GEOLOGICAL SURVEY OF CANADA
BULLETIN 549

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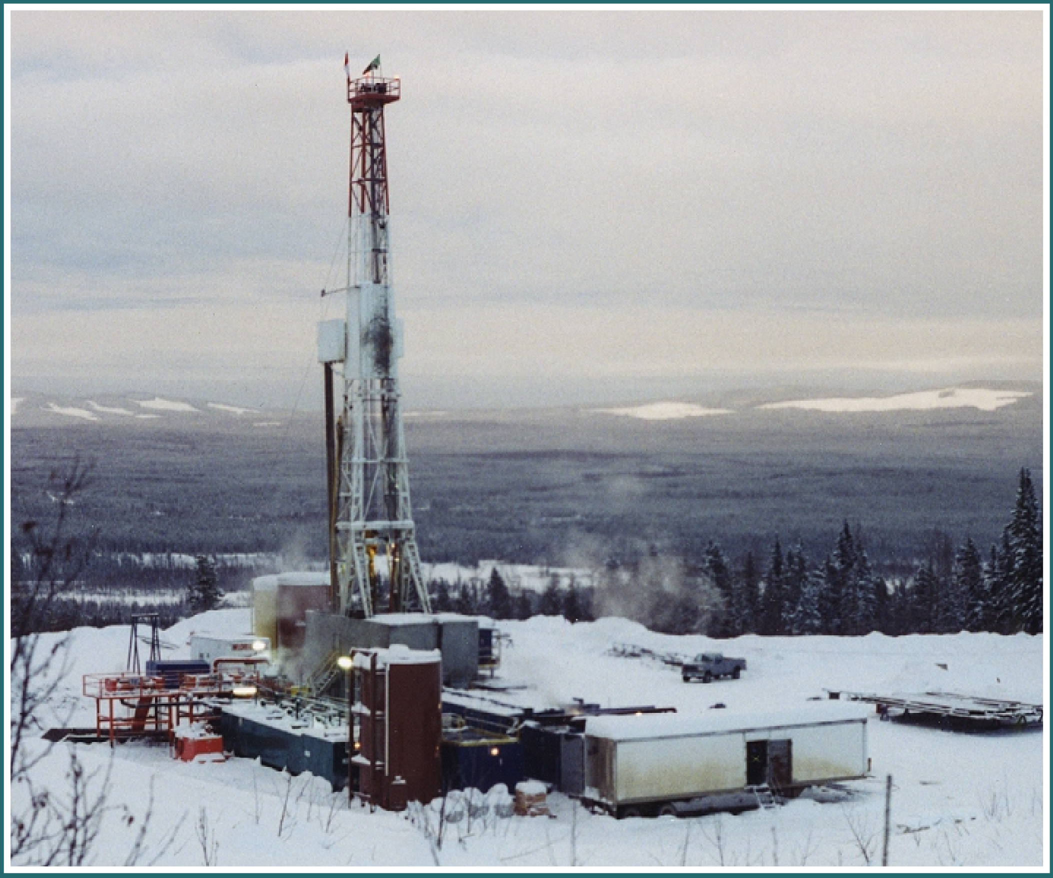
F.M. Dawson, D.L. Marchioni, T.C. Anderson, and W.J. McDougall



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Drilling for coalbed methane, northeast British Columbia (photo courtesy of D.L. Marchioni)

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# AN ASSESSMENT OF COALBED METHANE EXPLORATION PROJECTS IN CANADA


## *ABSTRACT*

This study is a critical assessment of the coalbed methane exploration opportunities in the major coal-bearing basins in Canada. Using data from wellbores containing coal, together with experience obtained from studies in other basins, this study provides 1) a defined set of key geological criteria necessary for successful coalbed methane generation, retention and production; 2) a critical review of the possible geological and operational reasons for the outcome of various exploration area projects; 3) recommendations for the areas that offer the greatest potential for economic coalbed methane accumulations.

## *RÉSUMÉ*

La présente étude est une évaluation critique des possibilités d'exploration du méthane des gisements de charbon dans les principaux bassins houillers canadiens. En se basant sur des données provenant des forages et sur l'expérience acquise lors de l'exécution d'études dans d'autres bassins, cette publication présente 1) un ensemble défini de critères géologiques requis conduisant à la genèse, à la rétention et à la production réussies du méthane des gisements de charbon; 2) un compte rendu critique des raisons géologiques et opérationnelles susceptibles d'expliquer les résultats de divers programmes régionaux d'exploration; et 3) des recommandations sur les régions offrant le plus grand potentiel d'accumulations de méthane des gisements de charbon d'intérêt économique.

## *SUMMARY*

The Geological Survey of Canada conducted an assessment of historic coalbed methane exploration data to evaluate the effectiveness of the previous work undertaken by various companies exploring coalbed methane prospects in Canada. Through a detailed analysis of geological, engineering and completion data it was possible to determine whether exploration opportunities might still exist where they had either been overlooked or misinterpreted in the initial exploration program.

To enable a critical review of historic exploration data, a set of key geological parameters necessary for successful coalbed methane generation, storage and producibility was defined. These parameters are:

- Coal rank – for significant thermogenic gas generation, a rank of 0.70% $Ro_{max}$ or greater should be achieved. Coal of lower rank can, under special geological conditions, store large volumes of biogenic methane (e.g., Powder River Basin).
- Coal composition – the maceral composition of coal controls the fracture density of the reservoir. Bright vitrinite-rich coal tends to be more highly cleated than dull, inertinite-rich coal.
- Coal quality – the ash content should be low. The cleaner the coal, the larger the volume of gas that can be adsorbed onto the coal matrix.
- Seam thickness – seam thickness should allow sufficient storage of gas resource.
- History – the thermal history of a coal-bearing basin determines the amount of gas retention within a coal reservoir. Coal can be degassed from uplift or changes in temperature, resulting in undersaturated coal.
- Depth of reservoir – coal must be at a depth of over 250 m. This ensures sufficient reservoir pressure to allow coal gas to be adsorbed onto the coal matrix. It is also shallow enough to minimize the effect of overburden-pressure-induced permeability reduction (< 2000 m).

- Reservoir permeability – permeability should allow the gas to desorb and flow via the natural fracture system to the borehole.
- Water mitigation – there should be minimal remediation required for any produced waters.

A total of 59 target areas, containing more than 140 exploration boreholes, was examined. The target areas were grouped into four distinct styles of exploration play: restricted basin, shallow foreland basin, deep foreland basin and foothills and mountain regions. For each play type, existing historical data were analyzed and potential exploration targets defined. Multiple targets were ranked based upon prospectivity.

The restricted basin play is characterized by location. The coal deposit is located in a region where more conventional onshore gas supplies are limited or not present. This type of play might have economic advantages because of the higher wellhead price that can be obtained for the gas produced. In the restricted basin play, the most prospective target is the Tsable River coalfield on Vancouver Island. Other targets with potential are the Nanaimo coalfield on Vancouver Island, and the Cumberland and Stellarton basins in Nova Scotia.

The shallow foreland basin play is characterized by low gas content from thick, laterally continuous coal zones, where a large land position is possible. Gas production per well is expected to be low, but the wide lateral extent of the shallow coal might make a large, multiple-well project economically viable. In the shallow foreland basin play, the thick coal of the Tertiary Coalspur/Ardley zone are the most prospective. A number of exploration targets are available and subsurface mapping is required to choose the optimal target location.

The deep foreland basin play is represented by the deep coal of the Lower Cretaceous Mannville Group. The depth of the coal zone (900 to > 2500 m) dictates that some form of permeability enhancement is required to allow the coal's natural fracture system to be open and capable of transporting desorbed gas to the wellbore. Several exploration targets might have permeability enhancement of the coal's natural fracture system as a result of coal beds draping over underlying pre-Cretaceous unconformity highs or basement faults. There are indications (gas content and core descriptions) that two coalbed methane targets (Battle Lake and Norcen Por Fir) have enhanced permeability. To find other targets, subsurface mapping of coal distribution and structure is required. To optimize the exploration opportunity it might be possible to recomplete existing wells that have penetrated the coal zones in search of deeper hydrocarbon targets, although this type of reservoir stimulation has not been successful to date.

The foothills and mountain regions play type perhaps offers the greatest opportunity, but also the greatest risk, for coalbed methane exploration and development. Thick coal seams falling within the thermogenic rank window, coupled with an attractive exploration depth range result in significant potential for large, shallow gas fields. Permeability barriers might exist because of residual compressional stress regimes associated with the Laramide Orogeny. Specific targets should therefore be located on the axes of anticlinal or synclinal structures. In southeast British Columbia, the Elk Valley syncline represents the most attractive exploration opportunity. In the central Alberta foothills, specific targets should focus on the Gates Formation coal at depths between 500 and 900 m. In northeast British Columbia, the Quintette anticline of the Phillips Flatbed prospect appears to have good potential.

## *SOMMAIRE*

La Commission géologique du Canada a effectué une évaluation des données historiques sur l'exploration du méthane dans les gisements de charbon afin d'évaluer l'efficacité des travaux d'exploration réalisés antérieurement au Canada par diverses sociétés dans des zones d'intérêt renfermant ce type de méthane. L'analyse détaillée des données géologiques, techniques et de complétion a permis de déterminer s'il existait encore des possibilités d'exploration qui auraient été négligées ou mal interprétées lors des premiers programmes d'exploration.

Un ensemble de paramètres géologiques clés indispensables à la genèse, au stockage et à la productibilité du méthane des gisements de charbon a été défini afin de faire un examen critique des données historiques d'exploration. Ces paramètres sont les suivants :

- Rang du charbon — pour une production significative de gaz thermogénétique, ce rang doit être de 0,70 % $Ro_{max}$ ou plus. Le charbon de rang inférieur est susceptible, dans des conditions géologiques particulières, de renfermer de gros volumes de méthane biogénétique (p. ex. le bassin de Powder River).
- Composition du charbon — la composition macérale du charbon contrôle la densité de fracturation des réservoirs. Le charbon brillant à haute teneur en vitrinite a tendance a être plus fissuré que le charbon mat à haute teneur en inertinite.
- Qualité du charbon — la teneur en cendres devrait être faible. Plus le charbon est épuré, plus élevé est le volume de gaz adsorbé dans sa matrice.
- Épaisseur du filon — le filon de charbon devrait être suffisamment épais pour permettre un stockage suffisant de ressources en gaz.
- Histoire thermale — l'histoire thermale d'un bassin houiller détermine la quantité de gaz retenu dans les réservoirs à charbon. Le charbon peut être exempt de gaz en raison d'un soulèvement ou de changements de température, ce qui en fait un produit sous-saturé.
- Profondeur du réservoir — le charbon doit se trouver à une profondeur supérieure à 250 m. Ainsi la pression de formation sera suffisante pour permettre au gaz de houille d'être adsorbé dans la matrice du charbon. Cette profondeur permettra aussi de minimiser les conséquences de la réduction de la perméabilité attribuable à la pression géostatique (<2000 m).
- Perméabilité du réservoir — la perméabilité devrait permettre au gaz de se désorber et de s'écouler par le réseau naturel de fractures jusqu'au puits.
- Atténuation des effets de l'eau — l'atténuation requise des effets de l'eau produite sur l'environnement devrait être minimale.

Cinquante-neuf régions-cibles, renfermant plus de 140 forages d'exploration, ont été examinées. Elles ont été regroupées en quatre zones d'exploration de style distinct : bassin restreint, bassin d'avant-pays de faible profondeur, bassin d'avant-pays de grande profondeur et région des contreforts et des montagnes. Pour chaque type de zone d'exploration, on a analysé les données historiques disponibles et défini des cibles potentielles d'exploration. De nombreuses cibles ont été classées selon le degré de potentialité des ressources.

La zone de bassin restreint est caractérisée par son emplacement. Le gisement houiller est situé dans une région où les ressources terrestres en gaz classique sont limitées ou inexistantes. Ce type de zone est susceptible de présenter des atouts économiques en raison du prix élevé du gaz de tête de puits qu'elle produit. Dans la zone de bassin restreint, la cible la plus prometteuse est le district houiller de Tsable River dans l'île de Vancouver. Le district houiller de Nanaimo, également dans l'île de Vancouver, et les bassins de Cumberland et de Stellarton, en Nouvelle-Écosse, constituent d'autres cibles renfermant un potentiel.

La zone de bassin d'avant-pays de faible profondeur est caractérisée par un volume de gaz faible provenant de zones houillères latéralement continues de forte épaisseur, et sans doute très vastes. La production de gaz par puits est susceptible d'être faible, mais la vaste étendue latérale du charbon de faible profondeur pourrait rendre économiquement viable un programme d'exploration à puits multiples. Dans la zone de bassin d'avant-pays de faible profondeur, l'épaisse zone houillère de Coalspur/Ardley d'âge tertiaire est la plus prometteuse. On y trouve plusieurs cibles d'exploration; la réalisation de la cartographie de subsurface permettrait de choisir la meilleure région-cible.

La zone de bassin d'avant-pays de grande profondeur est représentée par le charbon du Groupe de Mannville du Crétacé inférieur. La profondeur de la zone houillère (de 900 à >2 500 m) indique qu'une certaine amélioration de la perméabilité serait nécessaire pour ouvrir le réseau naturel de fractures du charbon, ce qui faciliterait le transport du gaz désorbé jusqu'au puits d'injection. Dans plusieurs cibles d'exploration, il se peut que la perméabilité du réseau naturel de fractures ait été améliorée par suite du moulage, par les filons de charbon, des failles du socle ou des hauteurs de discordances sus-jacents, antérieurs au Crétacé. Certaines données, dont la teneur en gaz et les descriptions des carottes, indiquent que la perméabilité de deux cibles de méthane des gisements de charbon (Battle Lake et Norcen Por Fir) a été accrue. La recherche d'autres cibles nécessitera la réalisation d'une cartographie de subsurface de la répartition et de la structure du charbon. Afin d'optimiser les possibilités d'exploration, il serait peut-être souhaitable de refaire la complétion de puits existants qui ont pénétré les zones houillères à la recherche de cibles d'hydrocarbures plus profonds, même si ce type de simulation de gisement n'a pas donné grands résultats jusqu'à ce jour.

Le type de zone de la région des contreforts et des montagnes présente les débouchés les plus importants mais également les risques les plus élevés pour l'exploration et la mise en valeur du méthane des gisements de charbon. D'épais filons de charbon présents dans le créneau de rang thermogénétique ainsi qu'un éventail de profondeurs d'exploration intéressants constituent un potentiel prometteur pour de vastes champs de gaz naturel peu profonds. Des régimes résiduels de contraintes de compression associés à l'orogenèse laramienne peuvent avoir entraîné la formation de barrières de perméabilité. Par conséquent, des cibles spécifiques devraient se rencontrer sur les axes des structures anticlinales ou synclinales. Dans le sud-est de la Colombie-Britannique, le synclinal de la vallée Elk représente le potentiel le plus intéressant pour l'exploration. Dans les contreforts du centre de l'Alberta, des cibles particulières devraient être axées sur le charbon de la Formation de Gates à des profondeurs se situant entre 500 et 900 m. Dans le nord de la Colombie-Britannique, l'anticlinal de Quintette, situé dans la zone d'intérêt de Phillips Flatbed, semble renfermer un important potentiel.

# INTRODUCTION

This publication presents an assessment of the exploration opportunities for coalbed methane in Canada. The study, completed over a period of three months, reviewed publicly available geological, engineering and production data from wellbores that sampled and tested various coal intervals from the major coal-bearing basins in Canada. Data were made available through the Canadian Coalbed Methane Forum (CCMF), the Geological Survey of Canada (GSC), and the Energy and Utilities Board of Alberta (EUB).

A set of geological parameters was established that includes the ideal key threshold values for successful coalbed methane gas generation, storage and producibility. The thresholds presented are guidelines and base levels that allow different exploration plays to be evaluated and compared to each other.

For each well, the target zones and/or structure were defined. Then data analyses and interpretations were conducted to determine whether the completed wellbore tests adequately assessed the coalbed methane potential of the coal reservoirs. Data quality is highly variable, ranging from simple vitrinite reflectance measurements from cuttings to extensive wellbore production reports and comprehensive geological analyses. A total of 59 boreholes was evaluated.

From the results of this in-depth technical assessment, several coalbed methane prospective areas were delineated. These areas fall within four distinctive exploration play categories: 1) restricted basins, 2) shallow foreland basin, 3) deep foreland basin and 4) foothills and mountain regions. For each category, there are positive and negative geological and engineering elements unique to the type of play.

Specific exploration targets that had been drilled as part of the historical coalbed methane exploration data set are defined and ranked in terms of prospectivity. For each high priority target area, a recommended “next step of assessment” is defined, which in the authors’ opinion, should be undertaken. This next step may entail subsurface mapping or wellbore recompletion, depending on the stage of evaluation completed before this assessment and as the exploration risk assumed.

## Methodology

For this study, 59 potential target areas were evaluated. In each area, at least one coalbed methane exploration borehole was drilled and the data from this borehole used as a basis for evaluating whether the key geological parameters had been met. If the data were of poor or questionable quality, the authors attempted to rationalize the data. In some boreholes, this was not possible and the data were not used in the evaluation. For each coalbed methane area, the information and assessment are presented in the following order:

- *Data acquisition* – description of the drilling methods, sample collection, technical analyses and formation testing procedures.
- *Geology* – a summary of the local geology in the project area. In particular, the distribution and thickness of coal seams are documented, as well as the presence of geological features that might impair or enhance coalbed methane prospectivity.
- *Gas content* – tabulation of gas desorption data generated during this study or available locally.
- *Coal quality* – a summary of the available coal quality data, particularly those parameters with direct influence on coalbed methane generation and retention, such as rank and ash content.
- *Adsorption isotherms* – details of any isotherm data, calculation of reservoir capacity and reservoir saturation.
- *Formation testing* – summary of drillstem tests (DSTs), injection tests and any other tests that provide information about the porosity, permeability and potential producibility of the target coal.
- *Technical assessment* – a critical review of all operational and testing components of the project to highlight any aspects, geological or operational, that contributed to its success or abandonment. It was of primary concern to highlight areas where a high level of economic potential might have been downplayed or masked by faulty assumptions, drilling practices or testing procedures.

This critical assessment, together with experience gathered in other basins, was used to produce:

- a set of key geological criteria that in the authors’ opinion are necessary for successful coalbed methane generation, retention and production
- a critical review of the possible geological and operational reasons for the outcome of the exploration area projects
- a series of recommendations highlighting the areas that offer the highest potential for economic coalbed methane accumulations

but also lower micropermeability (Dawson and Clow, 1992). This is thought to occur as a result of the ash component reacting not only as a diluent but also as a blocking mechanism for the migration of gas through the coal matrix. Inherent ash (material that cannot be removed by washing) appears to have an impact four times greater than free ash on the gas storage capacity of the coal. Coal that is low in free ash and inherent ash (i.e., less than 10%), will generally have a much greater storage capacity than coal with higher ash content.

### *Seam thickness*

Seam thickness is an obvious geological threshold that must be satisfied in order to have sufficient coal resources for gas storage. The thicker the coal zone or “reservoir”, the greater the potential gas storage within that coal horizon. In some cases, the thicker seams might not be the most attractive targets because of lower gas content. The formula used by the Gas Research Institute (GRI) for resource assessment is:

$$Gip = 1359.7 * A * h * ß * Gc$$

Where:

- Gip = gas-in-place (cubic metres)
- A = drainage area (acres)
- h = seam thickness (feet)
- ß = coal density (g/cc)
- Gc = gas content (cubic feet/ton)

In this study, it is assumed that coal seams less than 1 m thick are too thin to be considered prime coalbed methane exploration targets, unless they are part of a coal zone greater than 1.5 m thick.

### *Reservoir thermal history and saturation*

For coal to achieve a rank maturity within the thermogenic window during the coalification process, basin temperatures have to be greater than 60°C. As coal generates gas, large quantities are adsorbed onto the coal matrix. The excess gas is driven off into the surrounding formations. At the temperature at which thermogenic gas is generated, coal has a specific volume of gas storage capacity. It has been demonstrated by numerous adsorption isotherm tests that the higher the temperature of adsorption, the lower the adsorptive capacity of the coal (Kim, 1975). Cooling of the basin after gas generation, as in the case of the Western Canada Sedimentary Basin, allows the coal to achieve a higher adsorption capacity. As a result, in most cases, the coal is undersaturated because of the additional adsorptive capacity. In order for the coal to achieve maximum gas saturation, either additional gas must flush through the coal matrix system to be adsorbed by the coal, or the basin must return to the original temperature.

In highly permeable reservoirs, dissolved thermogenic or biogenic gas has the opportunity to migrate to the coal reservoir and subsequently be adsorbed into the coal matrix. This type of gas migration and storage is postulated for the fairway zone of the San Juan Basin (Kaiser et al., 1992), where biogenic gas was carried by meteoric water downdip into the basin until it hit a permeability barrier. This barrier created a zone where the coal was saturated and overpressured.

### *Depth of reservoir*

The principle of methane adsorption within a coal seam is defined by reservoir pressure. The higher the reservoir pressure, the greater the volume of methane gas that a coal seam can retain through adsorption. At a given point, the coal will have reached total gas capacity and increasing the pressure will not increase the reservoir storage capability. Most reservoir pressure is from overburden pressure, as reflected by the observation that the deeper the seam the higher the gas content. A minimum coal-seam depth is usually required before adsorbed gas volumes are high enough to warrant exploration and development. Usually the minimum depth threshold is 250 m, although each geological prospect is unique. In some cases, other geological factors influence the depth threshold where coal gas is retained. For example, if the basin underwent a complicated geological history involving uplift and reburial after coalification, much of the gas might be desorbed at the earlier, shallower depth. The coal seams might not be recharged with gas after reburial (e.g., northern Bowen Basin of Australia).

Dawson and Clow (1992) showed that the retained gas content of coal depends on the regional water table associated with major rivers. To attain saturated gas conditions within coal reservoirs, the coal must lie below the base elevation of the major river valleys.

### *Reservoir permeability*

The most critical threshold impacting the producibility of a coal reservoir is permeability. Coal seams can be classified as low permeability reservoirs similar to the tight gas sands of northwest Alberta. However, a major distinction, which many companies fail to recognise, is the added complication of the ductile behaviour of the coal under pressure.

The permeability for coal seams ranges from a high of 25 mD (San Juan Basin) to less than 0.01 mD (Mannville coal of the Alberta Plains). There are two levels of permeability that must be addressed in a coal reservoir: micropermeability and macropermeability**.** Micropermeability is defined by the microscopic fractures that allow the adsorbed gas to migrate from the coal matrix to the macro fracture system. Macropermeability is defined as the reservoir permeability of the visible fracture system of the coal deposit, and is usually the permeability measured during conventional wellbore tests (DST, injection or falloff). In order for the reservoir to have successful production, both systems must be present.

For micropermeability to be present, the coal must be of suitable rank and maceral composition to have generated an interconnected micro-cleat and bedding plane fracture system. Macropermeability is developed through permeability enhancement associated with folding or flexuring of the coal seams. In the tectonically disturbed terrain of the mountains and foothills, coal is commonly folded and faulted, leading to extensive fracture development.

However, in many cases the coal, because of its friable nature, behaves in a ductile, plastic manner rather than undergoing brittle deformation. This results in the coal becoming highly sheared and comminuted. Whatever permeability was present is essentially obliterated and the coal behaves more like plasticine. Foothill and mountain regions subjected to high tectonic deformation usually contain such coal. For example, Canmore region coal has a high volume of gas, which is released on mining (up to 2 Mmcf/d). However, under reservoir conditions, boreholes produced less than 50 Mcf/d as a result of the low reservoir permeability.

The key to finding tectonically enhanced permeability is to target coal that has been folded but not sheared. In foothill and mountain regions, the exploration targets are the fold axes of major synclinal and anticlinal structures, where the coal has undergone some degree of tensional flexuring but has not been subjected to the shearing associated with thrust faults. In some cases the structures in the hanging wall of major thrust faults may be less complex than those in the footwall of the underlying plate. It is assumed that when the strata dip at greater than 45° there is a higher risk of coal seam faulting and shearing. In the Plains region, stratigraphic drapes over underlying Paleozoic structural features or sand channel bodies provide sufficient relief within the coal seam to develop tensional fracture systems that enhance reservoir permeability.

In any exploration program for coalbed methane, permeability is the most critical and least predictable of the geological thresholds that must be satisfied. Numerous companies have explored for coalbed methane in Alberta and British Columbia and have not been successful because of the permeability barriers. Understanding this geological problem and tailoring the exploration program to minimize the risk as much as possible are necessary to satisfy this geological threshold.

### *Water mitigation*

In most economically viable coalbed methane production areas worldwide, water production is a byproduct of gas production. Coal and water are produced simultaneously and are intimately related; the presence of water in the reservoir is an indication of permeability. Without water production, the reservoir probably has low permeability and gas production will either be minimal or decline rapidly. In some reservoir settings, such as the Elk Valley of southeast British Columbia, the water quality appears to be fresh, so minimal remediation would be required for any produced waters. However, in other cases, such as the Mannville Group coal of the Alberta Plains, the produced waters are high in total dissolved solids (TDS) and require special treatment and disposal techniques, which would add to production costs.

## BRITISH COLUMBIA COASTAL REGION

### Tsable River project

In 1996, Quinsam Coal Corp. initiated an exploration project in the Tsable River area on the east coast of central Vancouver Island (Fig. 1). Core was collected from six wells, and 13 samples were desorbed as part of an assessment of the coalbed methane potential of the Comox Basin (Ryan, 1997). Gas content averaged 2.8 cc/g a.r. (as received) with a maximum of 5.5 cc/g (Table 1). Gas content showed a general increase with depth.

*Data acquisition.* Drilling was conducted with a truck-mounted rig. A wireline core barrel was attached at the top

**Table 1**
**Gas content, Tsable River area**

| Sample no. | Well | Seam no. | Top (m) | Thick (m) | Total gas (a.r.) (cc/g) | Total gas (a.f.) (cc/g) |
|---|---|---|---|---|---|---|
| 1 | TR96-01 | 1 | 166.5 | 0.38 | 2.24 | 2.91 |
| 2 | TR96-01 | 1 | 168.25 | 0.29 | 1.59 | 3.53 |
| 3 | TR96-05 | 2 | 127.4 | 0.35 | 1.90 | 2.38 |
| 4 | TR96-05 | 1 | 158.6 | 0.37 | 2.32 | 3.03 |
| 5 | TR96-05 | 1 | 159.3 | 0.34 | 2.31 | 3.02 |
| 6 | TR96-05 | 1 | 159.9 | 0.36 | 1.79 | 2.79 |
| 7 | TR96-06 | 1 | 227.3 | 0.40 | 3.15 | 3.77 |
| 8 | TR96-06 | 1 | 228.2 | 0.22 | 2.43 | 2.91 |
| 9 | TR96-06 | 1 | 228.6 | 0.26 | 3.10 | 3.71 |
| 10 | TR96-07 | 3 | 278.9 | 0.10 | 3.55 | 5.42 |
| 11 | TR96-15 | 3 | 296.8 | 0.20 | 3.13 | 4.47 |
| 12 | TR96-15 | 3 | 300.9 | 0.20 | 3.31 | 4.31 |
| 13 | TR96-18 | 4 | 376.2 | 0.32 | 5.51 | 6.46 |

## Theoretical gas content analysis

Theoretical gas content values are derived using the Ryan equation (Ryan, 1992). This equation relates gas storage capacity to depth of coal reservoir assuming 100% gas saturation of the coal. The relationship between gas saturation capacity and depth has been modified from the original capacity curve developed by Kim (1975).

The Ryan equation allows the characteristics of coal quality (ash and moisture content) as well as coal rank values to be input into a computer program. Theoretical methane storage capacity is determined as a function of coal rank and composition at varying depths.

## Geological parameters

In order for any coalbed methane exploration and development project to be successful, a number of geological thresholds must be satisfied. These thresholds influence the resource potential of each deposit, but the impact of each is variable and unique to any given reservoir. The main geological elements that control the generation, storage, and producibility of coal gas from coal seams are:

- Coal rank – for significant thermogenic gas generation, a rank of 0.70% $Ro_{max}$ or greater should be achieved. Coal of lower rank can, under special geological conditions, store large volumes of biogenic methane (e.g., Powder River Basin).

- Coal composition – the maceral composition of coal controls the fracture density of the reservoir. Bright vitrinite-rich coal tends to be more highly cleated than dull, inertinite-rich coal.

- Coal quality – the ash content should be low. The cleaner the coal, the larger the volume of gas that can be adsorbed onto the coal matrix.

- Seam thickness – seam thickness should allow sufficient storage of gas.

- Thermal history – the thermal history of a coal-bearing basin determines the amount of gas retention within a coal reservoir. Coal can be degassed from uplift or changes in temperature, resulting in undersaturated coal.

- Depth of reservoir – coal must be at more than 250 m depth. This ensures sufficient reservoir pressure to allow coal gas to be adsorbed onto the coal matrix. It is also shallow enough to minimize the effect of overburden-pressure induced permeability reduction (< 2000 m).

- Reservoir permeability – permeability should allow the gas to desorb and flow via the natural fracture system to the borehole.

- Water mitigation – there should be minimal remediation required for any produced waters.

### *Coal rank*

Coal is a unique hydrocarbon reservoir that is not only the source of hydrocarbon generation, but also the reservoir for hydrocarbon storage, particularly methane gas. Coal has the capability of storing large quantities of gas, as much as 10 times that of a conventional reservoir. During the maturation process from peat to anthracite, coal increases in rank and undergoes processes of devolatilization and expulsion of moisture. At an $Ro_{max}$ of about 0.6 %–0.7 %, thermogenic methane begins to form. Below this threshold biogenic methane may be generated, but not in the same quantities as that generated by thermal processes. The maximum generation and porosity storage of methane occurs in the 0.85 %–1.0 % $Ro_{max}$ range.

### *Coal composition*

The composition of the coal (maceral type) is significant with respect to the micropermeability of the potential reservoir. Inertinite-rich coal is likely to have lower gas content than vitrinite-rich coal. Research studies conducted by the GSC (Dawson and Pratt, 1992) have demonstrated that banded coal (i.e., thin layers of vitrinite and dull coal) have a higher micropermeability than more uniform coal lithotypes. This micropermeability is critical to the producibility of the reservoir. The gas must have a pathway to flow from the matrix to the macro-fracture system that links to the borehole. A well-developed cleat system (orthogonal joint system within the coal) provides that mechanism. Bright, vitrinite-rich coal is better cleated than dull coal, whereas dull coal has well developed fracture interfaces parallel to the bedding. The combination of both maceral types in a banded coal allows both vertical and horizontal connectivity of the reservoir.

### *Coal quality*

Coal quality plays a major role in determining the overall storage potential of a coal reservoir. Essentially, the cleaner the coal, the greater the volume of gas that can be adsorbed within the coal seam. The ash (inorganic component of the seam) acts as a diluent within the coal matrix and does not contribute to the storage capacity. Coal with ash content higher than 15% not only has lower gas storage capability,

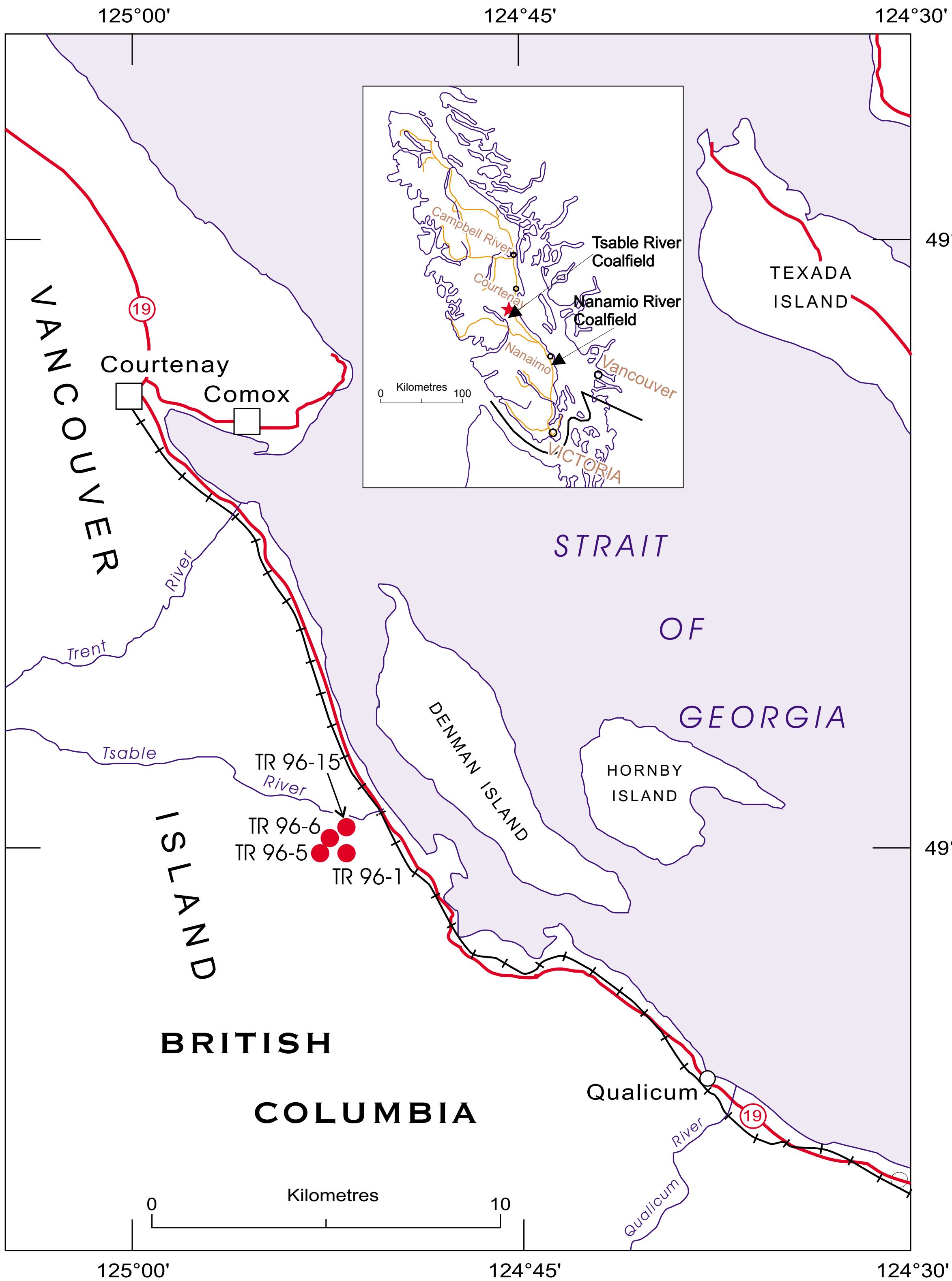


***Figure 1.*** *General location map of the Tsable River and Nanaimo River coalfields.*

of the coal-bearing sequence. Desorption samples were collected from six wells over a range of depths, and from four seams. Core recovery times were short and lost gas is a minor component of total gas content (3 to 6%).

Most of the wells were located close to mapped fault planes and on the upthrown blocks. No formation or production testing was undertaken.

*Geology.* The Tsable River area lies within the Comox coal basin. The target coal is within the Upper Cretaceous Comox Formation of the Nanaimo Group (Fig. 2). This formation has four economically important seams with cumulative thicknesses ranging from 3 to 8 m.

Mapping by Cathyl-Bickford (1992) indicates an area of low-angle dips disrupted by three sets of faults: northwest- and northeast-trending faults and a third set comprising bedding plane shear zones. Seams commonly contain shear zones and low-angle faults. Previous exploration has identified two seams of economic interest in the area, with thicknesses of 2.0 to 2.5 m and 1.0 to 1.2 m, respectively. Based on 1991 exploration, proven reserves of 35 million tons have been calculated (S. Gardner, pers. comm.).

The exploration area lies at the northern end of the Cowichan Fold and Thrust Belt, and it has been suggested that rank postdated deformation. Consequently, rank is unlikely to increase in deeper parts of the basin and gas content will be influenced only by depth.

*Gas content.* Gas has been reported from a few deep wells in the Tsable River area and mine emission data can also be used to indicate gas content, which averages 8 to 12 cc/g at a depth of 250 m (Cathyl-Bickford, 1991).

In the Quinsam drilling program, four seams in six wells were sampled to provide 13 desorption tests. As-received gas content is relatively low, from 1.59 to 5.51m$^3$/t, and increases with depth (Fig. 3). Variable ash content from 14.6 to 55% has influenced these values, and normalized gas content is somewhat higher, from 2.38 to 6.46 m$^3$/t (Table 1, Fig. 3).

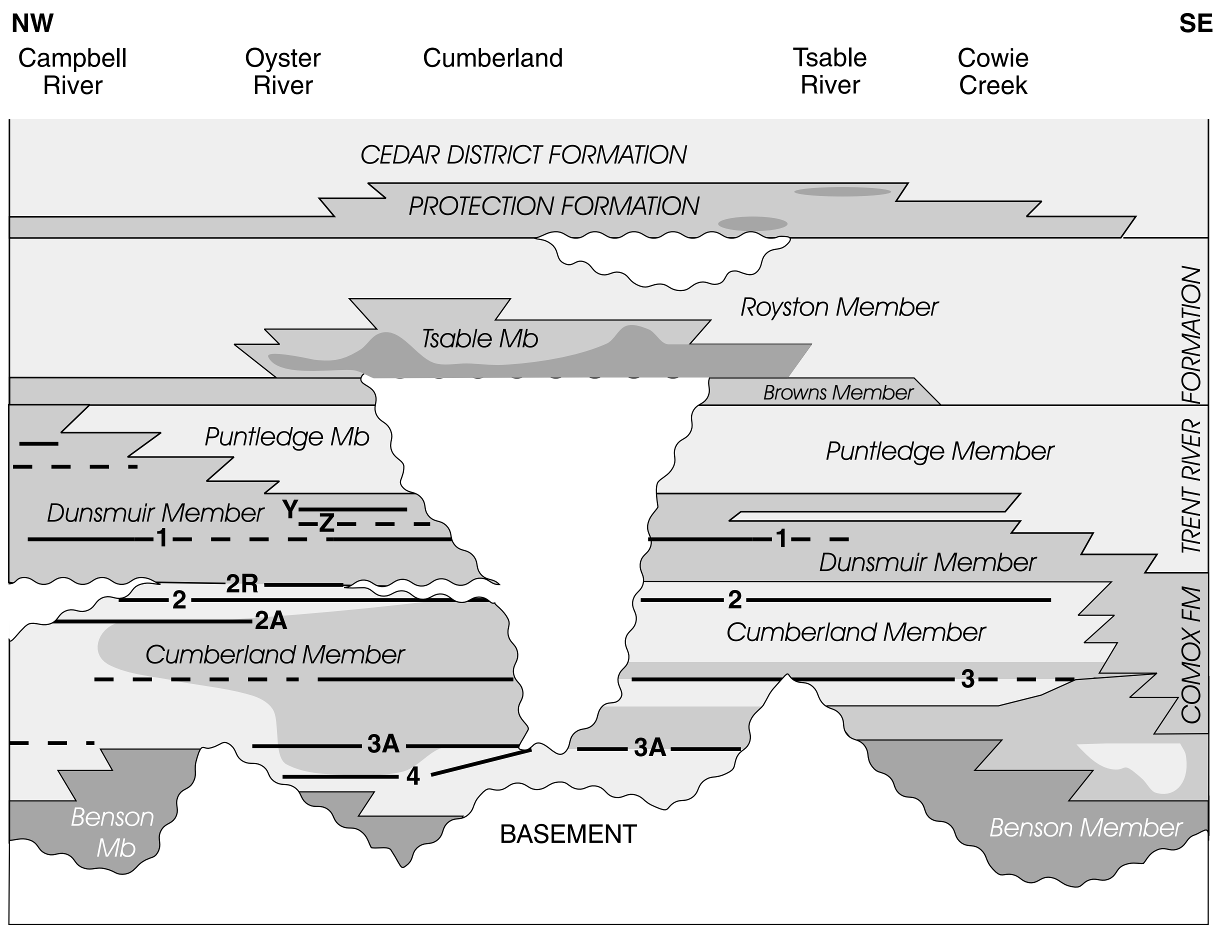


***Figure 2.*** *General stratigraphic column of coal-bearing strata in the Tsable River area.*

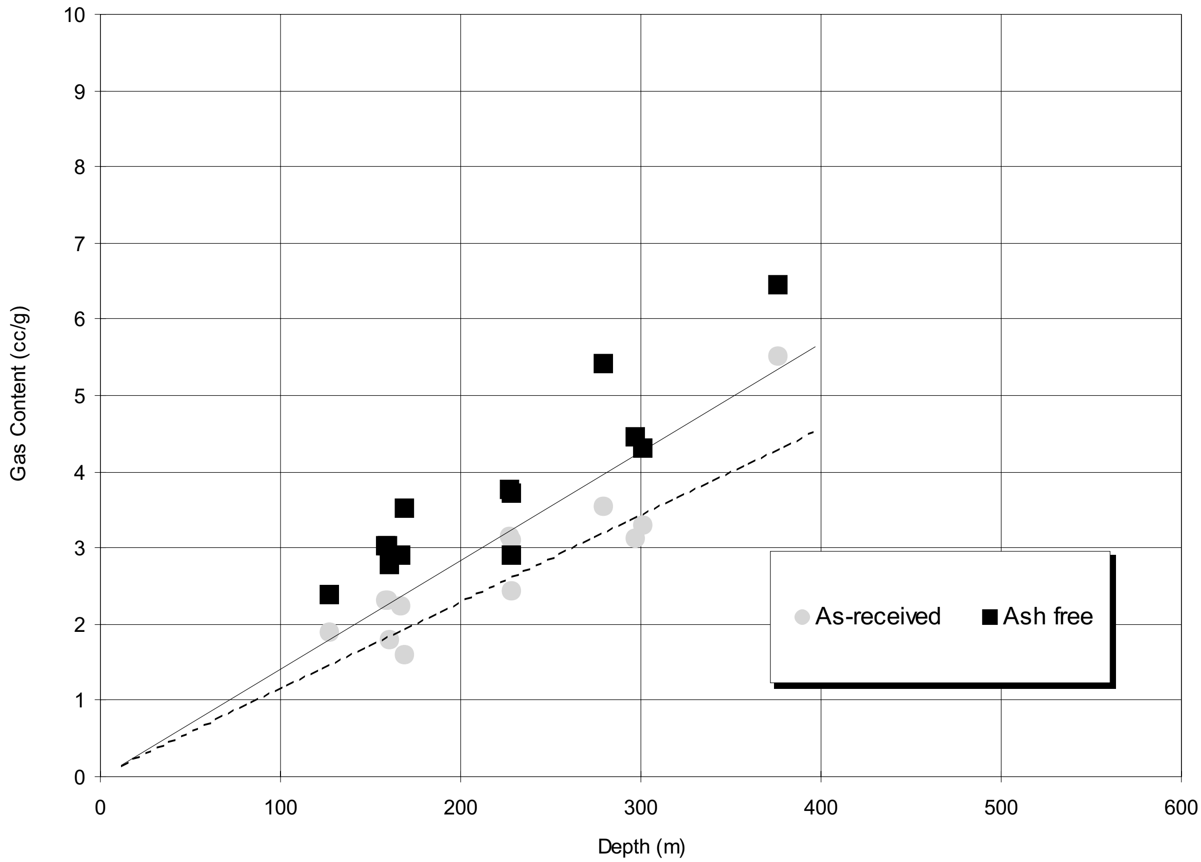


***Figure 3.*** *As-received and normalized gas content versus depth, Tsable River area.*

Gas content is lower than predicted using either the Ryan or Kim equations, suggesting undersaturation of the coal. The relatively low gas content is probably a function of the shallow depth range sampled (127 to 376 m). A straight line correlation of the as-received gas content predicts values of about 8 $m^3$/t at 600 m at the typical ash content determined for the sampled seams.

*Coal quality*. Vitrinite reflectance on four samples ranged from 0.82 to 0.84%, indicating a high volatile A bituminous rank. Ash content was relatively high in the desorption samples, ranging from 14.6 to 55.0% with an average of 25%.

*Adsorption isotherms.* No adsorption isotherms were performed on the samples.

*Formation testing.* No formation tests have been conducted on any exploration boreholes.

*Technical assessment.* The drilling/desorption program showed that the Tsable River area coal has moderate gas content (up to 5.5 cc/g at 376 m) and may be undersaturated. The short core recovery times and observations of geological personnel indicate that gas content has most likely been accurately assessed.

The relationship between gas content and depth indicates potential values up to 8 cc/g at 600 m. Resource estimates for part of the southern end of the Comox Basin indicate at least 8 billion cubic metres of gas in place (Ryan, pers. comm.).

No permeability or production data are available, so it is not possible to estimate recoverable reserves or potential production rates. The size of the resource and the potential for markets on Vancouver Island indicate that this area holds potential for coal bed methane exploitation.

## Nanaimo coalfield

The Nanaimo coalfield has an extensive history of underground mining commencing in the 1800s. In 1986, BP Canada drilled two exploration wells for conventional hydrocarbons. Coal of the Pender and Comox formations was intersected and gas outbursts recorded. No testing of the coalbed methane potential of the wells was undertaken and the boreholes were subsequently plugged and abandoned.

In 1984, Novacorp International (previously Algas Resources) initiated a seven-hole exploration program to assess the coalbed methane potential of the Douglas Main seam of the Pender Formation. These wells were never put into production and the project was subsequently abandoned. No further work has been undertaken to assess the coalbed methane potential of the region.

*Data acquisition.* Data for this interpretation are drawn from the published synthesis of Cathyl-Bickford (1992). Limited data are available with respect to the measured gas content, and only summary values are presented.

*Geology.* The main targets for coalbed methane potential are the coal seams of the Douglas coal zone. Up to four seams are present, of which the Douglas Main seam has the greatest potential. The other seams are thin and discontinuous and are not considered to have significant coalbed methane potential. The Douglas Main seam is highly variable in thickness, ranging from less than 1 m to greater than 21 m. The average thickness of the seam is 2.5 m. Changes in thickness are because of local rolls and folds. The coal tends to have a predominantly mudstone roof and floor, but sandstone washouts have removed some of the roof material.

The Nanaimo coalfield contains a number of gently dipping (< 15°) open folds cut by small-scale thrust faults. The Nanaimo River transcurrent fault cuts through the centre of the basin, but offset of this fault is limited.

Most of the underground workings extended to a maximum depth of 300 m. The coal measures extend beyond this depth and have been traced by seismic to a depth of 1200 m.

*Gas content.* Gas content data were collected during the Novacorp drilling in 1984-86. Detailed gas content values are not available, but the measured values are reported to have ranged from 5 to 12 cc/g. Gas emissions from the Morden Colliery indicate that gas content is as high as 23.8 cc/g. This is two to four times higher than the desorption data and should be suspect. However, perhaps the relatively impermeable roof and floor strata of the Douglas seam led to overpressuring of the coal.

