosity and permeability for the seam C have not been calculated for well J4.

In-situ stress

The vertical stress, porosity and coal seam permeability from three wells are plotted with depth as presented in Figures 2 to11. The overall trend of the effective vertical stress increases linearly with depth with a slope of about 45^0. This pattern is similar to that found for many other coal basins of India and other countries (Mucho and Mark, 1994; Townend and Zoback, 2000). There is a marked change of slope of the curve within the coal seams. The vertical stress magnitude and effective vertical stress magnitude vary from 24.94 to 17.80 MPa and 7.50 to 10.25 MPa respectively. The effective vertical stress i.e. the effective overburden load at the coal seam A, B, C, D, E (Top and bottom) varies from 7.50 to 10.02 MPa, 9.41 to 9.42 MPa, 9.28 to 10.25 MPa, 8.39 to 8.40 MPa, 7.79 to 8.69 MPa respectively (Figures 2 to11). These show decrease of stress gradient inside the coal seams. Stress gradient changes with the density of rocks. Variations in stress gradients are also observed in the high-density rocks, occurring at floor of the coal seams in the same well.

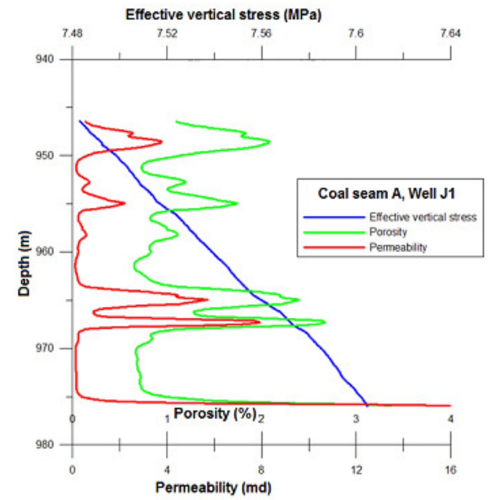

Figure 2: Plot showing the porosity, permeability and effective vertical stress for well J1, seam A.

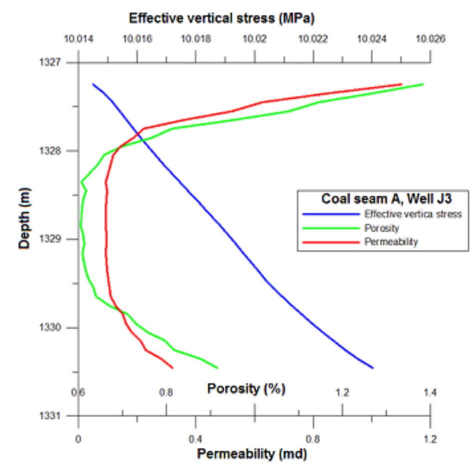

Figure 3: Plot showing the porosity, permeability and effective vertical stress for well J3, seam A.

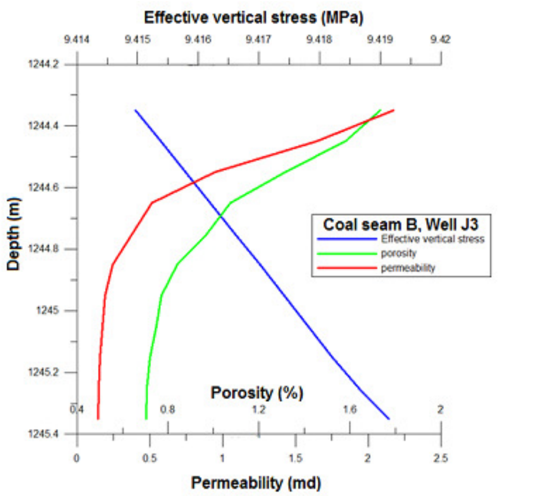

Figure 4: Plot showing the porosity, permeability and effective vertical stress for well J3, seam B.

