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Total gas-in-place, gas composition and reservoir properties of coal of the Mannville coal measures, Central Alberta

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ABSTRACT

The Lower Cretaceous Mannville coal measures in south central Alberta host one of the most successful horizontal coal methane developments, yet the contribution of thin coal seams and other organic rich strata to total gas-in-place and producible gas remains unaccounted. In this study, well log, core, fluid, and gas analyses in the Mannville coal measures are evaluated in order to quantify and characterise the total gas-in-place resource that may be accessed by a horizontal well completed in the main coal seam which is the usual practise. Regionally, the estimated gas capacity and content of the coals increases from northeast to southwest in parallel with the depth of burial and the level of organic maturation (rank), although local variations exist. The isotopic composition of the methane of coals currently at depths greater than 1500 m have a strong thermogenic signature, shallower coals have a mixed biogenic–thermogenic signature, and the shallowest coals have a strong biogenic signature. The trend in gas composition is less well defined with the highest carbon dioxide contents occurring in the area of the lowest and highest ranks. Generally, the percentage of heavier gases (C_2–C_5) increases with maturity/depth of burial, but some low rank coals (Ro% ≈ 0.30) in eastern Alberta and Saskatchewan contain significant C_2–C_5 hydrocarbons. The origin of the heavier gases in the low rank coals is unclear; migration from a deeper source is the most likely explanation.

The gas adsorption capacity of the coals varies regionally with depth of burial (pressure), coal rank, and ash content. The highest adsorption capacity at reservoir pressure and temperature, approaches 400[1] scf/t, but most coals have values between 260 and 320 scf/t. The gas content of the coals, as measured by desorption, ranges from 230 to 350 scf/t and averages 310 scf/t. Most of the coals are saturated with gas within the accuracy of the analyses. Notable exceptions occur adjacent to the Saskatchewan border where the lower rank coals may be markedly under saturated. The amount of methane in solution (calculated) at a reservoir pressure of ≈1000 psig (6.9 MPa) is calculated to be between 7 and 10 scf/t (≈3% of total gas).

Currently, Mannville coal gas production is limited to an area in central Alberta of about 2200 km^2 (850 miles^2). Outside the producing fairway, sustained commercial production has not been achieved due to low permeability. In the producing and prospective fairway, the net thickness of the coal within ±20 m of the main coal seam, varies from 0 to 10.8 m and averages 5.1 m. Here the thickest coal seam ranges up to 4.7 m thick and averages 1.9 m.

Due to limited gas content data from core for all seams and wells, a protocol was developed to extrapolate existing core data to non-cored seams and wells through petrophysical logs. The protocol takes into consideration the correlation between gas and ash content and the maturity of the coals. The total coal gas resource density in the current area of production and prospective areas determined by applying this protocol for the average well has a low estimate of 5.4 BCF/mi^2[(2)] (m^3/km^2), a median estimate of 5.9 BCF/mi^2, and a high estimate of 6.1 BCF/mi^2.

1. Introduction

Coal measures of the Lower Cretaceous Mannville Group and overlying Upper Cretaceous Belly River Group and Horseshoe Canyon Formation have been developed for coal gas (CBM) through an area of about 10,000 mile^2 (26,000 km^2) of south-central Alberta. The total estimated coal gas-in-place resource is about 500 TCF[3] (1.41 × 10^{13} m^3), of which about 65% occurs in the Mannville Formation (ERCB, 2011). Currently, coalbed methane comprises about 6% of the total natural gas produced in Canada. To date, the Mannville coals cumulatively have produced about 1 TCF (28.3 × 10^9 m^3; ERCB, 2011; NEB, 2014).

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[1] 1 cm^3/g (SI unit) ≈ 34 scf/t (oil field units).
[2] 1 BCF/mi^2 (= billions of cubic feet/miles^2) ~1.1E7 m^3/km^2
[3] TCF = trillion cubic feet.

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Through most of central and western Alberta, the Upper Mannville and stratigraphically equivalent coals have been shown in well tests to contain substantial gas-in-place with estimates ranging from about 2–10 BCF/mi^2 with the higher gas-in-place values corresponding to the deeper and thicker coal intervals. However, sustained successful commercial production has been limited geographically to an area centred on the Corbett Creek area, where current production is cumulatively about 500 mmcf[4]/day from about 215 wells. Outside of this producing fairway, the low permeability of the coals has resulted in the lack of commercial production irrespective of the drilling or completion techniques employed. Even in areas of commercial production, the production profiles, total gas-in-place (TOGIP), and gas composition are highly variable (i.e. Hyland et al., 2010; Bearinger and Majcher, 2010) and commonly viewed as unpredictable.

In Alberta, the Alberta Energy Regulator (AER, formerly the Energy Resources Conservation Board- ERCB) provides guidelines (ERCB, 2006; ERCB, 2010; ERCB, 2012) for establishing the gas content in coals, which in turn is used routinely by reserve auditing firms for evaluations and for determination of coalbed methane well density (spacing units). Under the AER guidelines, coalbed methane production is considered to be gas produced from coal seam completions, where a coal seam is defined as a lithologic unit comprised of greater than 50% organic matter by weight and greater than 30 cm in thickness. In developed and prospective areas, the Mannville coal measures include multiple coals, many of which are thinner than 30 cm, and interbeds and over and underlying organic rich mudstones. These thin coals and organic rich lithologies can reasonably be expected to contribute to the producible gas from horizontal wells drilled and completed in the targeted coal as shown in other coals by Bustin and Bustin (2011a, 2011b). Hence, the gas content quantified using the AER protocol underestimates the producible gas. Well spacing based on these estimates will be too low and not necessarily optimal for resource development. Additionally, based on experience with shale gas evaluation, it can be assumed that in addition to gas stored in the adsorbed state, that free gas in adjacent non-coal lithologies and in solution in all lithologies will exist (Bustin and Bustin, 2009, 2011a, 2011b).