*Coal quality.* Coal of the Douglas Coal Zone is high volatile A bituminous to high volatile C bituminous in rank. Ash content is highly variable, in part reflecting the depositional setting, but also the structural overprinting of the seam. The Douglas Main seam tends to be friable and sheared, with no clearly defined cleat system. Ash content is widely variable, ranging from 6.5 to 33.5%. The high ash components are probably a result of the thin, discrete ash bands mixing during shearing of the coal. Where the Newcastle seam splits off the base, the remaining coal is defined as the Douglas seam. In these localities, the coal is blocky with a well-developed cleat system. Ash content ranges from 8 to 13%.

*Adsorption isotherms.* No adsorption isotherms were completed for the coal samples.

*Formation testing.* No formation tests were performed on the wellbores.

*Technical assessment.* The Nanaimo coalfield was designated as a prime coalbed methane exploration target as a result of the perceived need for natural gas supplies on Vancouver Island. The underground mines had a history of being “gassy” and outbursts were common. Coal lies at attractive depths and is of a suitable rank for thermogenic gas generation. Although gas content is not high, it could provide a significant resource base. The main detractor for coalbed methane exploration and development in the Nanaimo coalfield is the surface land position. Much of the prospective area has undergone extensive urban development. Surface facilities would have to compete with the burgeoning housing market in the Nanaimo region and there would definitely be resistance to the installation of numerous coalbed methane production wellbores.

## BRITISH COLUMBIA FOOTHILLS AND MOUNTAINS

### Southeast region

#### *Mobil/Chevron Fernie Basin project*

Mobil/Chevron drilled two exploration locations in the Fernie Basin in 1990 (Fig. 4). The first, b-82-L, was abandoned after two attempts to penetrate the overlying Elk Formation. The second borehole, at location a-65-E, successfully completed and terminated in the Moose Mountain Member of the Morrissey Formation. Seven coal zones were sampled for gas content. The upper two seams were tested for permeability (Fig. 5). No production tests were conducted on the borehole. Following completion of drilling, the sites were abandoned. Both Chevron and Mobil have discontinued coalbed methane exploration activity.

*Data acquisition.* During drilling of borehole b-82-L, numerous problems were encountered. Eventually the site was abandoned because of excessive water flow. The analysis of remaining boreholes from the Mobil/Chevron exploration program will be restricted to data from borehole a-65-E.

Borehole a-65-E was located on Morrissey Creek, southeast of the town of Fernie in the southwestern corner of the Dominion Coal Block - Parcel 82 (Fig. 4). The hole was

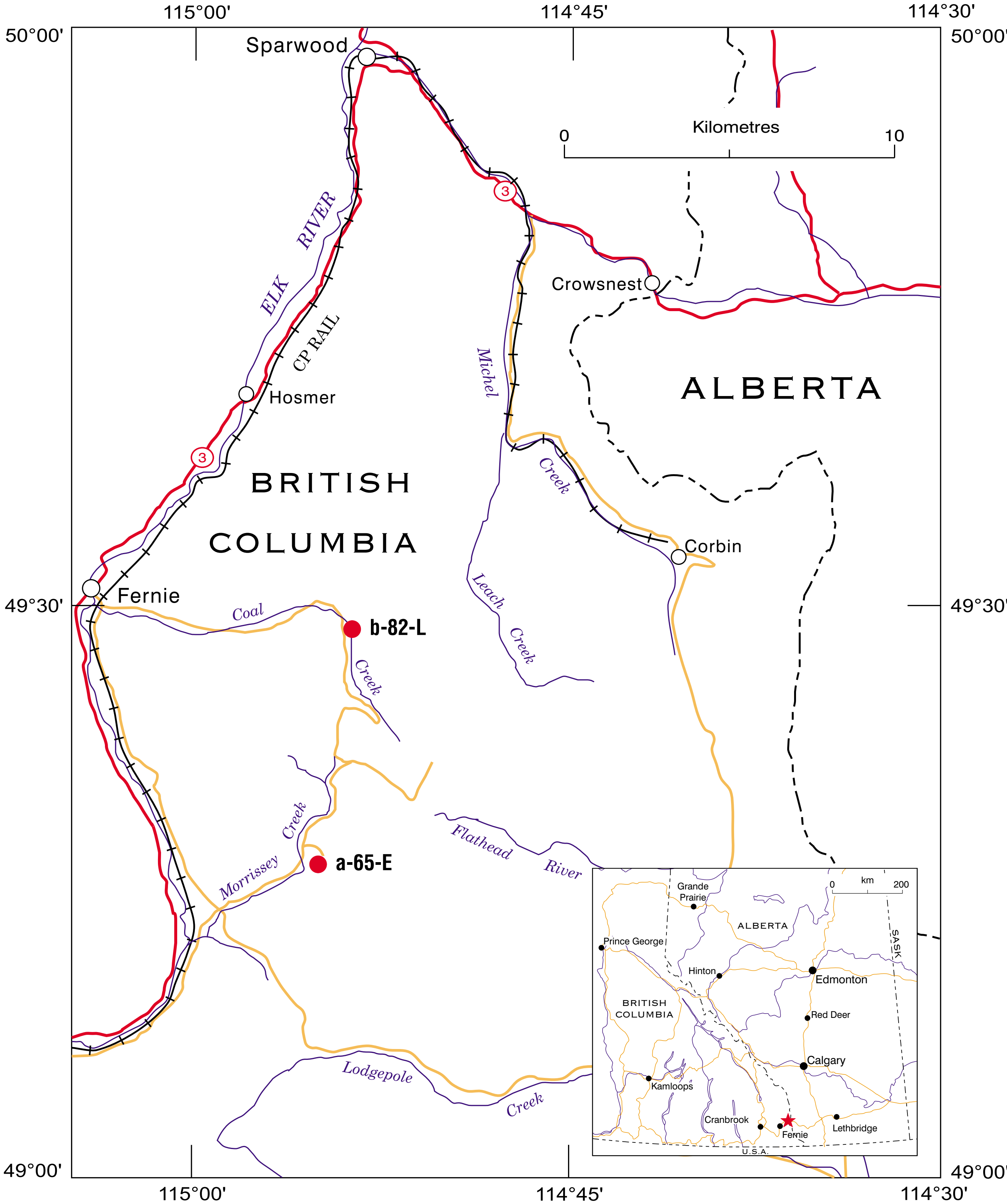


***Figure 4.*** *General location map of the Mobil/Chevron Elk Valley exploration boreholes.*

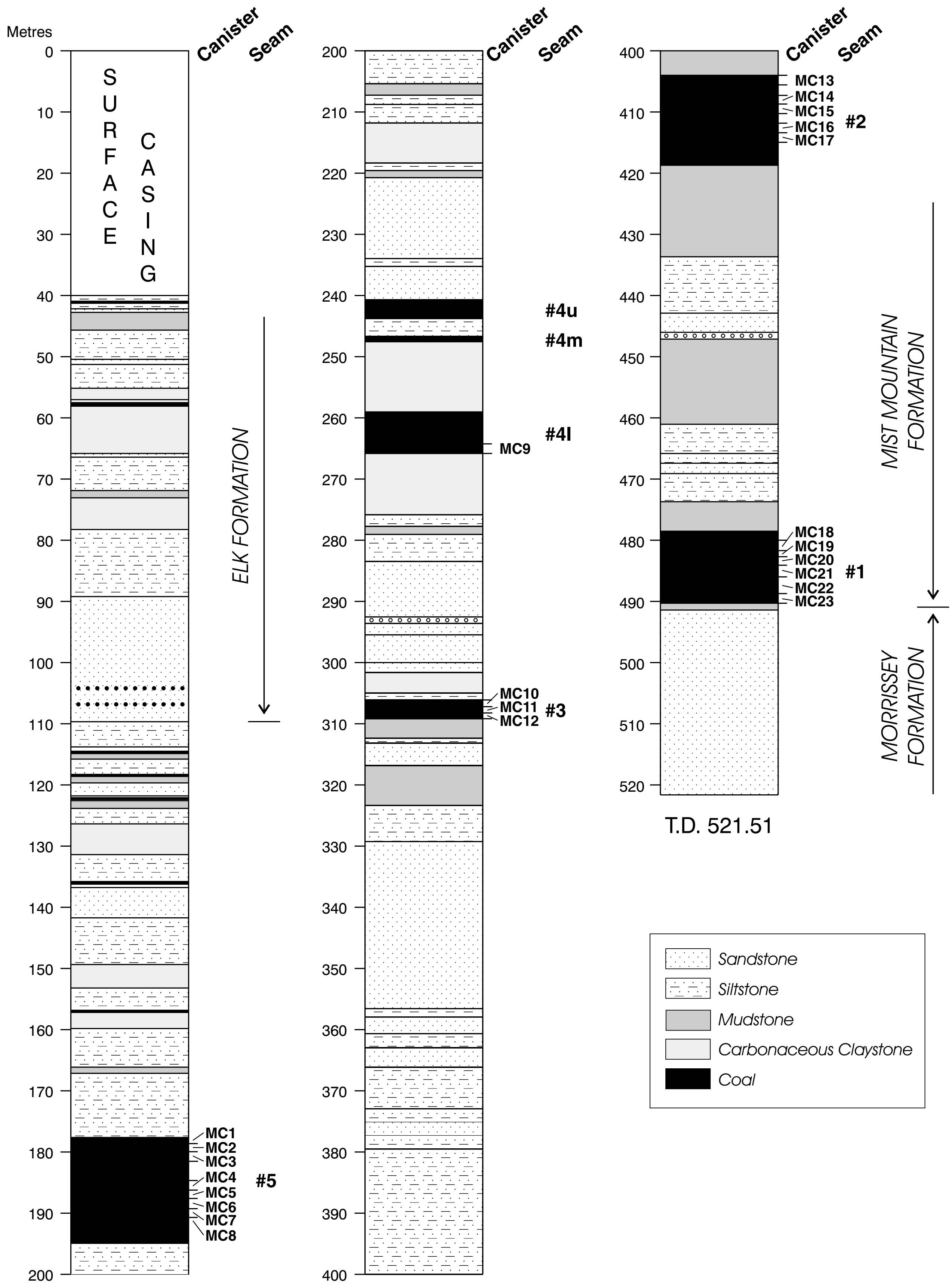


***Figure 5.*** *Stratigraphic section of the Mist Mountain Formation intersected in the a-65-E borehole.*

drilled using a diamond drill rig to facilitate continuous coring of the Mist Mountain Formation. HQ diameter (63.5 mm) core was collected from 49.6 m to total depth. Seven major coal zones were intersected and 23 canister samples were collected. The original drilling plan was to use water as the drilling fluid, but excessive fines production forced the conversion to a more conventional mud-based system. At a depth of 415 m, the original drill string became stuck in the borehole and the remaining 106 m was cored using an NQ diameter (47.6 mm) core barrel. Following completion of the coring, numerous problems were encountered during the logging and permeability testing of the seams, primarily because of strata instability.

*Geology*. Borehole a-65-E was located on the western limb of the McEvoy Synclinorium (the major structure of the Fernie Basin). The hole was spudded near the top of the Mist Mountain Formation and a total of 491 m of coal-bearing strata was encountered. It is believed that the total thickness of the formation is more than 600 m in this region. Mist Mountain Formation strata are characterized by interbedded, fine-grained sandstone, siltstone, mudstone, and thick coal seams. Seven major coal horizons were intersected along with several thin coal/coaly shale stringers in the upper 130 m of the section (Fig. 5). The major seams were designated 1 to 5 and are equivalent to the major coal seams mined at the open pit mines to the north at Sparwood. Coal ranges in thickness from 1.8 to 14.39 m. Cumulative thickness is 54.16 m, of which 39.57 m comes from three seams (1, 2 and 5). Seam intersections and thicknesses are summarized in Table 2.

A major thrust fault (Flathead Thrust) was intersected at 130 m in the borehole. It is believed that the coal measures intersected lie within the Lookout reserve block of Parcel 82, Dominion Coal Block. Strata below the fault dip gently at less than 20°, whereas in the vicinity of the fault, the dip approaches 70°. Core recovery in the coal seams averaged 60 to 70%. The core descriptions indicate that most of the coal was highly shattered and/or crushed.

**Table 2**
**Seam intersections and thicknesses, Mobil/Chevron a-65-E**

| Seam no. | Depth of intersection (m) | Seam thickness (m) |
|---|---|---|
| 5 | 177.4-191.0 | 13.07 |
| 4 upper | 240.8-243.7 | 2.81 |
| 4 middle | 246.8-248.6 | 1.8 |
| 4 lower | 259.0-265.8 | 6.43 |
| 3 | 306.2-309.8 | 3.55 |
| 2 | 403.9-418.8 | 14.39 |
| 1 | 478.5-490.8 | 12.11 |
| Cumulative thickness | | 54.16 |

*Gas content.* Twenty-three canister samples were collected from borehole a-65-E using a wireline core barrel system. As a result, the lost gas component of the total gas volume was generally less than 10%. Depth of sample interval and measured gas content are presented in Table 3. Gas content ranges from 1.36 to 16.56 cc/g. Normalized values range from 3.02 to 17.90 cc/g. The seam with the highest gas content (No. 2) corresponds to the zone where coal and water sloughing into the borehole resulted in the rods becoming stuck and the HQ drill string being abandoned. It appears that this zone represents a high-permeability horizon, although drillstem tests suggest low permeability. The apparent contradiction of data is discussed further in the formation testing section.

Gas content generally increases with increasing depth except for Seam 1 (Fig. 6). No obvious explanation is apparent for the low gas content in this seam, but similar low levels have been observed in the Fernie Basin for the lower Mist Mountain Formation coal. The one commonality between the lower gas content and the basal seams is the high inertinite content of the coal, but the relationship is not clear.

*Coal quality*. The coal quality of samples from borehole a-65-E is widely variable. Ash content ranges from 6.6 to 74.11% (average 21.24%). Equilibrium moisture content is less than 1%, and coal rank is classified as medium to low

**Table 3**
**Desorption data, Mobil/Chevron a-65-E**

| Sample no. | Seam no. | Depth (top) (m) | Depth (base) (m) | Normalized gas (cc/g) | Measured gas (cc/g) |
|---|---|---|---|---|---|
| MC-1 | 5 | 178.31 | 178.61 | 5.25 | 1.36 |
| MC-2 | 5 | 178.61 | 180.14 | 7.63 | 6.94 |
| MC-3 | 5 | 180.14 | 181.66 | 6.91 | 4.9 |
| MC-4 | 5 | 184.71 | 186.23 | 6.78 | 5.98 |
| MC-5 | 5 | 186.23 | 187.76 | 8.03 | 6.85 |
| MC-6 | 5 | 187.76 | 189.28 | 6.63 | 6.2 |
| MC-7 | 5 | 189.28 | 190.8 | 5.93 | 5.42 |
| MC-8 | 5 | 190.8 | 191.72 | 5.86 | 5.43 |
| MC-9 | 4 | 263.96 | 265.48 | 6.56 | 5.13 |
| MC-10 | 3 | 306.02 | 307.54 | 10.65 | 8.6 |
| MC-11 | 3 | 307.54 | 309.07 | 10.91 | 9.12 |
| MC-12 | 3 | 309.07 | 310.59 | 10.63 | 8.33 |
| MC-13 | 2 | 404.16 | 405.69 | 14.37 | 8.55 |
| MC-14 | 2 | 407.21 | 408.74 | 17.9 | 16.56 |
| MC-15 | 2 | 408.74 | 410.26 | 15.48 | 13.6 |
| MC-16 | 2 | 411.78 | 413.31 | 13.07 | 10.76 |
| MC-17 | 2 | 413.31 | 414.83 | 16.75 | 14.56 |
| MC-18 | 1 | 479.76 | 480.82 | 5.66 | 4.12 |
| MC-19 | 1 | 480.82 | 481.89 | 4.25 | 3.4 |
| MC-20 | 1 | 481.89 | 483.41 | 4.3 | 3.91 |
| MC-21 | 1 | 483.41 | 484.94 | 4.82 | 2.87 |
| MC-22 | 1 | 484.94 | 487.98 | 4 | 2.49 |
| MC-23 | 1 | 487.98 | 491.03 | 3.02 | 2.34 |

volatile bituminous. Proximate analyses are summarized in Table 4. A plot of measured gas content versus ash (Fig. 7) illustrates an inverse trend of increasing gas content with decreasing ash.

*Adsorption isotherms.* Four adsorption isotherms were completed on representative coal samples from the four major seams (1, 2, 4 and 5). Langmuir volumes on an as-measured and ash-free basis are summarized in Table 5. Seams 1, 2 and 4 all have similar curves and similar capacities, whereas Seam 2 has a significantly higher Langmuir capacity. This may be explained by the ash value of the sample and perhaps by a higher vitrinite content of the coal. Calculated gas capacity curves were compared to measured gas content values for the same samples (assuming hydrostatic reservoir conditions). This revealed apparent undersaturation of the four samples by levels ranging from a low of 25% to a high of 63%. The seams lowest in the section (i.e., at greatest depth) have the lowest saturation.

**Table 4**
**Proximate analyses, Mobil/Chevron a-65-E**

| Sample no. | As-received moisture (%) | Ash (%) | Volatile matter (%) | Fixed carbon (%) | Sulphur (%) |
|---|---|---|---|---|---|
| MC-1 | 7.18 | 74.11 | 6.71 | 12 | 0.11 |
| MC-2 | 15.36 | 9.07 | 10.98 | 64.59 | 0.27 |
| MC-3 | 14 | 29.06 | 13.82 | 43.12 | 0.2 |
| MC-4 | 12.73 | 11.79 | 15.43 | 60.05 | 0.28 |
| MC-5 | 18.02 | 14.7 | 13.46 | 53.82 | 0.21 |
| MC-6 | 13.91 | 6.6 | 16.59 | 62.9 | 0.21 |
| MC-7 | 17.12 | 8.65 | 14.44 | 59.79 | 0.28 |
| MC-8 | 16.25 | 7.39 | 14.22 | 64.14 | 0.4 |
| MC-9 | 13.47 | 21.85 | 12.95 | 51.73 | 0.46 |
| MC-10 | 0.55 | 19.23 | 14.12 | 66.1 | 0.6 |
| MC-11 | 3.63 | 16.39 | 15.02 | 64.96 | 0.62 |
| MC-12 | 1.63 | 21.7 | 13.76 | 62.91 | 0.41 |
| MC-13 | 5.62 | 40.5 | 12.27 | 41.61 | 0.06 |
| MC-14 | 3.6 | 7.48 | 12.86 | 76.06 | 0.24 |
| MC-15 | 13.55 | 12.14 | 12.44 | 61.87 | 0.16 |
| MC-16 | 8.19 | 17.69 | 20.51 | 53.61 | 0.12 |
| MC-17 | 10.71 | 13.09 | 13.74 | 62.46 | 0.16 |
| MC-18 | 6.24 | 27.19 | 13.99 | 52.58 | 0.45 |
| MC-19 | 1.72 | 20.05 | 12.79 | 65.44 | 0.41 |
| MC-20 | 1.38 | 9.24 | 14.11 | 75.27 | 0.56 |
| MC-21 | 2.58 | 40.49 | 12.52 | 44.41 | 0.26 |
| MC-22 | 2.82 | 37.6 | 14.36 | 45.22 | 0.31 |
| MC-23 | 3.97 | 22.47 | 12.86 | 60.7 | 0.52 |

*Formation testing.* Following completion of the drilling, several injection tests were conducted to determine the permeability and reservoir pressure of the coal reservoirs. Tests were conducted on Seams 4L and 5. Originally Seam 2 was to be included, but continued sloughing of coal into the borehole precluded testing this horizon.

The “slug test” injection system involves lowering a string of BQ diameter drill rods into the borehole, inflating a set of straddle packers, filling the rods with water, and allowing the natural hydrostatic head to push water to the surface. Pressure transducers and volumetrics are used to measure the pressure conditions of the test zone during the flow period. By adding an extra section of pipe at the surface, the wellbore can effectively be “shut-in” to allow pressure buildup and reservoir pressures to be calculated. This technique of reservoir testing is more suitable for high-permeability water wells and is not totally applicable to low-permeability coal reservoirs. During the testing of Seams 4L and 5, critical measurements, such as head during wellflow and accurate positioning of the pressure transducer, were not recorded, resulting in severe limitations to data interpretation. No semi-log interpretation was possible and the pressure data were strongly affected by afterflow.

Open-hole flow testing for two weeks followed the injection tests. From the preliminary tests completed, fluid flow from Seams 4L and 5 was estimated at 0.04 $m^3$/d, while the fluid flow during the open-hole test was 29 $m^3$/d. It was determined that most of the fluid flowing into the borehole was from Seam 2, for which there were no formation tests. Permeability estimates for Seams 4L and 5 were conservatively estimated at 0.3 and 0.1 mD, respectively. However, these values are probably the minimum limit because the normal methods of calculating permeability (log/log plots and Horner plots) could not be used. The fluid flow from the Seam 2, coupled with the continual sloughing of coal material into the borehole from this interval, suggests that the permeability of this seam is substantially higher than the 0.5 mD, possibly 1 to 10 mD.

**Table 5**
**Adsorption isotherms, Mobil/Chevron a-65-E**

| Sample number | Depth (m) | Langmuir equation | Gas capacity cc/g) | Normalized gas capacity (cc/g) | Measured gas content (cc/g) | Saturation (%) |
|---|---|---|---|---|---|---|
| 1 | 480 | V=16.8*P/(P+900) | 16.8 | 23 | 3.91 | 25 |
| 2 | 404 | V=23.0*P/(P+1100) | 23 | 28.7 | 8.55 | 47.5 |
| 4 | 270 | V=14.7*P/(P+840) | 14.7 | 19.7 | 5.13 | 45.9 |
| 5 | 178 | V=15.8*P/(P+770) | 15.8 | 20.5 | 6.94 | 63.3 |

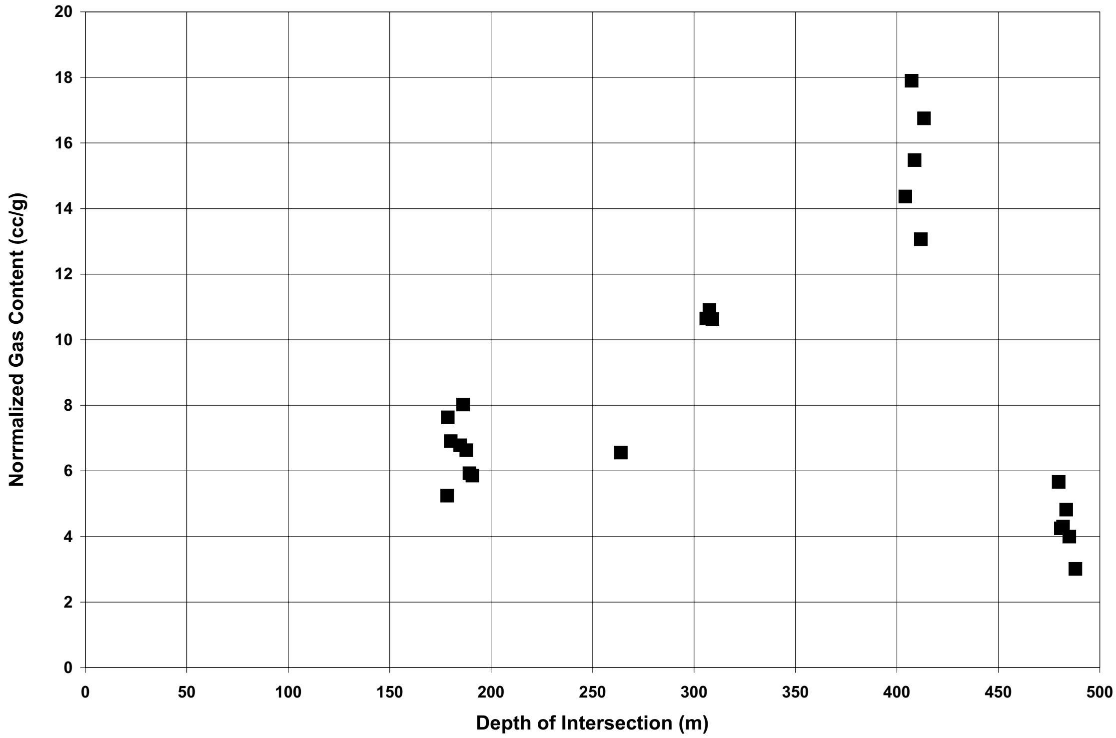


***Figure 6.*** *Normalized gas content versus depth of intersection for all coal samples, wellbore a-65-E.*

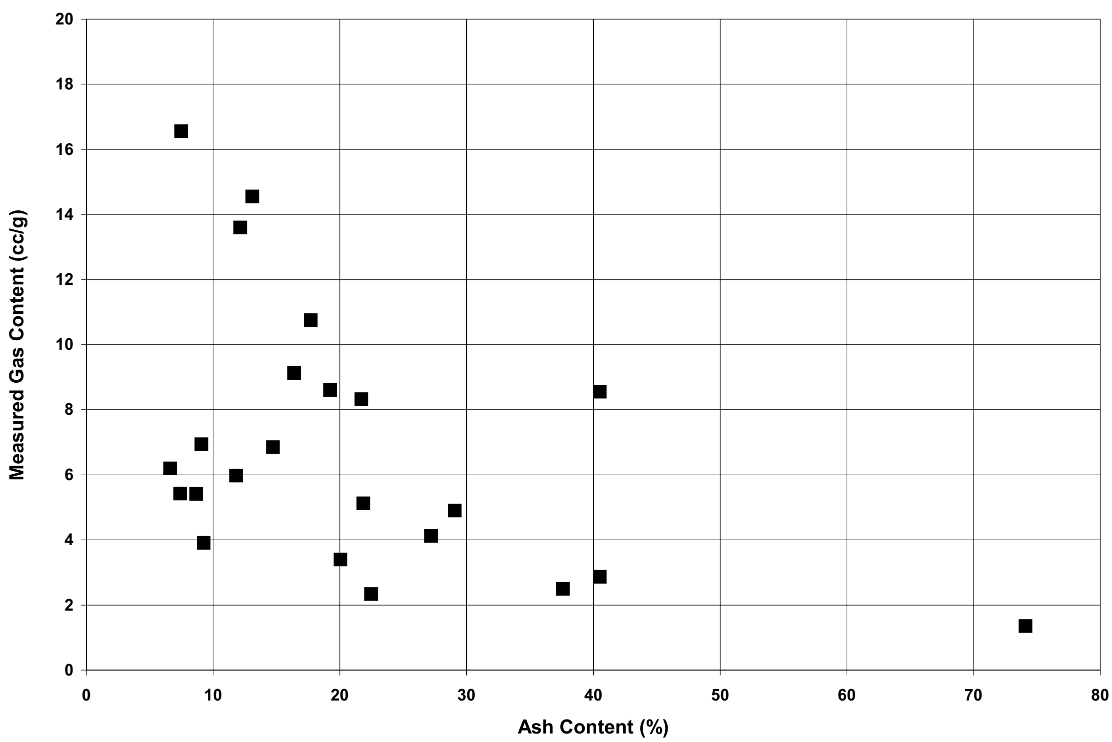


***Figure 7.*** *Gas content (as measured) versus ash content for all coal samples, wellbore a-65-E.*

Reservoir pressures were difficult to measure because the shut-in periods for the tests were not long enough to allow type curves to be developed and matched. Mobil personnel believed that the permeability data collected from the wellbores were not valid and that any values calculated for reservoir characteristics would be suspect. The depth of the two seams tested were 187 m (Seam 5) and 264 m (Seam 4L). Gas content was low and the coal appeared to be significantly undersaturated. Reservoir pressure was also expected to be low because of the shallow depths.

During open-hole flow tests, gas was produced at the same time as borehole fluids. It was interpreted that this gas was probably free gas residing in the natural fracture systems, because the reservoir pressure had not been lowered to sufficient levels to allow desorption to begin. The gas source appeared to be primarily Seam 2, since preliminary permeability values for Seams 4L and 5 are less than 1 mD.

*Technical assessment.* The Mobil/Chevron test well in the Fernie Basin was designed to evaluate the coalbed methane potential of the Mist Mountain Formation coal near the Dominion Coal Block and the Lodgepole. Interest for coalbed methane in this region stemmed from the position of the Westcoast transmission gas pipeline, which cuts through the exploration area. Test borehole a-65-E intersected thick coal containing a large volume of methane gas at relatively shallow depth. Of the seven coal intersections (five seams), Seam 2 appears to have the greatest potential. Water influx, friable, self cavitating coal and the release of "free gas" and water into the borehole suggest that this horizon may have sufficient permeability to sustain coalbed methane production. Seam 1 has lower than expected gas content, possibly because of maceral composition. The upper seams, 4L and 5, have higher gas contents, but because of the depth of intersection, appear to be undersaturated and have lower potential reservoir producibility than Seam 2.

The location of the well is in the "Pipeline Reserve Block" of Parcel 82 of the Dominion Coal Block. The coal-bearing strata dip at a shallow angle. Structural complications appear to be minimal. The resource area of the Pipeline Block is large, and with the thickness of Seam 2 alone (14.4 m) and an in situ gas content of 14 cc/g, in-place gas resources are estimated at 601.7 Mcm/section (21.25 Bcf/section).

### Gulf Canada Resources Fernie Basin project

In the winter and early spring of 1990, Gulf Canada Resources Limited drilled two coalbed methane exploration boreholes in the Fernie Basin, near the region being drilled by Mobil/Chevron (Fig. 8). The boreholes were slimline diamond drillholes designed specifically as stratigraphic tests. Selected coal core samples were collected from both boreholes for desorption testing. No further work was undertaken by Gulf in the region following completion of the drilling program.

*Data acquisition.* Borehole 82-G-7/a-72-C was drilled to a maximum depth of 295 m. The diameter of the borehole was slimline (8.9 cm), and designed purely as a stratigraphic test. Core was obtained from 32 m to total depth and 15 desorption samples were collected from seven coal intersections. Gas content was low, averaging less than 1 cc/g. This was partly because of the shallow depth of intersection of the coal. No reservoir tests were conducted on the borehole and, following completion of the well, the site was abandoned and the drilling rig moved to 82-G-7/c-12-L.

This second borehole was drilled to a depth of 600 m. Eight coal zones were intersected and 15 canister samples collected for desorption. No wellbore reservoir tests were completed, as the borehole diameter was too narrow for straddle packer tools. Several adsorption isotherms were completed following the desorption tests.

*Geology.* Both exploration boreholes intersected coal-bearing strata of the Mist Mountain Formation. The total coal-bearing interval was more than 600 m thick. It is not known which section of the formation was intersected in the borehole. Locating the boreholes on a regional geology map showed borehole a-72-C on the eastern limb of the McEvoy syncline, near the southern limit of the Fernie Basin. The borehole intersected the coal measures on the southern extent of the Flathead Ridge escarpment. Topography is steep and there are indications that the coal measures lie at a higher elevation than the regional water table of Lodgepole Creek. This difference in topography might explain the low gas content encountered.

Borehole c-12-L is located on the western limb of the Fernie Basin, in the centre of the Pipeline Resource Block of Parcel 82 of the Dominion Coal Blocks. Both boreholes were spudded in or near the top of the Mist Mountain Formation and the intersected coal measures are believed to be from the upper to middle part of the formation. Coal seam thicknesses range from 0.47 to 7.36 m. Correlation between the two boreholes was not possible so the seams were labeled sequentially from the base. Coal intersections are summarized in Table 6. Total cumulative coal thickness for a-72-C is 28.8 m, of which eight seams are 1 m or greater in thickness. In borehole c-12-L, total cumulative coal thickness is 24.41 m, with eight seams greater than 1m in thickness. Several of the thicker coal seams appear to have minor partings. In most of the coal intersections, the roof and floor of the seam appear to be gradational, consisting of carbonaceous mudstone. The stratigraphic section for wellbore c-12-L is shown in Figure 9.

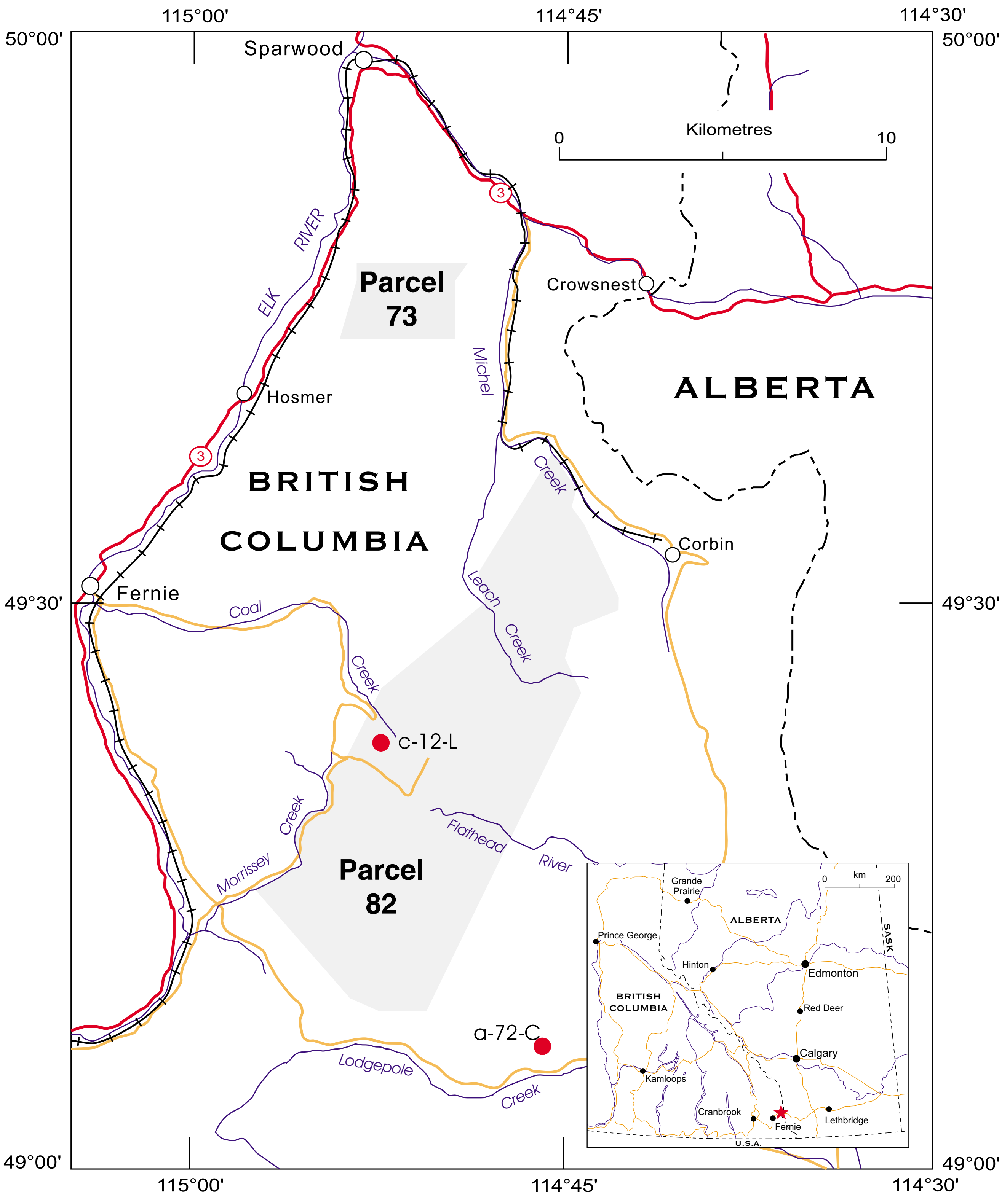


***Figure 8.*** *General location map of Gulf Lornel boreholes a-72-C and c-12-L.*

**Table 6**
**Seam intersections, Gulf Fernie wells**

| Seam number | Borehole a-72-C Depth (top) (m) | Depth (base) (m) | Net coal thickness (m) | Borehole c-12-L Depth (top) (m) | Depth (base) (m) | Net coal thickness (m) |
|---|---|---|---|---|---|---|
| 9 | 80.00 | 88.50 | 9.50 | 306.20 | 309.35 | 1.25 |
| 7U | 98.00 | 99.00 | 1.00 | 320.7 | 321.17 | 0.47 |
| 7L | 100.50 | 101.00 | 0.50 | 325.10 | 326.50 | 1.40 |
| 6 | 112.00 | 114.10 | 2.10 | 417.12 | 419.92 | 1.67 |
| 5U | 154.50 | 155.00 | 0.50 | 425.10 | 426.96 | 1.86 |
| 5L | 160.50 | 162.50 | 2.00 | 429.70 | 430.30 | 0.60 |
| 4U | 175.50 | 176 | 0.8 | 479.00 | 481.15 | 2.15 |
| 4L | 177.50 | 191.10 | 3.60 | 492.20 | 492.75 | 0.55 |
| 3 | 191 | 191.30 | 1.30 | 493.10 | 494.90 | 1.42 |
| 2 | 215.00 | 222.50 | 7.50 | 505.60 | 513.20 | 5.68 |
| 1 | 230.00 | 231 | 1.00 | 575.00 | 589.10 | 7.36 |
| Total | | | 28.80 | | | 24.41 |

*Gas content.* Core samples were logged and placed into desorption canisters for each borehole. Thirty canister samples (15 from each borehole) were collected. All canisters were desorbed at 20°C. Gas content was widely variable (Table 7), reflecting the depth of intersection and coal quality of the sample. In borehole a-72-C, measured gas content was below 2 cc/g, even when the depth of intersection was greater than 200 m. Perhaps this was a result of the extreme topography in the region. It is highly likely that the intersected coal lies at elevations higher than the regional topographic elevation of Lodgepole Creek. There is insufficient reservoir pressure (in the form of "in seam" water) to allow the methane gas to be retained in an adsorbed state. Similarly low measured values for gas content were recorded in the Geological Survey of Canada's research project at the Greenhills mine, near Elkford. No coal quality information was available for these samples.

Gas content for c-12-L was significantly higher, reflecting the increased depth and relative elevation of the coal intersection. Average "as measured" gas content for the coal in c-12-L was 6.96 cc/g. A summary of desorption data is presented in Table 7. In Figure 10, a plot of normalized gas content versus depth of intersection for data from borehole c-12-L suggests a general relationship of increasing gas content with depth, although samples from the seams at 446 and 479 m have lower gas contents. There is no obvious reason for the lower gas content, although a similar relationship was observed for the basal seam in the Mobil/ Chevron a-65-E well. One reason might be the high inertinite maceral content.

**Table 7**
**Desorption data, Gulf Fernie wells**

| Sample number | Borehole a-72-C Depth of intersection (m) | Measured gas content (cc/g) | Borehole c-12-L Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|---|
| 1 | 80.5-81.0 | 0.99 | 306.1-307.0 | 6.34 | 6.81 |
| 2 | 81.0-82.6 | 1.69 | 307.7-308.7 | 3.62 | 4.54 |
| 3 | 82.6-84.1 | 1.64 | 397.2-398.7 | 10.9 | 13.09 |
| 4 | 84.1-85.7 | 1.49 | 418.1-419.3 | 11.57 | 18.14 |
| 5 | 85.7-87.2 | 1.84 | 424.7-426.1 | 10.48 | 11.05 |
| 6 | 87.2-88.7 | 1.25 | 430.7-431.3 | 10.91 | 14.99 |
| 7 | 111.9-113.0 | 0.39 | 446.8-448.0 | 3.29 | 5.40 |
| 8 | 133.2-134.0 | 0.18 | 479.1-480.1 | 3.41 | 4.57 |
| 9 | 177.4-178.0 | 0.24 | 480.1-480.8 | 6.74 | 8.22 |
| 10 | 178.9-180.0 | 0.34 | 509.0-510.5 | 5.61 | 10.58 |
| 11 | 189.9-191.0 | 0.31 | 510.5-511.4 | 12.35 | 15.98 |
| 12 | 216.7-218.0 | 0.06 | 512.3-512.8 | 10.60 | 16.23 |
| 13 | 218.2-219.0 | 0.26 | 575.5-577.0 | 8.81 | 10.40 |
| 14 | 219.8-221.0 | 0.13 | 578.9-579.9 | 11.40 | 12.74 |
| 15 | 232.4-233.0 | 0.56 | 580.2-581.6 | 13.44 | 15.07 |

*Coal quality.* Coal quality analyses were performed only on the samples collected from borehole c-12-L. Coal samples are widely variable in ash content, ranging from 6.36 to 46.97%. Moisture content is less than 2%, and the volatile matter indicates that the coal is medium to low volatile bituminous in rank. Proximate analyses are summarized in Table 8. A plot of measured gas content versus ash indicates a general trend of increasing gas content with decreasing ash (Fig. 11).

*Adsorption isotherms.* Adsorption isotherms were run on three samples from borehole c-12-L. Sample depths were 424, 510 and 580 m. Table 9 shows Langmuir equations and degree of saturation. Gas saturation was calculated by comparing the adsorption capacity of the coal at intersection depth to the measured gas content. Saturation levels ranged from 52 to 75%, and increased with depth, reflecting the increase in reservoir pressure.

*Formation testing.* Because the two Gulf wellbores were licensed for stratigraphic tests, the drilling program did not allow for any well testing. In addition, the diameter of the boreholes (8.9 cm) was too narrow for straddle packer formation testing equipment to be used. Consequently, following completion of the core drilling, the boreholes were plugged and abandoned.

*Technical assessment.* The two boreholes drilled by Lornel Consultants for Gulf Canada Resources Limited were designed as stratigraphic test wells to determine the gas content of the Mist Mountain Formation coal on the southeast and western flanks of the Fernie Basin. The wells were slimhole diamond drillholes and core samples were collected by wireline methods. Comprehensive drilling procedures and sample testing appear to have been undertaken. Results from desorption testing indicated significant coalbed methane potential in the region of borehole c-12-L. These results were confirmed by the Mobil/Chevron drilling completed at a-65-E.

The a-72-C well location was on a high topographic ridge where coal measures dip gently to the west/northwest. The coal was probably located above the regional water table, resulting in minimum methane being retained within the seam. The potential for coalbed methane development is poor, unless the boreholes are located farther into the McEvoy syncline. Unfortunately, the farther west the exploration target is, the deeper in the axis of the McEvoy Syncline the coal occurs.

### *Saskoil Fernie Basin project*

Saskatchewan Oil and Gas (Saskoil) undertook a preliminary coalbed methane exploration drilling program

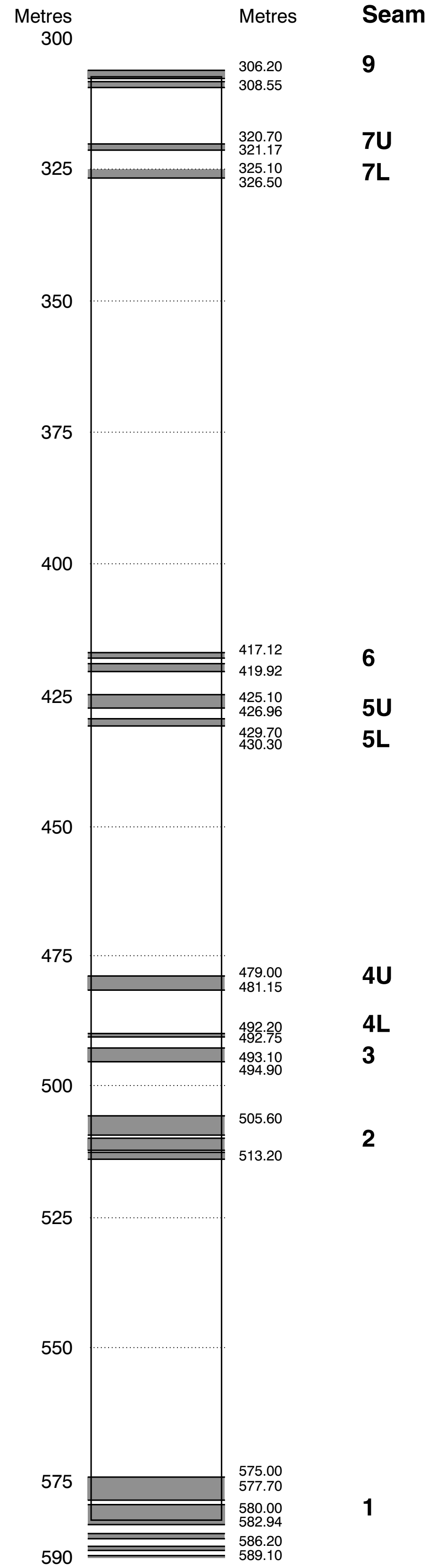


***Figure 9.*** *Stratigraphic section of the Gulf Lornel c-12-L borehole.*

**Table 8**
**Proximate analyses, Gulf Fernie c-12-L**

| Sample number | Depth of intersection (m) | Moisture (%) (a.d.b.) | Ash (%) (a.d.b.) | Volatile matter (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Sulphur (%) |
|---|---|---|---|---|---|---|
| 1 | 306.1-307.0 | 1.00 | 6.89 | 20.87 | 71.27 | 0.53 |
| 2 | 307.7-308.7 | 0.63 | 20.27 | 19.80 | 59.30 | 0.54 |
| 3 | 392.7-398.7 | 0.68 | 16.64 | 17.63 | 65.05 | 0.70 |
| 4 | 418.1-419.3 | 1.44 | 37.84 | 14.31 | 46.41 | 0.38 |
| 5 | 424.7-426.1 | 4.92 | 6.36 | 18.37 | 70.35 | 0.60 |
| 6 | 430.7-431.3 | 1.76 | 27.17 | 15.21 | 55.86 | 0.64 |
| 7 | 446.8-448.0 | 0.75 | 40.48 | 13.92 | 44.85 | 0.68 |
| 8 | 479.1-480.1 | 0.93 | 25.33 | 15.74 | 58.00 | 0.48 |
| 9 | 480.1-480.8 | 0.89 | 18.04 | 17.79 | 63.28 | 0.67 |
| 10 | 509.0-510.5 | 1.16 | 46.97 | 12.33 | 39.54 | 0.24 |
| 11 | 510.5-511.4 | 0.92 | 22.73 | 15.54 | 60.81 | 0.36 |
| 12 | 512.3-512.8 | 0.63 | 34.72 | 16.97 | 47.68 | 0.57 |
| 13 | 575.5-577.0 | 0.68 | 15.30 | 14.85 | 69.17 | 0.42 |
| 14 | 578.9-679.9 | 0.72 | 10.55 | 16.12 | 72.61 | 0.25 |
| 15 | 580.2-581.6 | 0.78 | 10.80 | 15.99 | 72.43 | 0.29 |

during the winter of 1990. Four stratigraphic test wells were completed at depths ranging from 307 to 598 m. The boreholes were located on the south and western flank of the Fernie Basin (Fig. 12). Two wells (KPP90-1 and KPP90-2) were located in the Morrisey Creek valley to assess the potential of the Dominion Coal Block. This area was chosen because the drilling permit restricted drilling depth to 600 m. In the valley, most of the Mist Mountain Formation can be penetrated within this depth limit. The other two boreholes (KPP90-3 and KPP90-4) were drilled along the Lodgepole Creek valley to assess the potential of the block of coal-bearing land bounded by the Dominion Coal Block to the northwest and by subcrop to the southeast. This parcel of land was attractive for coalbed methane exploration because it was the only block without overlapping coal licenses. At the time of exploration (1990), the gas rights ownership issues had not been resolved and companies were concerned about the implications of drilling for coalbed methane in areas where conventional coal licenses were concurrently held. Saskoil subsequently posted the Lodgepole Creek lands for petroleum and natural gas (P&NG) rights, but were unsuccessful in their bid.