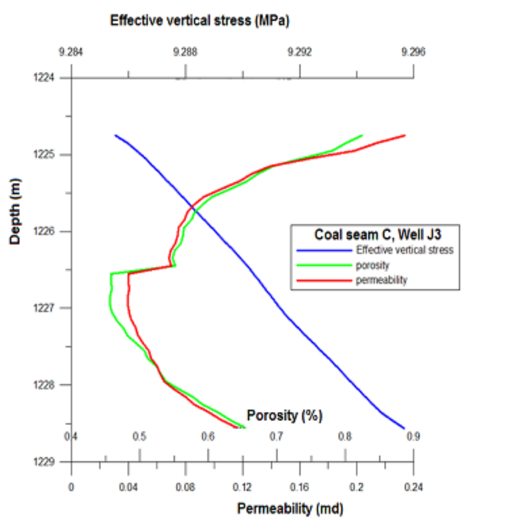

Figure 5: Plot showing the porosity, permeability and effective vertical stress for well J3, seam C.

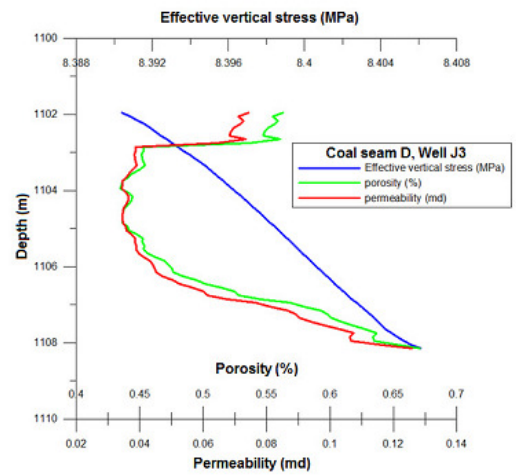

Figure 6: Plot showing the porosity, permeability and effective vertical stress for well J3, seam D.

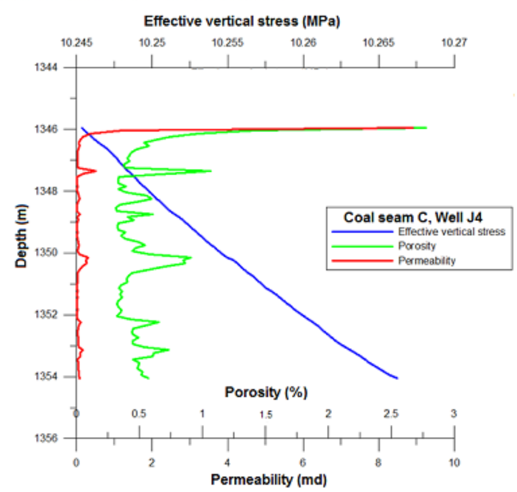

Figure 7: Plot showing the porosity, permeability and effective vertical stress for well J4, seam C.

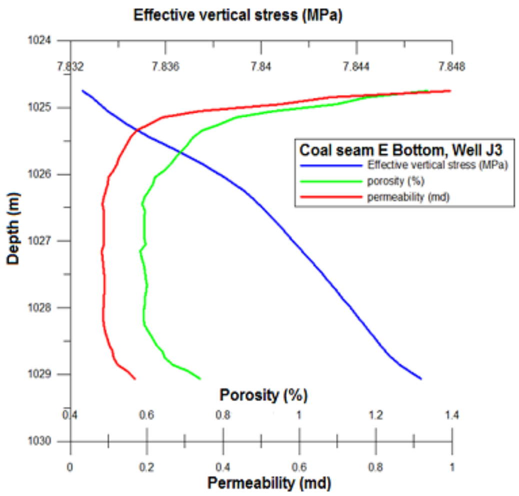

Figure 8: Plot showing the porosity, permeability and effective vertical stress for well J3, seam E (Bottom).