The main purpose for this study is to establish, in the producing and prospective fairway, how much gas is in place, its composition, and origin in the coal measures (coal and other organic rich facies), as well as determine how much gas will be produced from a horizontal well drilled and completed in what typically is the thickest coal seam in the succession. A secondary purpose of the study is to determine the optimum configuration (spacing, length and orientation) of the horizontal well(s), which will be addressed in a companion paper. This study also addresses the question as to why commercial gas production from the Mannville coals is limited to the Corbett area even though Mannville coals with high gas-in-place are broadly distributed over a much larger area of central Alberta.

In this paper, we first refine the regional resource potential of the Upper Mannville coal measures in a study area of south-central Alberta based on analyses of core samples, well logs, and fluids. Within the area of production and recent exploration, we summarise and interpret the variation in gas content of the thickest coal and other coals that lie stratigraphically within ±20 m of the main seam. The ±20 m interval lies within the anticipated drainage volume of a horizontal well landed in the main seam based on reservoir and economic analysis. Other lithologies within this interval are anticipated to contribute to production based on reservoir modelling. In Bustin and Bustin (in press), the contribution of the non-coal organic rich lithologies to the total gas-in-place is considered. These two studies provide the metrics for reservoir modelling, which is the subject of a companion study (in preparation) that evaluates the total producible gas from the coal measures (coal plus non-coal facies) via horizontal wells of various configurations and spacing.

[4] mmcf = million cubic feet

1.1. Stratigraphy, structural settings, and tectonic history

The stratigraphy and sedimentology of the Mannville Group has been exhaustively studied, due to the economic importance of the conventional and unconventional petroleum and coal resources, the heterogeneity of the units, and the widespread distribution of the Group. A general overview of the stratigraphy and structural settings as it bears on this study is provided below.

The Mannville Group is a Lower Cretaceous (Aptian to mid Albian) succession of marine, transitional marine, and non-marine deposits that underlay a large portion of Western Canada (Hayes et al., 1994; Figs. 1 and 2). The Mannville Group thickens from as thin as 40 m on the stable platform to the east to over 700 m in the Rocky Mountain foothills to the west. The Mannville Group was deposited in the then asymmetric Western Canadian Sedimentary Basin with sediment sourced mainly from the evolving Cordillera to the west. In Alberta, the coals occur at depths ranging from about 265 m to as deep as 3600 m adjacent to the deformed belt and cumulative coal thicknesses range from 0 to 16.5 m, including seams as thick as about 12 m (Fig. 1; Langenberg et al., 1997).

The Mannville Group has been divided into Lower and Upper units. The Lower Mannville was deposited on an erosional surface of deeply eroded Early Cretaceous, Jurassic, and Paleozoic rocks (Fig. 2). The Lower Mannville in-filled the topography on the unconformity and consists of valley fill sandstone and associated clastic rocks (i.e. Wadsworth et al., 2002; Chalmers et al., 2013). The Upper Mannville Group is an overall regressive succession that varies from alluvial sediments and incised valley fill deposits in southern and central Alberta, through to coastal plain and transitional marine sediments to the northwest, where equivalent strata are assigned to the Spirit River, Gething, and/or Gates formations. The Upper Mannville Group is overlain by a ravinement surface that is the base of the overlying Joli Fou Formation, except in the northwest part of the basin.

Coal occurs in both the Lower and Upper Mannville Group; however, the most important coals, and those exploited for coalbed methane, are restricted to the Upper Mannville Group (undifferentiated). The Upper Mannville coal zone is comprised of interbedded sandstones, mudstones, siltstones, and coals. The mudstones and siltstone are variably carbonaceous and grade to coal.[5] The same general stratigraphy extends throughout the basin, although in detail many facies changes occur. Detailed and extensive cross-sections of the Upper Mannville Group across western Canada have been published (Langenberg et al., 1997) and are not repeated here. The coal measures are interpreted as deposits of northward prograding coastal plains during regression of the Boreal Sea.

Local deposition and fault controlled Paleozoic structural highs and lows impact the local stratigraphy and particularly the frequency, lateral continuity, and thickness of the coals (i.e. Wadsworth et al., 2002; Chalmers et al., 2013). Overall, the coals thicken from the stable platform in the east to what was the evolving foredeep to the west with the thickest coals locally approaching 12 m and the gross thickness of coal about 20 m. The number of major seams (thicker than 1.5 m) is generally one or two and the number of thin seams varies up to 8. Economically important stratigraphically equivalent coals in outcrop in the deformed belt to the west are assigned to the Gates and Gething formations.

The Mannville coals are humic in origin and comprised of interbedded bright and dull bands. The sedimentology of the coals have been studied in detail by Wadsworth et al. (2002) and Banerjee and Kalkreuth (2002) who have interpreted the petrographic composition of the coals within a sedimentological framework. Gentzis (2009) has described the fabric and mechanical properties of the coals.

The post depositional history of the Mannville Group includes deep burial, with the depth of burial increasing to the southwest. A major

[5] The definition of coal used in the study is a deposit comprised of greater than 50% by weight or 70% by volume of organic matter.