The boreholes were licensed as slimline stratigraphic test wells and were limited to a maximum depth of 600 m. The coal-bearing section of the Mist Mountain Formation was cored and multiple desorption canister tests were completed. Several injection/falloff tests were run following completion of drilling to determine reservoir permeability. No further work was undertaken on the boreholes and they were subsequently plugged and abandoned.

*Data acquisition.* The four stratigraphic tests wells, KPP90-1 to KPP90-4, were spudded in the southern part of the Fernie Basin, adjacent to Morrisey and Lodgepole creeks, about 25 km southeast of Fernie (Fig. 12). The Flathead Ridge forms a steep escarpment that tends to restrict the choice of drillsite locations, without extensive road building. Drilling equipment consisted of a diamond drill modified to conform to B.C. oil and gas regulations [installation of blowout preventers (BOP's)]. Borehole diameter was 98 mm and the coal core was retrieved using wireline.

Fifty-one canister samples were collected. The depth of intersection of the coal ranged from 70.58 to 589.54 m.

**Table 9**
**Adsorption isotherms, Gulf Fernie c-12-L**

| Sample depth (m) | Langmuir equation | Measured gas content (cc/g) | Gas capacity (cc/g) | Gas saturation (%) |
|---|---|---|---|---|
| 424 | V=25.31*P/(P+1076) | 10.49 | 20.07 | 52 |
| 510 | V=22.66*P/(P+1103) | 12.21 | 18.53 | 66 |
| 580 | V=21.50*P/(P+1131) | 13.50 | 17.91 | 75 |

Note: Assumed pressure gradient is 9.817 kPa/m (0.434 psi/ft).

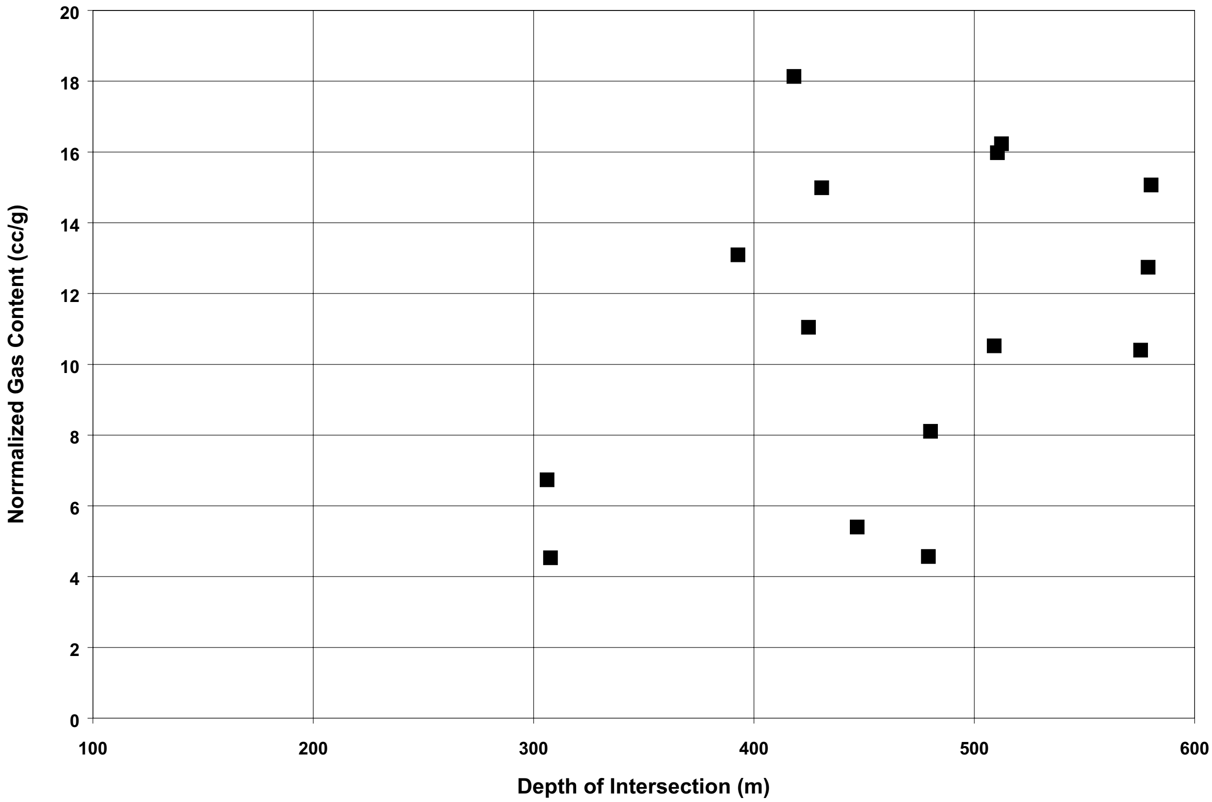


*Figure 10.* *Normalized gas content versus depth of intersection, Gulf Fernie c-12-L canister samples.*

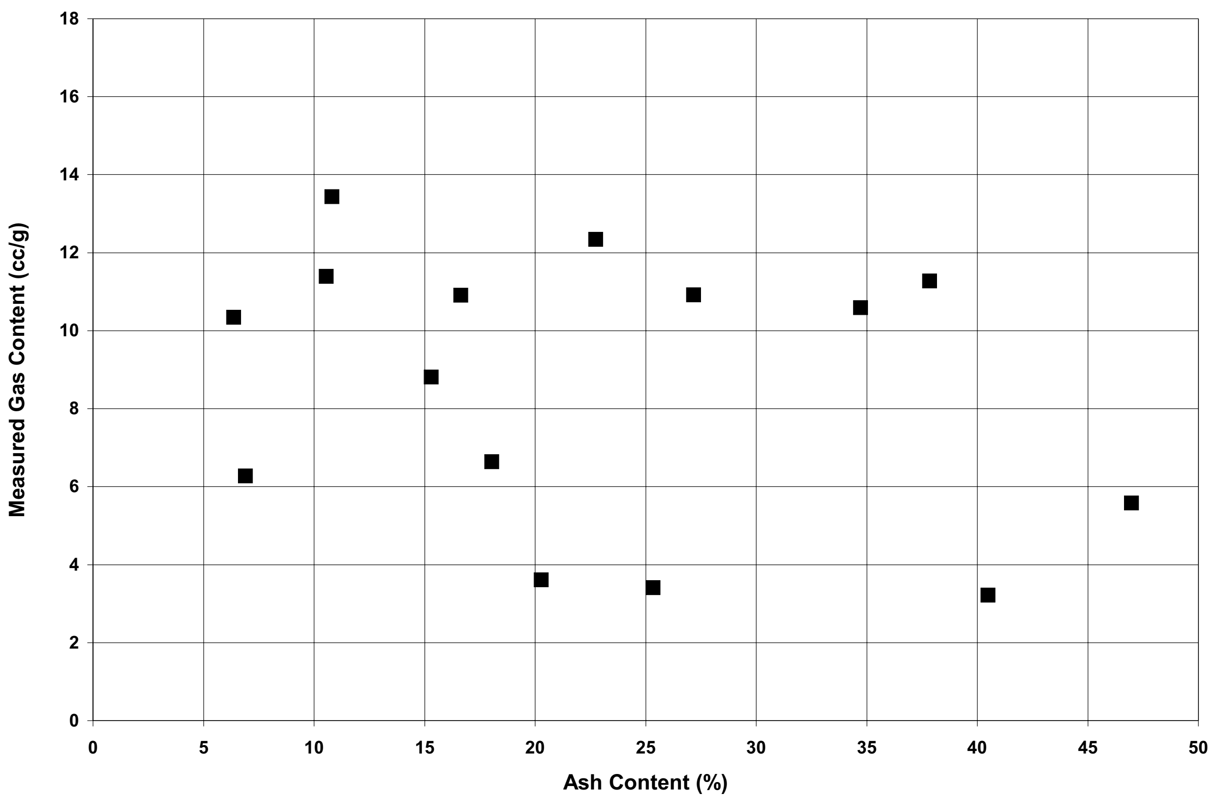


*Figure 11.* *Measured gas content versus ash content for all coal samples, Gulf Fernie c-12-L.*

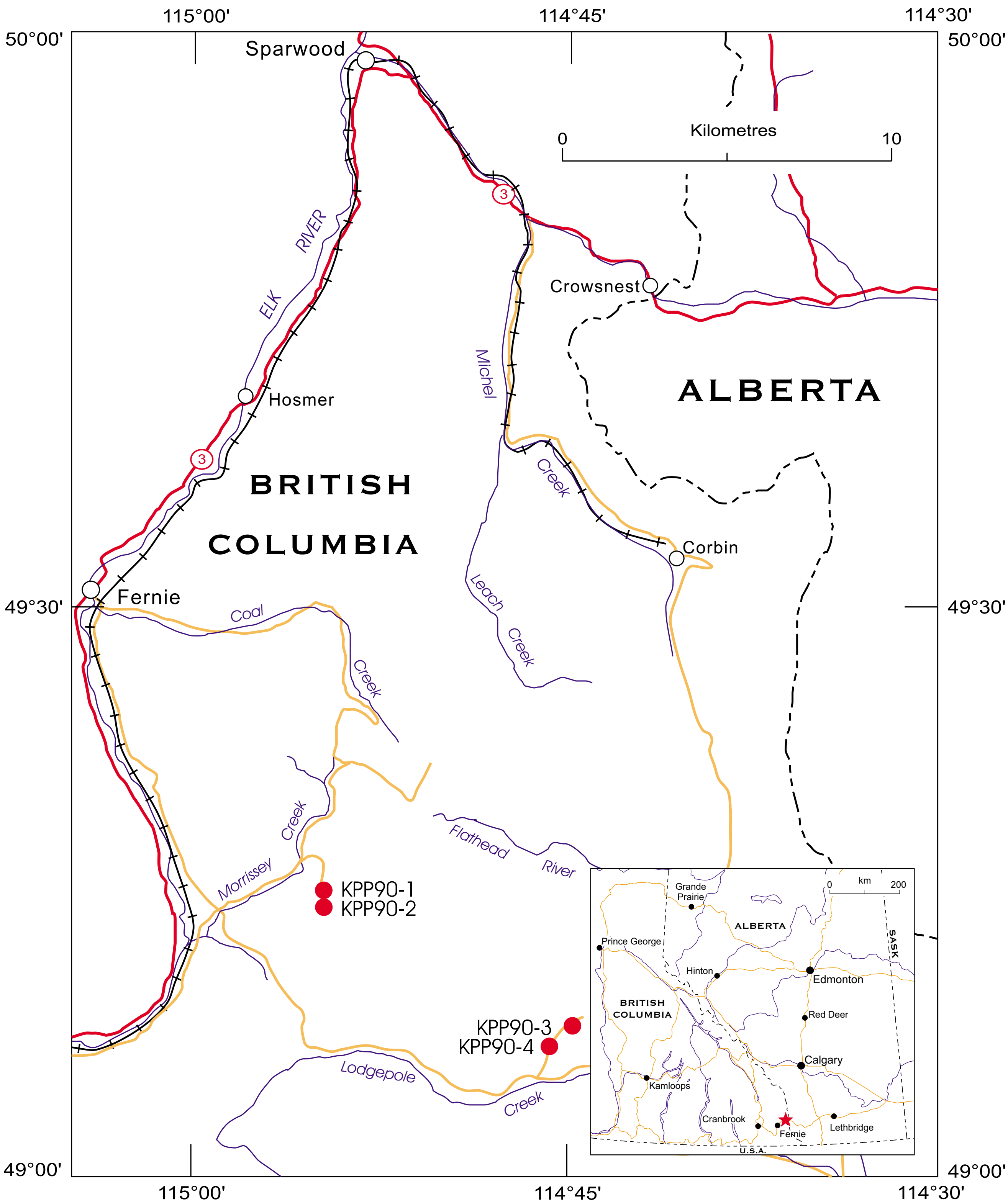


***Figure 12.*** *General location map of Saskoil's KPP90-1 to KPP90-4 exploration wells.*

Slimline logging tools were used and a complete suite of geophysical logs is available for each well. Gas content values obtained for the boreholes in the Lodgepole Creek area (KPP90-3 and KPP90-4) were disappointing (averaging less than 1 cc/g), and post-drilling wellbore tests were restricted to the Morrisey Creek wells (KPP90-1 and KPP90-2). Extensive petrographic analyses of the coal, several adsorption isotherms, and gas and water analyses were conducted on the main seams of KPP90-2. After tests were completed, the holes were plugged and abandoned .

*Geology.* Saskoil's coalbed methane exploration target was the Mist Mountain Formation coal at depths from 300 to 600 m. The depth limitations imposed by drilling regulations resulted in one borehole (KPP90-2) not intersecting the thick basal seams of the formation. In KPP90-3 and KPP90-4, the basal seam was not intersected and the upper seams of the Mist Mountain Formation were penetrated at depths of less than 150 m. Coal thickness was variable, ranging from less than 1 m to greater than 17 m. A tentative correlation of seams between all boreholes was made, and the coal zones designated by number in ascending order from the base of the Mist Mountain Formation.

Borehole KPP90-1 was spudded at the top of the Mist Mountain Formation and penetrated coal zones 1 to 9 (Fig. 13). Borehole KPP 90-2 was then drilled to intersect the seams higher in the stratigraphic section. The borehole was spudded in the Elk Formation and only penetrated to the base of the No. 4 coal zone (Fig. 14). Based on a composite type section created from boreholes KPP90-1 and KPP90-2, the Mist Mountain Formation is about 500 m thick and contains up to 11 coal zones (Fig. 13, 14). This formation is overlain by the Elk Formation, which contains at least two coal zones (Seams 12 and 13 in KPP 90-2). Cumulative net coal in the Mist Mountain Formation is estimated at 63 m, of which 75% lies within the lower four seams and 50% lies within the lowermost Seams 1 and 2. The upper seams (7 to 10) appear to be most discontinuous, with numerous partings. It appears that the coal plies commonly split off from the roof or floor to produce individual rider seams. Individual coal seams are usually less than 1.5 m thick, although the correlative coal zone is commonly greater than 10 m thick.

In boreholes KPP90-3 and KPP90-4, Mist Mountain Formation strata containing coal zones 2 to 6 were intersected (Fig. 15, 16). Zone 1 was the principal exploration target, but a fault repeat of Zone 4 prevented the borehole from being drilled deep enough to intersect the basal seam. The fault zone that was intersected in both boreholes is believed to be responsible for the depressed gas content of the canister samples collected. The coal intersected in KPP90-3 and KPP90-4 was similar to that in the first two boreholes. The thick coal zones appear to be concentrated in the lower half of the Mist Mountain Formation, and the lower coal zones (2 to 4) account for about 60% of the cumulative net coal in the boreholes. It is believed that Zone 1 lies about 340 m deep in KPP90-3 and 384 m in KPP90-4 (60 m below Zone 2; Fig. 15, 16). Why the lowest coal zones were not intersected in the boreholes is unknown. These coal zones were certainly within the depth capability of the drilling rig. It is suspected that drilling difficulties were encountered as a result of water influx into the wellbore once the fault zone (at a depth of 122 m in KPP90-3 and 185 m in KPP90-4) was intersected. Coal intersections and net coal thicknesses for each borehole are summarized in Table 10.

Core recovery from the drilling was commonly less than 60%. Descriptions of the thick basal seams indicate that the coal was crushed and sheared, and mainly dull with minor bright bands. This is typical of the basal seams of the Mist Mountain Formation and reflects the high inertinite content.

*Gas content.* Coal cores were collected and placed into desorption canisters for all four exploration boreholes. Wireline core retrieval facilitated short lost gas times. The lost gas component was generally less than 10%. Gas content varied widely, from 11.91 cc/g in borehole KPP90-1, to less than 1 cc/g in KPP90-3. On an ash-corrected (normalized) basis, gas content ranges from 1.54 to 14.31 cc/g and averages 7.17 cc/g. Gas content is summarized in Table 11. In boreholes KPP90-3 and KPP90-4, gas content was extremely low, averaging less than 1 cc/g. The coal appeared to be effectively degassed. This could have been the result of the shallow depth of intersection, but was probably due more to the presence of the fault zone near coal zone 4. Drilling reports indicate that significant water flow was encountered in the wellbore once the fault zone had been intersected. It is believed that the active water flow effectively flushed the adsorbed gas from the coal zones.

After eliminating the anomalous gas content values encountered in KPP90-3 and KPP90-4, a plot of normalized gas content versus depth of intersection was made (Fig. 17). Gas content generally increases with increasing depth to about 350 m. Beyond this depth, gas content decreases with increasing depth. This phenomenon has been observed in other exploration boreholes (Mobil and Gulf) in this region of the Fernie Basin and might be related to the compositional characteristics of the basal seams of the Mist Mountain Formation. Maximum normalized gas content values were recorded from Seam 4L (14.31 cc/g) in borehole KPP90-1 and Seam 8 (13.06 cc/g) in KPP90-2. It is interesting to note that in the adjacent borehole, Seam 8 has a gas content of less than 5.4 cc/g. This variability is probably a result of the shallow depth of intersection in KPP90-1.

*Coal quality.* Coal quality analyses consisted of ash and moisture determinations for all canister samples. In addition, petrographic analyses were completed on selected samples.

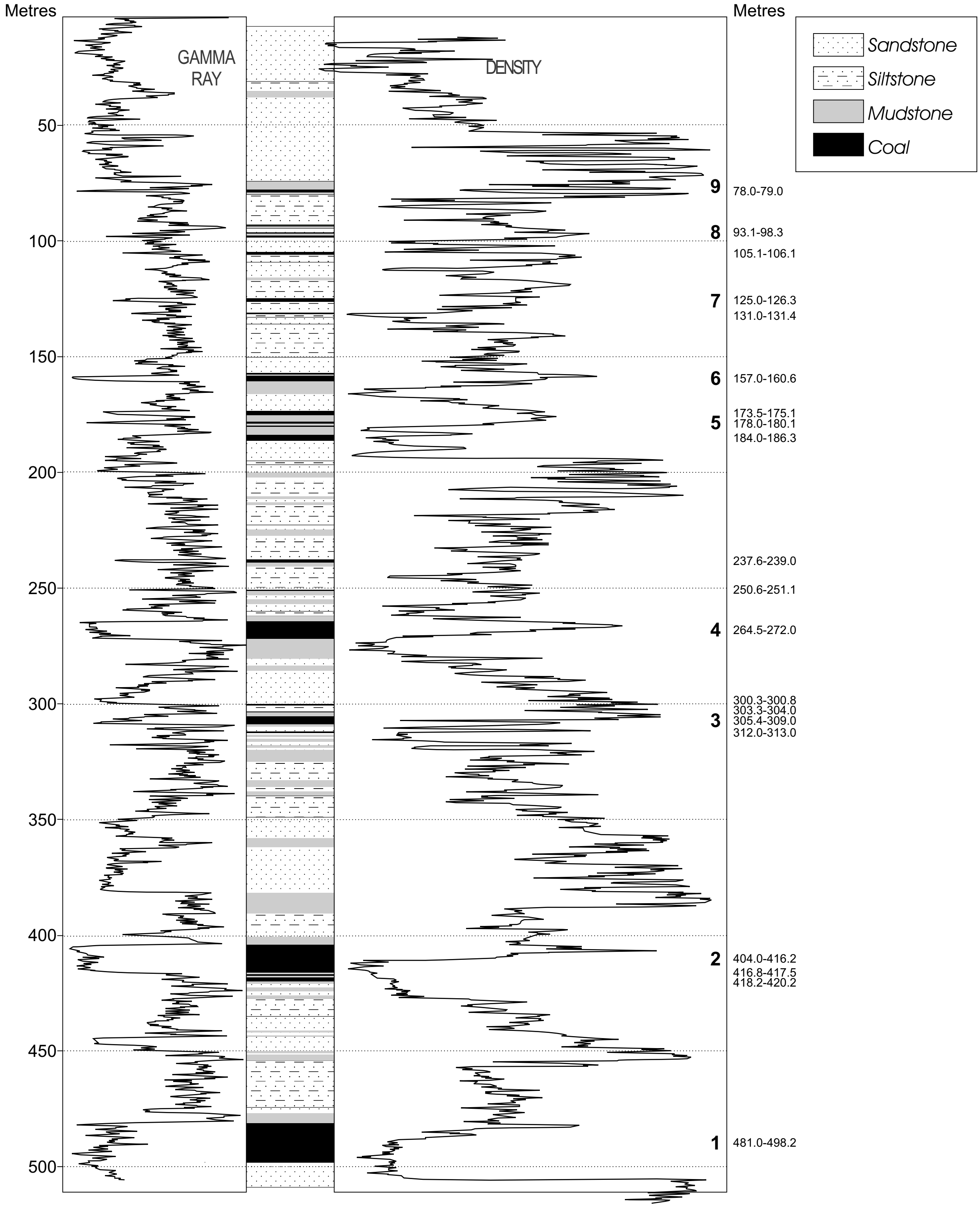


***Figure 13.*** *Detailed stratigraphic section of the KPP90-1 borehole.*

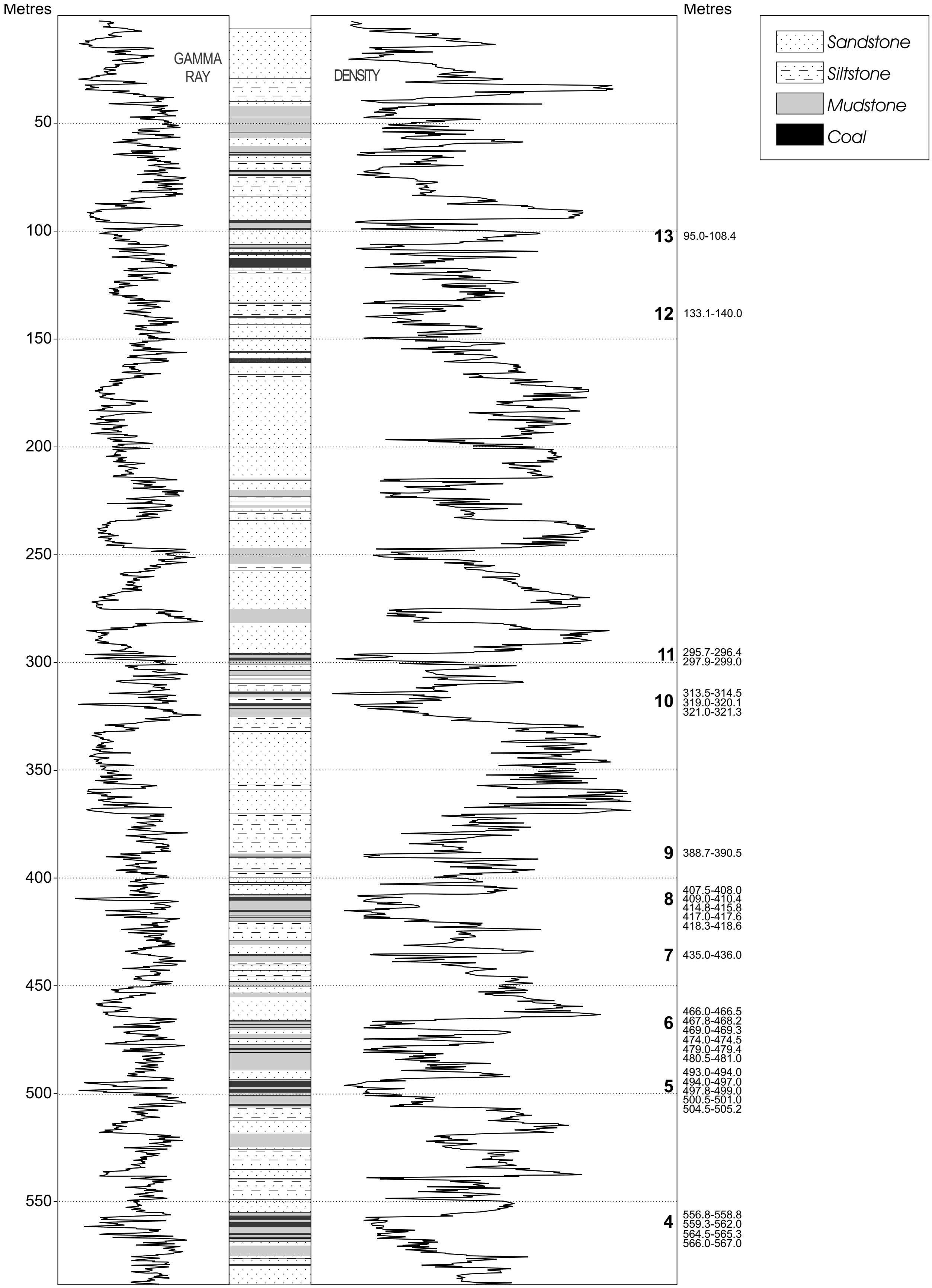


***Figure 14.*** Detailed stratigraphic section of the KPP90-2 borehole.

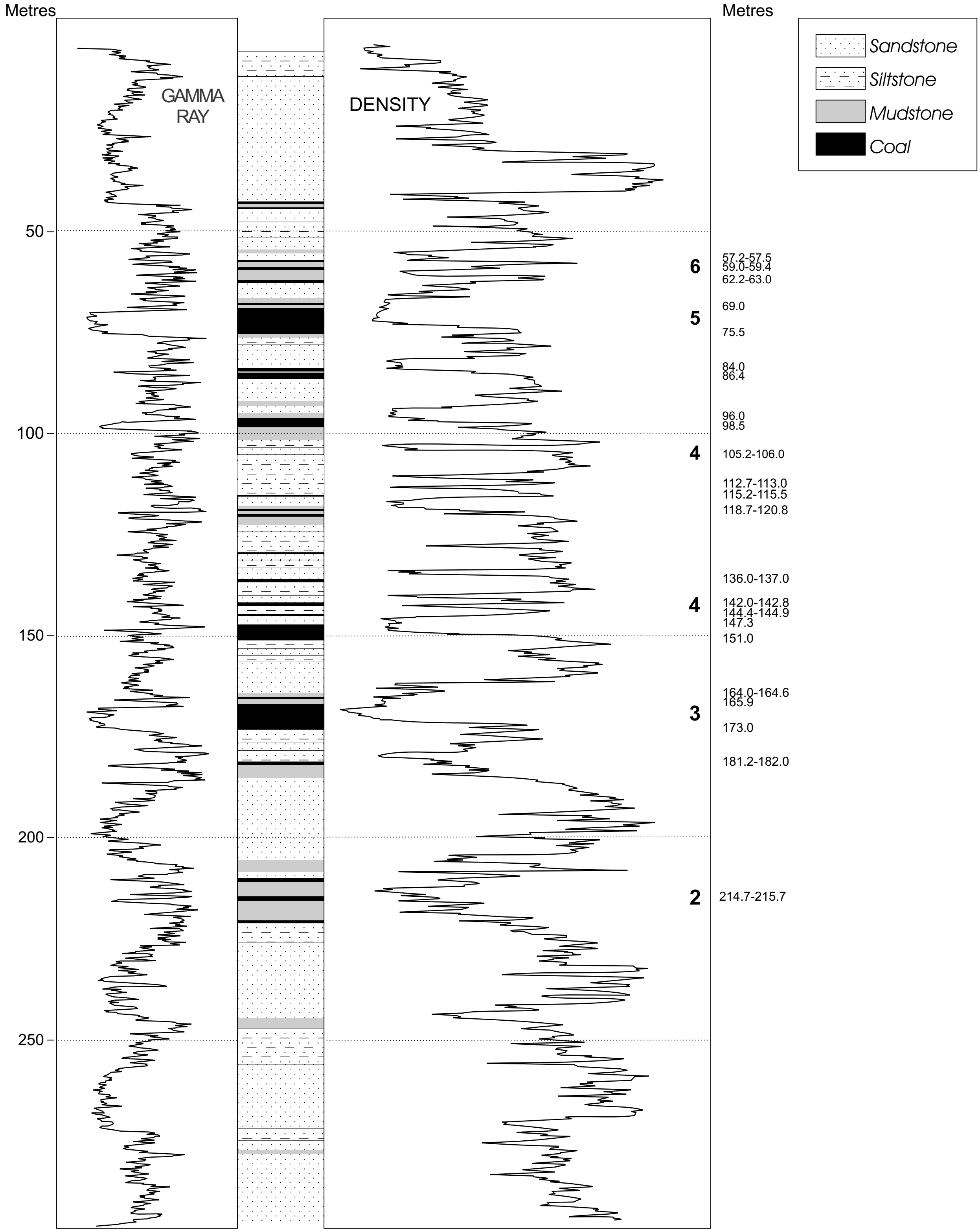


***Figure 15.*** *Detailed stratigraphic section of the KPP90-3 borehole.*

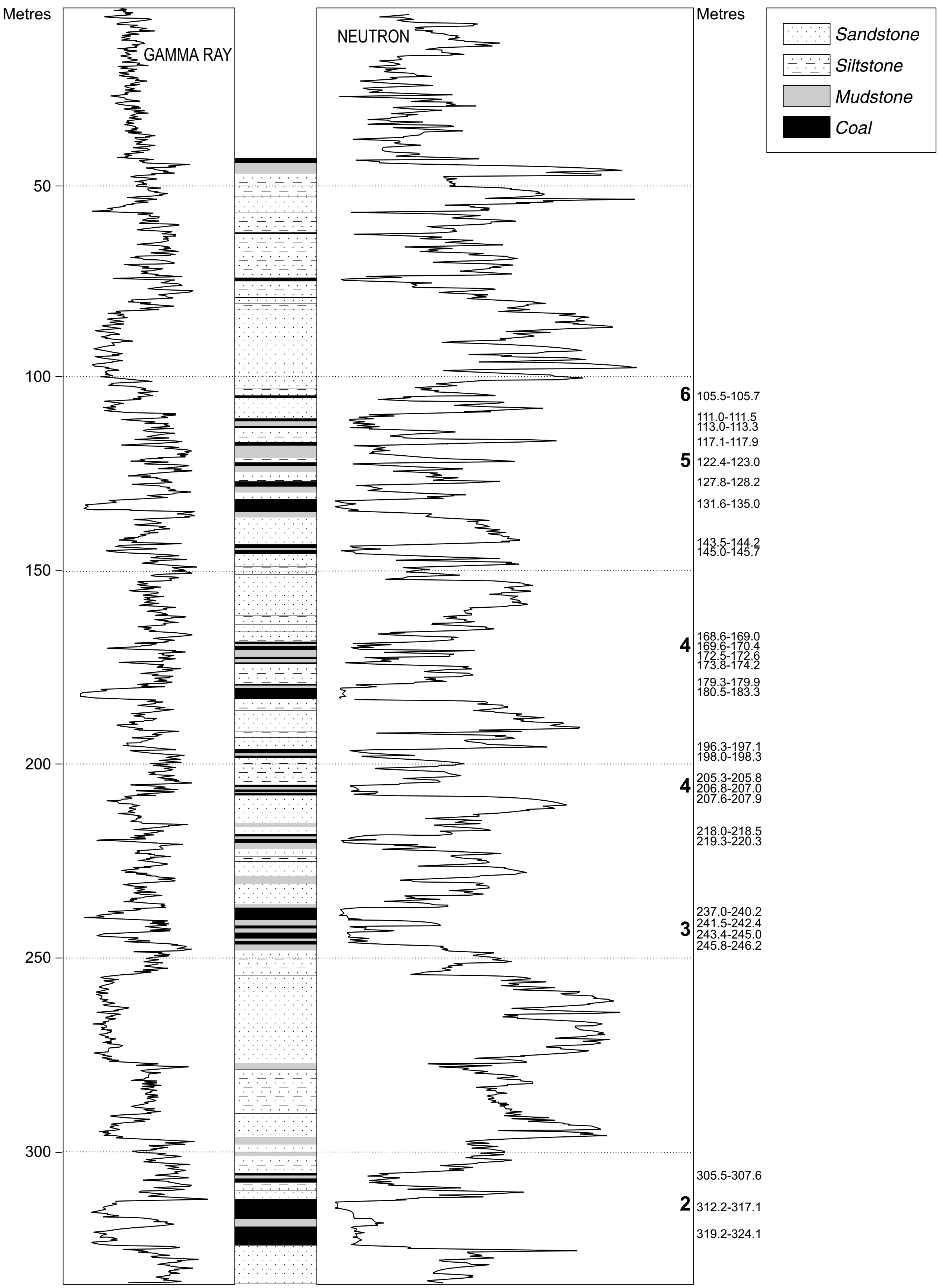


***Figure 16.*** *Detailed stratigraphic section of the KPP90-4 borehole.*

**Table 10**
**Coal intersections, Saskoil Fernie wells**

| Coal zone | KPP90-1 (m) | Net coal (m) | KPP90-2 (m) | Net coal (m) | KPP90-3 (m) | Net coal (m) | KPP90-4 (m) | Net coal (m) |
|---|---|---|---|---|---|---|---|---|
| 13*** | —- | —- | 95.0-108.4 | 3.3 | —- | —- | —- | —- |
| 12*** | —- | —- | 133.1-140.0 | 1.2 | —- | —- | —- | —- |
| 11 | —- | —- | 295.7-299.0 | 1.8 | —- | —- | —- | —- |
| 10 | —- | —- | 313.5-321.3 | 2.4 | —- | —- | —- | —- |
| 9 | 78.0-79 | 1 | 388.7-390.5 | 1.3 | —- | —- | —- | —- |
| 8 | 93.1-106.1 | 2.1 | 407.5-418.6 | 3.8 | —- | —- | —- | —- |
| 7 | 125.0-131.4 | 1.7 | 435.0-436.0 | 1 | —- | —- | —- | —- |
| 6 | 157.0-160.6 | 2.8 | 466.0-481.0 | 2.6 | 57.2-63.0 | 1.5 | 111.0-117.9 | 1.6 |
| 5 | 173.5-186.3 | 4.6 | 493.0-505.2 | 6.5 | 69.0-75.0 | 6 | 122.4-135.0 | 3.4 |
| —- | —- | —- | —- | —- | 84.0-86.4 | 2.2 | 143.5-145.7 | 1.4 |
| 4u* | —- | —- | —- | —- | 96.0-98.5 | 2.5 | 168.6-172.6 | 1.3 |
| 4u* | —- | —- | —- | —- | 105.2-106.0 | 0.8 | 173.8-174.2 | 0.4 |
| 4l* | —- | —- | —- | —- | 112.7-120.8 | 1.8 | 179.3-183.3 | 4.4 |
| 4u | 237.6-251.1 | 1.9 | 556.8-562.0 | 4.7 | 136.0-137.0 | 1 | 196.3-198.3 | 1.1 |
| 4l | 264.5-272.0 | 7.5 | 564.5-567.0 | 1.8 | 142.0-151.0 | 4.7 | 205.3-220.2 | 2.4 |
| 3 | 300.3-313.0 | 5.8 | —- | —- | 163.0-173.0 | 6.8 | 237.0-246.2 | 4.7 |
| 3l | —- | | —- | —- | 181.2-182.0 | 0.8 | —- | —- |
| —- | —- | | —- | —- | 214.7-215.7 | 1 | —- | —- |
| 2 | 404.0-420.2 | 14.9 | —- | —- | —- | —- | 305.5-324.1 | 11.9 |
| 1 | 481.0-498.2 | 17.2 | —- | —- | —- | —- | —- | —- |
| Total | | 59.5 | | 30.4 | | 28.1** | | 32.6 |

* Intersections of Seam 4 in KPP90-3 and KPP90-4 are interpreted as fault repeats.
** Total net cumulative coal in borehole KPP90-3 and KPP90-4 includes the fault repeat of Seam 4. Excluding the fault repeats reduces cumulative coal thickness to 24.0 m and 26.5 m, respectively.
***Seams 12 and 13 are interpreted as lying within the Elk Formation. The top of the Mist Mountain Formation is placed at the top of Seam 11.

The coal ash content varied widely, ranging from a low of 2.3% in Seam 4L, borehole KPP90-4, to 73.37% in Seam 8 in borehole KPP90-1. Coal quality data are summarized in Table 12. The geophysical log response for the coal intersected in the four boreholes indicates that the upper coal contains abundant partings and that few seams are greater than 1.5 m thick of net coal. Reflectance values of 1.32 to 1.8% $Ro_{max}$ indicate rank of medium to low volatile bituminous. Rank generally increases with increasing depth.

A plot of measured gas content versus ash for samples KPP90-1 and KPP90-2 (Fig. 18) illustrates the relationship between decreasing gas content and increasing ash. Most of the canister samples have an ash value greater than 15%; the average ash content for these canister samples is 33.28%. Most of the ash values appear to be high, which may be a result of the poor core recovery. When coal is cored and recovery is less than 90%, it is common for low ash components to be lost and only the higher ash portions to be retained. The high ash content might also explain why gas content was low. The two samples that had measured gas contents greater than 11 cc/g had relatively low ash contents of 16.79 and 8.81% (Tables 11 and 12).

*Adsorption isotherms.* One adsorption isotherm was conducted on the Saskoil exploration wells. The sample chosen occurred at the 408 m depth of KPP90-1. Reservoir temperature was assumed to be 24° C. The ash value of the sample was 14.8%. Measured gas content was 6.81 cc/g. The Langmuir equation on an "as measured" basis is:

$$V = 21.9 * P / (P + 1036)$$

Assuming a hydrostatic pressure gradient of 9.817 kPa per metre, the saturated gas capacity of the coal at reservoir depth would be 17.37 cc/g. The measured gas content at 6.81 cc/g is at about 39% saturation. The reason for the undersaturation is unclear. It might be related to the elevation of the coal intersection relative to the regional topography and groundwater table. If this gas capacity value is typical for Mist Mountain Formation coal in the region, then all the coal seams are significantly undersaturated. Gulf Canada adsorption isotherms for the same coal intervals yielded similar gas capacity values.

*Formation testing.* Three formation tests were run to determine the reservoir properties of the Mist Mountain Formation coal. An injection/fall-off test was completed in KPP90-1, and two conventional drillstem tests were completed in KPP90-2.

**Table 11**
**Desorption data, Saskoil Fernie wells**

| Borehole name | Seam no. | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| KPP 90-1 | 9 | 78.09 | 1.44 | 2.05 |
| KPP 90-1 | 8 | 93.34 | 0.41 | 1.54 |
| KPP 90-1 | 8 | 105.05 | 3.90 | 5.40 |
| KPP 90-1 | 6 | 159.05 | 3.43 | 3.91 |
| KPP 90-1 | 5 | 174.07 | 3.15 | 3.94 |
| KPP 90-1 | 5 | 184.16 | 3.12 | 4.10 |
| KPP 90-1 | 4U | 238.10 | 5.09 | 6.65 |
| KPP 90-1 | 4L | 264.99 | 11.91 | 14.31 |
| KPP 90-1 | 4L | 270.54 | 5.09 | 8.13 |
| KPP 90-1 | 3 | 305.61 | 2.53 | 5.02 |
| KPP 90-1 | 3 | 307.64 | 3.06 | 5.74 |
| KPP 90-1 | 2 | 405.92 | 6.09 | 6.88 |
| KPP 90-1 | 2 | 408.04 | 6.81 | 8.25 |
| KPP 90-1 | 2 | 412.59 | 6.67 | 8.02 |
| KPP 90-1 | 2 | 415.03 | 5.98 | 7.22 |
| KPP 90-1 | 2 | 418.10 | 2.05 | 6.49 |
| KPP 90-1 | 1 | 481.61 | 5.58 | 6.79 |
| KPP 90-1 | 1 | 484.80 | 3.31 | 4.57 |
| KPP 90-1 | 1 | 486.32 | 4.32 | 5.46 |
| KPP 90-1 | 1 | 490.84 | 3.86 | 5.17 |
| KPP 90-1 | 1 | 494.41 | 2.74 | 4.22 |
| KPP 90-1 | 1 | 497.18 | 5.72 | 7.12 |
| KPP 90-2 | 11 | 295.95 | 9.13 | 11.09 |
| KPP 90-2 | 8 | 409.07 | 11.91 | 13.06 |
| KPP 90-2 | 5 | 497.69 | 5.84 | 12.35 |
| KPP 90-2 | 5 | 498.70 | 8.48 | 12.85 |
| KPP 90-2 | 5 | 504.95 | 2.81 | 8.12 |
| KPP 90-2 | 4U | 559.14 | 3.80 | 8.36 |
| KPP 90-2 | 4U | 560.00 | 6.12 | 9.01 |
| KPP 90-2 | 4U | 561.49 | 6.37 | 8.21 |
| KPP 90-2 | 4L | 564.04 | 3.38 | 9.84 |
| KPP 90-2 | 3 | 589.54 | 1.48 | 5.48 |
| KPP 90-3 | 5 | 70.58 | 0.92 | 1.04 |
| KPP 90-3 | 4U | 96.02 | 0.37 | 0.45 |
| KPP 90-3 | 4L | 112.70 | 0.20 | 0.45 |
| KPP 90-3 | 4L | 149.96 | 0.05 | 0.10 |
| KPP 90-3 | 3 | 166.99 | 0.06 | 0.07 |
| KPP 90-4 | 6 | 110.59 | 0.65 | 1.32 |
| KPP 90-4 | 4U | 143.62 | 0.09 | 0.11 |
| KPP 90-4 | 4U | 145.01 | 0.09 | 0.12 |
| KPP 90-4 | 4U | 168.68 | 0.11 | 0.19 |
| KPP 90-4 | 4L | 180.17 | 0.11 | 0.19 |
| KPP 90-4 | 4L | 181.63 | 0.30 | 0.31 |
| KPP 90-4 | 3 | 239.64 | 0.18 | 0.47 |
| KPP 90-4 | 2 | 306.59 | 0.16 | 0.35 |
| KPP 90-4 | 2 | 313.51 | 0.05 | 0.07 |
| KPP 90-4 | 2 | 314.73 | 0.06 | 0.08 |
| KPP 90-4 | 2 | 316.00 | 0.03 | 0.06 |
| KPP 90-4 | 2 | 320.00 | 0.18 | 0.24 |
| KPP 90-4 | 2 | 320.33 | 0.05 | 0.07 |
| KPP 90-4 | 2 | 322.45 | 0.24 | 0.37 |

**Table 12**
**Proximate analyses, Saskoil Fernie wells**

| Borehole name | Seam number | Depth of intersection (m) | Ash (%) (a.d.b.) | Moisture (%) (a.d.b.) |
|---|---|---|---|---|
| KPP 90-1 | 9 | 78.09 | 29.65 | 0.51 |
| KPP 90-1 | 8 | 93.34 | 73.37 | 0.83 |
| KPP 90-1 | 8 | 105.05 | 27.68 | 0.59 |
| KPP 90-1 | 6 | 159.05 | 12.32 | 0.59 |
| KPP 90-1 | 5 | 174.07 | 19.99 | 0.58 |
| KPP 90-1 | 5 | 184.16 | 23.83 | 0.62 |
| KPP 90-1 | 4U | 238.10 | 23.51 | 0.60 |
| KPP 90-1 | 4L | 264.99 | 16.79 | 0.55 |
| KPP 90-1 | 4L | 270.54 | 37.40 | 0.58 |
| KPP 90-1 | 3 | 305.61 | 49.64 | 0.77 |
| KPP 90-1 | 3 | 307.64 | 46.69 | 0.68 |
| KPP 90-1 | 2 | 405.92 | 11.51 | 0.55 |
| KPP 90-1 | 2 | 408.04 | 17.44 | 0.44 |
| KPP 90-1 | 2 | 412.59 | 16.85 | 0.63 |
| KPP 90-1 | 2 | 415.03 | 17.21 | 0.62 |
| KPP 90-1 | 2 | 418.10 | 68.42 | 0.58 |
| KPP 90-1 | 1 | 481.61 | 17.78 | 0.46 |
| KPP 90-1 | 1 | 484.80 | 27.51 | 0.59 |
| KPP 90-1 | 1 | 486.32 | 20.88 | 0.53 |
| KPP 90-1 | 1 | 490.84 | 25.32 | 0.44 |
| KPP 90-1 | 1 | 494.41 | 35.04 | 0.51 |
| KPP 90-1 | 1 | 497.18 | 19.63 | 0.58 |
| KPP 90-2 | 11 | 295.95 | 17.64 | 0.61 |
| KPP 90-2 | 8 | 409.07 | 8.81 | 0.74 |
| KPP 90-2 | 5 | 497.69 | 52.76 | 0.78 |
| KPP 90-2 | 5 | 498.70 | 34.04 | 0.79 |
| KPP 90-2 | 5 | 504.95 | 65.40 | 0.72 |
| KPP 90-2 | 4U | 559.14 | 54.58 | 0.69 |
| KPP 90-2 | 4U | 560.00 | 32.09 | 0.58 |
| KPP 90-2 | 4U | 561.49 | 22.47 | 0.78 |
| KPP 90-2 | 4L | 564.04 | 65.68 | 0.83 |
| KPP 90-2 | 3 | 589.54 | 72.96 | 0.63 |
| KPP 90-3 | 5 | 70.58 | 11.92 | 0.49 |
| KPP 90-3 | 4U | 96.02 | 18.79 | 0.70 |
| KPP 90-3 | 4L | 112.70 | 56.16 | 0.61 |
| KPP 90-3 | 4L | 149.96 | 50.12 | 0.60 |
| KPP 90-3 | 3 | 166.99 | 18.35 | 0.56 |
| KPP 90-4 | 6 | 110.59 | 50.89 | 0.63 |
| KPP 90-4 | 4U | 143.62 | 19.94 | 0.51 |
| KPP 90-4 | 4U | 145.01 | 24.34 | 0.53 |
| KPP 90-4 | 4U | 168.68 | 42.66 | 0.49 |
| KPP 90-4 | 4L | 180.17 | 44.05 | 0.60 |
| KPP 90-4 | 4L | 181.63 | 2.30 | 0.56 |
| KPP 90-4 | 3 | 239.64 | 62.32 | 0.73 |
| KPP 90-4 | 2 | 306.59 | 55.17 | 0.36 |
| KPP 90-4 | 2 | 313.51 | 35.53 | 0.58 |
| KPP 90-4 | 2 | 314.73 | 28.17 | 0.40 |
| KPP 90-4 | 2 | 316.00 | 52.17 | 0.46 |
| KPP 90-4 | 2 | 320.00 | 23.93 | 0.48 |
| KPP 90-4 | 2 | 320.33 | 20.66 | 0.51 |
| KPP 90-4 | 2 | 322.45 | 34.97 | 0.40 |
| **Mean** | | | 33.28 | |