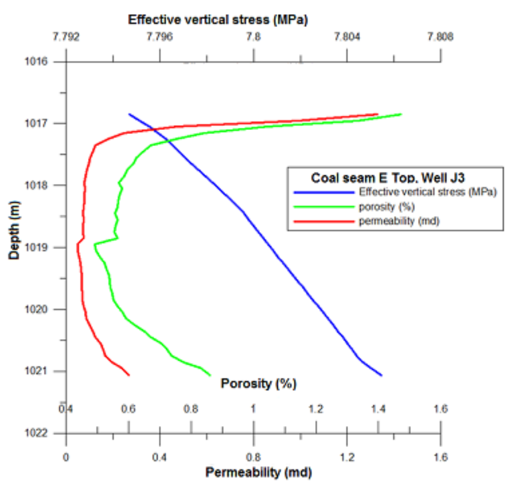

Figure 9: Plot showing the porosity, permeability and effective vertical stress for well J3, seam E (Top).

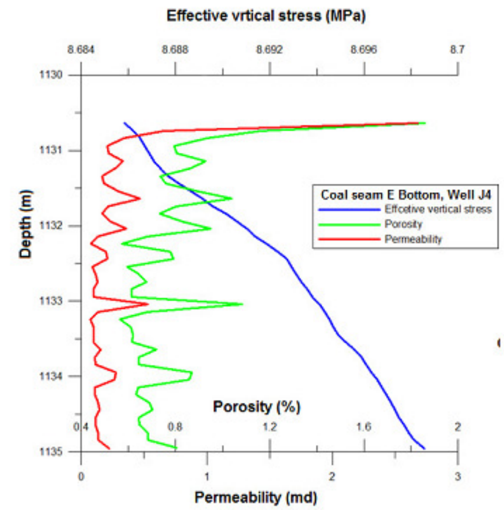

Figure 10: Plot showing the porosity, permeability and effective vertical stress for well J4, seam E (Bottom).

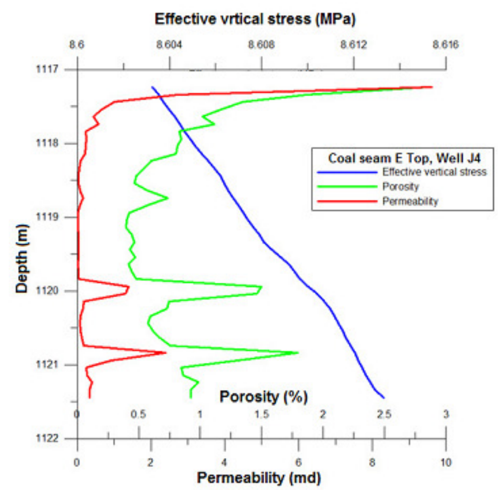

Figure 11: Plot showing the porosity, permeability and effective vertical stress for well J4, seam E (Top).

Coal seam Porosity and Permeability

Coal seam porosity and permeability plots of three wells (Figures 2 to 11) show decrease in porosity and permeability values within coal seams. Equation (6) has been used for computation of permeability from log derived porosity for five coal seams of three wells with cleat spacing of 0.2m. Permeability varies with the cube of porosity as used in equation (6). Coal seam permeability decreases with depth as depicted in the plots (Figures 2 to 11). Cleat volume (porosity) value ranges from 0.3% to 1.45% and coal seam permeability value varies from 0.01 to about 1 md in these wells.

Porosity and permeability increases from seam B to seam E in well J3 and from seam C to E in well J4. Coal seam A in well J1 is showing the maximum porosity and permeability whereas the same seam in well J3 is showing the minimum porosity and permeability values. This indicates that the porosity and permeability value decreases with depth due to increase in effective vertical stress. As reservoir pressure increases, the permeability decreases. The best fit regression curve between permeability and effective vertical stress, considering all five seams in three CBM wells of Jharia coalfield show exponential relationship with goodness of fit (R_2) of 0.28 (Figure 12).