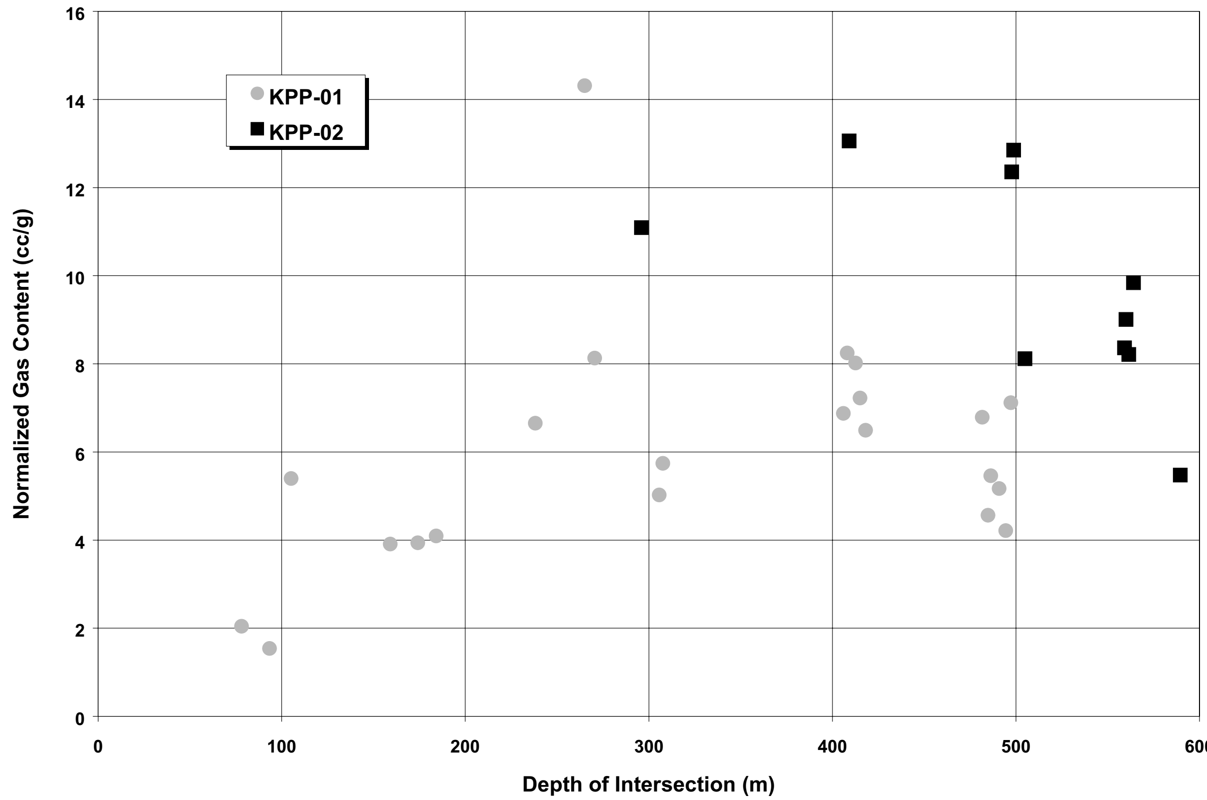


***Figure 17.*** *Normalized gas content versus depth of intersection, KPP90-1 and KPP90-2 canister samples.*

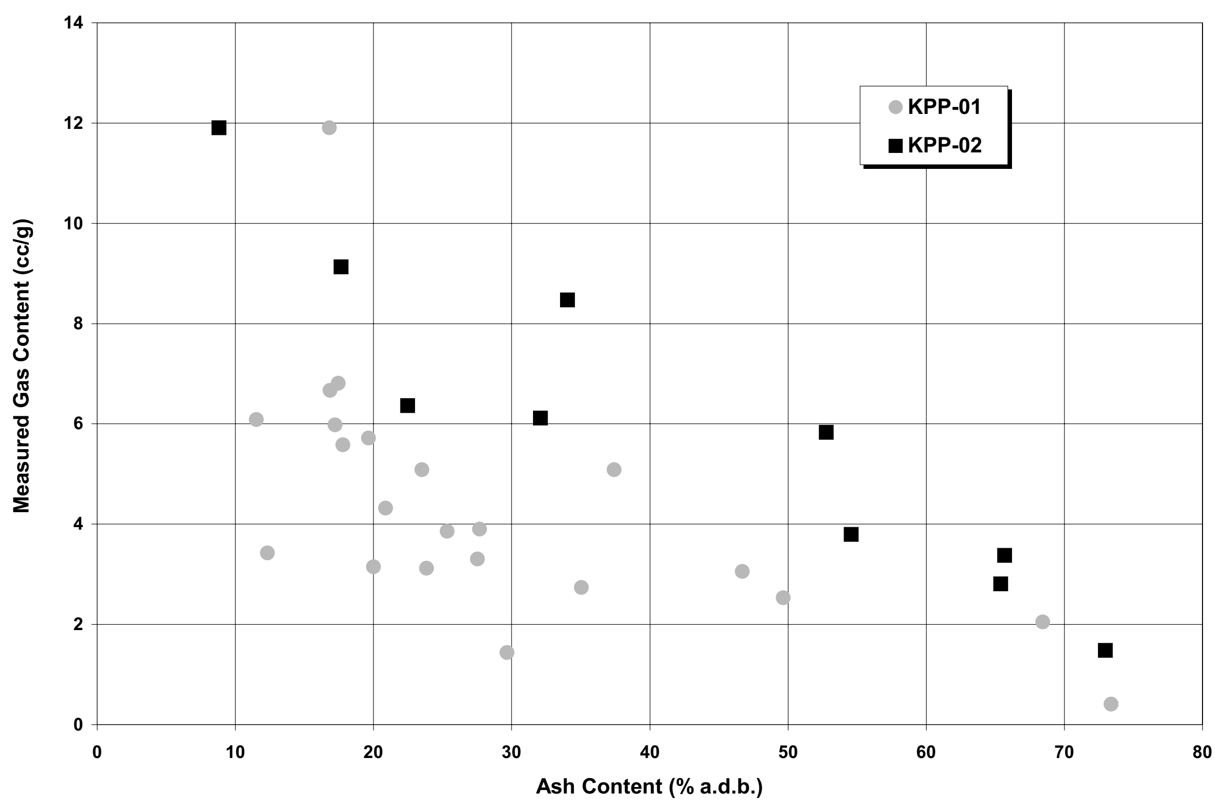


***Figure 18.*** *Measured gas content versus ash content, KPP90-1 and KPP90-2 canister samples.*

In KPP90-1, the selected test interval was from 261.9 to 281.6 m to straddle the 7.5 m thick 4L seam at 264 m. The pressure gradient was estimated at 9.933 kPa/m. Preliminary results suggested that permeability of the reservoir was 11 mD. However, the injection test was carried out for less than 1 hour, so any results should be viewed with caution.

In KPP90-2, the initial test was invalid because of the placement of a packer seat to include a highly fractured sandstone. The second test consisted of an open-ended drillstem test through perforated tubing. The bottom of the borehole (510 m to TD) was cemented in. Reports from the field office indicate that the test zone was inadvertently cemented over during this process. The inflatable packer was set at 491 m and the tubing perforated from 493 to 500 m. The target coal zone for testing was Seam 5 from 493.0 to 505.2 m (6.5 m of net coal). Permeability data collected yielded values of 0.3 mD to 0.4 mD. The test zone was a competent gassy coal zone. It is highly likely that the formation damage introduced from the cement would significantly retard the reservoir permeability. The true reservoir permeability may therefore be significantly higher.

*Technical assessment.* The Saskoil coalbed methane exploration program drilled four boreholes in advance of an attempt at land acquisition. These boreholes were the main impetus for the numerous coalbed methane exploration projects in the Fernie Basin in the early 1990s. At that time, the understanding of the dynamics of coalbed methane generation, storage and producibility were not well understood. Borehole locations were chosen primarily for accessibility and not by geological potential. As a result, the data produced from these exploration boreholes can be categorized as compromised. Coal intersections were commonly too shallow and gas contents correspondingly low. In KPP90-3 and 4, structural complications have contributed to degassing of the coal. Gas content might also be depressed as a result of the topographic elevation of the coal intersections relative to the regional topography and water table. Gas content in the Morrisey Creek region appeared to be lower than nearby boreholes belonging to Gulf and Mobil/Chevron. This might be related to the high overall ash content of the coal samples and to the poor core recovery.

### *Fording Coal project*

Fording Coal Limited undertook a limited coalbed methane exploration program during the winter of 1993. A slimhole wireline corehole was completed to a depth of 533 m, intersecting 44 m of coal from five major coal zones. Desorption tests (70 canisters) were conducted on four of the major seams, and gas contents averaged 10.6 cc/g with some samples containing over 15 cc/g. Gas content was variable and did not appear to increase as a function of increasing depth.

*Data acquisition.* The Fording exploration borehole was completed with a truck mounted Schramm rotary drill, commonly used for coal exploration. Wireline coring limits for this type of equipment are about 550 to 600 m. The borehole was located at the north end of an abandoned open pit on the east flank of the Greenhills syncline in the hanging wall of the Erickson fault (Fig. 19). Depth restrictions of the drill rig dictated that the major coal seams be intersected at a depth of less than 500 m, which forced the location of the wellbore to be within 800 m of the Erickson fault.

The borehole was drilled to the potential top of the coal measures (238 m) using an air hammer. The remainder of the borehole was cored using a wireline system and Christiansen split tube core barrel. Drilling fluids consisted of a bentonitic mud system to a depth of 380 m, followed by a synthetic polymer solution to the top of Seam D (511 m). The remaining 22 m were drilled with water to minimize formation damage. Core recovery was varied and averaged 80% within the coal zones.

Aftere coring, three injection tests were done using inflatable straddle packers. The zones tested were Seam D, upper Seam E, and upper Seam G. During these tests, some problems were encountered associated with leaks in the drill string, so complete pressure fall-off data were not available. In an attempt to obtain some useful information from these tests, the data were provided to Resource Enterprises International (REI) to input into a reservoir simulator. Estimates of reservoir permeability for the three zones are 1–3 mD, 3–6 mD and 1–3 mD for Seams D, E and G, respectively.

Preliminary results from the injection tests led Fording to cancel the proposed completion well and undertake a limited production test of the stratigraphic borehole. It was determined that no borehole stimulation would be initiated because of the low permeability and the interpreted near-wellbore damage. Three production tests, each lasting 10 days, were completed during a six-week period. Tests 1 and 2 encountered technical problems associated with the production equipment selected and with the friability of the coal. The third test appears to have tested only the seams where near wellbore damage is thought to have occurred. The well was subsequently abandoned.

*Geology.* The target of this coalbed methane exploration well was the coal of the Mist Mountain Formation of the Lower Cretaceous Kootenay Group. The coal measures comprise 600 m of interbedded sandstone, siltstone, mudstone and coal. Up to 13 coal seams are present, of which 10 are greater than 1 m thick. The stratigraphy and major coal seams are illustrated in Figure 20 and details of seam intersections are given in Table 13. In the coalbed methane exploration well, the upper seams (I to M) had been previously mined in the Lake open pit mine immediately to the south. They outcrop farther east. These seams have been

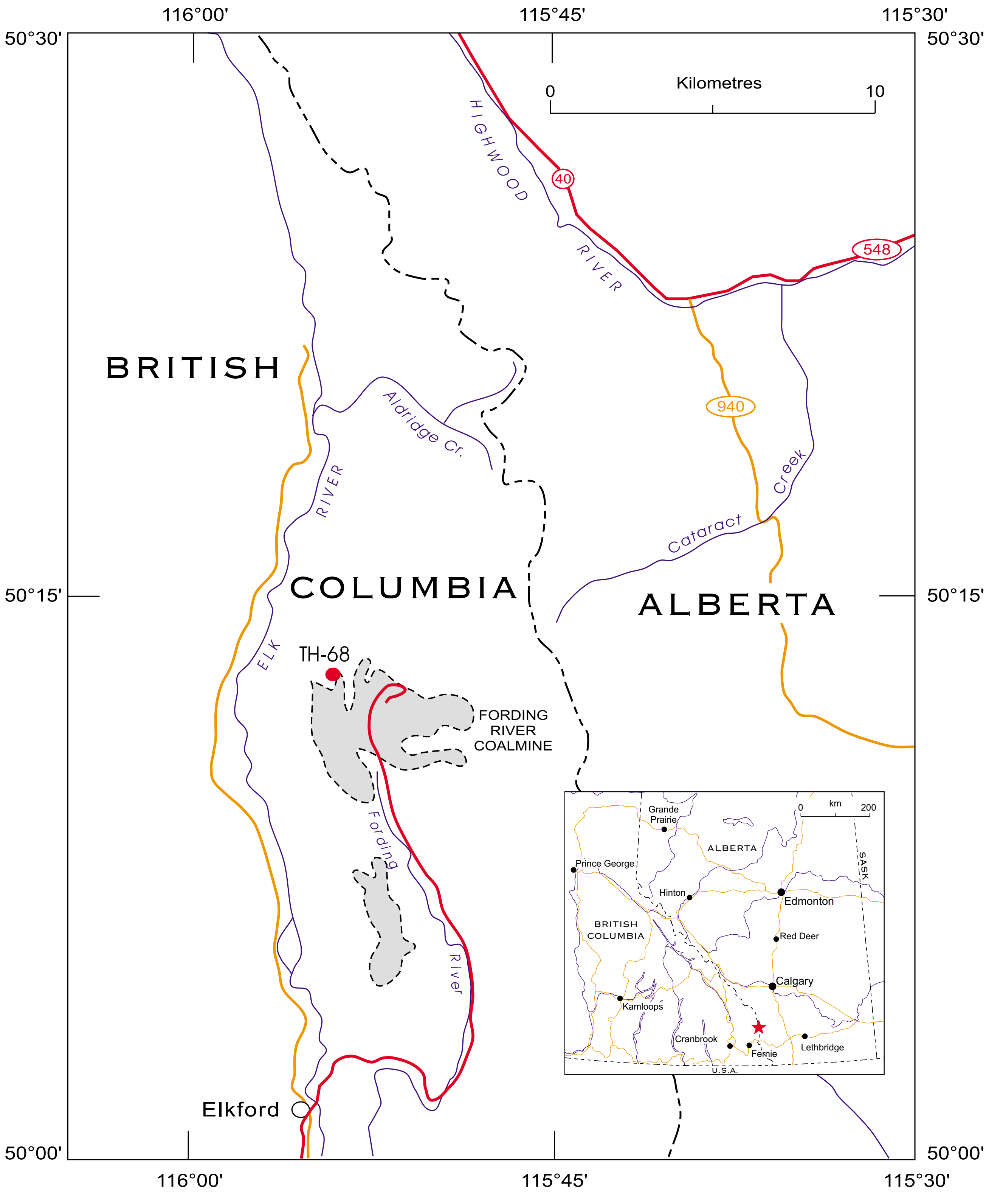


***Figure 19.*** *Location map of the Fording Coal Limited coalbed methane exploration borehole.*

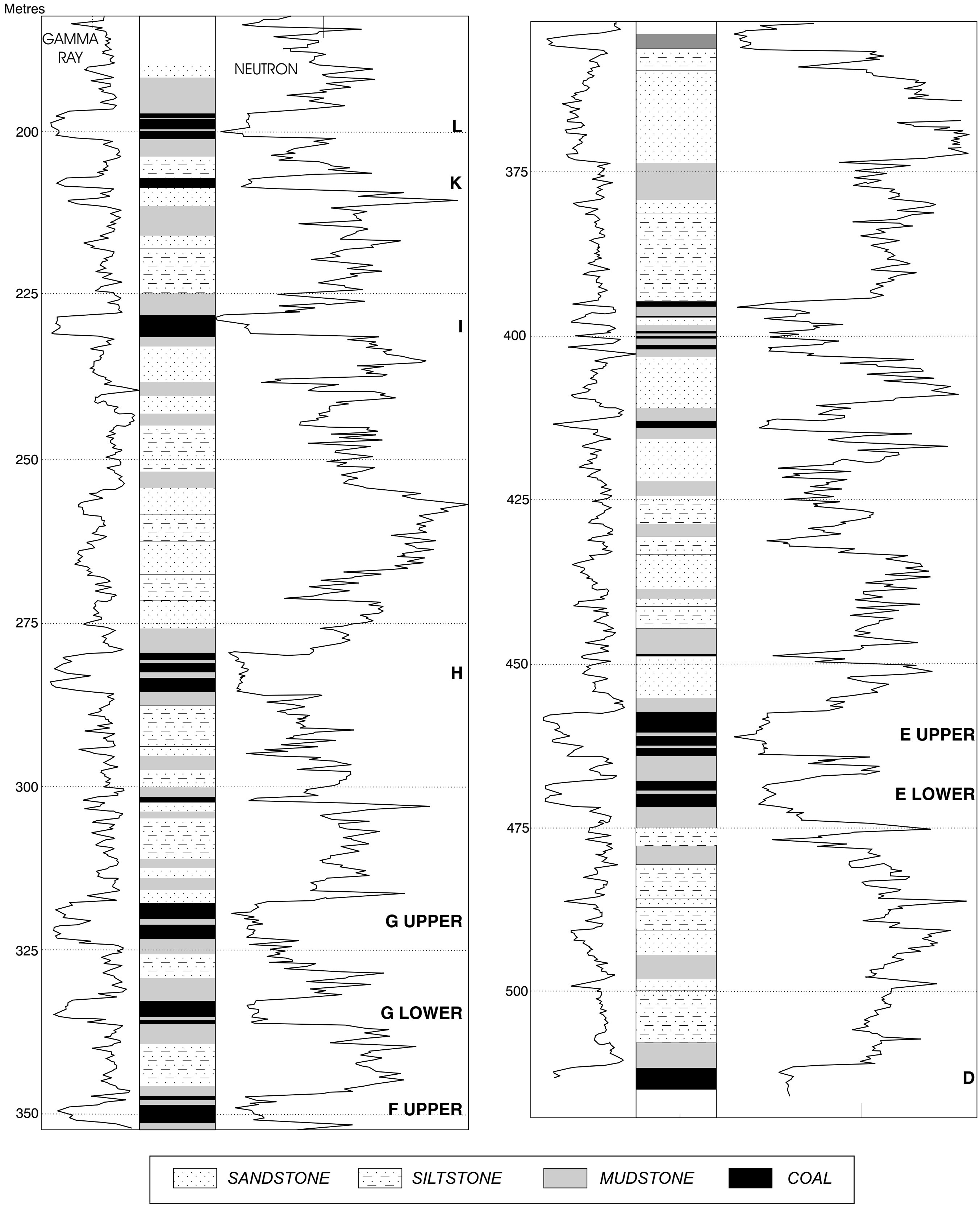


***Figure 20.*** *Detailed stratigraphic column of the Mist Mountain Formation for the Fording Coal Limited coalbed methane exploration borehole.*

exposed at the surface and at the pit highwall and appear to have been degassed. They do not have significant coalbed methane potential. The lower seams, H, G, F, E, D, C, and B, are not exposed in the highwall and do not outcrop to the east, but terminate against the Erickson Fault. Previous testing by Canmet in the early 1980s indicated that most of these seams have retained significant adsorbed methane. Of the lower targeted seams, B and C were not intersected because of drilling equipment depth limitations. The other seams were encountered within a depth range of 279.5 to 522 m (Fig. 20).

**Table 13**
**Coal intersections, Fording Coal TH-68**

| Seam name | Depth top (m) | Depth base (m) | Thickness (m) |
|---|---|---|---|
| H | 279.5 | 285.5 | 6 |
| G upper | 318 | 324.5 | 6.5 |
| G lower | 332.5 | 336.5 | 4 |
| F upper | 347 | 351 | 4 |
| F lower | 354 | 356 | 2 |
| E upper | 457.5 | 464 | 6.5 |
| E lower | 468 | 472 | 4 |
| D | 511 | 522 | 11 |

*Gas content.* Desorption results for the Fording coal samples are summarized in Table 14. Gas content data are presented on an as-received basis (summation of desorbed and lost gas), and on a dry ash-free basis (d.a.f.). The highest gas content is from Seams G and F (about 12 cc/g), at a depth range of 301.93 to 324.0 m and 353.4 to 355.3 m, respectively. Lowest gas content was obtained from the upper Seam E (6.7 cc/g), at a depth range of 394.1 to 401.9 m. On a dry ash-free basis, the upper and lower Seam E and Seam D have similar gas contents. A comparison between the theoretical gas capacity (based upon the Ryan equation) and the measured gas content, suggests that Seams G and F are oversaturated, while Seams E and D are undersaturated.

Figure 21 illustrates the variability in gas content versus depth and seam for the sample suite. Even after the samples were corrected for ash and moisture content, there still appeared to be a trend of lower gas content for Seam E (Fig. 22). This might be a result of the maceral composition or the high degree of shearing in the coal.

*Coal quality.* Figure 23 illustrates the relationship between ash content and gas content for the sample suite. Most of the coal samples had ash contents of less than 20% and corresponding gas contents of greater than 10 cc/g on an "as-measured basis". The graph illustrates that for ash values greater than 20%, the ash component tends to act as a diluent to gas content in the coal samples. For ash contents less than 20%, the slope of the curve is steeper and the data more scattered. The lower ash content contributing to this part of the curve might be in the form of disseminated mineral matter that inhibits the gas storage ability and the gas diffusion characteristics of the coal samples. Laboratory analyses of the coal samples provided only the ash contents and as-received moisture contents. An assumed sulphur value of 0.4% was used to correct to an ash-free basis.

Core samples were described for cleat and lustre before being placed within the desorption canisters. These descriptions indicated that most of the samples were dull to dull banded with poorly developed cleat. Where cleat was observed, it was concentrated within the thin, bright banded lenses.

*Adsorption isotherms.* One adsorption isotherm (Seam D) was completed for the exploration project. Langmuir volume and pressure data were not available but the six-point isotherm curve suggested that for Seams E and D, gas content was below saturation level, whereas Seams G and F might have been oversaturated. Gas analyses from the well tests indicated a $CO_2$ content in excess of 10%, which might account for the oversaturation. Reservoir pressure tests provided data to support the conclusion that the coal was slightly to highly underpressured. Predictions of theoretical values from coal quality data using Kim and Ryan equations suggested that the coal was undersaturated.

*Formation testing.* At the conclusion of drilling operations, a series of injection tests were run; a single packer test on Seam D, and straddle packer tests on Seams E and G. Some problems were encountered during testing. The drill string had a number of leaks, which obscured some of the pressure fall-off data for later flows into the formation. As a result of

**Table 14**
**Desorption data, Fording Coal TH-68**

| Seam name | Depth (top) (m) | Depth (base) (m) | Average gas content (a.m.b) (cc/g) | Average gas content (d.a.f.) (cc/g) | Theoretical gas capacity (cc/g) |
|---|---|---|---|---|---|
| G | 301.93 | 324 | 12.03 | 15.03 | 12.56 |
| F | 353.4 | 355.3 | 12.04 | 15.24 | 12.87 |
| E Upper | 394.1 | 401.9 | 6.7 | 11.33 | 13.57 |
| E Lower | 457.1 | 476.6 | 8.8 | 12.9 | 14.05 |
| D | 511.4 | 522.4 | 11.39 | 13.83 | 14.41 |

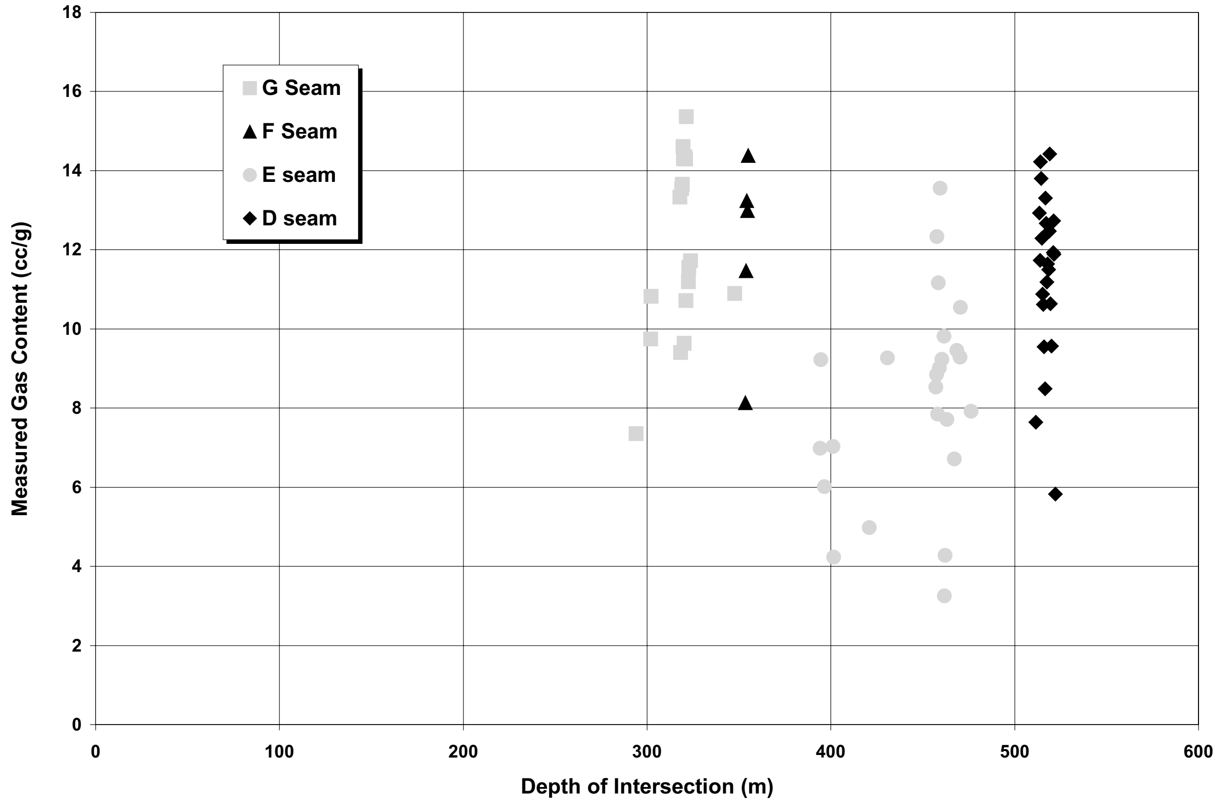


***Figure 21.*** *Gas content (as measured) versus depth of intersection, Fording coal samples.*

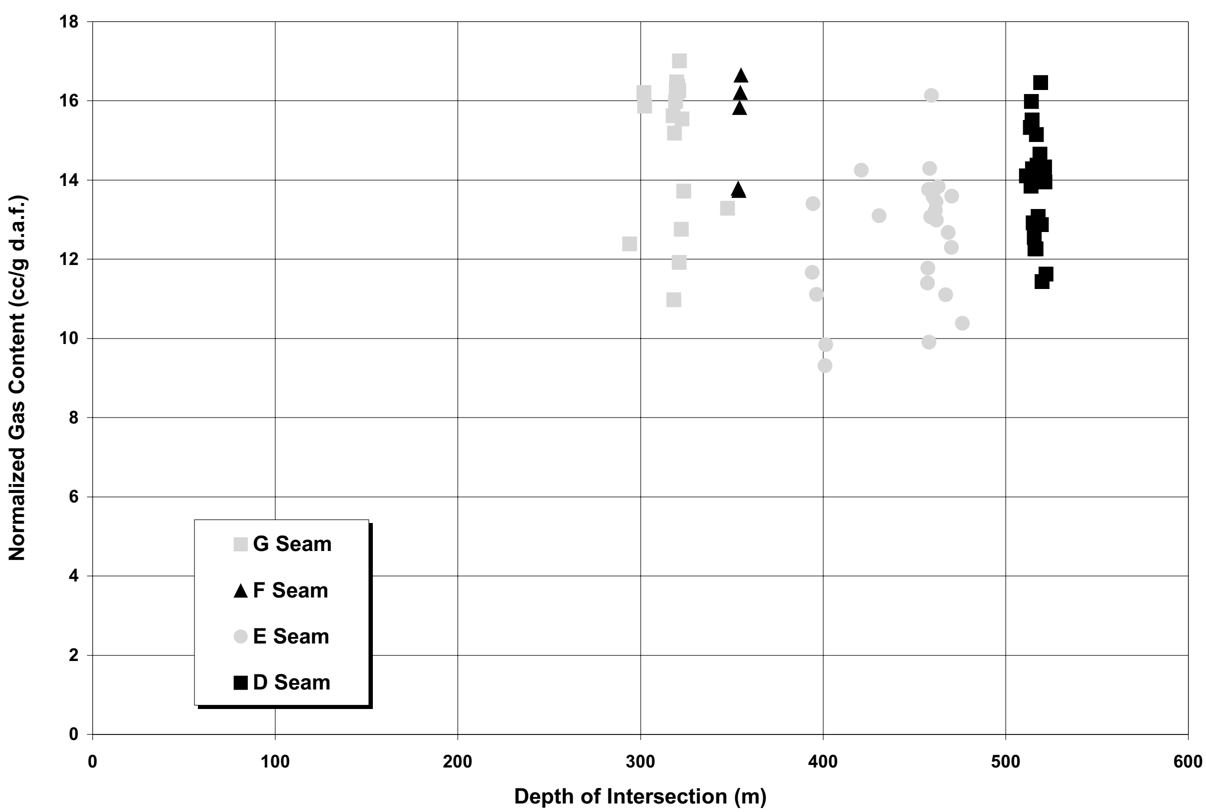


***Figure 22.*** *Normalized gas content versus depth of intersection, Fording coal samples.*

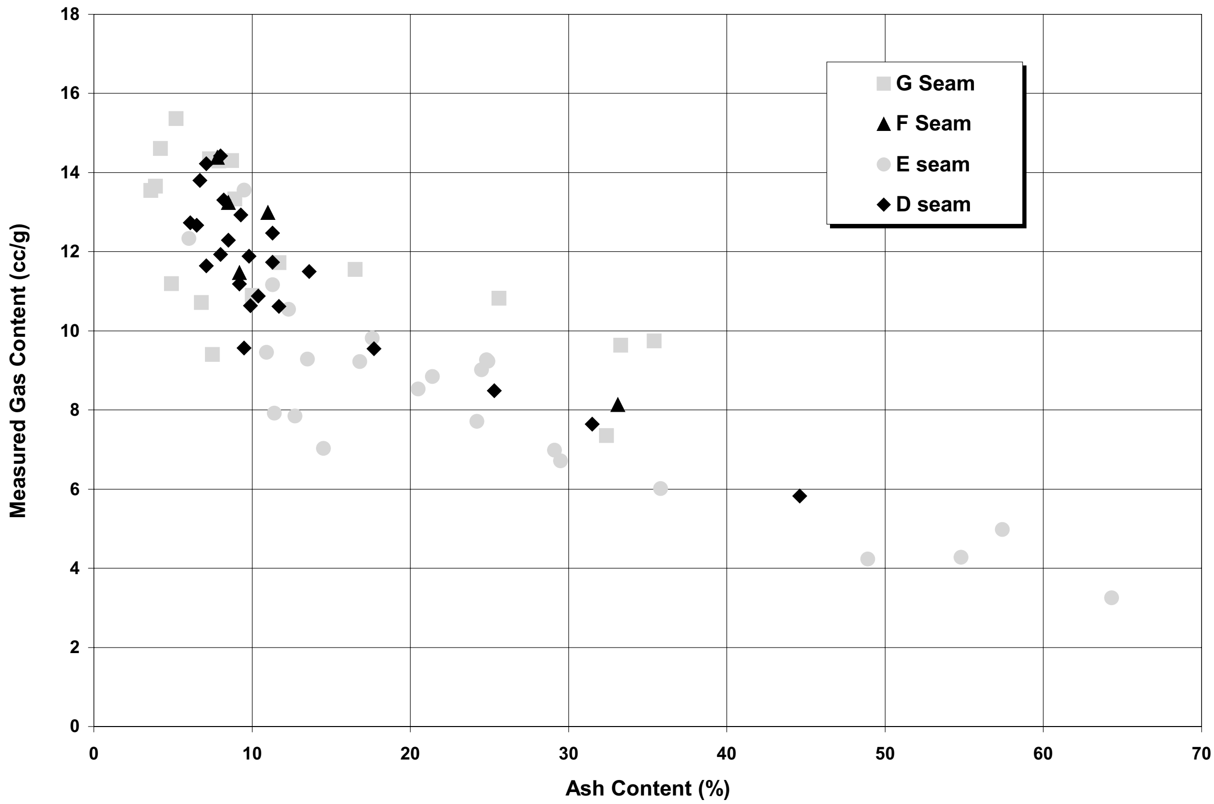


***Figure 23.*** *Gas content (as measured) versus ash content, Fording coal samples.*

the uncertainty of the data integrity, permeability and pressure values were presented as a range. These data are summarized in Table 15.

The data indicate that permeabilities are generally less than 5 mD but greater than 1 mD. Both Seams D and G are underpressured and Seam E is close to hydrostatic pressure, assuming a hydrostatic gradient of 9.817 kPa/m.

Reservoir simulations were conducted by REI, who concluded that at a permeability value of 3 mD, cavitation-type stimulation would not be effective and that hydraulic fracturing would be the preferred method of wellbore stimulation. At the time, the standard rule of thumb was “any reservoir with less than 5 mD permeability will not cavitate successfully”. The same consulting reservoir engineers have now lowered that threshold to 1 mD. In retrospect, it might have been possible to cavitate the Fording well.

**Table 15**
**Formation tests, Fording Coal TH-68**

| | SeamD | Seam E | Seam G |
|---|---|---|---|
| Permeability (mD) | 1-3 | 3-6 | 1-3 |
| Pressure (kPa) | 4343 | 4309 | 2930 |
| Gradient (kPa/m) | 8.59 | 9.5 | 9.05 |

The low permeability values and disappointing results from the wellbore simulator forced Fording to rethink their decision to drill a production well. They decided to undertake a limited production test on the stratigraphic wellbore. The borehole was cased to allow testing of Seams D, E, F and G. Production tubing and a submersible screw pump were lowered into the borehole and pump testing was initiated. Numerous problems were encountered during the pump tests. During the first test (12 days), coal fines entered the borehole and led to the pump seizing before the reservoir pressure was lowered enough to allow gas desorption to begin.

During the second 20 day test, mechanical failure resulted in the bottom hole assembly being lost in the borehole. Both of these tests were designed to determine the potential of Seams D and E. Limited gas production was achieved, primarily as the reservoir pressures were not lowered sufficiently. In the third test, the pump was suspended at a depth of 400 m, about 100 m above Seam D. It was believed that this sump height would prevent fines from affecting pump efficiency. Reservoir pressure was lowered to below 1400 kPa for Seam D for about 150 hours. Gas production peaked at 7 Mcf/d and then dropped to less than 1Mcf/d. These low production rates suggested to Fording that the well was not commercially viable. However, the lowered reservoir pressure of 1400 kPa for Seam D was still 300 kPa above the targeted desorption pressure and when the borehole was re-entered, the fill level was only 12 m below the pump (88 m above Seam D). It is highly likely that Seams E and D did not even contribute to the gas production obtained.

*Technical assessment.* The coalbed methane exploration borehole completed by Fording demonstrated that the Mist Mountain Formation coal contained significant quantities of methane gas. At depths of less than 400 m, Seams G and F contained a gas content higher than the theoretically derived gas capacity, based on rank and depth projections and using the "methcalc" program developed by Ryan (1992). Theoretical gas capacity values (calculated on a dry ash-free basis and assuming a rank of 1.25% Ro Max) for these two seams range from 12.56 cc/g for Seam G to 12.87 cc/g for Seam F. Measured values range from 15.03 to 15.24 cc/g, respectively, an increase of about 19% above saturation level. This apparent oversaturation might be the result of a larger amount of $CO_2$ present in the desorbed gas, or overpressuring.

Theoretical gas capacity values for Seams E and D range from 13.57 to 14.41 cc/g, in contrast to measured values of 11.3 and 13.82 cc/g, respectively. These seams appear to be between 5 and 15% undersaturated. Even though the gas content was corrected to a dry ash-free basis, there might still have been a diluent effect of the dispersed mineral matter in the coal of these seams, and caution should be used in drawing too many conclusions from the data. However, we can state that overall ash content in Seam E is generally higher and appears to impact the measured gas content.

Reservoir testing to determine key production characteristics, such as permeability and reservoir pressure, was undertaken but the data appear to be compromised because of leaks in the drill string. The limited production test encountered a number of technical problems, mostly stemming from the friable nature of the coal. The Mist Mountain Formation coal had fast diffusion rates and short desorption times. High gas content was recorded at shallow depths (i.e., low reservoir pressures), and increasing reservoir pressure by intersecting the coal at greater depth did not appear to significantly enhance the volume of methane stored within the coal. In these circumstances, the critical desorption pressure is commonly much lower than the reservoir pressure. Decreasing the reservoir pressure to a level approximating the critical desorption pressure results in de-stabilizing the wellbore and the influx of coal fines.

During the production tests completed by Fording, fines effectively filled up the borehole and covered two of the prospective pay zones. If Seams E and D had been allowed to reach critical desorption pressure without the borehole sloughing in and covering these zones, it is not known what the gas production would have been. Gas production volumes achieved were low, but do not reflect the producibility of the wellbore nor the coal measures of the Mist Mountain Formation.

## *Norcen Elk Valley project*

In 1990, Norcen Energy Resources initiated a project to evaluate the coalbed methane potential of the Elk Valley in southeast British Columbia (Fig. 24). The rationale for exploring in the Elk Valley was the presence of thick coal of medium to low volatile bituminous rank, and the reported presence of gas in shallow coal exploration boreholes. Initial exploration consisted of geological mapping and drilling four stratigraphic boreholes during the winter of 1991. Following completion of the initial drilling, Norcen posted the land and acquired a 7578 hectare drilling licence in January, 1992. In that year, a limited production test well was drilled adjacent to borehole 65. The well was cased and stimulated by fracing and Norcen conducted production tests for one month. Subsequently, the well was suspended and Norcen relinquished exploration rights to most of the posted lands.

*Data acquisition.* The four stratigraphic test holes (Elk Valley 64, 65, 66 and 67) were designed to intersect the entire coal-bearing section of the Mist Mountain Formation (Fig. 24). The boreholes were paired to allow some section overlap and drilled using conventional coal exploration equipment. Coal intervals were cored using a wireline retrievable system. Sixty-four canister tests were made from the recovered coal core samples to determine in situ gas content. Some non-coal cores were also sampled for rock mechanical properties. Following the completion of stratigraphic drilling, an injection test was completed in borehole A65 across Seam 10. Results from this test suggested high permeability values and overpressuring of the coal. However, subsequent reinterpretation of these test results indicated that the high permeability values were a result of the coal being fractured during the injection test. The apparent oversaturation of the coal was caused by a high $CO_2$ concentration, which in combination with the adsorbed methane, produced a higher gas capacity. The actual permeability values acquired from the limited testing indicate about 1 mD. The coal was slightly underpressured compared with hydrostatic conditions.

Norcen continued with exploration in the Elk Valley, and in 1992 drilled a limited production test. This well targeted Seams 8, 9 and 10 (lower Mist Mountain Formation), as the principal reservoirs. The drilling procedures and completion techniques employed caused significant problems, which probably adversely affected reservoir permeability, and ultimately the performance of the well. As a result of the disappointing production results, Norcen subsequently relinquished most of the licence area (except the portion where the production well was drilled).

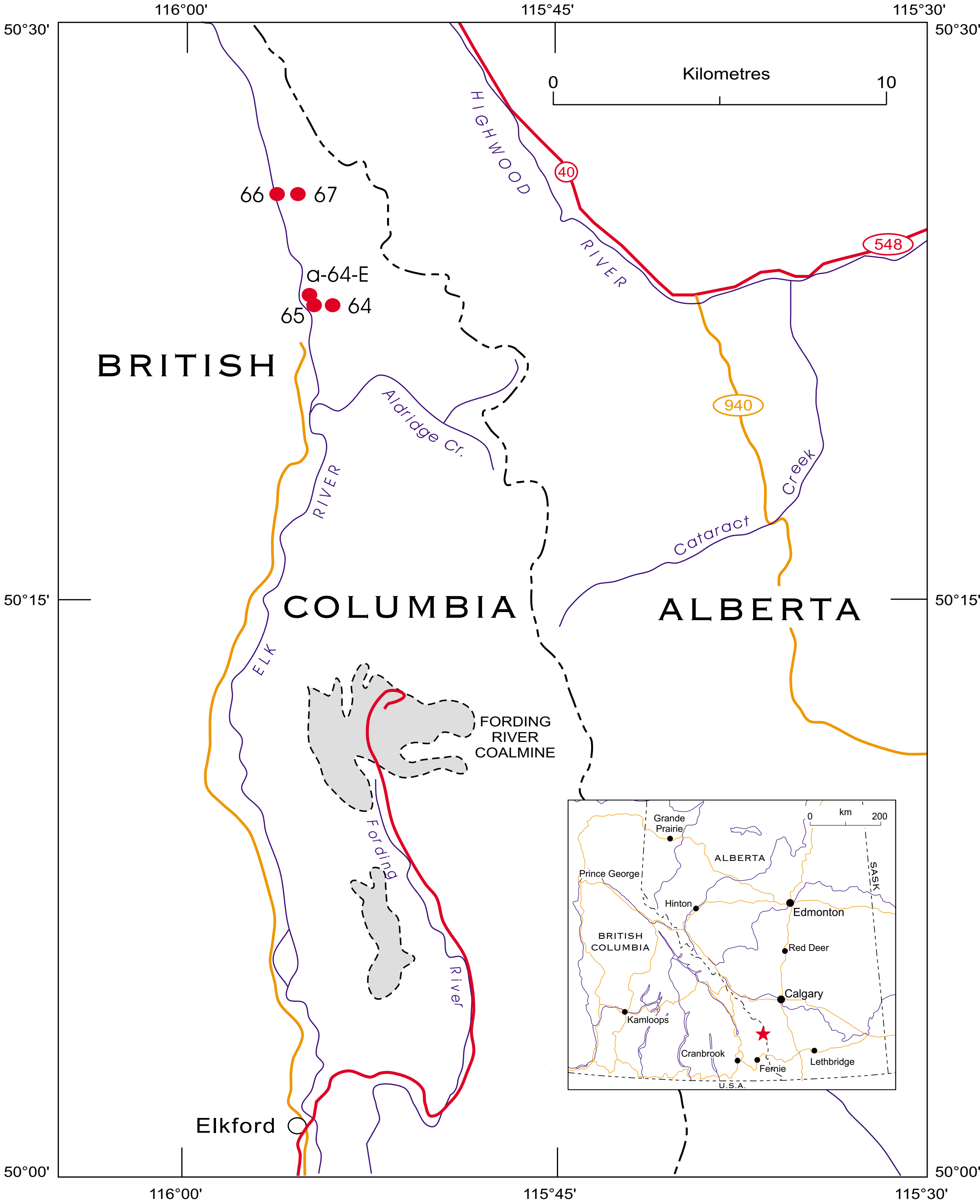


***Figure 24.*** *General location map of the Norcen Elk Valley exploration area.*

*Geology.* Coals intersected in the Elk Valley exploration boreholes belong to the Mist Mountain Formation and are Jurassic to Lower Cretaceous in age. The formation is about 650 m thick and contains up to 19 coal seams with a cumulative thickness of more than 54 m. The coal is laterally continuous, but there is some local variability in seam thickness and presence of splits or plies. Of the 19 seams that might be present, eight seams are thicker than 3 m (Table 16) and account for 69% of the total coal thickness. The thickest coal horizon is Seam 10, followed by Seams 4, 9 and 13. These horizons have been the principal exploration target for coalbed methane in southeast British Columbia. Figure 25 illustrates a detailed representative stratigraphic section for the Mist Mountain Formation in the Elk Valley area.

*Gas content.* Sixty-four canister samples (data are available for only 52 of the samples), were collected from four boreholes. Distribution of the samples by borehole and seam are shown in Table 17. The coal seams were intersected at depths ranging from 108 to 417 m (Fig. 26). Deeper intersections were not possible because of depth limitations of the drilling equipment. Gas content was variable and there appeared to be a broad relationship between measured gas content and ash (Fig. 27). Within the ash range of 0 to 30%, there is a wide variation in gas content. A plot of normalized gas content versus depth (Fig. 26) shows a general trend of increasing gas content with increasing depth from 100 to 250 m. At depths of more than 250 m, data are scattered, suggesting that other factors affect the gas storage of each seam. In other coalbed methane tests of the Mist Mountain Formation, coal in the lower part of the formation has a lower measured gas content. This is partly a result of the high inertinite content of the coal and also the presence of $CO_2$ as part of the adsorbed gas composition. Measured gas content ranges from 6.28 to 20.17 cc/g. For coal deeper than 250 m, the average gas content is 13.25 cc/g. Normalized gas content ranges from 6.59 to 21.64 cc/g. Average normalized gas content for coal deeper than 250 m is 16.23 cc/g.

*Coal quality.* Coal of the Mist Mountain Formation is medium to low volatile bituminous in rank with widely variable ash content. Generally the rank increases with depth. Ash values (from proximate analyses) for the canister samples range from 3.20 to 53.78% with an average of 16.7% (Table 18).

A significant compositional variation within the Mist Mountain Formation coal is the change in maceral composition with respect to stratigraphic level. The upper seams are rich in vitrinite (>70%), whereas the basal seams have a much higher inertinite content (45 to 55%). This

**Table 16**
**Coal intersections, Norcen Elk Valley wells**

| Seam no. | EV64 | EV65 | EV66 | EV67 | Average seam thickness (m) |
|---|---|---|---|---|---|
| 17B | | 4.7 | | | 4.7 |
| 17A | | 0.57 | | | 0.57 |
| 16 | | 3.9 | 0.97 | | 2.44 |
| 15 | | | 0.75 | | 0.75 |
| 14B | | 0.49 | 4.35 | | 2.42 |
| 14A | | 1.34 | 4.76 | | 3.05 |
| 13C | | 0.9 | 1.15 | | 1.15 |
| 13B | | | 1.1 | | 1.1 |
| 13A | | | 4.45 | 4.6 | 4.53 |
| 12 | | | 2.95 | | 2.95 |
| 11 | | 2.6 | | 4 | 3.3 |
| 11B | 0.4 | | | | 0.4 |
| 10B | 2.53* | | | | |
| 10 | | 7.55 | 6.65 | 9.75 | 7.55 |
| 10A | 3.71* | | | | |
| 9B | 2.75 | | 2.03 | | 2.39 |
| 9A | | | 4.5 | 4.08 | 4.29 |
| 8 | | | 2.08 | 3.13 | 2.61 |
| 4 | | | | 6.27 | 6.27 |
| 2 | 5.12 | | | 3.38 | 4.25 |
| Total | 14.51 | 22.05 | 35.74 | 35.21 | 54.72 |

* Seams 10A and 10B are splits of Seam 10 and have been averaged as one seam in the cumulative total.

**Table 17**
**Desorption data, Norcen Elk Valley wells**

| Borehole | Seam no. | Depth of intersection | Average gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Elk Valley 64 | 2 | 367.70 | 13.61 | 14.46 |
| Elk Valley 64 | 9 | 220.15 | 16.28 | 18.17 |
| Elk Valley 64 | 10 | 159.31 | 12.88 | 14.62 |
| Elk Valley 64 | 11 | 140.80 | 5.72 | 11.08 |
| Elk Valley 65 | 10 | 406.78 | 11.97 | 19.07 |
| Elk Valley 65 | 11 | 365.40 | 8.04 | 10.17 |
| Elk Valley 65 | 13 | 339.88 | 16.60 | 17.18 |
| Elk Valley 65 | 14 | 319.88 | 20.17 | 21.64 |
| Elk Valley 65 | 16 | 215.00 | 13.22 | 14.97 |
| Elk Valley 65 | 17 | 151.25 | 8.84 | 13.42 |
| Elk Valley 66 | 8 | 417.12 | 11.34 | 14.24 |
| Elk Valley 66 | 9 | 393.90 | 12.30 | 16.03 |
| Elk Valley 66 | 10 | 362.35 | 13.86 | 16.22 |
| Elk Valley 66 | 12 | 282.85 | 6.35 | 13.73 |
| Elk Valley 66 | 13 | 264.60 | 12.71 | 15.74 |
| Elk Valley 66 | 14 | 183.50 | 13.66 | 14.77 |
| Elk Valley 66 | 15 | 155.00 | 10.99 | 11.36 |
| Elk Valley 66 | 16 | 137.15 | 12.19 | 12.75 |
| Elk Valley 67 | 2 | 413.56 | 7.45 | 8.97 |
| Elk Valley 67 | 4 | 358.95 | 11.28 | 12.78 |
| Elk Valley 67 | 8 | 271.00 | 13.34 | 14.58 |
| Elk Valley 67 | 9 | 244.92 | 13.72 | 16.09 |
| Elk Valley 67 | 10 | 218.00 | 13.58 | 14.91 |
| Elk Valley 67 | 11 | 168.82 | 14.03 | 19.83 |
| Elk Valley 67 | 13 | 108.50 | 6.28 | 6.59 |

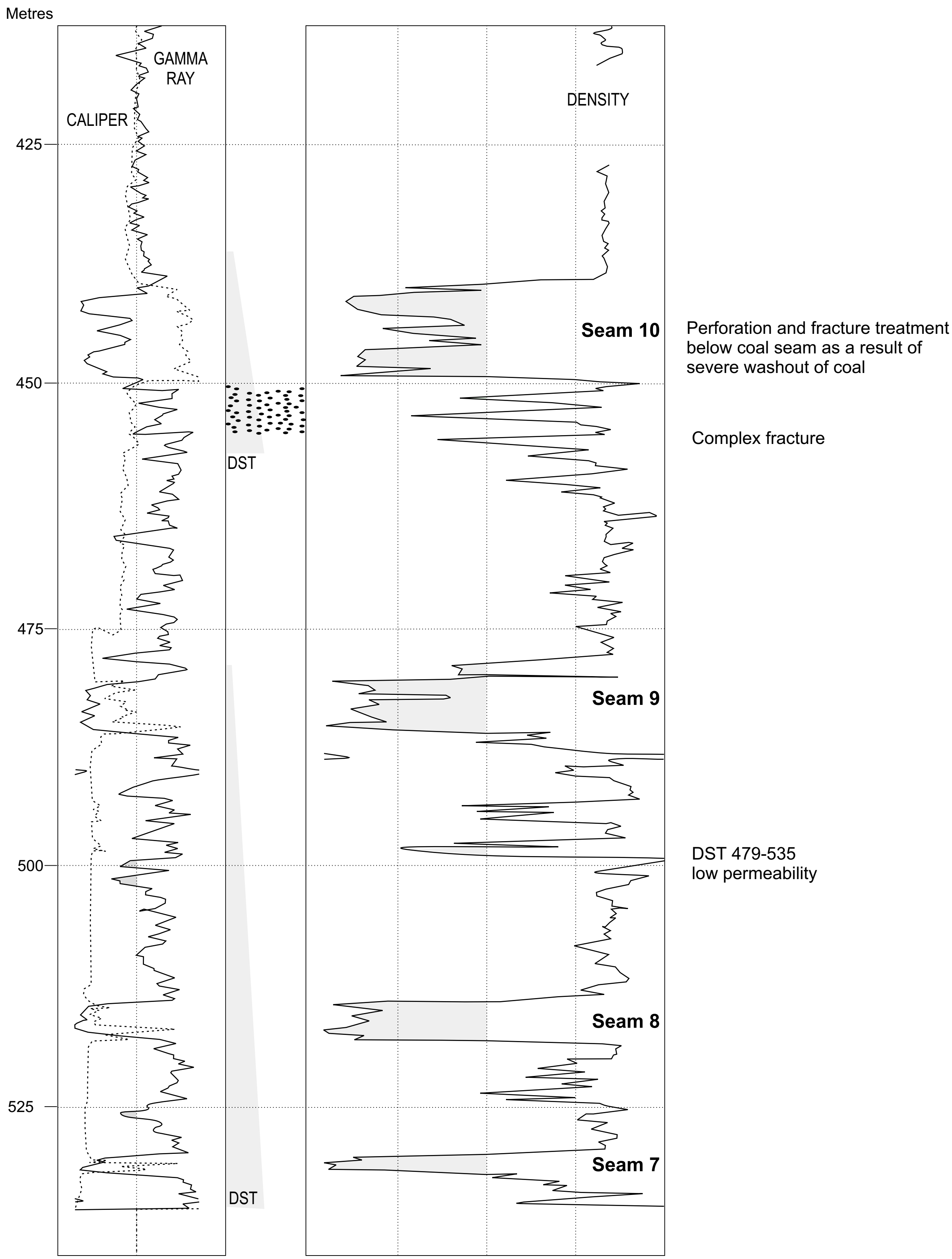


***Figure 25.*** *Detailed stratigraphic section of the Mist Mountain Formation in the Elk Valley Syncline exploration area.*

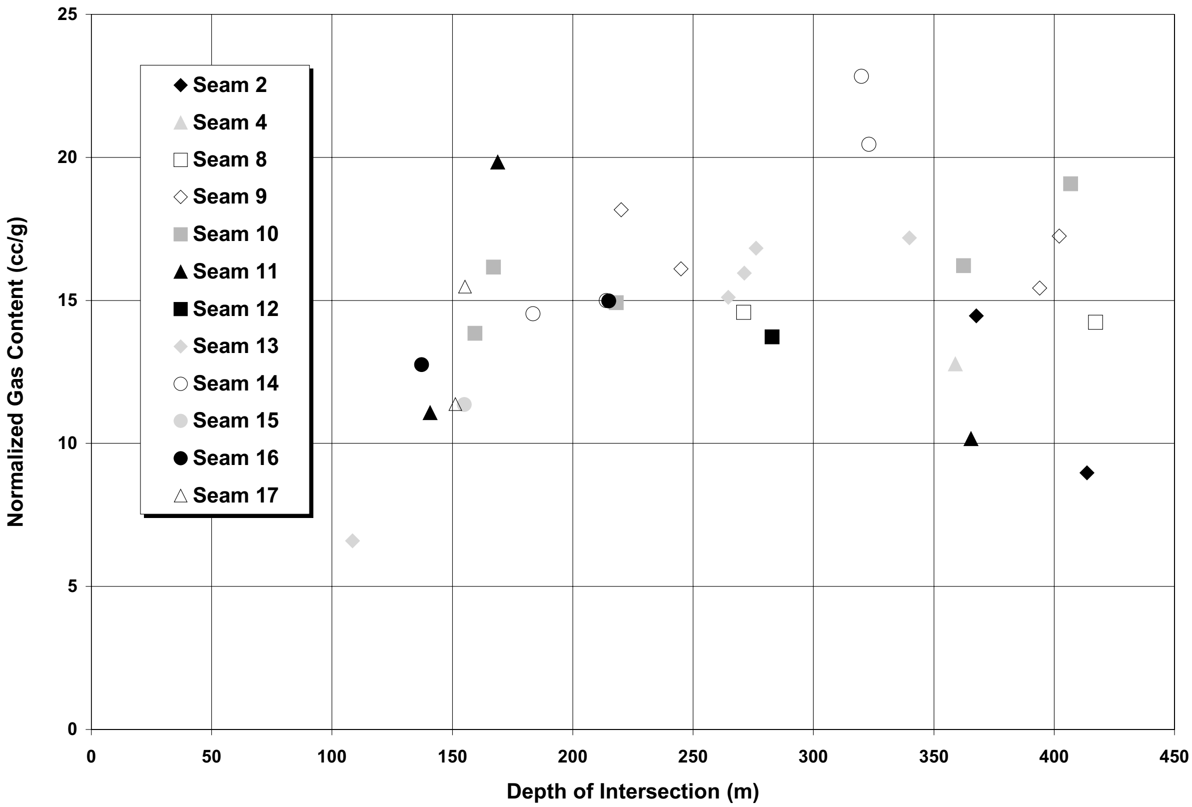


***Figure 26.*** *Normalized gas content versus depth of intersection, Elk Valley coal samples.*

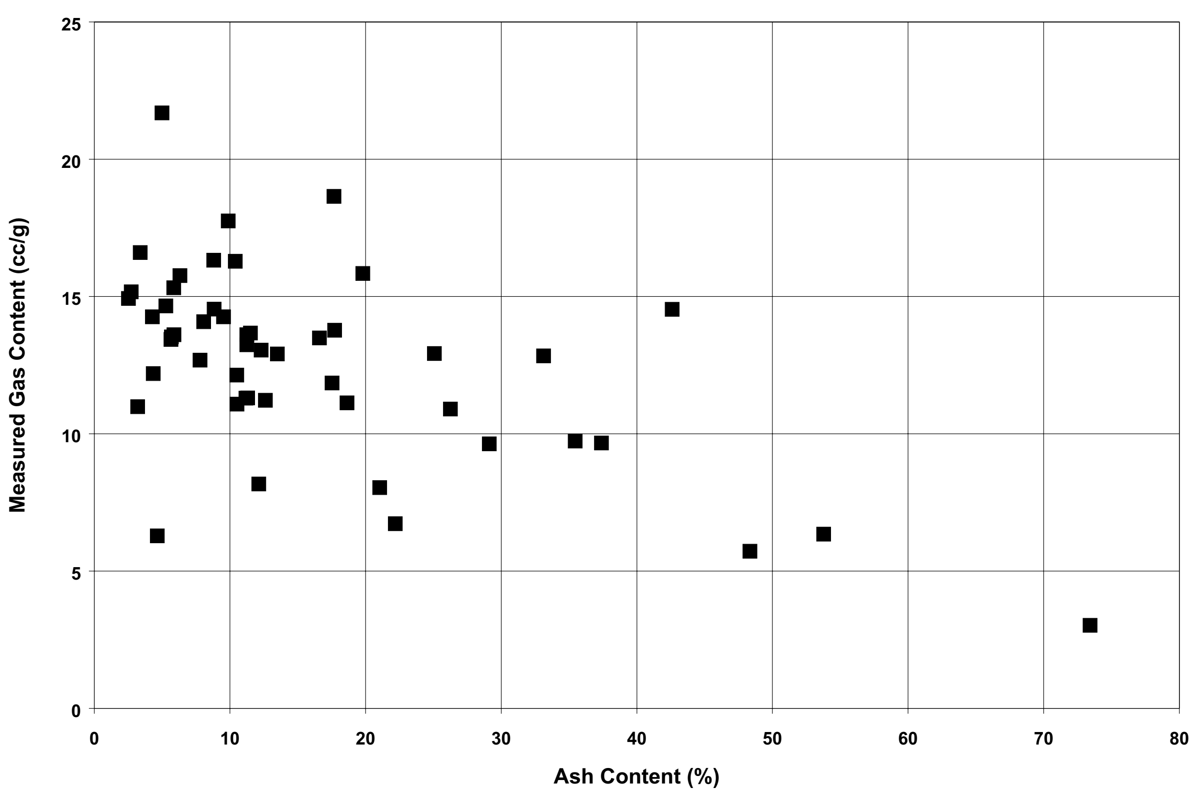


***Figure 27.*** *Measured gas content versus ash content for all Elk Valley samples.*

variability might explain the lower gas content in the lower seams. More significant is the impact of maceral composition on cleat development. In the vitrinite-rich coal, both face and butt cleats are well developed. In contrast, inertinite-rich coal has poor cleat development. The implications of this compositional variation with respect to the exploration targets chosen by Norcen will be discussed further under Technical Assessment.

*Adsorption isotherms.* After desorption experiments on the stratigraphic test wells, one sample (Seam 10) was retained for an adsorption isotherm experiment. Data from that isotherm are presented in Table 19. Initial results from the test suggested that a significant number of the coal samples tested were saturated or oversaturated (Fig. 28). Subsequent analyses of the data revealed that the gas composition of the canister samples contained up to 20% $CO_2$. This mixed gas component affects the Langmuir volume and pressure of the adsorption sample. Taking into account the $CO_2$ content, most of the coal samples appear to be slightly underpressured compared with assumed hydrostatic conditions. Adsorption curves for the Seam 10 sample, on as-measured and normalized bases are shown in Figure 29.

**Table 18**
**Proximate analyses, Norcen Elk Valley wells**

| Borehole | Seam number | Ash content (%) (d.b.) | Fixed carbon (%) (d.b.) | Volatile matter (%) (d.b.) |
|---|---|---|---|---|
| Elk Valley 64 | 2 | 5.87 | 72.14 | 21.99 |
| Elk Valley 64 | 9 | 10.40 | 70.77 | 18.82 |
| Elk Valley 64 | 10 | 11.73 | 67.62 | 20.65 |
| Elk Valley 64 | 11 | 48.34 | 36.62 | 15.04 |
| Elk Valley 65 | 10 | 17.27 | 62.46 | 20.28 |
| Elk Valley 65 | 11 | 21.04 | 57.70 | 21.26 |
| Elk Valley 65 | 13 | 3.39 | 71.73 | 24.88 |
| Elk Valley 65 | 14 | 11.34 | 64.31 | 24.35 |
| Elk Valley 65 | 16 | 12.25 | 62.92 | 24.83 |
| Elk Valley 65 | 17 | 39.35 | 40.42 | 19.24 |
| Elk Valley 66 | 8 | 20.72 | 59.28 | 20.01 |
| Elk Valley 66 | 9 | 23.35 | 56.97 | 19.67 |
| Elk Valley 66 | 10 | 13.85 | 65.37 | 20.77 |
| Elk Valley 66 | 12 | 53.78 | 31.04 | 15.19 |
| Elk Valley 66 | 13 | 19.70 | 55.78 | 24.52 |
| Elk Valley 66 | 14 | 7.64 | 65.21 | 27.15 |
| Elk Valley 66 | 15 | 3.20 | 67.95 | 28.86 |
| Elk Valley 66 | 16 | 4.35 | 66.52 | 29.13 |
| Elk Valley 67 | 2 | 17.17 | 63.67 | 19.17 |
| Elk Valley 67 | 4 | 11.70 | 70.71 | 17.59 |
| Elk Valley 67 | 8 | 8.45 | 72.40 | 19.15 |
| Elk Valley 67 | 9 | 14.62 | 64.21 | 21.18 |
| Elk Valley 67 | 10 | 8.89 | 69.40 | 21.71 |
| Elk Valley 67 | 11 | 24.15 | 55.70 | 20.16 |
| Elk Valley 67 | 13 | 4.65 | 71.91 | 23.43 |

*Formation testing.* Following completion of the four-hole stratigraphic drilling program, an injection/fall-off test was run on borehole 65. Preliminary results indicated that the coal was overpressured, with a pressure gradient of 12.4 kPa/m. Permeability estimates indicated that Seam 10 had a face cleat permeability of 75 mD and a butt cleat permeability of 25 mD. Simulations projected a peak gas flow of 440 Mcf/d, declining to 160 Mcf/d after 30 days. These results, coupled with the high gas content at shallow depth, encouraged Norcen to drill a production well (a-64-E/82-J-7), which was located immediately west of a-65.

The production test well was designed to evaluate Seams 8, 9 and 10, the lower two through open-hole completion and the upper Seam (10) with a hydraulic fracture through the intermediate casing. To eliminate formation damage, the borehole was supposed to have been drilled with clear water. However, discussions with Norcen personnel revealed that the well was apparently drilled with diesel fuel, although this could not be verified. The borehole was drilled with a large conventional oil and gas rig. The lack of fluid additives, coupled with the size of the drilling rig and circulation pumps, resulted in extensive borehole damage. Severe washouts occurred, particularly over the coal seam intervals.

**Table 19**
**Adsorption isotherm data,**
**Norcen Elk Valley (Seam 10)**

| Pressure (kPa) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|
| 344 | 4.84 | 5.59 |
| 689 | 8.13 | 9.37 |
| 1034 | 10.47 | 12.07 |
| 1379 | 12.19 | 14.06 |
| 1724 | 13.59 | 15.68 |
| 2068 | 14.53 | 16.76 |
| 2413 | 15.31 | 17.66 |
| 2758 | 16.09 | 18.56 |
| 3102 | 16.56 | 19.10 |
| 3447 | 17.19 | 19.82 |
| 3792 | 17.66 | 20.37 |
| 4136 | 18.13 | 20.91 |
| 4481 | 18.44 | 21.27 |
| 4826 | 18.75 | 21.63 |
| 5171 | 18.91 | 21.81 |
| 5516 | 19.06 | 21.99 |
| 5860 | 19.38 | 22.35 |
| 6205 | 19.69 | 22.71 |
| 6550 | 19.84 | 22.89 |
| 6894 | 20.00 | 23.07 |

Note: The above figures are based on an average ash content for Seam 10 of 13.31 %.

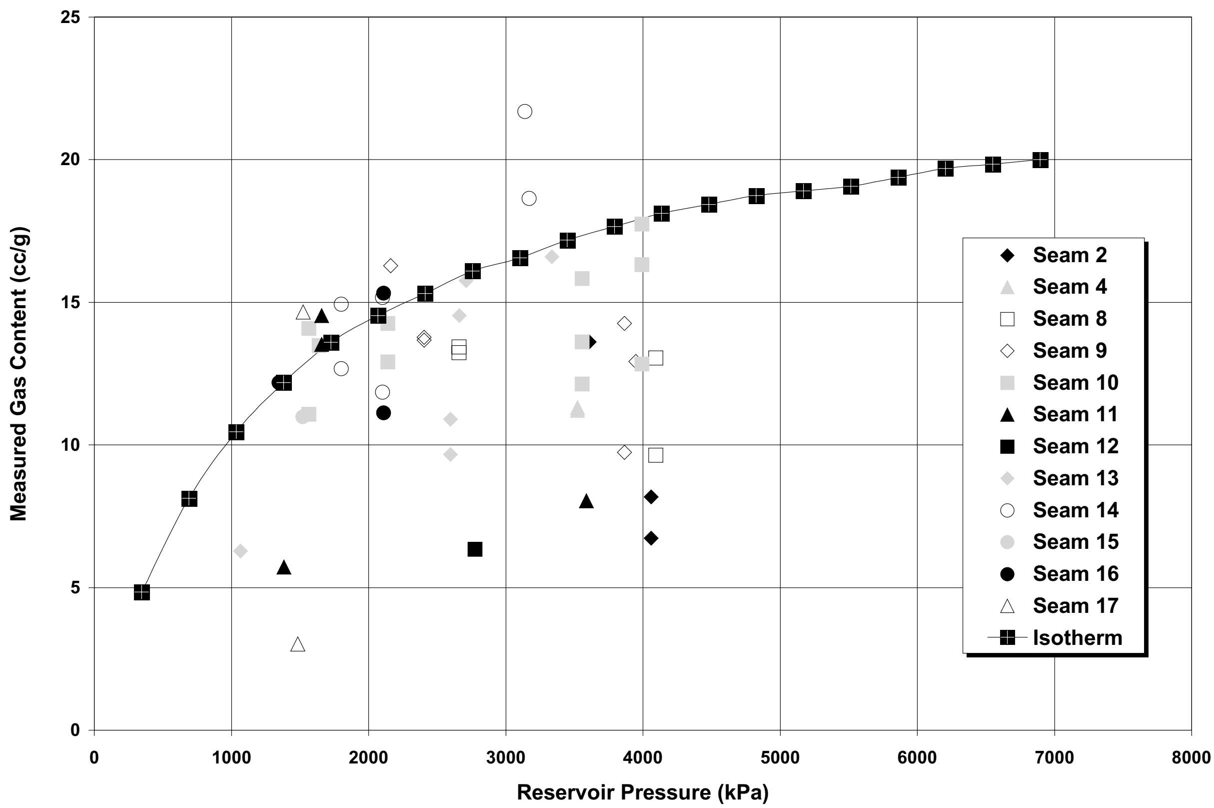


***Figure 28.*** *Comparison of measured gas content to adsorption isotherm values of Elk Valley samples.*

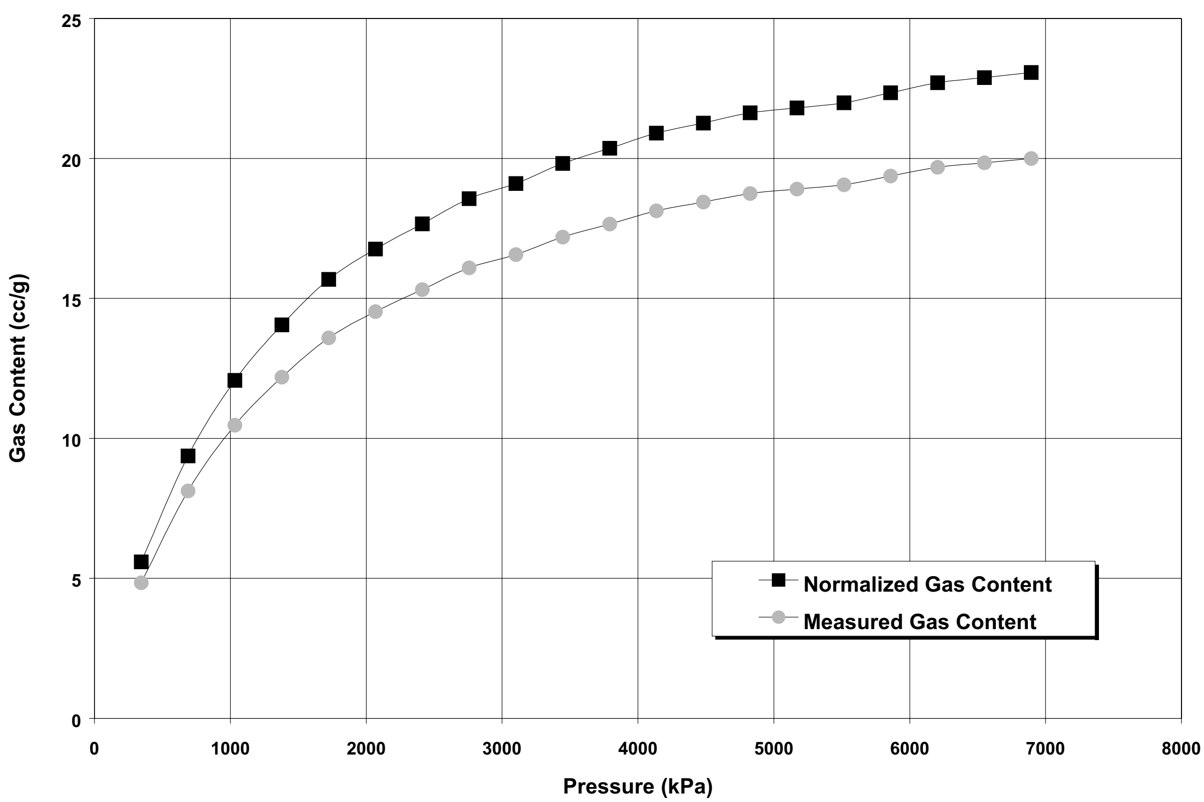


***Figure 29.*** *Adsorption isotherm for Seam 10, Elk Valley, illustrating measured and normalized gas curves. Adsorption temperature is 20°C.*

Testing of Seams 8 and 9 consisted of an injection/fall-off test, followed by a limited production test. The injection test consisted of an open-hole test with the packer set immediately above the intermediate casing liner. The test was conducted for two days, apparently in response to the low permeability readings obtained. Some variability in the pressure fall-off data indicated that the permeability results were suspect, partly because of the presence of a dual permeability system. The best match of the injection test data suggested a reservoir permeability of 0.7 mD. Final shut-in pressure was estimated at 5418 kPa, at a depth of 508.7 m. The formation pressure gradient for Seam 8 was calculated at 10.65 kPa/m, suggesting the reservoir was slightly overpressured. Production testing of Seams 8 and 9 (for less than two days) yielded limited minimal quantities of gas or formation water. No reservoir stimulation was attempted for these zones.

Following the completion of the open-hole test interval, a bridge plug was set at 477 m to allow a hydraulic fracture stimulation of Seam 10. The hydraulic fracture stimulation (frac) zone was completed in the 5 m interval immediately below the main coal zone. Perforating was done below the No. 10 coal zone to avoid the large cement volume that filled the extensive washouts during cementing of the intermediate casing, and to minimize plugging of the perforations because of the friable nature of the coal. It was believed that the fracture would propagate upward into the overlying coal horizon. The fracture stimulation consisted of 342 $m^3$ of fresh water and 47 tonnes of sand proppant. An injection/fall-off test was completed on the frac zone before production testing. However, the well was still in flowback condition during testing, so the analytical results are suspect.

Limited production tests were initiated for Seam 10, with a peak gas flow rate of 20,954.3 $m^3$/d. Flow rates stabilized at 2010.5 $m^3$/d and 9.857 $m^3$/d of gas and water, respectively, before pump problems forced the well to be shut in. Upon re-establishment of dewatering, gas and water flows were 1812.28 $m^3$/d and 5.087 $m^3$/d. Pumping problems still persisted and the well was finally shut in after a total production period of three weeks and cumulative production of 22,795.1 $m^3$of gas. A final pressure buildup test was completed, and extrapolated values of 4670 kPa for reservoir pressure and 0.9 mD for permeability were derived. The well was subsequently plugged with a bridge plug and is currently suspended.

*Technical assessment.* The Norcen Elk Valley coalbed methane exploration program was initiated to test the thick, gassy coal of the Mist Mountain Formation. The original target location was chosen as a result of historical reports of gas at the surface from shallow coal exploration boreholes. The four stratigraphic test wells demonstrated the presence of thick coal containing substantial quantities of methane gas at shallow depths. Original data interpretation suggested that the coal was oversaturated and that the formation coal had reservoir permeability values up to 71 mD. Reinterpretation of the data following the limited production test well revealed that the apparent overpressuring of the coal, as observed from the desorption curves, was caused in part by the produced gas having a significant $CO_2$ component (up to 29%). The high permeability values obtained in the initial injection tests were a result of the coal seam being fractured during the injection stage.

The limited production test well was designed to evaluate the production potential of Seams 8, 9 and 10. Open-hole testing for Seams 8 and 9 was conducted for only two days and the well was not stimulated. Although minimal quantities of gas and water were recovered, the wellbore was extensively damaged and it is not known how much formation damage was present in the two coal zones. If the well had been drilled with diesel fuel instead of clear fluids, then extensive swelling of the coal could have occurred. This would have blocked any fracture and cleat permeability present before drilling. A production test of only two days is inadequate to fully evaluate the potential of a zone, particularly with ongoing mechanical difficulties in the test mechanism.

The Seam 10 production test appears to have been compromised as a result of cement damage. Although the perforations might have penetrated the cement zone below the coal where the borehole is less washed out, there is no indication that when the fracture was completed, significant communication with the overlying seam was established. Experience from the Black Warrior Basin in Alabama has shown that hydraulic fractures completed at depths of less than 600 m are commonly T-shaped or horizontal. The gradational contact at the base of Seam 10 indicates that an impermeable carbonaceous mudstone floor would lie between the coal and the fracture zone. It is highly possible that the fracture could have extended up to the base of the coal and then run horizontally without penetrating the coal zone significantly. Following the fracture stimulation, mechanical difficulties continued to plague production operations, so that during the test, only short periods of uninterrupted pump time occurred. Examples from the San Juan Basin have demonstrated that interruptions in pumping of the reservoir commonly result in reduced productivity of the coal reservoir.

The location of the production test well was on the limb of the Alexander Creek syncline (Fig. 30). Dip of the strata was about 35°. In situ stress measurements for fracture closure were estimated at 13.5 kPa/m (3.0 kPa/m higher than the reservoir pressure), suggesting that the cleat system was closed and that the coal was still in a compressive regime. No exploration data exist for the reservoir stress or permeability

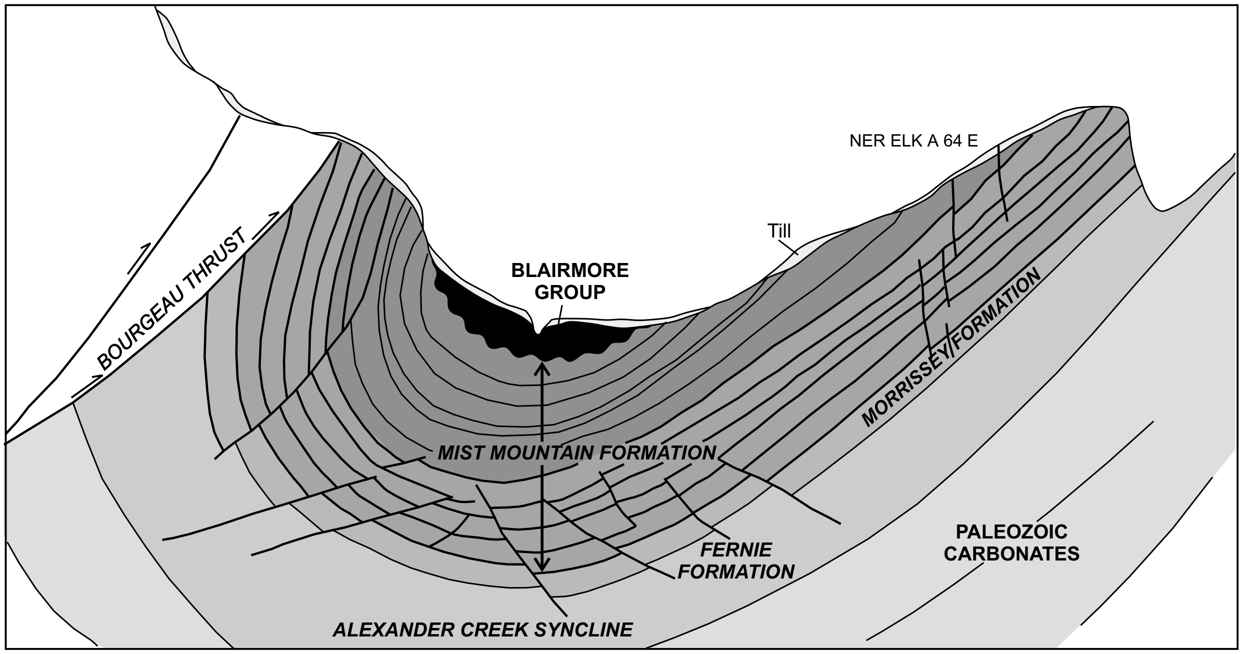


***Figure 30.*** *Schematic diagram of Alexander Creek Syncline illustrating regions of possible permeability enhancement.*

in the axis of the structure, where a more tensional regime, more favourable to methane production, might be present. The presence of thick coal containing large volumes of methane gas at shallow depths indicates that the Elk Valley area is a potential exploration target that requires further examination.

## Northeast region

### *Phillips Petroleum Flatbed project*

Phillips Petroleum Canada Ltd. drilled four coalbed methane exploration wells near the town of Tumbler Ridge in northeastern British Columbia in the winter of 1995/96 (Fig. 31). The wells targeted thick coal of the Lower Cretaceous Gates Formation, and a total of 13 coal zones were intersected. Cumulative thickness for the Gates Formation coal is over 30 m. Five "major" zones were identified (A, B, C, D and H) each ranging up to 6.7 m in thickness over a total stratigraphic interval of 175 m. The total combined thickness of these five zones averages 20 m. Major coal zones were penetrated at depths between 1200 and 1550 m in each well.

Core samples recovered from the coal seams were logged, and selected samples were placed in desorption canisters to determine gas content values. Measured gas content varied according to seam. Values normally ranged between 6.63 cc/g (212 scf/ton) and 25.80 cc/g (826 scf/ton). Proximate analyses of the samples gives a wide range of ash content, varying from 3.63% air-dried basis (a.d.b.) to 51.46% a.d.b. and averaging 14.43%. As expected, higher gas content values are related to lower ash content.

Coal quality data indicate that the coal in all zones has an average value of 26.31% volatile matter on a d.m.m.f. (dry mineral matter free) basis and falls into the medium volatile bituminous rank. These values are consistent with vitrinite reflectance values in the region.

Four adsorption isotherms were completed on well a-21-F, one for each of the lower coal zones (zones A, B, C and D). Langmuir volumes ranged from 19.8 to 25 cc/g with corresponding Langmuir pressures of 2230 and 2730 kPa, respectively. A comparison of measured values with adsorption values indicates that in well a-21-F, overpressured conditions exist for Seams C and D, and slightly underpressured conditions exist for Seams A and B.

*Data acquisition.* The Phillips Flatbed wells were drilled using two conventional oil and gas drilling rigs. Borehole diameter was 200 mm and drilling fluid was a polymer-based mud system or a compressed air circulating system. Upon reaching core point, the rotary drill string was removed and the hole cased and cemented to core point. The conventional drill string was replaced with a specialized wireline pipe and core barrel system. Coring was carried out using the polymer-based mud system. Normally, coring runs were taken in 2.5 m intervals. Inner core barrel retrieval


***Figure 31.*** *General location map for the Phillips Flatbed exploration area.*

times varied depending on depth and hole conditions, but normally ranged between 15 and 20 minutes. The coal was described, measured in detail, then quickly placed into sealed desorption containers. The containers were weighed and placed into a controlled temperature environment for desorption measurements. Canisters from each well were desorbed at varying temperatures. For example, well d-93-B was desorbed at 31$^{o}$C, d-17-G at 34 $^{o}$C, a-21-F at 50$^{o}$C and d-64-B at 31$^{o}$C and 35$^{o}$C. The cause of the higher temperature of canisters from well a-21-F was a fault in the box heating system.

*Geology.* The Phillips Flatbed wells intersected the Gates Formation coal measures at depths from 1150 m in d-93-B to 1400 m in d-64-B. Figures 32 to 35 present stratigraphic sections that illustrate details of the Gates strata intersected in each well and the correlation of identifiable coal zones.

Four major and several smaller coal zones were intersected. Correlatable zones were designated by letters in ascending order. For example, the lowest coal zone in the section is designated as “A” and individual coal zones above are designated “B” to “J” in ascending order. Where individual correlatable zones contained thinner correlatable seams, they were given an ascending number after the zone letter. For example, coal zone “E” has three, thin, identifiable seams designated as “E1” to “E3” in ascending order (see Fig. 33). Where an identified subseam coalesces with another subseam, they are identified as an undifferentiated lettered zone or seam (e.g., zone “G”). The coal zone designations identified in this report are not intended to correlate with other seam designation systems from the region. Where coal zones coalesce, the interval is designated by a joint letter nomenclature, e.g., “zone C-D” (see Fig. 34). Following are more detailed descriptions of the four informal stratigraphic units of the Gates Formation.

<u>Unit 4.</u> Unit 4 consists of the J coal zone interval and associated strata. It is generally 20 to 30 m thick. Coal zone J consists of up to five discrete and continuous seams separated by siltstone and carbonaceous mudstone. Individual seams are up to 1.6 m thick.

<u>Unit 3.</u> Unit 3 consists of a 35 m thick sequence of stacked conglomerate units with lesser amounts of sandstone and coal. This unit occurs in three of the wells but is absent in well d-64-B (Fig. 35). The absence of this unit is interpreted as a local facies change from north to south. Unit 3 contains coal zone “I”, located within the stacked conglomerate and sandstone layers. The coal zone’s presence within the middle of the conglomerate sequence suggests that several cycles of coarse clastic deposition occurred and that the upper cycles appear to be non-erosional in nature. The main seam in coal zone I ranges from 1 to 1.5 m thick.

<u>Unit 2.</u> Unit 2 consists of a 150 m thick stratigraphic interval that contains the main coal-bearing zones from B to H. The top of Unit 2, Seam H, lies directly below the Unit 3 conglomerate. The thickness of Seam H is variable and may indicate some localized scouring by the overlying conglomerate. In well d-17-G where Unit 3 conglomerate is absent, a 3 m thick seam is present and is included as an upper layer of zone H (Fig. 33) . It is possible that upper Seam H had been eroded where the conglomerate was deposited, but might be present where the conglomerate unit is absent.

Below zone H is a series of thinner but laterally consistent coal zones from G to E. Interburden between these zones is more inconsistent because of local coarser units. Zone G consists mainly of two separate coal seams, each up to 1.5 m thick. Zone F is a thin but continuous coal up to 0.5 m thick. Coal zone E consists of three distinct coal seams identified as E1, E2 and E3. Individual thicknesses range from 0.4 to 1.6 m.

Zone D is a thick coal seam that grades laterally into three individual seams (well d-17-G) separated by individual partings up to 1.0 m thick. Individual seam thicknesses range from 1.0 to 5.8 m.

Coal zone C, located up to 29 m below zone D, contains the thickest and most continuous coal seam interval. It rarely contains any partings and ranges from 4.8 to 6.7 m thick. Locally zones C and D coalesce to form one thick coal zone separated by an 80 cm thick mudstone parting (well a-21-F). Zone B, found about 25 m below zone C, is a thick, continuous seam ranging from 3.6 to 4.0 m.

<u>Unit 1.</u> Unit 1 is equivalent to the Torrens Member, defined as the base of the Gates Formation. It is a thick, massive quartzitic sandstone unit, interpreted as a wave-to tidal-dominated clastic shoreline deposit (Leckie and Walker, 1982). The Torrens Member is laterally continuous and for the most part represents a distinguishing feature of the Gates Formation. Although none of the four wells penetrated the total Unit 1 interval, it is estimated to be 35 to 40 m thick from other wells in the area. Unit 1 contains coal zone A, consisting of a single seam ranging from 3.0 to 3.7 m thick. Only two of the four Phillips wells were drilled to the zone A interval. Tables 20 to 23 are summaries of coal zone intervals intersected in each of the Phillips Flatbed wells.

The total combined net coal thickness varies from well to well, ranging up to 32 m. When individual seams less than 1 m thick are excluded, the cumulative coal thickness ranges up to 28.7 m, averaging 21.5 m. The combined average thickness for the five major zones is about 20.1 m (Table 24). Although overall core recovery from each well ranged