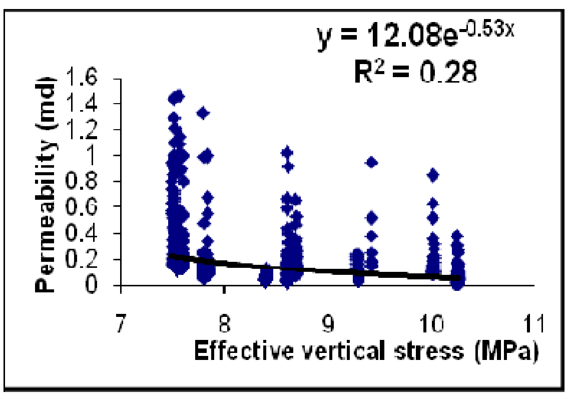

Figure 12: Plot showing the correlation between permeability and effective vertical stress for CBM wells, Jharia coalfield.

Conclusions

The values of in-situ effective vertical stress magnitude, cleat volume (porosity) and permeability of coal seams have been estimated from well log data of CBM wells in Jharia coalfield. Five numbers of coal seams are identified and correlated from the geological and geophysical log data. Porosity of coal seams in these wells, in general, ranges from 0.3% to 1.45%. Coal seam permeability ranges from 0.01 md to about 1 md.

The effective vertical stress magnitude varies from 7.5 to 10.25 MPa for coal seams A, B, C, D and E. Average permeability ranges from 0.5 to 1 md. Coal seam porosity and permeability decrease with the increase of in-situ stress. Stress gradient becomes steeper within coal seams.

Stress gradient also varies with depth within same well as well as within same coal seam. There is little variation of porosity and permeability values within same coal seam. Exponential relationship between coal seam permeability and the effective vertical stress, found from this study, needs to be further confirmed by analysing data from more numbers of wells. The well log derived in-situ stress magnitude, cleat volume (porosity) and permeability with depth would be useful for coalbed methane reservoir studies and design of test well pattern for coalbed methane exploration.

Acknowledgement

Authors express their sincere gratitude to Sri A. K. Singh, CMD, CMPDI, Ranchi, India for permission to use the well log data of CMPDI, Ranchi.

Authors are also thankful to Sri N. K. Khurana, Director (T/CRD), CMPDI and Sri A. N. Sahay, Director (T/RD&T), CMPDI for their encouragement and support.

Co-operation and help, extended by Sri P. K. Hazra, Chief Manager (Geophysics) and Sri S. K. Gupta, Suptd. Geophysicist, Exploration Division, CMPDI, Ranchi are also thankfully acknowledged. Authors are indebted to CIL for financial support from CIL R&D grant.

References

Archie, G. E., 1942, The Electrical resistivity log as an aid in determining some reservoir characteristics; Transactions of the American Institute of Mining and Metallurgical Engineers, 146, 54-62.

Bell, J. S. and Bachu, S., 2003, In situ stress magnitude and orientation estimates for Cretaceous coal-bearing strata beneath the plains area of central and southern Alberta; Bulletin of Canadian Petroleum Geology, 51(1), 1-28.

Harpalani, S. and G. Chen, 1995, Estimation of changes in fracture porosity of coal with gas emission; Fuel, 74, 1491-1498.

Mucho, T. P. and Mark, C., 1994, Determining Horizontal Stress Direction Using Stress Mapping Technique, Proc. of 13th Int. Conf. on Ground Control in Mining, Morgantown, WV, 277-289.

Robertson, E. P. and Christiansen, R. L., 2005, Modeling Permeability in Coal using Sorption-Induced Strain Data, SPE Annual Technical Conference and Exhibition, Texas, USA, October 9-12, paper id., SPE 97068.

Scott, A. R., 1999, Review of key hydrogeologic factors affecting coalbed methane producibility and resource assessment, Oklahoma Coalbed-Methane Workshop, December 1, Norman, Oklahoma, Oklahoma Geological Survey Open File Report of 6-99.

Scott, A. R. 2002, Hydrogeologic factors affecting gas content distribution in coal beds; International Journal of Coal Geology; 50(1-4), 363-387.

Townend, J. and Zoback, M. D., 2000, How Faulting Keeps the Crust Strong; Geology; 28, 399-402.

Yang, Y., Peters, M., Cloud, T. A. and Van Kirk, C. W., 2006, Gas productivity related to cleat volumes derived from focused resistivity tools in Coalbed Methane (CBM) Fields; Petrophysics; 47(3), 250-257.