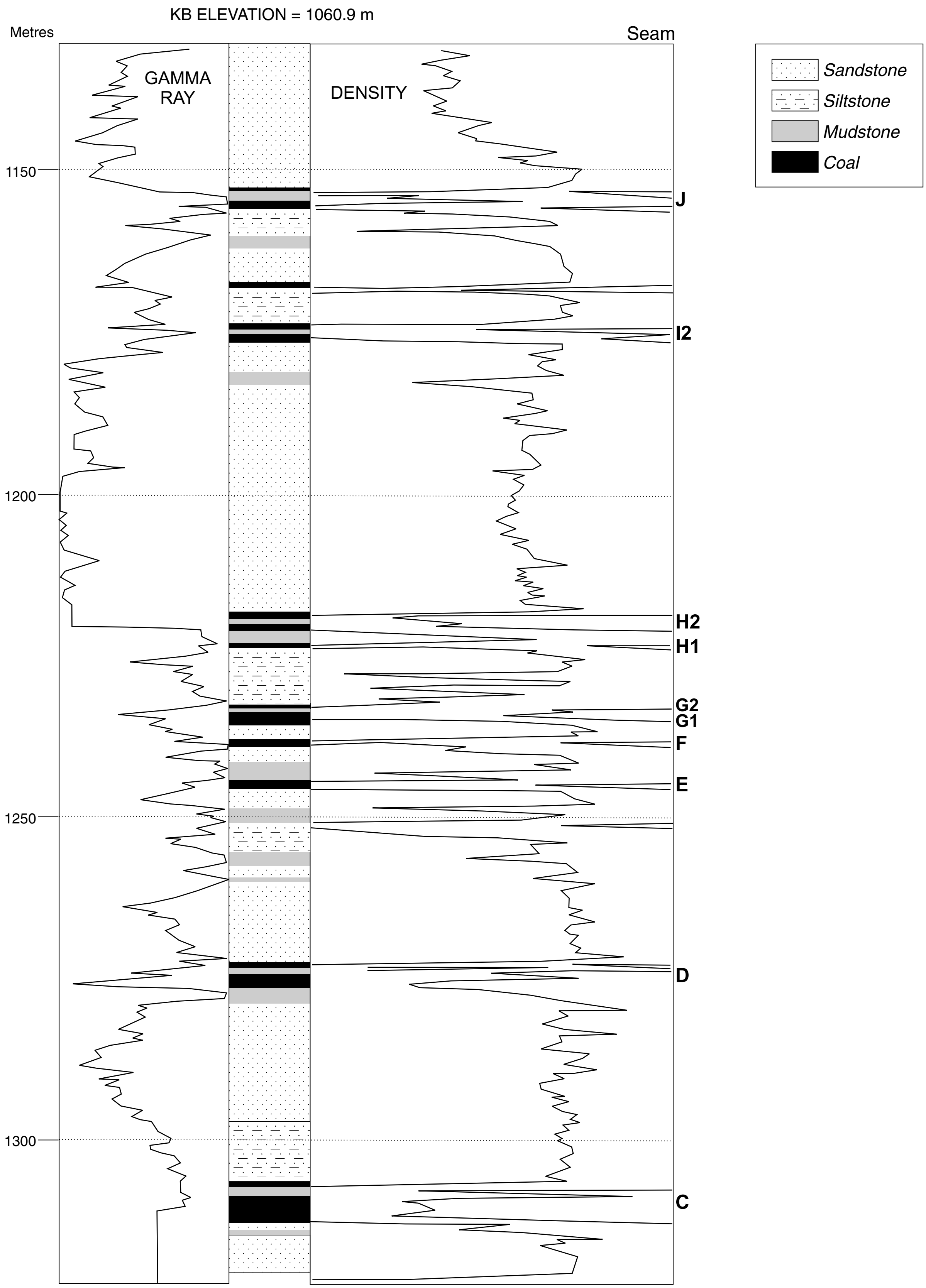


***Figure 32.*** *Detailed stratigraphic section of the Phillips d-93-B/93-I-15 borehole.*

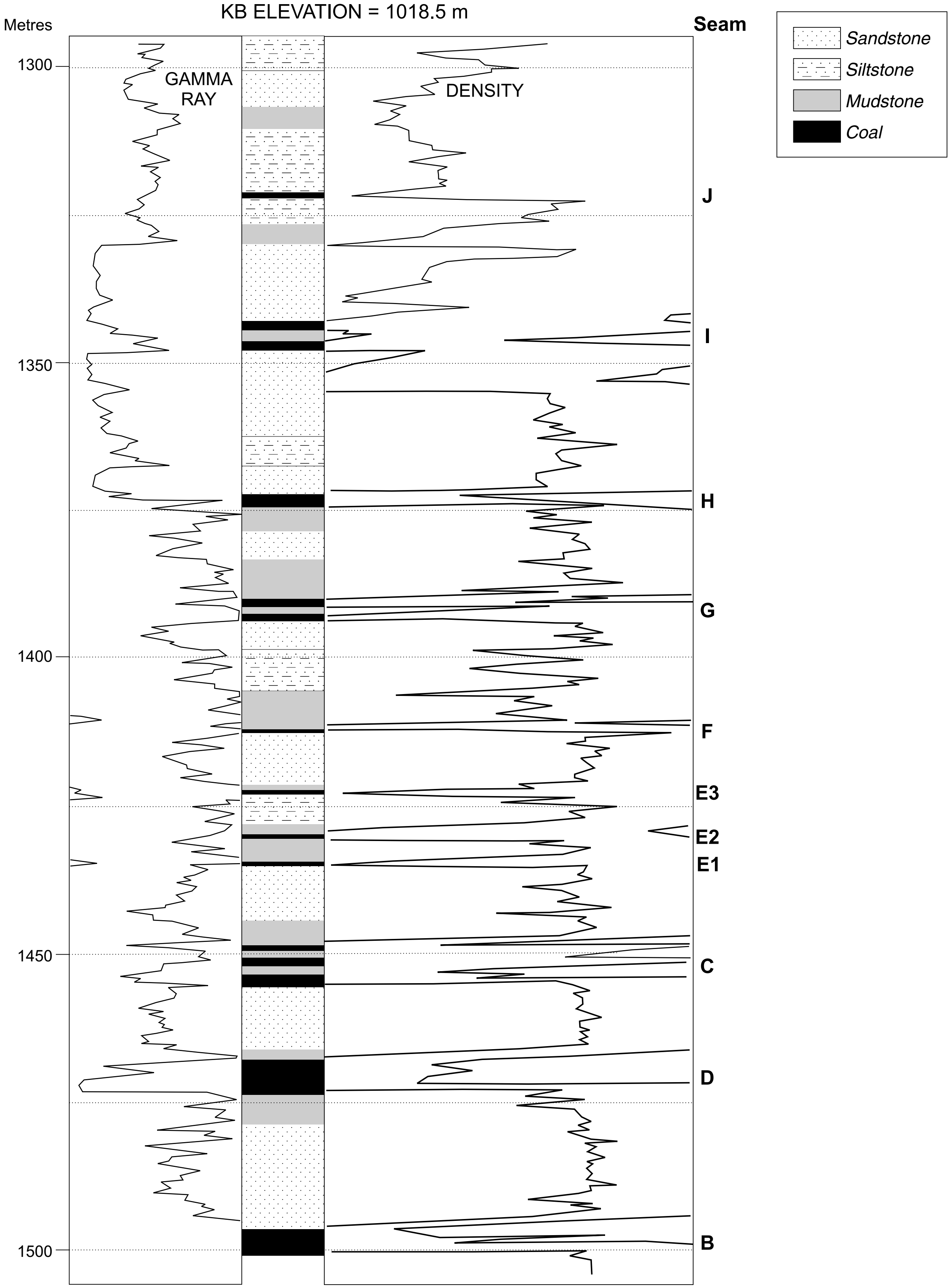


***Figure 33.*** *Detailed stratigraphic section of the Phillips d-17-G/93-I-15 borehole.*

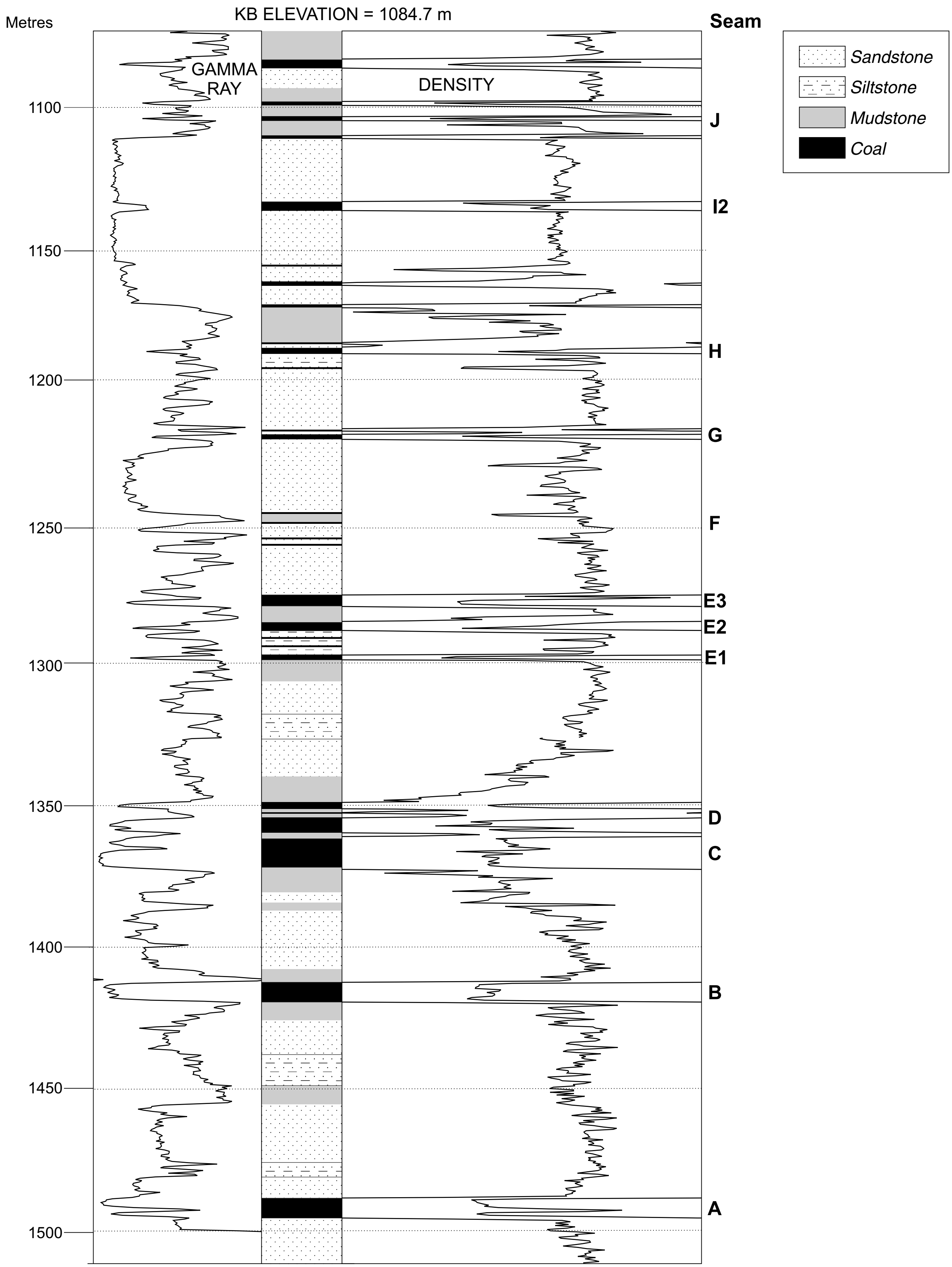


***Figure 34.*** *Detailed stratigraphic section of the Phillips a-21-F/93-I-15 borehole.*

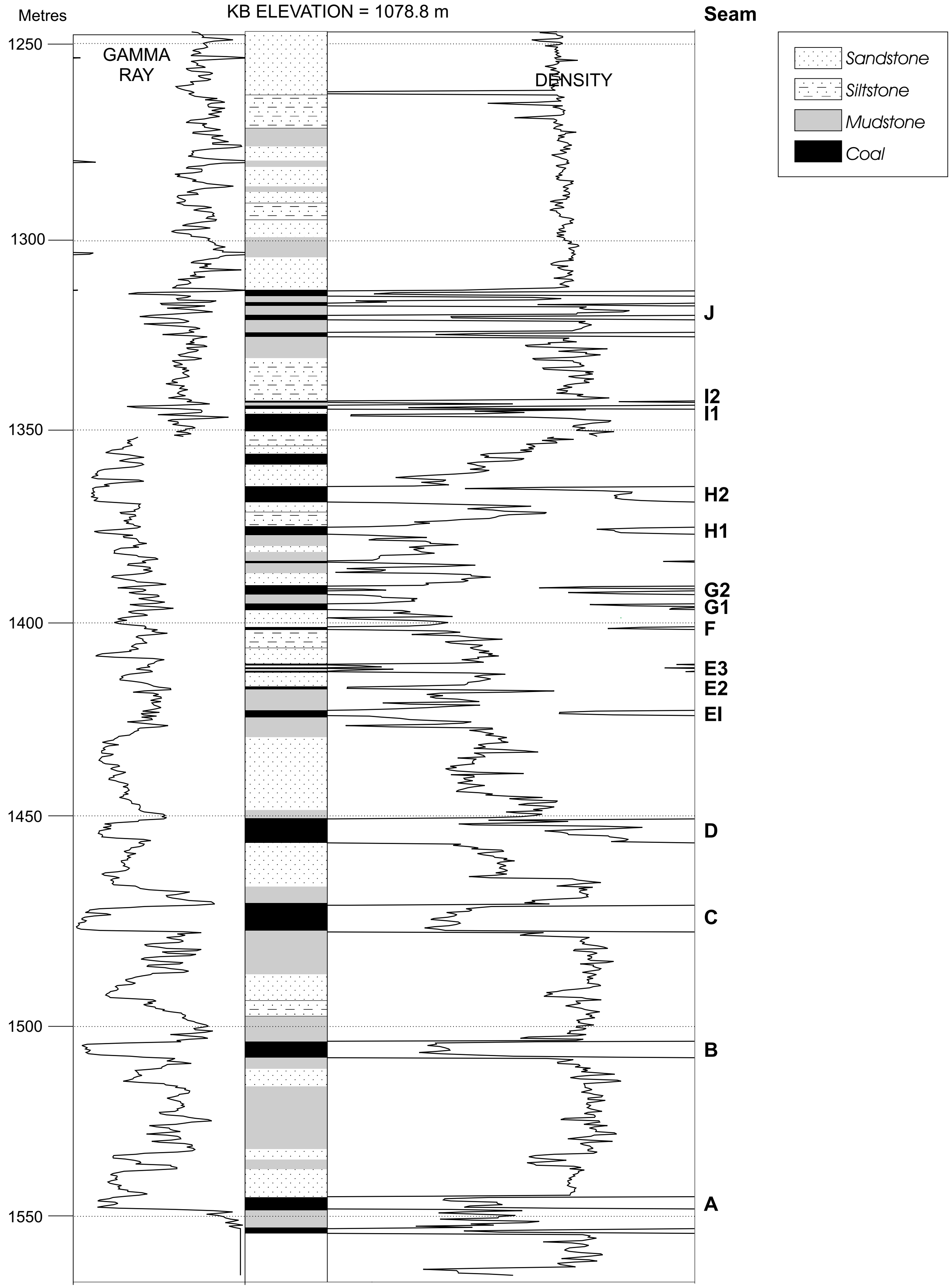


***Figure 35.*** *Detailed stratigraphic section of Phillips d-64-B/93-I-15 borehole.*

**Table 20**
**Well d-93-B coal zone summary**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Gross zone thickness (m) | Net zone thickness (m) |
|---|---|---|---|---|
| J | 1153.44 | 1154.4 | 0.96 | 0.66 |
| J | 1155.67 | 1156.1 | 0.43 | 0.43 |
| J | 1157.81 | 1157.97 | 0.16 | 0.16 |
| I2 | 1182.73 | 1184 | 1.27 | 1.27 |
| H | 1218.55 | 1220.85 | 2.3 | 2.3 |
| G1 | 1233.02 | 1234.28 | 1.26 | 1.26 |
| E3 | 1244.16 | 1244.83 | 0.67 | 0.67 |
| D | 1272.43 | 1272.72 | 0.29 | 0.29 |
| D | 1273.6 | 1277.04 | 3.44 | 3.44 |
| C | 1306.42 | 1311.58 | 5.16 | 4.81 |
| Total | | | 15.94 | 15.29 |

**Table 21**
**Well d-17-G coal zone summary**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Gross zone thickness (m) | Net zone thickness (m) |
|---|---|---|---|---|
| I | 1345.60 | 1347.00 | 1.4 | 1.4 |
| H | 1372.25 | 1374.64 | 2.39 | 2.39 |
| G2 | 1389.60 | 1391.15 | 1.55 | 1.25 |
| E2 | 1428.60 | 1430.10 | 1.5 | 1.5 |
| E1 | 1433.90 | 1434.30 | 0.4 | 0.4 |
| D | 1448.05 | 1449.08 | 1.03 | 1.03 |
| D | 1450.00 | 1451.00 | 1.0 | 1.0 |
| D | 1451.30 | 1451.60 | 0.3 | 0.3 |
| D | 1452.52 | 1454.48 | 1.96 | 1.96 |
| C | 1467.56 | 1473.22 | 5.66 | 5.66 |
| B | 1496.25 | 1500.10 | 3.85 | 3.59 |
| Total | | | 21.04 | 20.48 |

between 90 and 95%, coal seam core recovery was generally poor and variable.

*Gas content.* Desorption samples were collected for 11 individual coal zones. Table 25 summarizes the distribution of desorption canisters according to well and zone.

A summary of average gas desorption results is given in Table 26. As-measured desorption results are widely variable, ranging from 3.54 to 25.80 cc/g. The two lowest values of 3.54 cc/g, (canister No. 46) and 5.35 cc/g (canister No. 48) appear to be anomalously low relative to the ash and gas content data from adjacent canister tests. It might be possible that these two values are invalid because of a leak in the canister seal. If these low values were eliminated from the data set, the lowest gas content value recorded would be 6.63 cc/g. Lost gas volumes vary between 8 and 20% and average 16%. Trip times ranged between 15 and 20 minutes.

Average “as measured” gas content data for all samples is 16.31 cc/g. The upper coal zones (Seams E to J) have

**Table 22**
**Well a-21-F coal zone summary**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Gross zone thickness (m) | Net zone thickness (m) | True net thickness (m) |
|---|---|---|---|---|---|
| J | 1138.5 | 1140.5 | 2 | 2 | 1.64 |
| I2 | 1172.6 | 1174.4 | 1.8 | 1.8 | 1.47 |
| H | 1207 | 1208.3 | 1.3 | 1.3 | 1.06 |
| G | 1226.5 | 1227.4 | 0.9 | 0.9 | 0.74 |
| G | 1228 | 1229 | 1 | 1 | 0.82 |
| E3 | 1266.15 | 1268.55 | 2.4 | 2 | 1.64 |
| E2 | 1273.1 | 1274.07 | 0.97 | 0.97 | 0.8 |
| E1 | 1280.55 | 1281.4 | 0.85 | 0.85 | 0.7 |
| D | 1315.35 | 1316.79 | 1.44 | 1.44 | 1.18 |
| D | 1319 | 1322.4 | 3.4 | 3.4 | 2.79 |
| C | 1323.56 | 1331.05 | 7.49 | 7.49 | 6.14 |
| B | 1358.1 | 1362.8 | 4.7 | 4.7 | 3.85 |
| A | 1409.4 | 1413.89 | 4.49 | 4.49 | 3.68 |
| Total | | | 32.74 | 32.34 | 26.51 |

*Note: True thickness for well a-21-F was calculated using an average dip to core axis of 55°.

**Table 23**
**Well d-64-B coal zone summary**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Zone thickness (m) | Net coal thickness (m) |
|---|---|---|---|---|
| J | 1315.00 | 1315.80 | 0.80 | 0.80 |
| J | 1317.80 | 1318.45 | 0.65 | 0.65 |
| J | 1321.10 | 1322.00 | 0.90 | 0.90 |
| J | 1325.50 | 1326.35 | 0.85 | 0.85 |
| I | 1343.65 | 1344.65 | 1.00 | 1.00 |
| H2 | 1362.60 | 1366.25 | 3.65 | 3.65 |
| H1 | 1373.00 | 1374.50 | 1.50 | 1.50 |
| G1 | 1387.85 | 1389.90 | 2.05 | 1.45 |
| E3 | 1419.50 | 1420.70 | 1.20 | 1.20 |
| D | 1447.25 | 1453.10 | 5.85 | 5.85 |
| C | 1469.20 | 1475.90 | 6.70 | 6.70 |
| B | 1504.00 | 1507.96 | 3.96 | 3.96 |
| A | 1543.43 | 1546.45 | 3.02 | 3.02 |
| A | 1551.73 | 1552.61 | 0.88 | 0.88 |
| Total | | | 33.01 | 32.41 |

**Table 24**
**Summary of major coal zones, Phillips Flatbed**

| Major zone | Depth range of seam (m) | Net thickness range (m) | Combined thickness of partings (m) | Average net coal thickness (m) |
|---|---|---|---|---|
| H | 1207 – 1362 | 1.1 – 5.0 | 0 – 6.7 | 2.70 |
| D | 1272 – 1447 | 3.7 – 5.8 | 0 – 2.2 | 4.50 |
| C | 1306 – 1475 | 4.8 – 6.7 | 0 – 0.4 | 5.80 |
| B | 1330 – 1504 | 3.6 – 4.0 | 0 – 0.3 | 3.70 |
| A | 1365 – 1543 | 3.0 – 3.7 | 0.00 | 3.40 |
| Total | | | | 20.1 |

**Table 25**
**Number of desorption canisters according to well and zone, Phillips Flatbed project**

| Coal zone | d-93-B | d-17-G | a-21-F | d-64-B | Total |
|---|---|---|---|---|---|
| J | 2 | | | | 2 |
| I | 2 | | | | 2 |
| H | 1 | 2 | 1 | | 4 |
| G | 2 | 2 | | | 4 |
| F | | | | | 0 |
| E3 | 1 | | 2 | | 3 |
| E2 | | | 1 | | 1 |
| E1 | | 1 | | | 1 |
| D | 1 | 5 | 2 | 2* | 10 |
| C | 8 | 7 | 9 | 4 | 28 |
| B | | 4 | 4 | 3 | 11 |
| A | | | 3 | 2 | 5 |
| Total | 17 | 21 | 22 | 11 | 71 |

*Seam D samples for d-64-B were rotary chip samples.

**Table 26**
**Ranges and average gas content values, Phillips Flatbed project**

| Coal Zone | Gas content (low ) (cc/g) | Gas content (high) (cc/g) | Gas content (avgerage) (cc/g) | Normalized gas content (cc/g) | No. of analyses |
|---|---|---|---|---|---|
| A | 11 | 16 | 14 | 17 | 5 |
| B | 15 | 26 | 19 | 21 | 11 |
| C | 7.48 | 22.95 | 18.5 | 21 | 26 |
| D | 7.81 | 21.08 | 16.24 | 20.46 | 8 |
| E-J | 6.63 | 17.03 | 12.23 | 16.42 | 17 |

measured gas content values ranging from 6.63 to 17.03 cc/g, averaging 12.23 cc/g. In contrast, the lower seams (A, B, C and D) have average measured gas content values of 13.94, 18.59, 18.50 and 16.24 cc/g, respectively. When desorption data are corrected to a d.m.m.f. (dry mineral matter free) basis, average gas content for the Gates Formation is 19.42 cc/g, while individual seams still reflect the trend of decreasing gas content in the higher stratigraphic coal zones (Table 26).

Comparing normalized gas content to depth of intersection (Fig. 36), reveals a wide data scatter with a weak trend of increasing gas content with increasing depth. This relationship is not obvious and may actually be a manifestation of the lower gas content of the E to J coal zones. There are two possible reasons the coal does not display a definitive relationship between gas content and depth: 1) the narrow depth range of coal intersection, and 2) depth of intersection for all coal greater than 1000 m.

*Coal quality.* Ash content was widely variable, ranging from 3.86 to 51.46% a.d.b. and averaging 14.43% a.d.b. Sulphur content was generally low, averaging 0.62%. Mineral matter values were calculated using the Parr Formula (ash% x 1.08 + sulphur% x 0.55 = dry mineral matter free ash content) and ranged from a low of 4.37% to a high of 55.73%.

Volatile matter content ranged from 17.79 to 41.09% d.m.m.f. and averaged 26.31% d.m.m.f., placing the coal as low to medium volatile bituminous in rank. This rank translates into an $R_o$ max % range of 1.1 to 1.3, ideal for thermogenic methane generation.

A comparison of measured gas content value to mineral matter reveals a general trend of decreasing gas content with increasing mineral matter (Fig. 37). It can be seen that most of the data points fall within the 5 to 15% mineral matter range. Within this zone, measured gas content values are variable, ranging from 10 to greater than 25 cc/g. Note that coal zones E to J have lower normalized gas contents (with two exceptions) compared with the coal of the lower Gates Formation (zones A to D).

Measured gas content data was plotted against theoretical gas content values (as determined using the Kim equation; Kim, 1975). Results indicate that many of the canister tests contained sufficient quantities of gas to suggest that the coal is at or near saturation levels (Fig. 38). As observed in previous figures, the samples taken for coal zones E to J appear to be below theoretical saturation level, whereas numerous samples from Seams B, C and D are at or above saturation level. A plot of measured gas content values versus theoretical gas content values on a hole-by-hole basis (Fig. 39), suggests that the coal penetrated in borehole a-21-F is above saturation level and that the borehole may be overpressured. These results are consistent with field observations where significant gas kicks were recorded from the gas detector during the coring procedures and at every drill string connection. The graph (Fig. 39) also suggests that gas content recorded for samples from boreholes d-64-B and d-17-G is near saturation level. In contrast, the coal intersected in borehole d-93-B appears to be below saturation level. It should be noted that this coal (d-93-B) is from the upper zones (E to J).

In the Phillips Flatbed well bores, Gates Formation coal was intersected in the 1150 to 1550 m depth range. Figure 36 illustrates the marginal increase in gas content with increased depth. Increased depth of the main coal zones (A to D) does not significantly affect the volume of gas within the coal. Increase in resource potential (i.e., higher gas content) appears to be more controlled by coal quality, particularly the ash content.

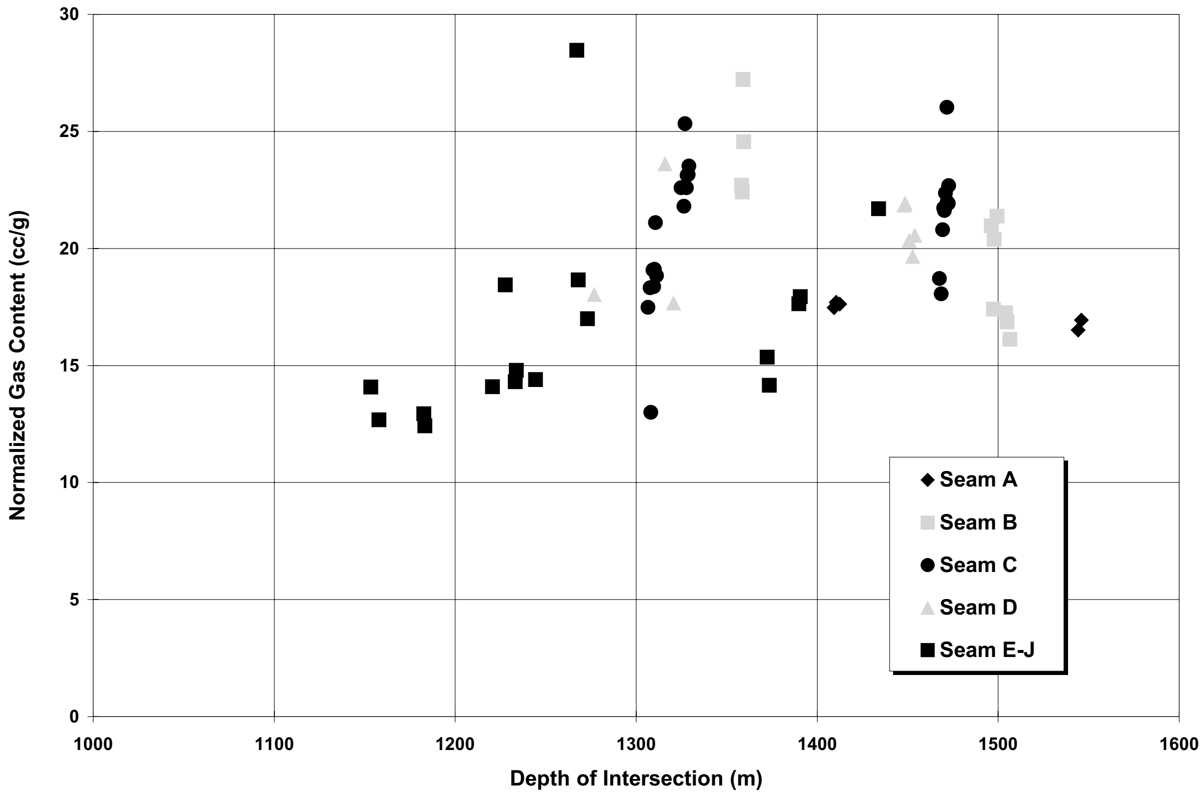


***Figure 36.*** *Normalized gas content (d.m.m.f. basis) versus depth of intersection by seam designation, Phillips Flatbed exploration area.*

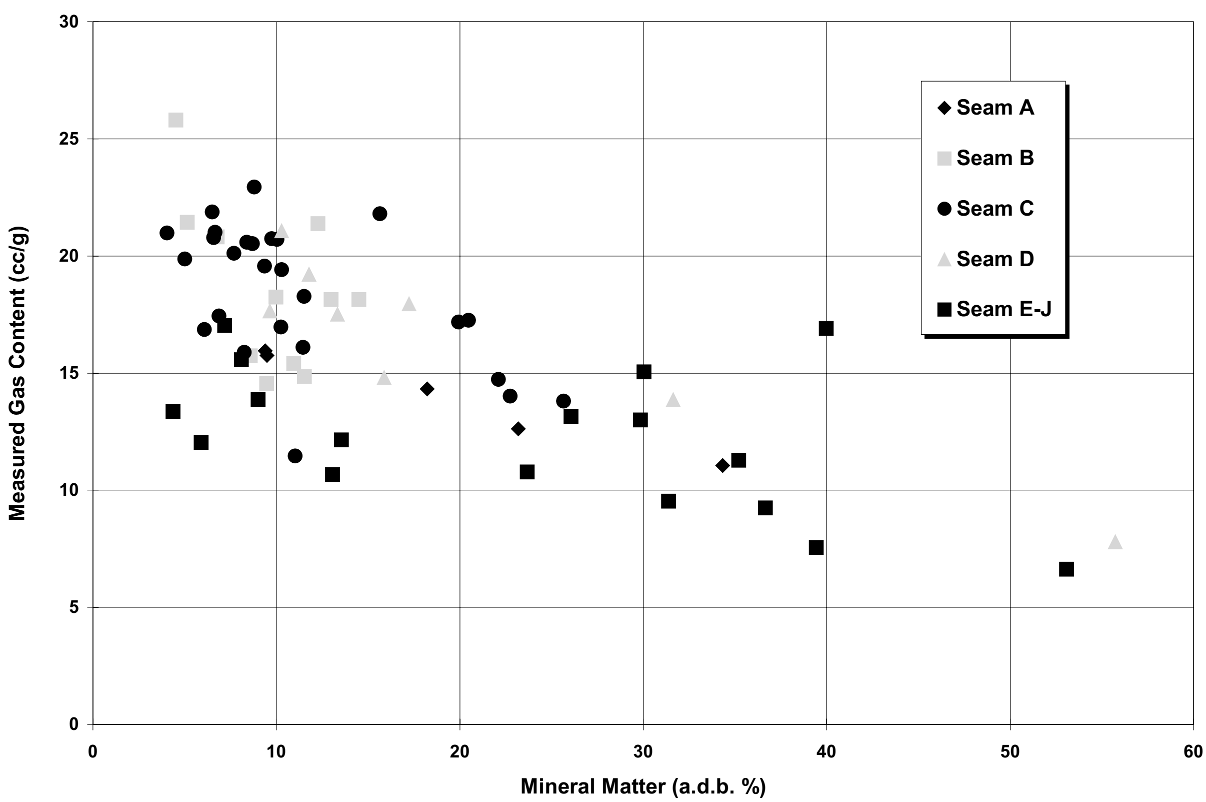


***Figure 37.*** *Measured gas content versus mineral matter by seam designation, Phillips Flatbed exploration area.*

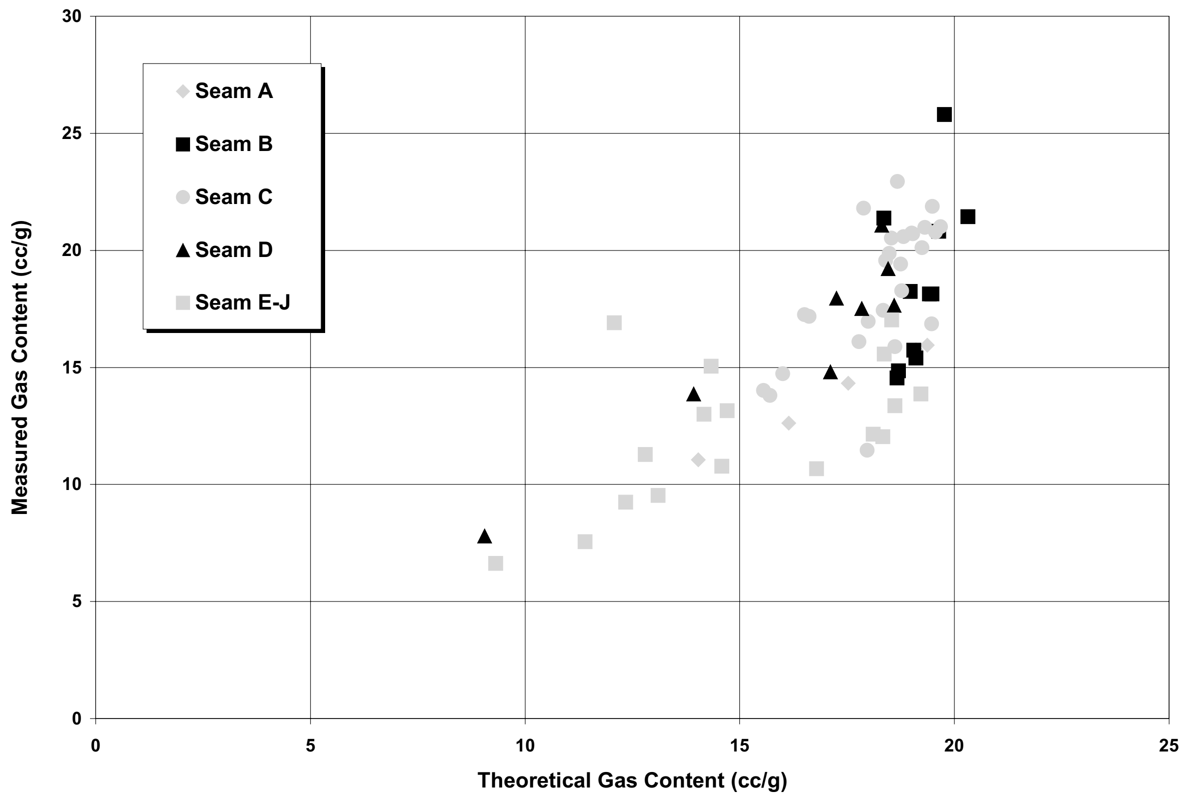


*Figure 38.* Measured gas content versus theoretical gas content by seam designation, Phillips Flatbed exploration area.

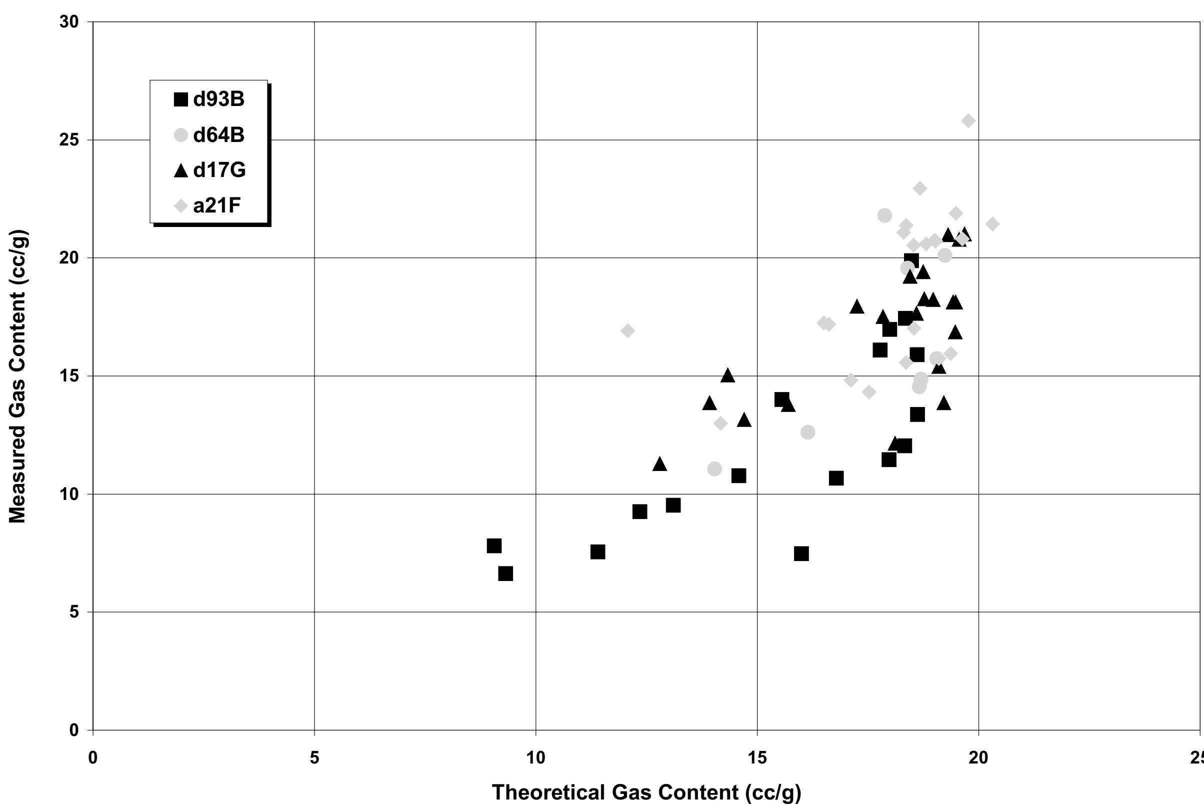


*Figure 39.* Measured gas content versus theoretical gas content by borehole, Phillips Flatbed exploration area.

*Adsorption isotherms.* Four samples were selected and sent to Dr. Marc Bustin of the University of British Columbia for methane adsorption testing. Each sample represented the main seams (A, B, C and D) from well a-21-F. Each sample was tested at seven incremental pressures from 374 kPa to12,807 kPa on a dry basis, then corrected to an ash-free basis. Results are presented in Figures 40 (equilibrium moisture basis) and 41 (ash-free, equilibrium moisture basis), and in Table 27.

On a dry, mineral matter free basis, the Langmuir volumes for methane adsorption ranged from 19.8 cc/g (635 scf/ton) to 25.0 cc/g (800 scf/ton). The equivalent Langmuir pressures are 2700 kPa and 2600 kPa, respectively. Actual measured gas content values for these samples were also plotted in Figures 40 and 41 using a pressure gradient constant of 11.31 kPa/m. The values for Seams A and B fall slightly below the equivalent isotherm line, whereas that for Seam D falls slightly above the corresponding isotherm curve. The measured Seam C value is significantly above its isotherm curve. These results suggest that Seams C and D are in an overpressured condition whereas Seams A and B are slightly underpressured in borehole a-21-F. The adsorption results confirm field observations of significant gas release during drilling. This also supports the fact that the measured gas content is greater than the theoretical values.

*Formation testing.* Following completion of the drilling of each borehole, drillstem tests were performed on selected intervals. A limited production test and well bore stimulation was completed on borehole d-64-B. The original plan to stimulate and produce from borehole a-21-F had to be abandoned because of borehole difficulties. Data for the formation tests and the limited production test is still held confidential by Phillips Petroleum.

*Technical assessment.* The four-hole exploration project undertaken by Phillips on the Flatbed lease was designed to prove the presence of coal gas in the Gates Formation coal. The wells identified 14 seams, five of which were considered major, with an cumulative thickness of 20 m. Coal seams were of medium volatile bituminous rank. Ash content was usually between 10 and 20%, averaging about 14%. Coal permeability varied according to composition, with the highest permeability in vitrinite-rich banded layers. Coal in the upper coal zones E to J and zone A had the lowest gas content, whereas the middle unit coal (zones B to F) contained the highest gas content. Measured gas values for dry ash-free coal ranged from 6.6 to 25.8 cc/g, and averaged 19.4 cc/g. Adsorption studies of zones A, B, C and D in well a-21-F show Langmuir volumes of 19.8 to 25.0 cc/g at 2700 kPa. Recovered gas methane values were between 78 and 92%. The upper coal had a slightly higher methane content. The range of $CO_2$ and $N_2$ values were 3 to 20% and 2 to 6%, respectively. Gas content was not expected to increase with increasing depth. However, gas quantities could remain attractive for depths as shallow as 500 m.

**Table 27**
**Summary of adsorption isotherm values**

| Seam | Depth (m) | Pressure (kPa) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| A | 1409 | 15930 | 15.75 | 17 |
| B | 1358 | 15350 | 20.81 | 22.41 |
| C | 1328 | 15010 | 20.74 | 23.13 |
| D | 1315 | 14860 | 21.08 | 23.61 |

Note: Reservoir pressure is based on an assumed gradient of 0.5 psi/foot (11.3 kPa/m) of overburden depth.

The original borehole location plan had designated borehole d-64-B to be drilled on the axis of the Quintette anticline. This is a small (2-3 km wide) anticlinal structure in the hanging wall of the Flatbed thrust. It was known from the initial planning of the program that the coal measures in the axis of the Quintette anticline would lie at depths greater than 1500 m and that permeability barriers might be encountered at this depth range. Gates Formation coal, determined from seismic reflectors, were predicted to lie at a depth of about 500 m in the crest of the structure. Misinterpretation of the seismic section led to d-64-B being drilled in the footwall of the Flatbed thrust and the coal was intersected in the1300 to 1550 m depth range.

Difficult conditions were experienced during the drilling of all the boreholes. The dipping strata commonly led to problems in keeping the borehole aligned vertically. In borehole a-21-F, the deviation was so great that the intermediate casing was actually penetrated during re-entry, leading to effective whip-stocking of the wellbore. These borehole problems prevented a-21-F from being tested for reservoir properties and production potential. This was unfortunate, as this borehole appeared to have the greatest potential for gas production. Adsorption isotherms indicated that the coal in this hole was oversaturated. Large responses from the gas detector indicated that free gas was flowing into the borehole. The coal was friable and caving was common, suggesting that the well could have cavitated.

Despite huge cost overruns, Phillips' exploration project was successful in proving the in-place gas potential of the Flatbed area. However, production testing was hindered by lack of target intersection and not being unable to evaluate the most prospective areas. It is believed that Phillips is looking for a partner to farm into the play with the intention of drilling a fifth borehole to test the potential of the Quintette anticlinal structure.

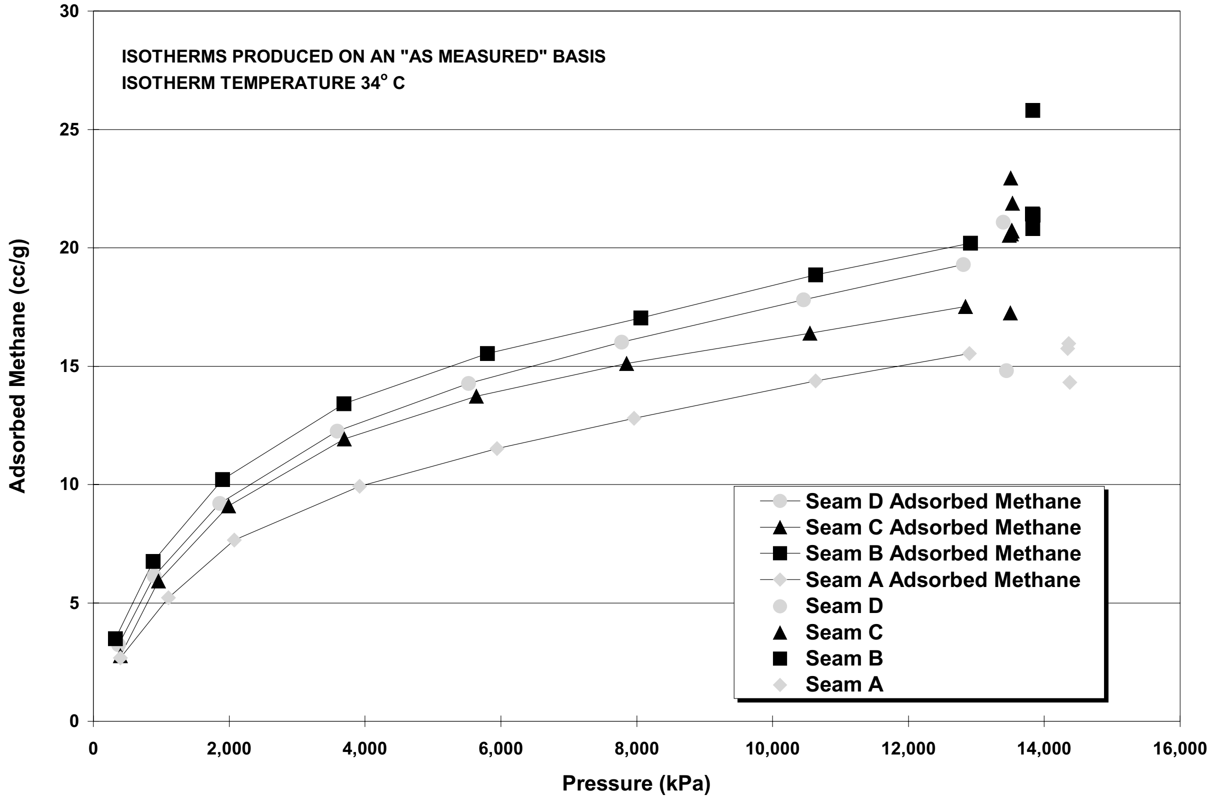


***Figure 40.*** *Adsorption isotherm for Seams A to D on an equilibrium moisture basis and as measured gas content versus pressure gradient (depth x 10.179) for borehole a-21-F.*

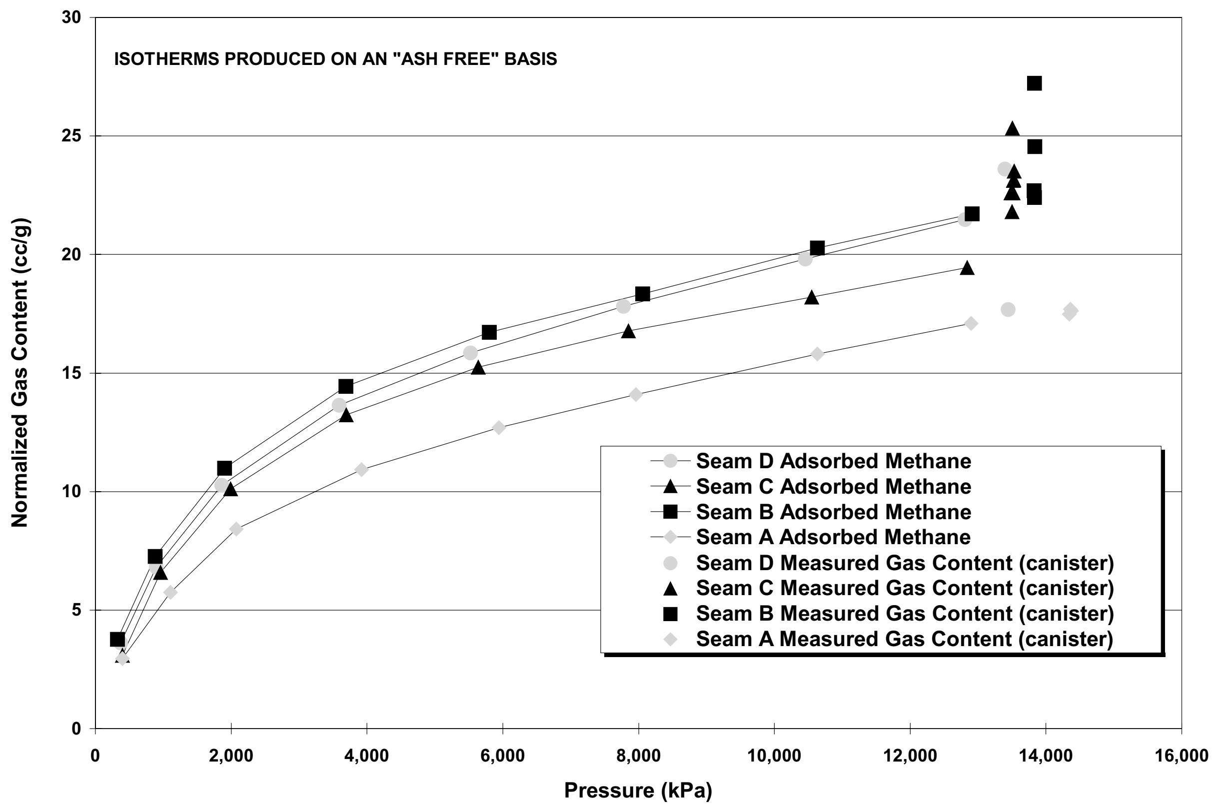


***Figure 41.*** *Normalized gas content and adsorption isotherm values for seams A to D on an ash-free equilibrium moisture basis versus pressure gradient (depth x 10.179) for borehole a-21-F.*

## ALBERTA FOOTHILLS AND MOUNTAINS

### Southwest region

#### *Canadian Hunter project*

Canadian Hunter Exploration Limited undertook a three-hole coalbed methane exploration project in the Coleman region in late 1989. The target of this program was the Mist Mountain Formation of the Kootenay Group. Depth of intersections ranged from as shallow as 390 m for Can Hunter No. 1 to over 1300 m for Can Hunter No. 3. It appears that the wells were placed to test the presence of coalbed methane in three structural thrust plates. Well No. 1, (4-18-11-3.W5M), was drilled in the hanging wall of the Livingstone Thrust, near the junction of Dutch Creek and the Oldman River (Fig. 42). Well No. 2 (6-14-8-5-W5M) was drilled about 5 km north of the Coleman gas plant, in the hanging wall of the McConnell Thrust. Well No. 3 (7-35-8-4-W5M) was drilled immediately north of Blairmore near the old Grassy Mountain open pit mine, in the hanging wall of the Turtle Mountain Thrust.

*Data acquisition.* The Canadian Hunter Exploration Limited coalbed methane project consisted of drilling vertical boreholes using conventional oil and gas drilling equipment. Selected intervals of the coal measures were cored using a wireline system modified for the drilling rig. Boreholes were drilled with a polymer/flocculated water-based mud system. Core recovery was variable, depending on the dip of the coal seams and the depth at which they were penetrated. Generally core recovery was greater than 80%. Cored intervals and the number of gas canisters for each borehole and seam are presented in Table 28. Following the completion of each hole to total depth (TD), selected intervals were tested using conventional drillstem test methods. Results were disappointing, so no production tests were attempted. The wells were plugged and abandoned.

*Geology.* In the Coleman region, the Mist Mountain Formation is about 90 to100 m thick and is unconformably overlain by the Cadomin Formation. Strata consist of predominantly fine-grained sandstone, medium grey siltstone and mudstone and coal. Up to eight seams have thicknesses ranging from less than 1 m to more than 7 m. Cumulative seam thicknesses for the three boreholes are summarized in Table 29.

The Mist Mountain Formation forms a wedge of clastic material that thins from west to east. The formation attains a maximum thickness of 650 m in the Elk Valley region of southeast British Columbia and gradually thins to a zero edge immediately to the east of the foothills and mountain belt near Burmis. The thinning of this wedge is caused by nondeposition as a function of distance from the source of sedimentation, as well as the erosional downcutting of the unconformably overlying Cadomin Formation.

In conjunction with the thinning of the overall stratigraphic interval, the number of coal seams decreases proportionally. In the Elk Valley region, as many as 30 coal seams have been recognized, whereas at Grassy Mountain (immediately north of Blairmore), only four main seams are present. The coal is widely variable in thickness and distribution as a result of the erosional unconformity and the depositional setting of the Mist Mountain Formation. Figures 43, 44 and 45 illustrate stratigraphic sections of the three Canadian Hunter boreholes. These figures indicate that

**Table 28**
**Cored intervals, Can Hunter Coleman boreholes**

| Borehole | 4-18-11-3-W5M | | 6-14-8-5-W5M | | 7-35-8-4-W5M | |
|---|---|---|---|---|---|---|
| | Depth range (m) | No. of canisters | Depth range (m) | No. of canisters | Depth range (m) | No. of canisters |
| Interval 1 | 500.0-525.0* | 4 | 1306.60-1316.70 | 13 | 394.30-403.65 | 18 |
| Interval 2 | — | — | 1382.75-1383.65 | 4 | 433.00-434.50 | 6 |
| Interval 3 | — | — | 1391.29-1391.59 | 1 | 477.83-478.13 | 1 |
| Interval 4 | — | — | 1395.60-1398.90 | 2 | 480.51-484.62 | 10 |

* In 4-18-11-3-W5M the only type of core collected was from sidewall samples.

**Table 29**
**Coal thickness, Can Hunter Coleman boreholes**

| Borehole | No. of seams | Cumulative thickness (m) | Stratigraphic interval (m) |
|---|---|---|---|
| Can Hunter No. 1 4-18-11-3-W5M | 8 | 17.95 | 78 |
| Can Hunter No. 2 6-14-8-5W5M | 12 | 24 | 90 |
| Can Hunter No. 3 7-35-8-4-W5M | 13 | 26 | 93 |

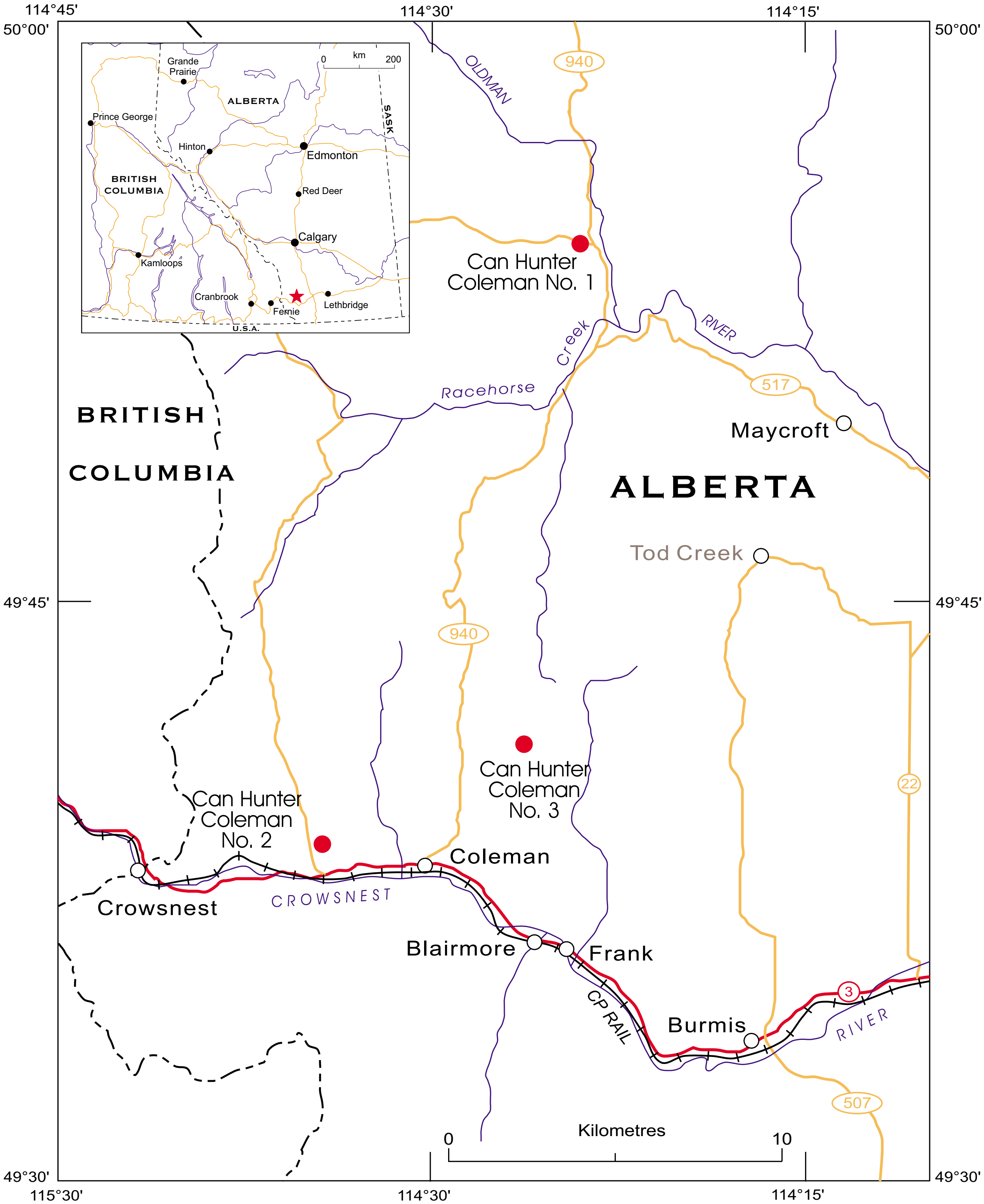


***Figure 42.*** *General location map of the Canadian Hunter Coleman exploration boreholes: Can Hunter Coleman No. 1 (4-18-11-3W5M); Can Hunter Coleman No. 2 (6-14-08-5W5M); Can Hunter Coleman No. 3 (7-35-08-4W5M).*

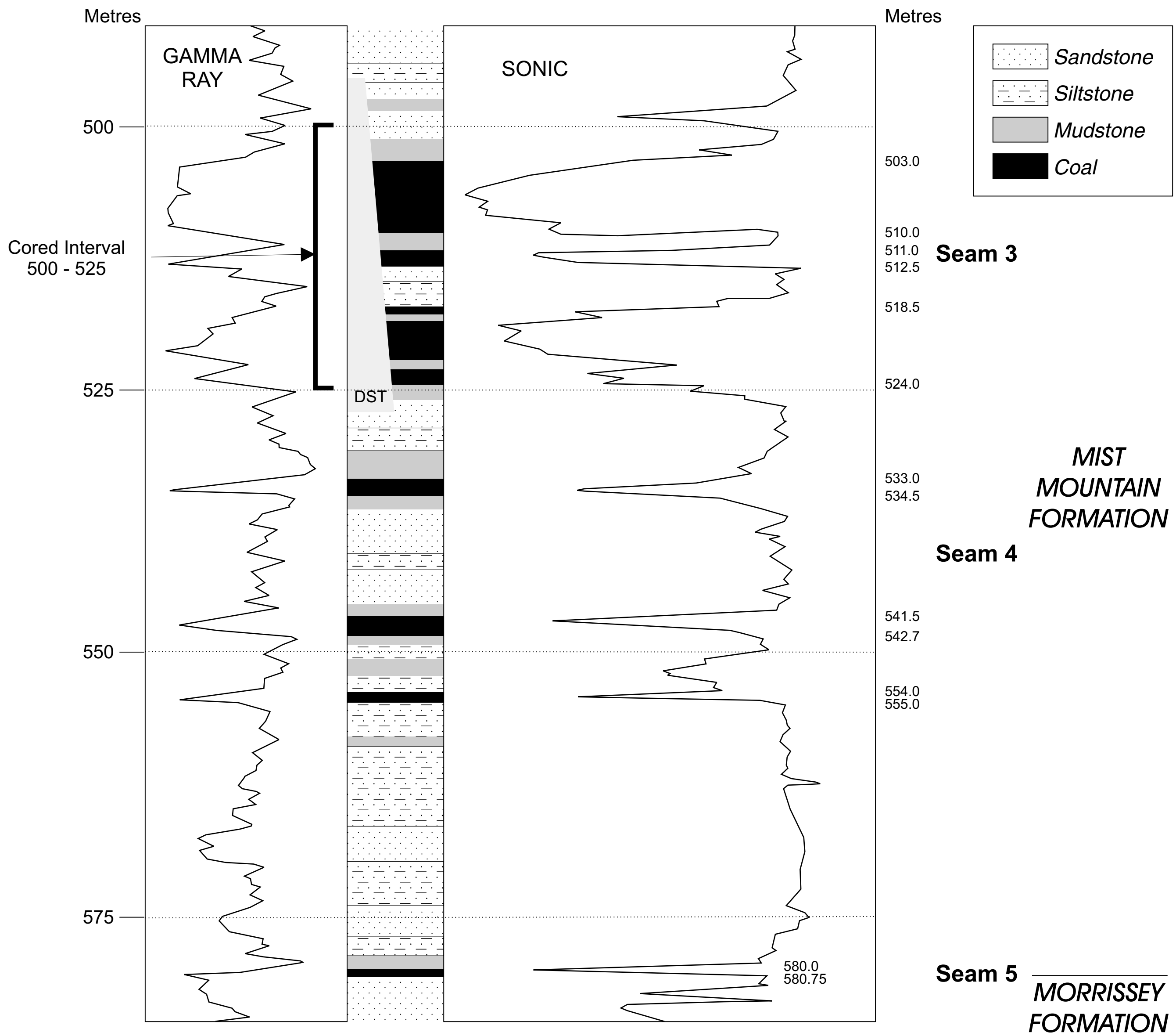


***Figure 43.*** *Detailed stratigraphic section of coal intersections for the Canadian Hunter No. 1 borehole.*

correlation of individual coal seams is almost impossible. This can be explained largely by the palinspastically restored location of the boreholes. Each borehole is located in the hanging wall of a different thrust plate, and the depositional location of the boreholes is estimated to be as much as 50 km apart.

*Gas content.* Fifty-five canister tests were conducted for two of the three exploration boreholes. In Can Hunter No. 1, only sidewall samples were collected (four tests) and no desorption tests were completed. Gas content was highly variable, depending on the number of partings within the sample interval. In Can Hunter No. 2, gas content ranged from 0.84 to 11.72 cc/g and averaged 6.97 cc/g. Normalized gas content (a.f.b.) averaged 9.87 cc/g. For Can Hunter No. 3, gas content ranged from 0.59 to 14.31 cc/g, averaging 5.75 cc/g. Normalized gas content (a.f.b.) averaged 7.92 cc/g. Gas content data are summarized in Tables 30 and 31.

An analysis of depth versus measured gas content indicates that the variability observed is not controlled by depth (Fig. 46). Even when normalized gas content is plotted against depth, there does not appear to be any significant trend (Fig. 47). A plot of measured gas content versus ash (Fig. 48) indicates a strong influence of ash upon gas content, particularly when the ash content is greater than 30%. Several canister values, particularly from Can Hunter No. 3, show low gas content, even though the ash content of the sample is less than 20%. In these samples it appears that other geological factors have influenced gas retention within

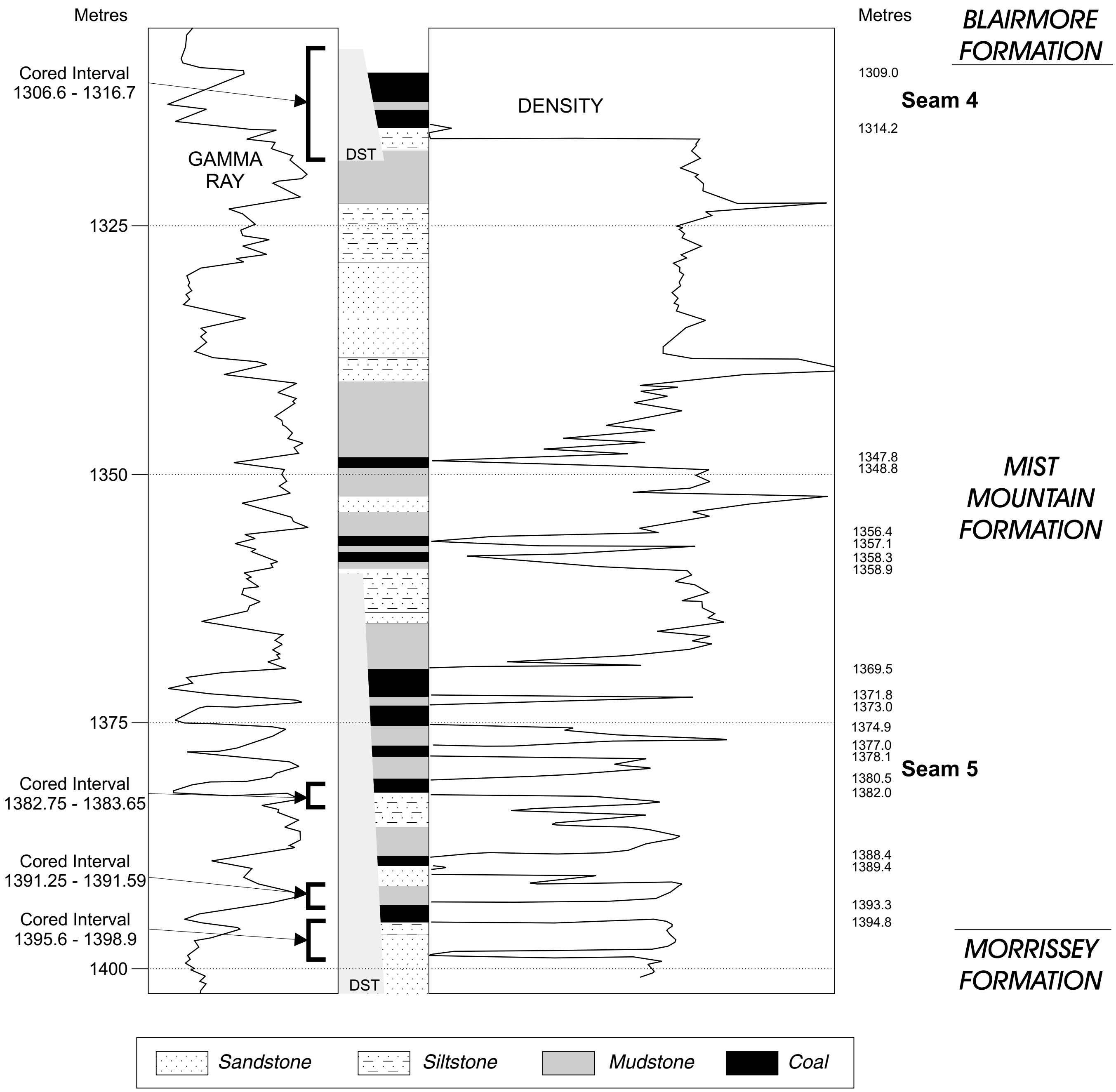


***Figure 44.*** *Detailed stratigraphic section of coal intersections for the Canadian Hunter No. 2 borehole.*

the coal seam. A plot of measured gas content versus degree of fracture development indicates a relationship of increased fracture density to increased gas content (Fig. 49). This may manifest itself in the form of higher diffusion rates

Core descriptions indicate that coal samples with a low fracture index (value=1), tend to have the cleat system infilled with calcite. The low gas content might be the result of adsorbed gas being locked into the coal matrix because of the limited fracture or cleat development and the high ash content of the coal. Desorption times were generally less than 30 days and it might be possible that the samples had not been completely desorbed before laboratory analyses.

*Coal quality*. Coal of the Mist Mountain Formation is high to medium volatile bituminous in rank. Volatile matter (dry basis) ranges from 18.78 to 29.29 % for Can Hunter No. 3 and from 18.7 to 25.3% for Can Hunter No. 2. Ash content of the samples is highly variable, averaging 32% for Can Hunter No. 2 and 27% for Can Hunter No. 3. As most of the

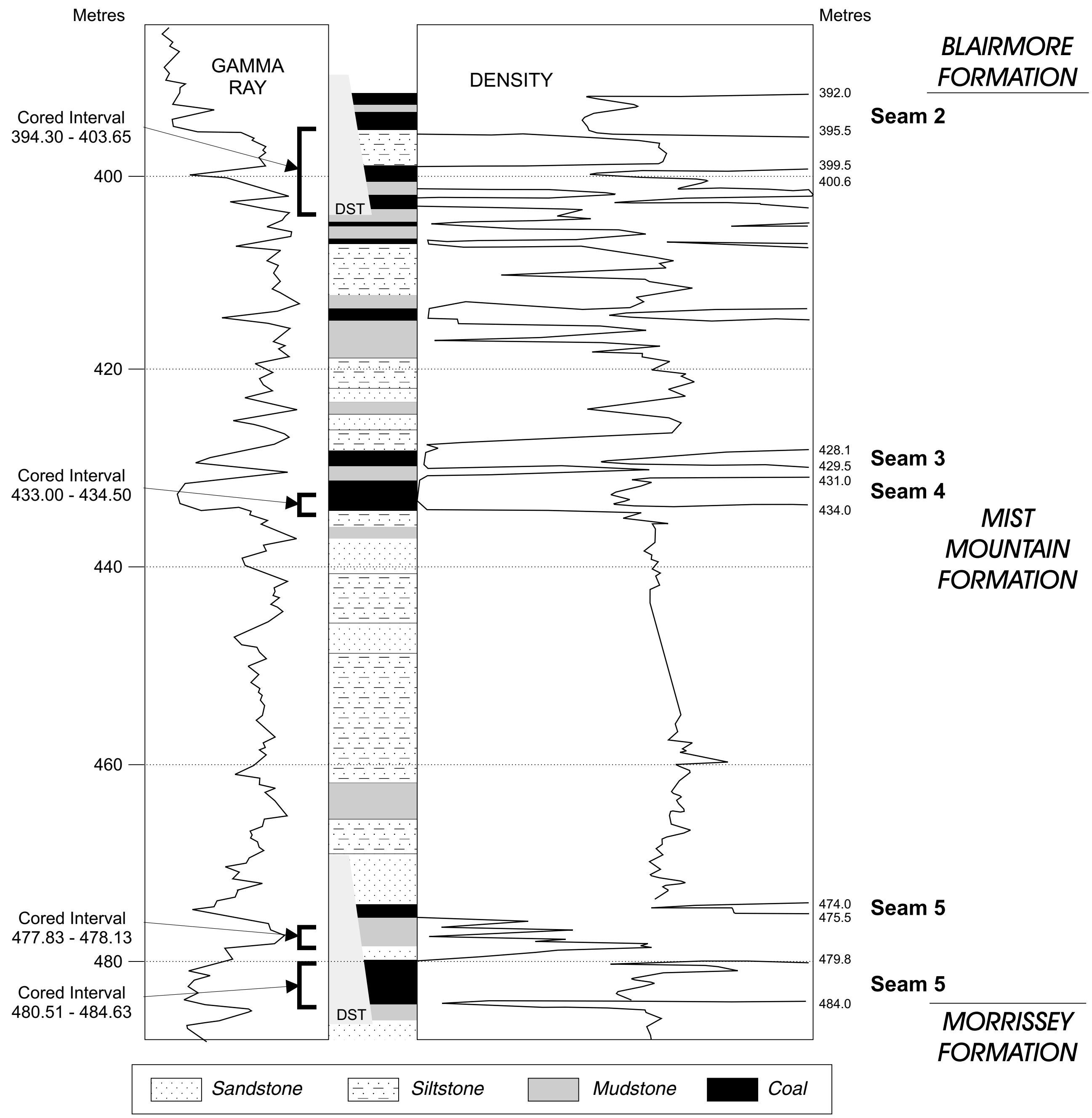


***Figure 45.*** *Detailed stratigraphic section of coal intersections for the Canadian Hunter No. 3 borehole.*

samples were 30 cm or less in length, it is surmised that few partings were included in the samples and that the coal must have a high inherent ash content. In Can Hunter No. 2, only four samples had ash contents of less than 15%. Similarly for Can Hunter No. 3, only 10 of the 34 canister tests had ash contents of less than 15%. Moisture content on an as-received basis was less than 4% and on an air-dried basis, less than 1%. Coal quality data are summarized in Tables 30 and 31.

*Adsorption isotherms.* Three adsorption isotherms, representing the upper, middle and lower seams were completed for the Can Hunter No. 3 well. Data are summarized in Table 32. The average Langmuir volume is 14.5 cc/g for the seams on an as-measured basis. Gas capacity values were calculated from the reservoir pressure determined by drillstem tests, and from the Langmuir equation derived for each adsorption isotherm test. For most canister tests, measured gas content was substantially less

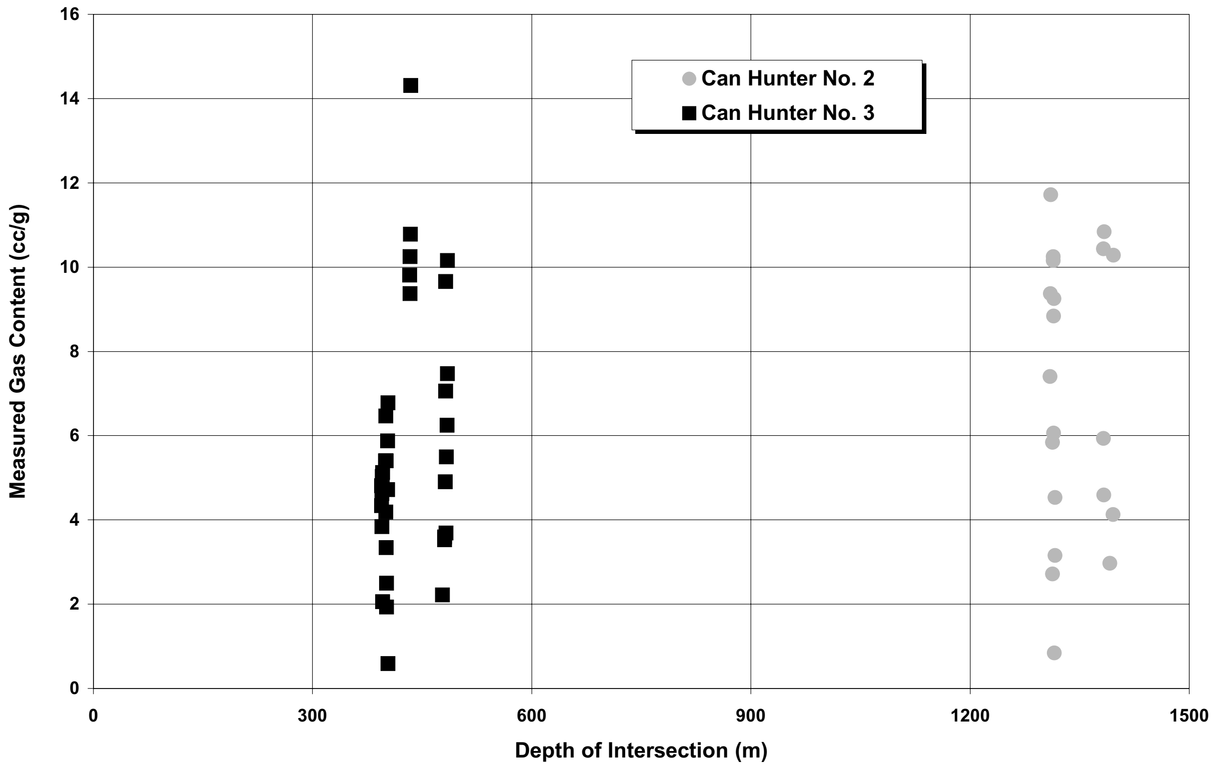


***Figure 46.*** *As measured gas content versus depth of intersection, Canadian Hunter Nos. 2 and 3.*

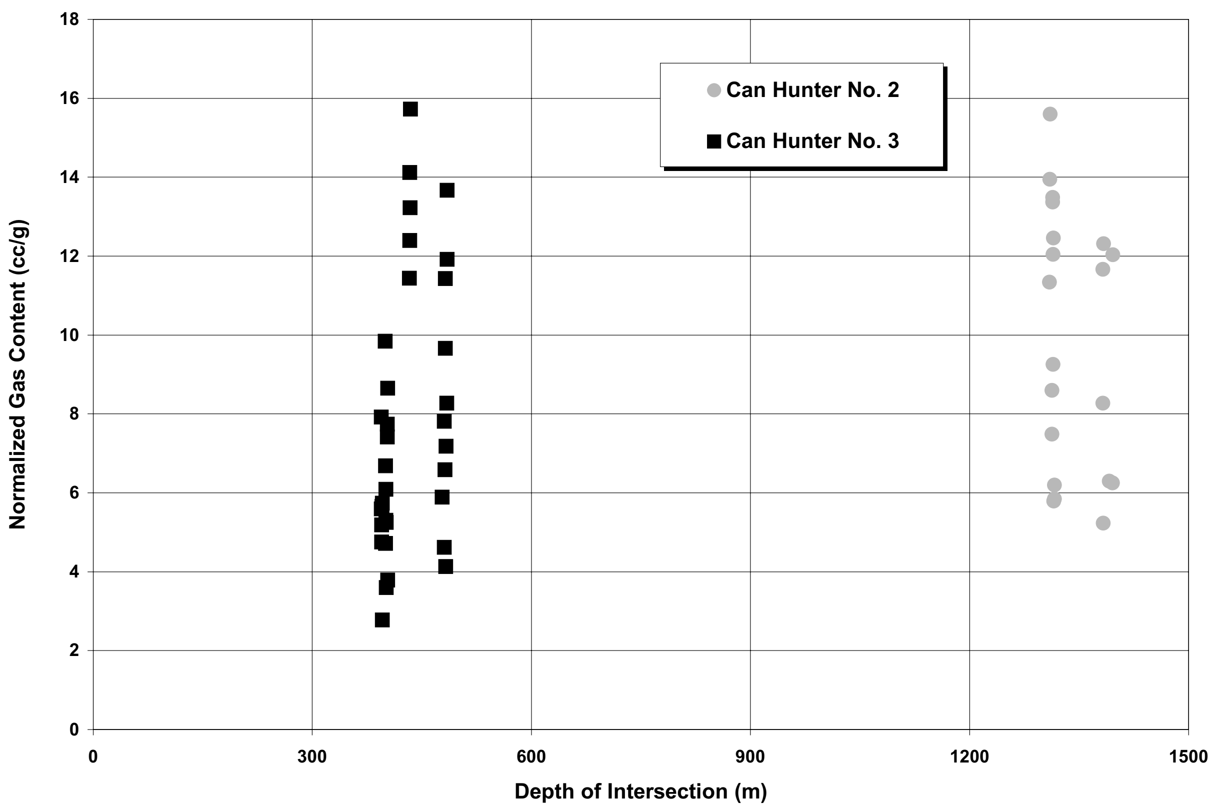


***Figure 47.*** *Normalized gas content versus depth of intersection, Canadian Hunter Nos. 2 and 3.*

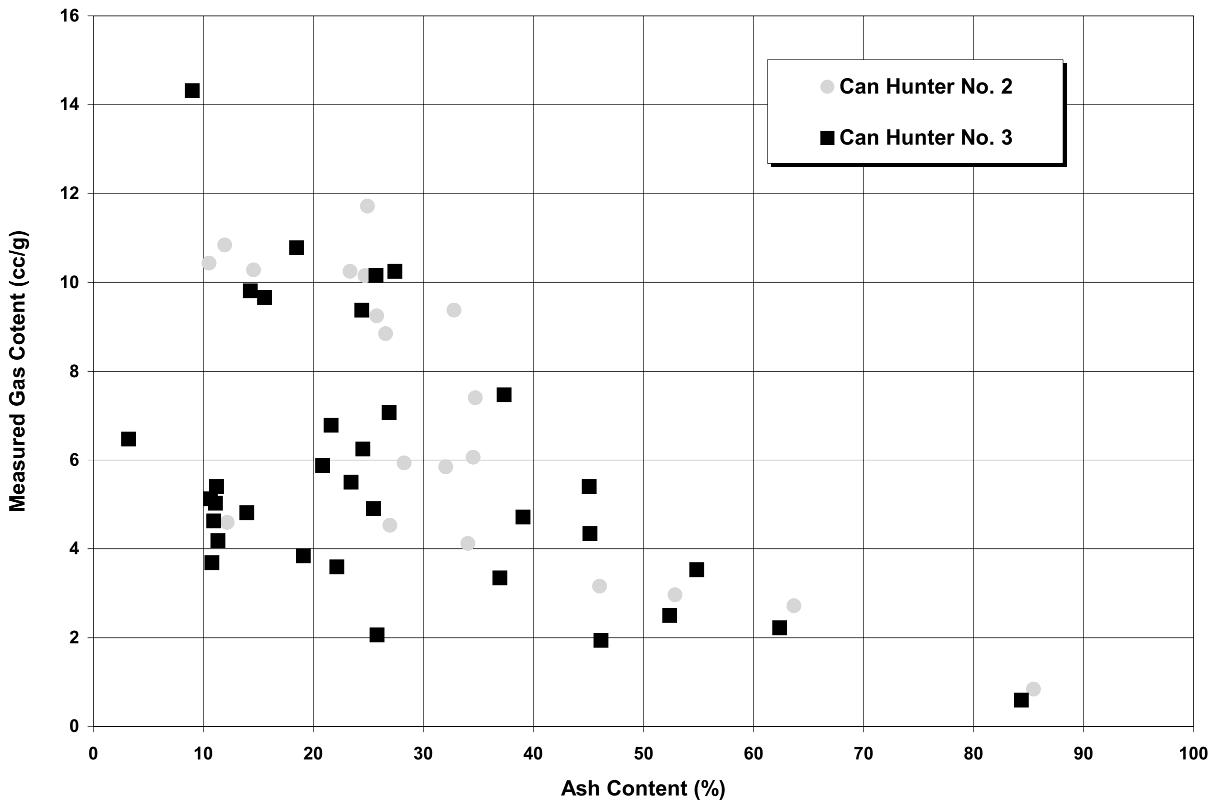


***Figure 48.*** *As measured gas content versus ash content for Canadian Hunter Nos. 2 and 3.*

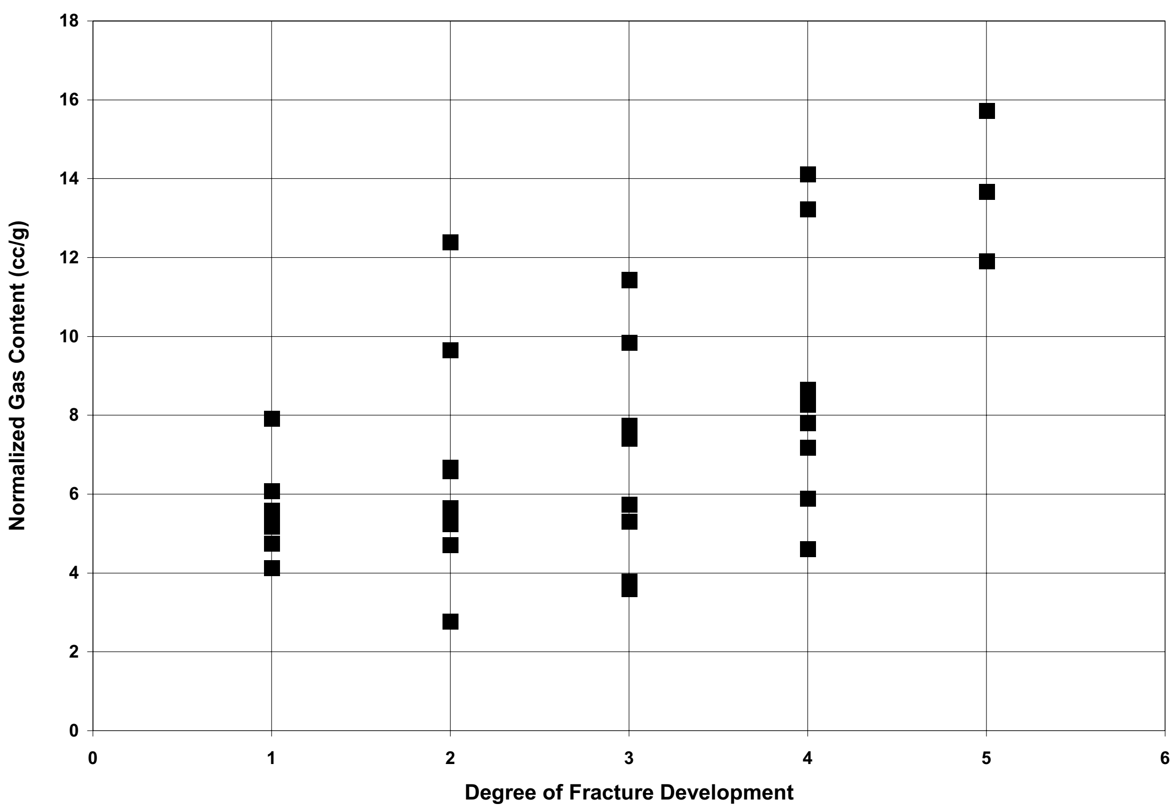


***Figure 49.*** *As measured gas content versus degree of fracture development. A large fracture number corresponds to well cleated coals with open fractures. A small number corresponds to coals that are either poorly cleated or the cleats of which are infilled with mineralization.*

than the theoretical gas capacity for the depth of seam intersection. This might be due in part to the high ash content of the coal, although the adsorption isotherm samples had high ash content.

*Formation testing.* One drillstem test was performed on Can Hunter No. 1, two on Can Hunter No. 2, and two on Can Hunter No. 3. All cases had mechanical problems, from plugged tools to premature release of safety valves. As a result, semi-log, transient analysis was not possible. Data are summarized in Table 33.

Results from the drillstem tests indicate the coal has low permeability. Fluid production was minimal and was primarily recovered drilling fluid. Gas production was essentially non-existent. The boreholes were drilled with a polymer-based mud system and there might have been some formation damage. However, even assuming some form of invasion, the drillstem test data indicate that the permeability values for the coal in these boreholes ranges from less than 1 to 2 mD.

*Technical assessment.* The exploration strategy of Canadian Hunter's Coleman coalbed methane project was to evaluate the gas potential of the Mist Mountain Formation coal in the proximity of the Coleman gas plant. Coal was intersected at varying depths and as-measured gas content values were widely variable. This variability appears to be controlled more by sample quality than depth of intersection. Ash content ranged from 3.2% to greater than 85%. Even after normalizing gas content to an ash-free basis, there was still a wide range of variability. This is probably a result of the compositional characteristics of the coal and, perhaps, the reservoir pressure present in any given coal seam. Canadian Hunter drilled three exploration boreholes in three different thrust plates of the front ranges of the Canadian Rockies. In contrast to the more open fold belt of the main ranges where the Fernie Basin is located, the Front Range region is dominated by imbricate and bedding plane thrust faults. In all locations, the target coal lies in the hanging wall of a major thrust where residual compressive stresses are probably still present. No attempt was made to locate the boreholes on the axes of structures where there may be flexure induced permeability enhancement. As a result, it would be expected that the coal would be essentially "tight", probably as a result of the closing of the cleat system. Reservoir permeability values would be expected to be low. The drillstem tests were essentially invalidated because of mechanical difficulties. However, in all tests, gas production and shut-in reservoir pressures were low, suggesting that the permeability values are probably less than 2 mD. It must also be remembered that the drillstem test generally does not leave tools in the borehole long enough to eliminate the near wellbore effects. Given that these exploration boreholes were drilled with conventional mud-based fluid systems, some formation damage would be expected that would impinge on the overall reservoir permeability. Although the drill program was successful in proving up "in situ" gas resources, the exploration target locations did not optimize structural enhancements of the reservoirs.

**Table 30**
**Desorption data, Can Hunter Coleman No. 2**

| Depth of intersection (m) | Seam no. | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content (%) (d.b.) |
|---|---|---|---|---|
| 1309.60 | 4 | 7.41 | 11.34 | 34.71 |
| 1309.90 | 4 | 9.38 | 13.95 | 32.78 |
| 1310.20 | 4 | 11.72 | 15.60 | 24.90 |
| 1312.70 | 4 | 5.84 | 8.60 | 32.03 |
| 1313.00 | 4 | 2.72 | 7.49 | 63.68 |
| 1313.60 | 4 | 10.25 | 13.37 | 23.33 |
| 1313.90 | 4 | 10.16 | 13.49 | 24.70 |
| 1314.20 | 4 | 8.84 | 12.04 | 26.56 |
| 1314.50 | 4 | 6.06 | 9.26 | 34.52 |
| 1314.80 | 4 | 9.25 | 12.46 | 25.75 |
| 1315.10 | 4 | 0.84 | 5.79 | 85.44 |
| 1316.10 | 4 | 3.16 | 5.84 | 46.00 |
| 1316.40 | 4 | 4.53 | 6.20 | 26.94 |
| 1382.53 | 5 | 5.94 | 8.27 | 28.24 |
| 1382.75 | 5 | 10.44 | 11.66 | 10.52 |
| 1383.05 | 5 | 4.59 | 5.23 | 12.18 |
| 1383.35 | 5 | 10.84 | 12.31 | 11.93 |
| 1391.29 | 5 | 2.97 | 6.30 | 52.85 |
| 1395.60 | 5 | 4.13 | 6.25 | 34.03 |
| 1396.30 | 5 | 10.28 | 12.03 | 14.55 |

**Table 31**
**Desorption data, Can Hunter Coleman No. 3**

| Depth of intersection | Seam no. | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content (%) (d.b.) |
|---|---|---|---|---|
| 394.30 | 1 | 4.34 | 7.92 | 45.14 |
| 394.55 | 1 | 4.81 | 5.59 | 13.95 |
| 394.80 | 1 | 3.84 | 4.75 | 19.10 |
| 395.05 | 1 | 4.63 | 5.19 | 10.92 |
| 395.30 | 2 | 5.03 | 5.66 | 11.11 |
| 395.60 | 3 | 5.13 | 5.74 | 10.64 |
| 395.90 | 2 | 2.06 | 2.78 | 25.79 |
| 399.70 | 3 | 5.41 | 9.84 | 45.07 |
| 400.00 | 2 | 4.19 | 4.72 | 11.33 |
| 400.30 | 2 | 6.47 | 6.68 | 3.20 |
| 400.60 | 1 | 5.41 | 6.09 | 11.18 |
| 400.85 | 3 | 3.34 | 5.30 | 36.95 |
| 401.10 | 2 | 2.50 | 5.25 | 52.37 |
| 401.40 | 3 | 1.94 | 3.60 | 46.13 |
| 402.45 | 3 | 4.72 | 7.74 | 39.06 |
| 402.75 | 3 | 5.88 | 7.42 | 20.82 |
| 403.05 | 4 | 6.78 | 8.65 | 21.62 |
| 403.35 | 3 | 0.59 | 3.79 | 84.35 |
| 433.00 | 3 | 9.81 | 11.44 | 14.26 |
| 433.30 | 4 | 10.25 | 14.12 | 27.40 |
| 433.60 | 2 | 9.38 | 12.40 | 24.40 |
| 433.90 | 4 | 10.78 | 13.23 | 18.48 |
| 434.20 | 5 | 14.31 | 15.73 | 9.01 |
| 477.83 | 4 | 2.22 | 5.89 | 62.36 |
| 480.51 | 4 | 3.53 | 7.82 | 54.83 |
| 480.81 | 4 | 3.59 | 4.62 | 22.13 |
| 481.64 | 2 | 4.91 | 6.58 | 25.46 |
| 481.94 | 3 | 9.66 | 11.44 | 15.56 |
| 482.24 | 2 | 7.06 | 9.66 | 26.89 |
| 482.59 | 1 | 3.69 | 4.13 | 10.76 |
| 482.89 | 4 | 5.50 | 7.18 | 23.43 |
| 484.02 | 4 | 6.25 | 8.28 | 24.50 |
| 484.32 | 5 | 10.16 | 13.67 | 25.68 |
| 484.62 | 5 | 7.47 | 11.92 | 37.33 |

**Table 32**
**Adsorption isotherm data, Can Hunter Coleman No. 3**

| Sample | Depth (m) | Ash (%) (a.d.b.) | Moisture e.q. (%) | Langmuir volume (cc/g) | Langmuir volume ash free (cc/g) | Langmuir pressure (kPa) | Gas capacity* @ reservoir (cc/g) |
|---|---|---|---|---|---|---|---|
| Upper Seam | 395 | 31.47 | 1.1 | 14.9 | 21.8 | 2220 | 10.38 |
| Middle Seam | 434 | 19.03 | 1 | 14 | 17.2 | 1200 | 12.27 |
| Lower Seam | 482 | 34.74 | 1.1 | 14.4 | 21 | 2360 | 10.09 |

* Note: Gas capacity calculated from Langmuir equation for each seam interval and reservoir pressure at sample depth.

**Table 33**
**Drillstem test data, Can Hunter boreholes**

| Borehole | DST interval (m) | Thickness of coal tested (m) | Initial flow rate ($m^3$/d) | Comments |
|---|---|---|---|---|
| Can Hunter No. 1 | 495.0-527.0 | 42.6 | 52.5 | No flow on final flow test – possibly a plugged tool |
| Can Hunter No. 2 | 1306.5-1317.0 | 4.8 | 5.4 | Poor shut-in pressure and low permeability |
| Can Hunter No. 2 | 1360.0-1426.0 | 9.3 | 6-115 | Poor shut-in pressure and low permeability |
| Can Hunter No. 3 | 389.0-404.0 | 4.4 | no gas | Poor shut-in pressure and low permeability |
| Can Hunter No. 3 | 469.0-487.0 | 5.5 | no gas | Poor shut-in pressure and low permeability |

### *Algas Coleman project*

Algas Resources Ltd. initiated an experimental coalbed methane exploration project in 1977 to determine the viability of de-gassing coal that was being produced from the Coleman Collieries Vicary Creek underground mine. The well (8-19-9-4-W5M) was located about 17 km north of the town of Coleman in southern Alberta (Fig. 50). The well was part of a series drilled by Algas near what were then operational coal mines in the Alberta foothills.

*Data acquisition.* The Coleman well was drilled to a total depth of 359 m. Coring was undertaken through the coal intersections at depths from 265 m to total depth. Three cored intervals were completed: 238 to 239 m, 265.5 to 278.7 m and 347.0 to 359.5 m. Twenty core runs were made but core recovery was very poor, averaging less than 20% in the coal intersection and 40% overall. Coal core samples were theoretically desorbed but no detailed data are available. Because of the poor core recovery, the quality of desorption data is somewhat suspect.

Following completion of drilling, drillstem tests were run over three intervals. Results from the tests indicated that the permeability of the coal intervals was low. Production casing was set to a depth of 336.5 m and a slotted liner production string casing installed from 336.5 to 350.6 m depth. The well was subsequently completed for production testing and an injection test was completed before production. Gas production was low (peak rate of 72 Mcf/d) and the well was subsequently plugged and abandoned.

*Geology.* The Coleman well intersected the main seams (designated as V2) of the Mist Mountain Formation. In the borehole, the V2 seam lies immediately under the conglomerate unit of the Blairmore Formation (Fig. 51). The contact is unconformable and commonly represented by a conglomerate unit. Downcutting has in places removed sections of the Mist Mountain Formation. A major thrust fault was intersected in the borehole, and the V2 seam and overlying Blairmore strata are repeated. The fault is interpreted to lie at a depth of about 306 m, immediately above a thin shaly coal unit that caps the Blairmore conglomerate.

The Blairmore Formation consists of interbedded greenish-grey siltstone and mudstone with occasional, thick, fine-grained, massive sandstone beds. The formation is essentially barren of coal. At the base of the formation lies a thick (30 to 40 m), massive, conglomeratic sandstone unit, known locally as the Blairmore conglomerate. This unit is distinctive in the Crowsnest Pass region of southern Alberta and can be recognized in outcrop. The contact with the underlying Mist Mountain Formation is disconformable and is commonly marked by local and regional downcutting of the Blairmore conglomerate into the Mist Mountain Formation. The erosional downcutting increases from west to east. This results in effective thinning of the Mist Mountain section.

The underlying Mist Mountain Formation ranges from 650 m in the Elk Valley to the west to less than 30 m at the edge of the Alberta foothills belt to the east. In the region of the Vicary Creek mine near Coleman, the formation is about 100 m thick and consists of interbedded, fine-grained sandstone, siltstone, and mudstone with several thick coal seams. In the Algas Coleman well, only the upper 43 m of the formation was intersected as a result of the thrust fault repeat.

In the Coleman well, two major coal zones (V1 and V2) were intersected. The third intersection is a fault repeat of the V2 seam. The upper V2 seam consists of an upper ply (7.6 m) with several thin partings, and a thinner, lower ply (1.9 m). The two zones are separated by a 1 m thick parting. Seam V1 consists of an interbedded sequence of coal and mudstone, encompassing 12.95 m, with a cumulative net coal thickness of 9 m. Table 34 lists coal intersection data.

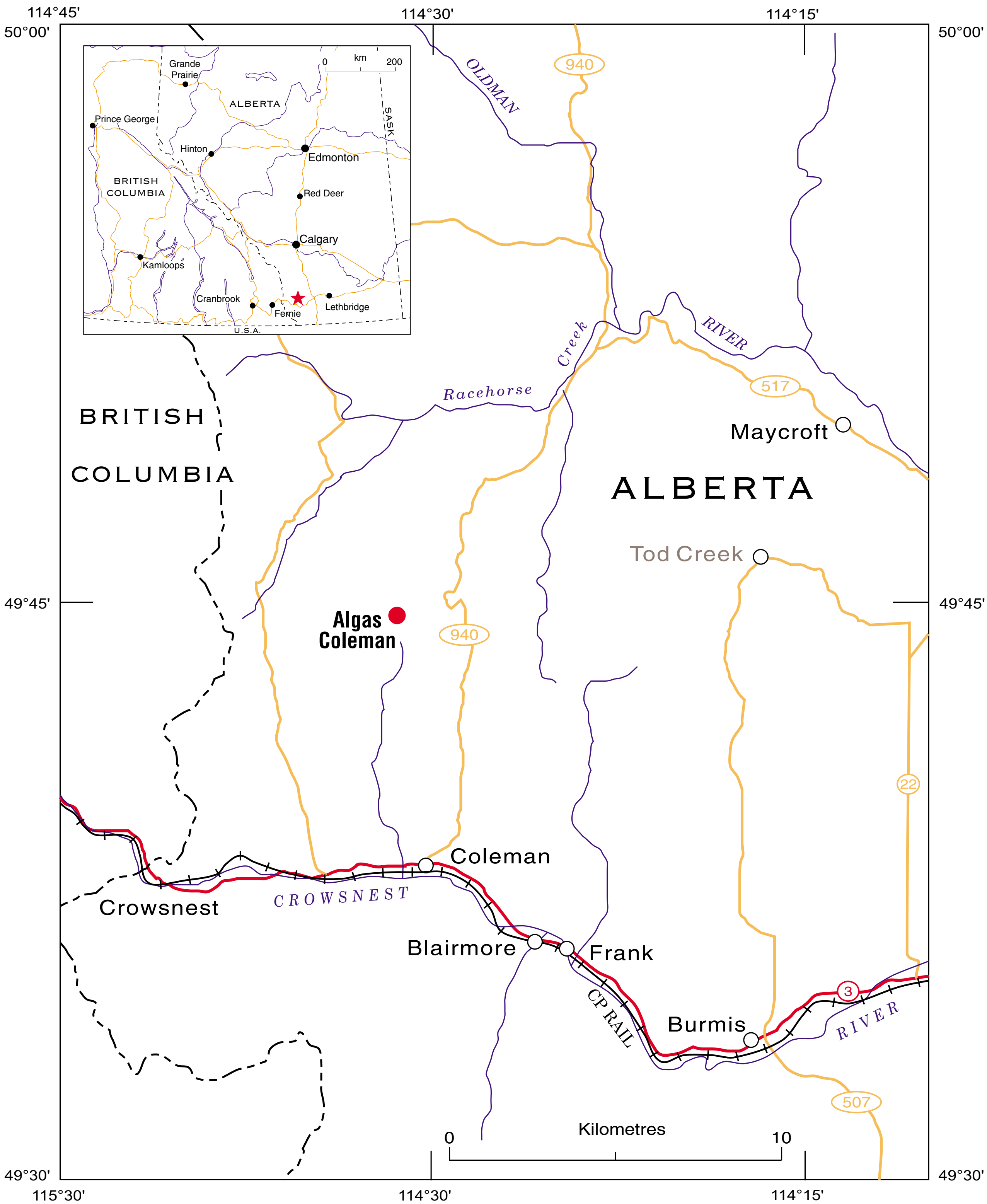


*__Figure 50.__ General location map of the Algas Resources Coleman (08-19-09-04W5M) exploration borehole.*

*Gas content.* Geological reports indicate that six desorption canister tests were conducted for the Coleman exploration well. Four samples were collected from the V2 upper seam and two samples from the V2 lower. Detailed desorption data do not appear to be available but a summary range of 11.4 to 13.4 cc/g is reported.

*Coal quality.* Coal of the Mist Mountain Formation is classified as medium-volatile bituminous A. Reflectance study and maceral analysis of one coal sample from the V2 seam indicated an average $Ro_{max}$ of 1.24 % and vitrinite content of 79%. Proximate analyses are summarized in Table 35. The poor core recovery suggests that the overall coal quality of the samples presented in this table does not represent the true seam quality characteristics.

*Formation testing.* Three drillstem tests were completed on coal intervals in the 8-19 wellbore. The tests were closed chamber tests with inflatable packers. Results indicated that the coal seams had low permeability and low pressure. The permeability values might be affected by formation damage from the heavy mud drilling fluid used, and reservoir pressure would be expected to be low because of the shallow depth of intersection. Drillstem test information is summarized in Table 36.

**Table 34**
**Coal intersections, Algas Coleman borehole**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Total coal zone (m) | Net coal thickness (m) |
|---|---|---|---|---|
| V2* | 265.30 | 275.80 | 10.50 | 9.50 |
| V1 | 283.40 | 296.35 | 12.95 | 9.00 |
| V2 | 344.82 | 353.82 | 9.00 | 7.80 |

*Note: Upper intersection of V2 seam is fault repeat.

**Table 35**
**Proximate analyses, Algas Coleman borehole**

| Sample depth | Moisture (%) (a.r.b.) | Ash (%) (a.r.b.) | Volatile matter (%) (a.r.b.) | Fixed carbon (%) (a.r.b.) |
|---|---|---|---|---|
| 265.80 | 12.60 | 13.70 | 19.10 | 54.60 |
| 266.80 | 2.70 | 8.80 | 26.40 | 62.10 |
| 269.90 | 0.50 | 15.30 | 23.80 | 54.40 |
| 271.40 | 3.30 | 13.30 | 23.20 | 60.20 |
| 347.70 | 7.90 | 32.30 | 16.00 | 43.80 |
| 351.00 | 1.70 | 16.80 | 27.20 | 54.30 |

Following completion of the drillstem tests, production casing was cemented into the borehole to a depth of 336.5 m. A slotted liner was inserted to extend from the base of the production casing to total depth. Gas production was initiated and the average rate was less than 0.1 Mcf/d. The low rates were probably a result of cement damage to the well bore. After the wellbore was fracture stimulated, production rates increased up to 71 Mcf/d, with an average of 31 Mcf/d. The well was placed on production for a period of nine months, between April 1978 and December 1978. During this period, the pumps required servicing and reworking several times. After each down time, gas production appeared to be hindered by the influx of water into the de-watered portion of the coal reservoir.

After nine months, the borehole was re-entered to allow a hydraulic fracture stimulation of the upper V2 seam. Abrasijet slots were cut through the production casing to access the upper seam. Dual production was maintained for two months. Maximum gas production for this period was 25 Mcf/d. The lower seam was subsequently plugged and testing of the upper seam initiated. Gas production decreased to 4 Mcf/d. Analysis of data at the end of the production test indicated that the Abrasijet slots either did not penetrate the casing or were cut in the wrong location. This could explain the minimal gas production from the upper zone. Total gas produced from the Coleman well was 3.3 Mmcf ($93.45 \times 10^3 m^3$).

Two injection tests were conducted on the lower V2 seam to determine reservoir permeability. The second test, on the same interval, was invalidated because the coal had been fractured by the first test. Results from test No. 1 suggested that reservoir permeability was 0.19 mD. Formation damage from cement invasion might affect this number and the true reservoir permeability might be significantly higher.

*Technical assessment.* The Algas Resources coalbed methane exploration well was designed to test the presence of coalbed methane in Mist Mountain Formation coal and to determine producibility of these beds. The borehole was located near the Vicary Creek mine. It is not known whether the major thrust fault intersected in the well had been predicted or not. The coal appeared to have reasonably high gas content but the production of gas from these seams was hindered by completion techniques.

**Table 36**
**Drillstem test data, Algas Coleman borehole**

| DST no. | Test interval (m) | Initial shut-in pressure (kPa) | Final shut-in pressure (kPa) | Flow rate (Mcf/d) | Fluid recovery |
|---|---|---|---|---|---|
| 1 | 262.3-278.4 | 1117 | 779 | 0.29 | 18.3 m mud |
| 2 | 343.1-359.5 | 1675 | 1228 | 0.051 | None (tool failure) |
| 3 | 281.5-298.9 | 1448 | 1282 | 0.127 | 54.9 m mud and water |

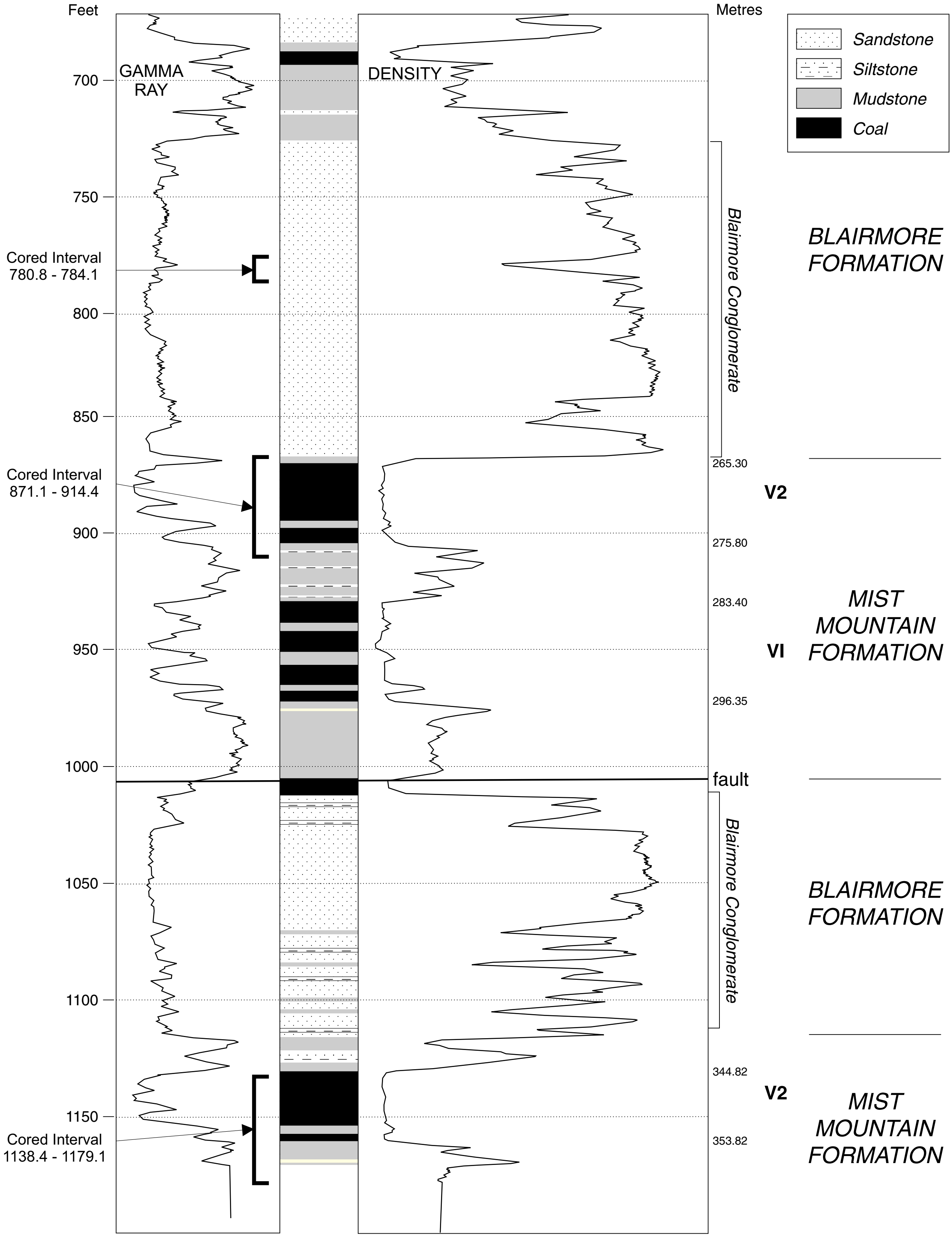


***Figure 51.*** *Detailed stratigraphic section of the Algas Coleman borehole.*

The well was drilled with a heavy polymer-based mud system and production casing was cemented into the borehole. Both these completion techniques allowed foreign material into the coal pore and fracture system, and caused significant formation damage. Reservoir permeability was calculated as low, but would have been compromised by the near wellbore formation damage. Subsequent evaluation of the production zones indicated that the upper V2 zone was not stimulated properly. Most gas production came from the lower V2 seam. Gas production levels greater than 100 Mcf/d might be possible using new completion techniques and deriving gas from all three coal intervals.

### *Algas Sullivan project*

Algas Resources Ltd. drilled the Sullivan Creek coalbed methane exploration well to assess the coalbed methane potential of Mist Mountain Formation coal in the foothills region of southern Alberta. The borehole, located about 40 km west of Longview, was completed in October, 1977 (Fig. 52). Total depth of the borehole was 244 m. Following completion of the drilling and wellbore testing, the borehole was plugged and abandoned.

*Data acquisition.* The Sullivan Creek well was drilled to a total depth of 244 m, generally considered too shallow for sufficient coal gas storage. The borehole was drilled using a truck-mounted rotary drill. Selective coring was done through the coal measures. Three intervals (187.8 to 193.6 m, 202.4 to 208.5 m and 216.1 to 243.9 m) were cored using a wireline split tube barrel. Thirty-five core runs were made but recovery was very poor, averaging less than 20% in the coal interval. Coal core samples were theoretically desorbed but no detailed data are available. With the poor core recovery, the quality of desorption data is somewhat suspect.

Following completion of drilling, a closed chamber drillstem test was run on the No. 2 seam interval. Results from the test indicated low permeability for the coal interval. Production casing was set to a depth of 192 m and a slotted liner production string casing installed from 195 to 198 m with the remaining 46 m left open hole. The well was subsequently completed for production testing and an injection test completed before production. Gas production was low (peak rate of 72 Mcf/d) and the well was subsequently plugged and abandoned.

*Geology.* The principal target of the Sullivan Creek exploration well was the thick Mist Mountain Formation coal. The borehole was spudded in the overlying Blairmore Formation, the base of which was intersected at a depth of 91.5 m. A complete section of Mist Mountain Formation was drilled or cored. The base of the Mist Mountain Formation is marked by the Morrissey Member of the Moose Mountain Formation and was intersected at 232.6 m (Fig. 53). Total thickness of the Mist Mountain Formation in the Sullivan wellbore is 141.1 m. Strata dip at about 35° and true formation thickness is 120.4 m. Strata consist of interbedded dark grey, fine-grained sandstone and siltstone with lesser amounts of mudstone and coal zones. The base of the formation is conformable with the underlying Moose Mountain Formation, and the upper contact is abrupt and erosional with the overlying conglomerate of the Blairmore Formation.

Eight coal zones were intersected in the borehole. These zones ranged from less than 1 m to greater than 13 m (apparent thickness). The zones were numbered sequentially from the base up. Depth of intersection, zone thickness, net coal thickness and true net coal thickness are tabulated in Table 37. Total cumulative net coal (true thickness) is 14.48 m, of which 55% lies within zones 1 and 2.

*Gas content.* No gas content data are available, although one sample from a depth of 216.2 m (zone No. 1) had a reported gas content of 7.8 cc/g. However, no information is available about where the gas samples were collected. Core recovery was less than 20% and any gas content or coal quality data available are suspect.

*Coal quality.* No coal quality data are reported, although one sample from a depth of 216.2 m was analyzed for rank and maceral composition. The coal has a reflectance value of 1.81 $Ro_{max}$ and a volatile matter content of 13.9%. This indicates that the rank of the coal is at the border between low volatile bituminous and semi-anthracite. Vitrinite content for the sample is 52%.

*Formation testing.* One drillstem test was completed on seam No. 2 in the Sullivan Creek wellbore. The drillstem test was a closed chamber test using inflatable packers. Test results indicated that the coal seam had low permeability and low reservoir pressure. The permeability value might have been affected by formation damage from the heavy mud

**Table 37**
**Coal intersections, Algas Sullivan borehole**

| Zone name | Depth of intersection (m) | Zone thickness (m) | Net coal thickness (m) | True net thickness (m) |
|---|---|---|---|---|
| 1 | 214.5-227.8 | 13.30 | 5.10 | 4.34 |
| 2 | 201.5-205.8 | 4.30 | 4.30 | 3.66 |
| 3 | 186.4-187.5 | 1.10 | 1.10 | 0.94 |
| 4 | 172.6-173.3 | 0.70 | 0.70 | 0.60 |
| 5 | 167.4-168.0 | 0.60 | 0.60 | 0.51 |
| 6 | 150.1-151.2 | 1.10 | 1.10 | 0.94 |
| 7 | 136.7-138.7 | 2.00 | 1.06 | 0.90 |
| 8 | 121.3-125.2 | 3.90 | 3.05 | 2.59 |

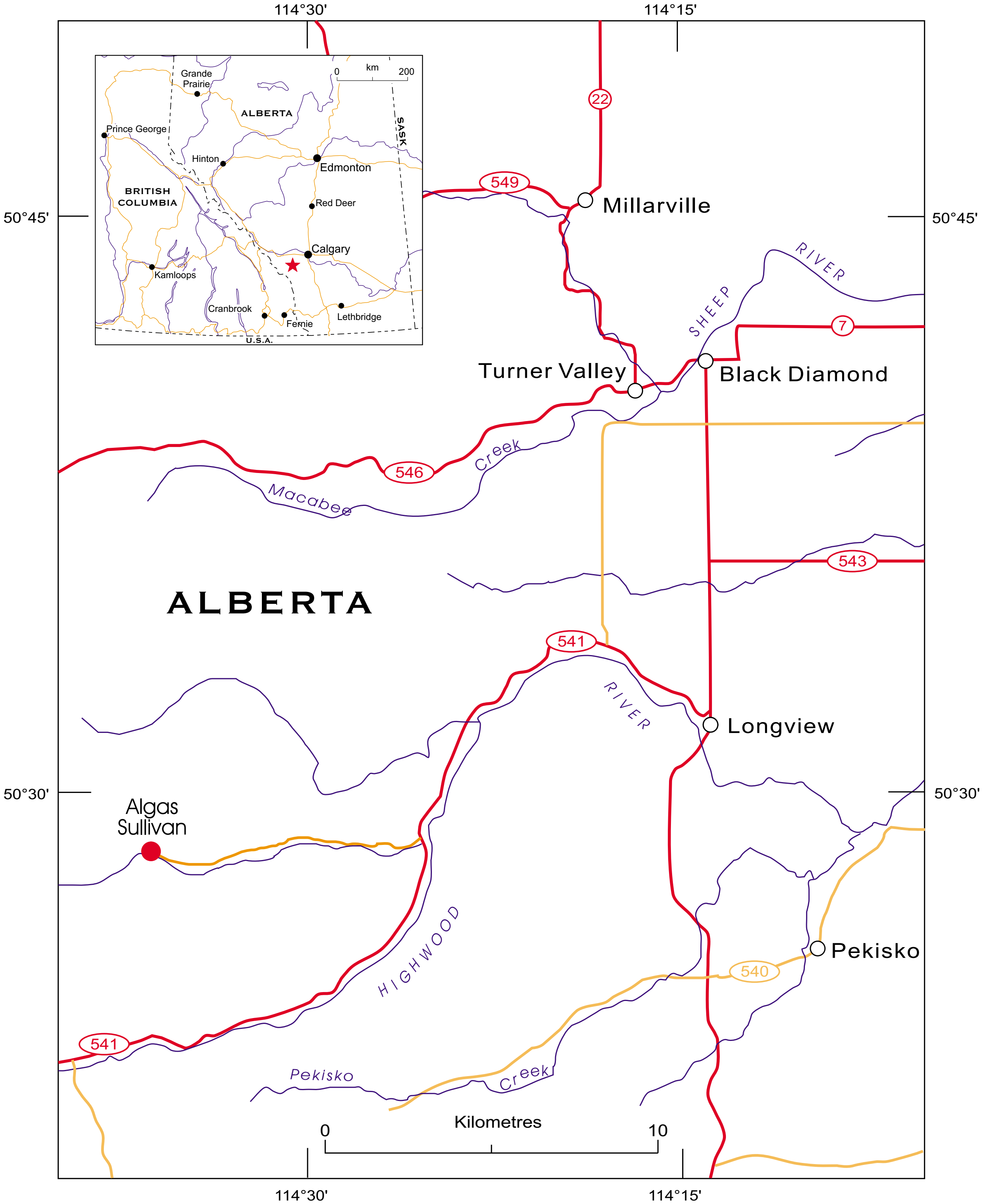


***Figure 52.*** *General location map of the Algas Sullivan Creek (10-34-15-05W5M) exploration borehole.*

drilling fluid used. Low reservoir pressure would be expected because of the shallow depth of intersection. Drillstem test information is summarized in Table 38.

Following completion of the drillstem test, production casing was cemented into the borehole to a depth of 192 m. A slotted liner was inserted to extend from the base of the

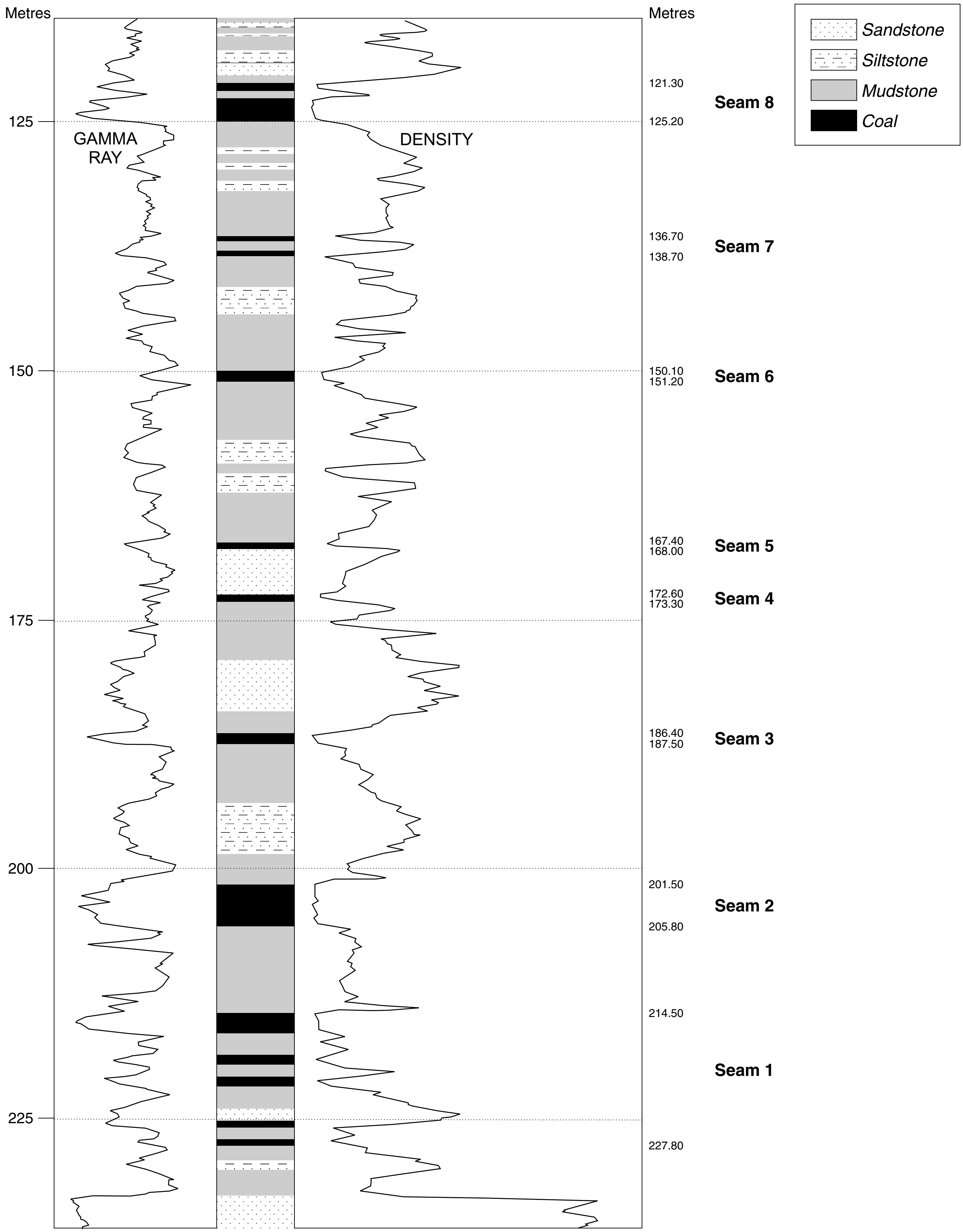


***Figure 53.*** *Detailed stratigraphic section of the Mist Mountain Formation for the Sullivan Creek borehole.*

**Table 38**
**Drillstem test data, Algas Sullivan borehole**

| DST no. | Test interval (m) | Initial shut-in pressure (kPa) | Final shut-in pressure (kPa) | Flow rate (Mcf/d) | Fluid recovery |
|---|---|---|---|---|---|
| 1 | 198.2-209.2 | 1453 | 1286 | 7.05 | 9.7 m muddy water |

production casing to 198.5 m. The borehole was plugged back to 207 m, effectively isolating the No. 2 zone for production testing. Gas production was initiated, with an average rate of 1 Mcf/d. Two injection tests were conducted on the No. 2 zone to determine reservoir permeability. Both tests yielded a value of 0.49 mD.

*Technical assessment.* The Algas Resources coalbed methane exploration well was designed to test the presence of coalbed methane in Mist Mountain Formation coal and to determine the producibility of the beds. The coal appeared to have a reasonably high gas content, but the production of gas from the main seam was minimal. Injection fall-off tests indicated that permeability of the reservoir was less than 0.5 mD. Given that the strata dip at 35°, it is probable that the coal was in a compressional stress regime. Production potential would be low, even if the wellbore was fracture stimulated.

## *Saskoil, Turner Valley*

The Saskoil Turner Valley well (8-10-19-3 W5) was a coalbed-methane-specific exploration well drilled by Saskoil/Mobil in June 1991 (Fig. 54). Several coal zones of the Mist Mountain Formation were intersected between 859.3 and 938.2 m. One seam contained net coal of 12.8 m (true thickness). Coal samples were collected from cuttings and cavings during clean out trips, and from a series of sidewall cores for desorption testing. Measured gas content ranged from 0.7 to 11.4 cc/g. Low values (0.7 to 1.1 cc/g) were determined for the sidewall core samples and do not represent in-situ gas content. Measured gas content of cuttings samples might also under-represent in-situ values.

*Data acquisition.* The drilling equipment for this borehole was a large conventional oil and gas rig. The original aim was to intersect the main coal zones and then core the intervals to obtain samples for desorption testing. During drilling, core point was missed because of mis-communication between the field and Calgary offices. As a result, the only desorption samples collected were from two sources: cuttings/cavings and sidewall cores. Canister 1 was apparently obtained during a pre-sidewall coring cleanout run and comprises cuttings and cavings. Canisters 2 and 3 were collected after sidewall coring and might have been obtained during a pre-logging cleanout run, while canisters 7 to 9 represent cavings sampled during a post-logging cleanout run. In all cases the cuttings/cavings samples were washed at 1.6 gravity to concentrate the coal. The time between first intersecting the coal seam and obtaining the samples was quite long (20 to 149 hours). Canisters 4 to 6 are each a composite of several sidewall cores obtained from three core runs.

*Geology.* The targeted coal-bearing interval was in the Jurassic–Cretaceous Mist Mountain Formation of the Kootenay Group. The formation was intersected at a depth of 850 m and is disconformably overlain by the basal conglomerate of the Blairmore Formation. The base of the Mist Mountain Formation is marked by a sharp contact with the underlying massive sandstone of the Moose Mountain Member of the Morrissey Formation (Fig. 55). Several distinctive coal zones were intersected in the interval 859 to 938 m with total net coal thickness of 22.7 m (Table 39). The main seam (Zone 2) is 18.0 m thick with 15.0 m of coal. Regional dip in the area is greater than 35° and correcting to true thickness results in Zone 2 being 15.3 m thick with a true net coal thickness of 12.8 m.

**Table 39**
**Summary of coal intersections, Saskoil Turner Valley**

| Coal zone | Interval (m) | Thickness (m) | | Net coal thickness (m) | |
|---|---|---|---|---|---|
| | | Intersected | True | Intersected | True |
| 5 | 859.3-875.1 | 15.8 | 13.4 | 2.9 | 2.5 |
| 4 | 883.7-890.2 | 6.5 | 5.7 | 1.5 | 1.3 |
| 3 | 894.7-898.0 | 3.3 | 2.0 | 0.6 | 0.5 |
| 2 | 904.7-922.7 | 18.0 | 15.3 | 15.0 | 12.8 |
| 1 | 933.6-940.3 | 6.7 | 5.7 | 2.7 | 2.3 |

*Gas content.* Nine samples were tested for gas content: three derived from sidewall cores and six from cavings/cuttings. Gas content (as received) ranged from 0.7 to 11.4 cc/g. The lowest values (0.7 to 1.1 cc/g) were obtained from the sidewall cores. The cuttings samples yielded higher values (4.7 to 11.4 cc/g; Table 40). Desorption curves for the sidewall cores showed unusual time-desorption relationships. Each showed a period, from about 100 hours or earlier, in which very little gas was desorbed. This was most pronounced in canister 5 in which the curve was essentially flat from about 50 to 400 hours. The curves and low gas content illustrate clearly that the sidewall coring method failed to provide representative samples of in-situ gas content. Although the samples were reported as coal, it is likely that there was significant contamination with sidewall mud cake.

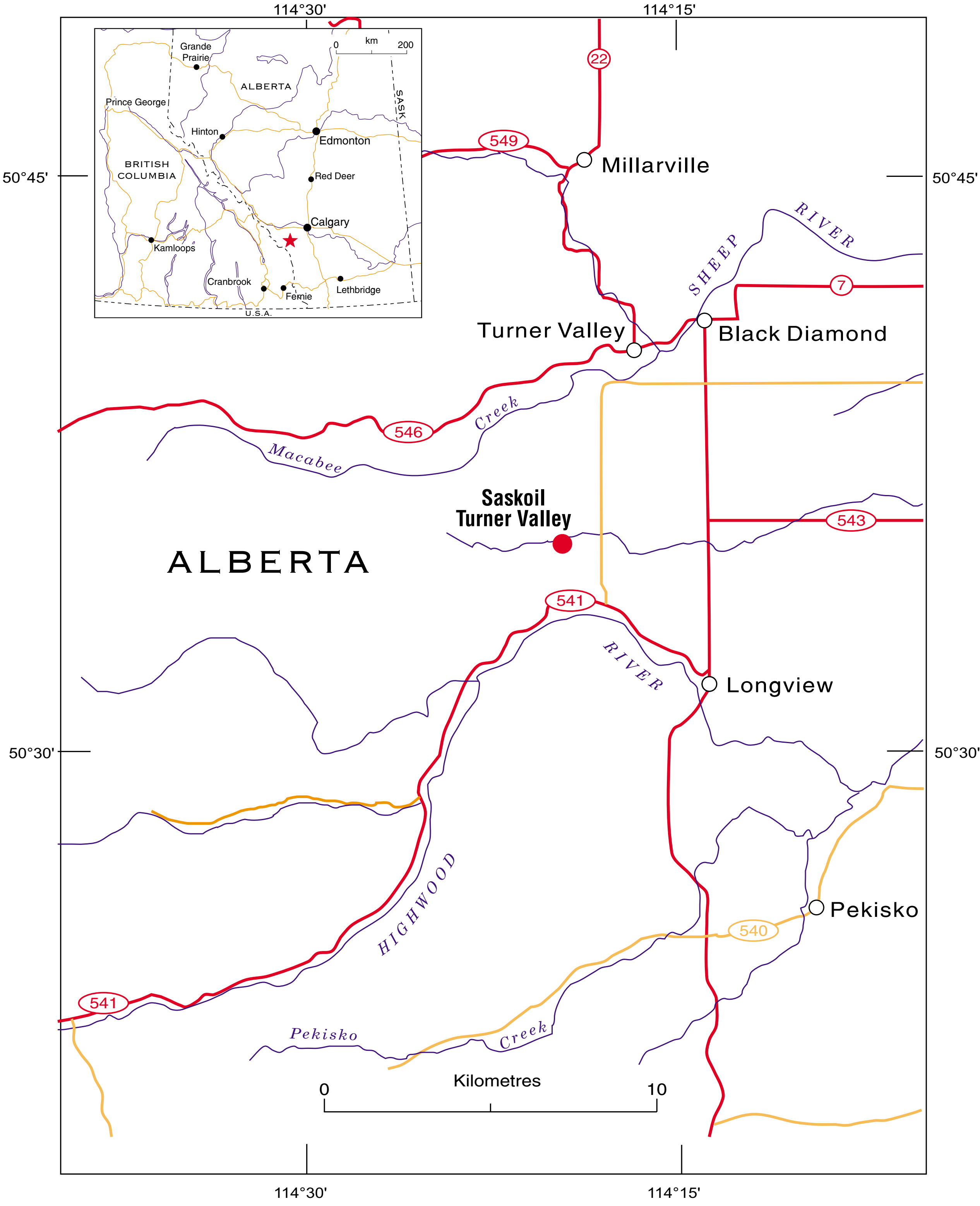


*Figure 54.* General location map of the Saskoil Turner Valley (08-10-19-03W5M) exploration borehole.

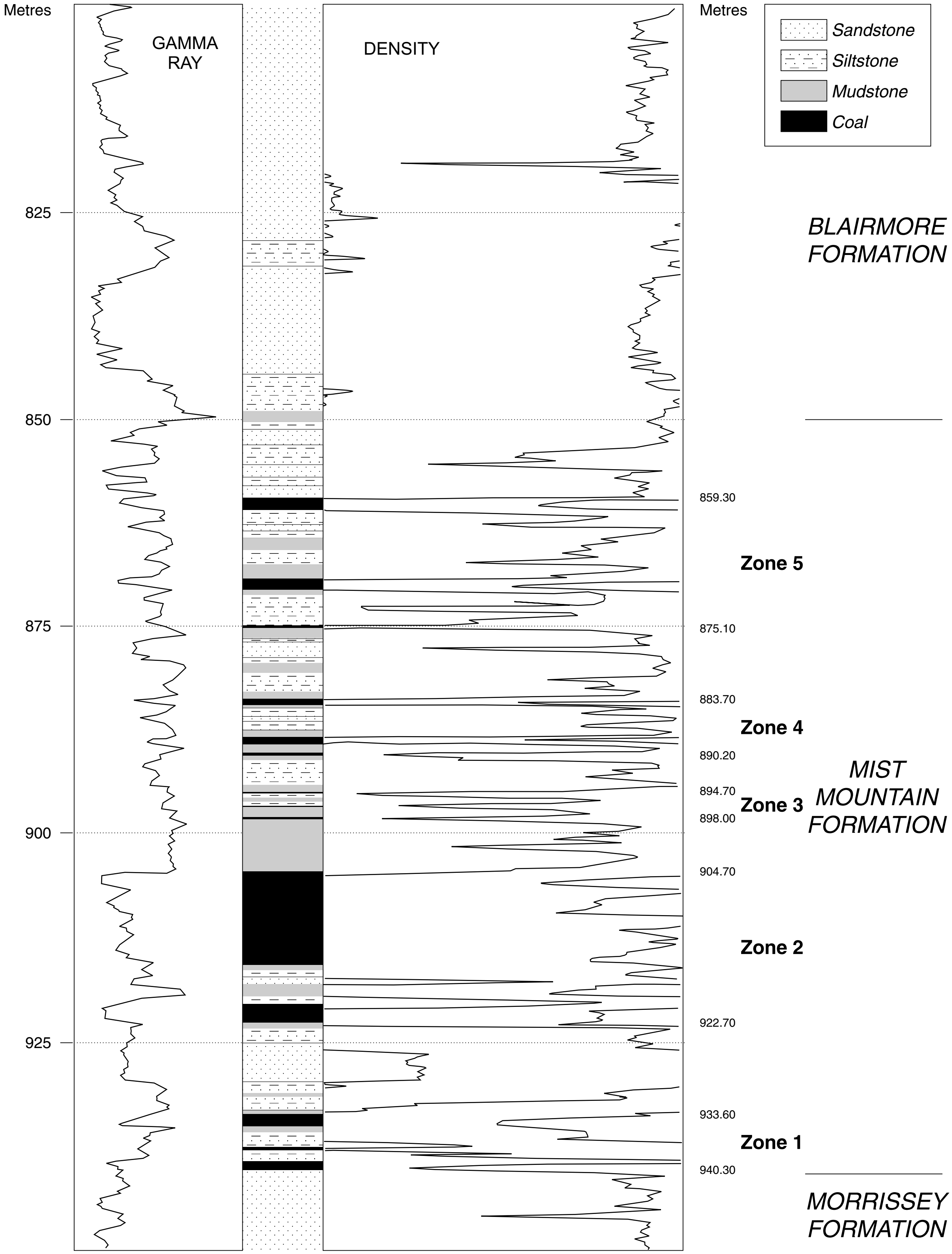


***Figure 55.*** *Detailed stratigraphic section of the Mist Mountain Formation coal measures intersected in the Saskoil Turner Valley borehole.*

**Table 40**
**Summary of gas content data, Saskoil Turner Valley**

| Canister number | Depth (m) | Gas content a.r.b. (cc/g) | Ash % | Gas content d.a.f. (cc/g) | Sample type | Comments |
|---|---|---|---|---|---|---|
| 1 | 850.0-940.0 | 11.40 | 17.60 | 14.20 | cuttings and cavings | 2 to 20 h since coal intersected |
| 2 | 850.0-940.0 | 10.00 | 19.60 | 12.70 | cavings | 30 to 49 h since coal intersected |
| 3 | 850.0-940.0 | 10.50 | 20.70 | 13.60 | cavings | |
| 4 | 906.1-908.8 | 1.10 | | | sidewall | |
| 5 | 909.4-913.8 | 0.80 | | | sidewall | |
| 6 | 907.5-920.7 | 0.70 | | | sidewall | |
| 7 | 850.0-940.0 | 5.30 | 16.00 | 6.40 | cavings | post-log cleanout 131 to 149 h since coal intersected |
| 8 | 850.0-940.0 | 4.7 | 14.1 | 5.6 | cavings | |
| 9 | 850.0-940.0 | 7.3 | 13.3 | 8.6 | cavings | |

The "Coal Analysis" log estimated gas content between 150 and 250 scf/t (4.7 and 7.6 cc/g). Desorbed gas content for cuttings samples were of similar magnitude. The theoretical "maximum producible methane" for coal of this rank is about 10 cc/g at 900 m for 20% ash coal, which is similar to the higher values obtained in these tests.

Gas content data show variable methane content from "not detected" to 75.6% (as received). This suggests that gas samples were taken before all air had been displaced from the desorption canisters.

*Coal quality.* Vitrinite reflectance analyses averaged 0.99% ($Ro_{max}$), indicating a rank of high volatile bituminous A, which is favourable for gas generation and storage. Ash content of the cuttings samples (washed with a liquid at 1.6 specific gravity) ranged from 13.3 to 20.7%. This indicated relatively high ash coal, as washing is expected to reduce ash content. A "Coal Analysis" log over the coal-bearing interval also indicated relatively high ash coal.

*Adsorption isotherms.* Two adsorption isotherms were conducted on cuttings samples from the Turner Valley well. Results are shown in Table 41. Calculated gas capacities (at 910 m and normal hydrostatic pressure) were consistent between the two samples, averaging 10.6 cc/g (as received) and 13.0 cc/g on a dry ash-free basis. It is likely that these samples were washed in a liquid with a specific gravity of 1.6 before testing. This tends to depress the adsorptive capacity of the coal, so the true gas capacity might be higher. The cuttings samples used for desorption were also washed, so the two sets of data can be directly compared. Measured gas content ranged from 4.7 to 11.4 cc/g indicating both undersaturated and fully saturated coal within the limits of this test regime.

*Formation testing.* Four drillstem tests were performed in this well but the tested zones appeared to be sandstone units rather than coal seams. This is an apparent contradiction to the purpose of the well, which was to determine the gas content and producibility of the coal seams.

*Technical assessment.* The coal-bearing interval intersected in the Saskoil Turner Valley well included at least one thick coal seam with a net coal thickness of 12.8 m. This seam was at a rank (high volatile bituminous A) favorable for methane generation and retention. Measured gas content ranged from 4.7 to 11.4 cc/ g (as received). The higher values are of economic potential.

It is likely that in-situ gas content was significantly higher than measured. Tests were performed on cuttings and cavings samples obtained at lengthy intervals following the initial intersection of the seams. Theoretically, if the coal reservoirs were at or below hydrostatic pressure, the column of drilling fluid would prevent the escape of gas from the seams until the cuttings began to move upward to the surface and the pressure declined. However, if the reservoir were overpressured, gas would start to escape immediately when the seams were intersected.

This assessment appears to be confirmed by the relationship between measured gas content and the time between initial coal intersection and sampling. The highest gas content occurred in Canister 1, which has a 2 to 20 hour lag time. Lowest values are in Canisters 7 to 9, which have the longest lag time (131 to 149 hours). Canisters 2 and 3 have intermediate gas content values and lag times (Table 40).

Furthermore, the small size of the cuttings offers a relatively large surface area to facilitate desorption of gas once the liquid pressure in the fluid return falls below

**Table 41**
**Adsorption isotherm data, Saskoil Turner Valley**

| Depth (m) | Langmuir pressure (kPa) | Langmuir volume (cc/g) | | Gas capacity (cc/g) | |
|---|---|---|---|---|---|
| | | eq. moist. | d.a.f. | eq. moist. | d.a.f. |
| 850-940 | 2566 | 12.90 | 16.70 | 10.00 | 12.90 |
| 850-940 | 2337 | 14.10 | 16.10 | 11.20 | 13.20 |

reservoir pressure. Consequently, gas loss occurring when cuttings are brought to the surface would be proportionally greater than expected from a core sample, and probably under-represents the in-situ gas content.

The cuttings were floated in liquid with a specific gravity of 1.6 before testing. This process can inhibit gas desorption by plugging the micropores in the coal. Although theoretical gas capacity and measured gas content were of similar magnitude, the adsorption isotherm samples were also washed, so Langmuir volumes might also be understated.

The method of sample collection and treatment prevented an accurate assessment of the gas content of the seams intersected in the Saskoil Turner Valley well. The thick coal seam and favourable rank suggest that this area holds potential for coalbed methane exploitation. However, further testing to more accurately assess gas content and permeability would be required before proceeding.

### *Algas Canmore project*

Algas Resources Limited undertook an experimental coalbed methane project in the late 1970s in the Canmore region of western Alberta (Fig. 56). Eight boreholes were drilled to a maximum depth of 288 m at two locations in the vicinity of the Canmore Mine. Two early boreholes (Canmore 1 and 2) were drilled to provide coal gas at relatively shallow depths. The Riverside wells were subsequently drilled to determine the presence of gas near the Riverside workings. Gas production was highly variable, in part because of the experimental nature of the program and also because of the many mechanical difficulties and breakdowns that occurred throughout the program. Commercial gas production was attempted in the Canmore 1 and 2 wells for a period of nearly three years (1978-1980) with limited success.

*Data acquisition.* The underground mines in the area had a history of producing methane gas from the coal seams and as much as 2 Mmcf/day of gas was being ventilated from the Riverside mine. The initial program of drilling two vertical boreholes in the Canmore/Wilson Creek region was to determine the presence of coal gas at depths ranging from 200 to 300 m. The principal target was the No. 6 seam, with an average true thickness of 6 to 7 m. Cores were cut from the main target coal seams and the samples placed in desorption canisters. Core recovery was poor, averaging less than 25%. Recovered coal was highly friable and crushed. Canisters were desorbed at ambient temperature conditions for one to six months. The data do not appear to have been corrected to STP (standard temperature and pressure) conditions or for head space volume variations.

Following drilling of the Canmore 1 to 3 wellbores, six shallow boreholes were drilled in the immediate vicinity of the Riverside mine. In this location, the Mist Mountain Formation coal lies at depths ranging from 50 to 125 m. The coal-bearing strata lie below the topographic elevation of the Bow River and high gas content was anticipated at shallow depths. The object of this six-hole drilling program was to experiment with gas production from two shallow wellbores. Four observation wells were drilled adjacent to the production wells. A number of experimental completion techniques were employed and the boreholes were put on limited production for 12 months. All wells have subsequently been plugged and abandoned.

The Algas Canmore project was undertaken in the late 1970s before the intense coalbed methane exploration of the Black Warrior and San Juan basins in the United States. The amount of data available for review is voluminous, but much it is of limited use. Documentation of the geological elements is poor, so for this section, data from all the boreholes were compiled into one section. Gas content data are limited and while there are proximate analyses for the coal samples, the poor core recovery suggests that it is questionable whether these analyses are representative of the coal seams. Gas content varies widely and probably reflects not only the depth at which the sample was collected, but also the length of time over which desorption experiments were completed.

*Geology.* The coal targeted in the Algas Canmore project belongs to the Mist Mountain Formation of the Lower Cretaceous Kootenay Group. The Mist Mountain Formation lies within the axis of the Mt. Allen Syncline, an overturned fold in the footwall of the Rundle Thrust. The eastern limb of the structure dips to the southwest at 30° to 50° and contains all of the workings that were operated by Canmore Mines Limited. The vertical to overturned western limb lies immediately below the Rundle Thrust, which placed Devonian carbonates on top of Lower Cretaceous strata.

Overburden ranges from less than 10 m at subcrop to greater than 2000 m toward the Devonian cliffs. Historically, the greater the depth of cover, the greater the occurrence of gas outbursts in the coal seams.

The Mist Mountain Formation is about 400 m thick and contains up to nine coal seams. Cumulative coal thickness for the formation is 15 m. The thickest coal seam is the No. 6 seam, which attains a thickness of 7.9 m (6.5 m true thickness). Strata consist of interbedded sandstone, siltstone and mudstone. Thick (>10 m) channel sandstone is common. A composite section of the Mist Mountain Formation is presented in Figure 57.

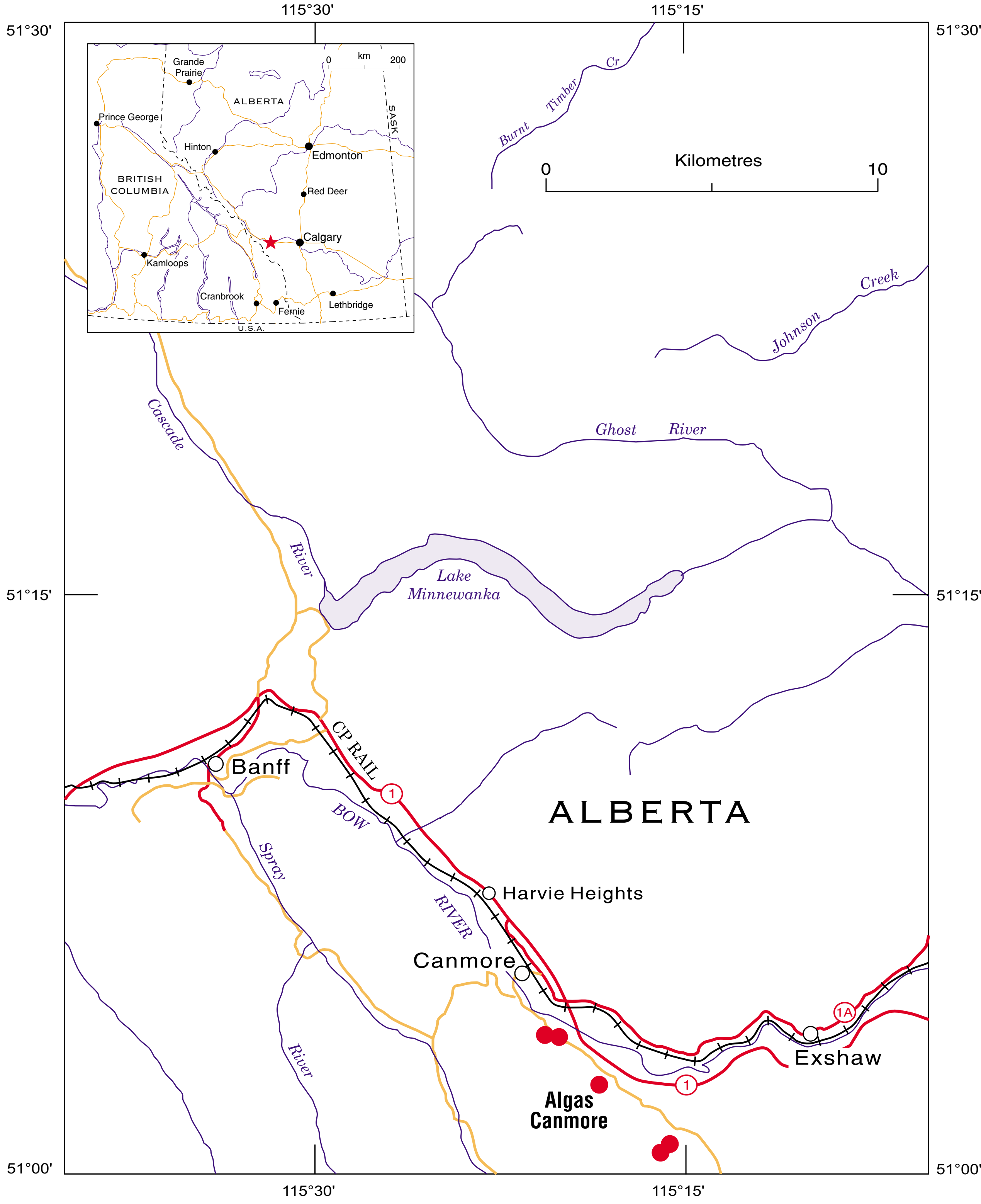


***Figure 56.*** *General location map of the Algas Resources Canmore exploration boreholes: Algas Canmore No. 1 (08-01-24-10W5M); Algas Canmore No. 2 (04-06-24-09W5M); Algas Canmore No. 3 (02-01-24-10W5M); Riverside No. 1 (09-21-24-10W5M); Riverside No. 2 (10-21-24-10W5M).*

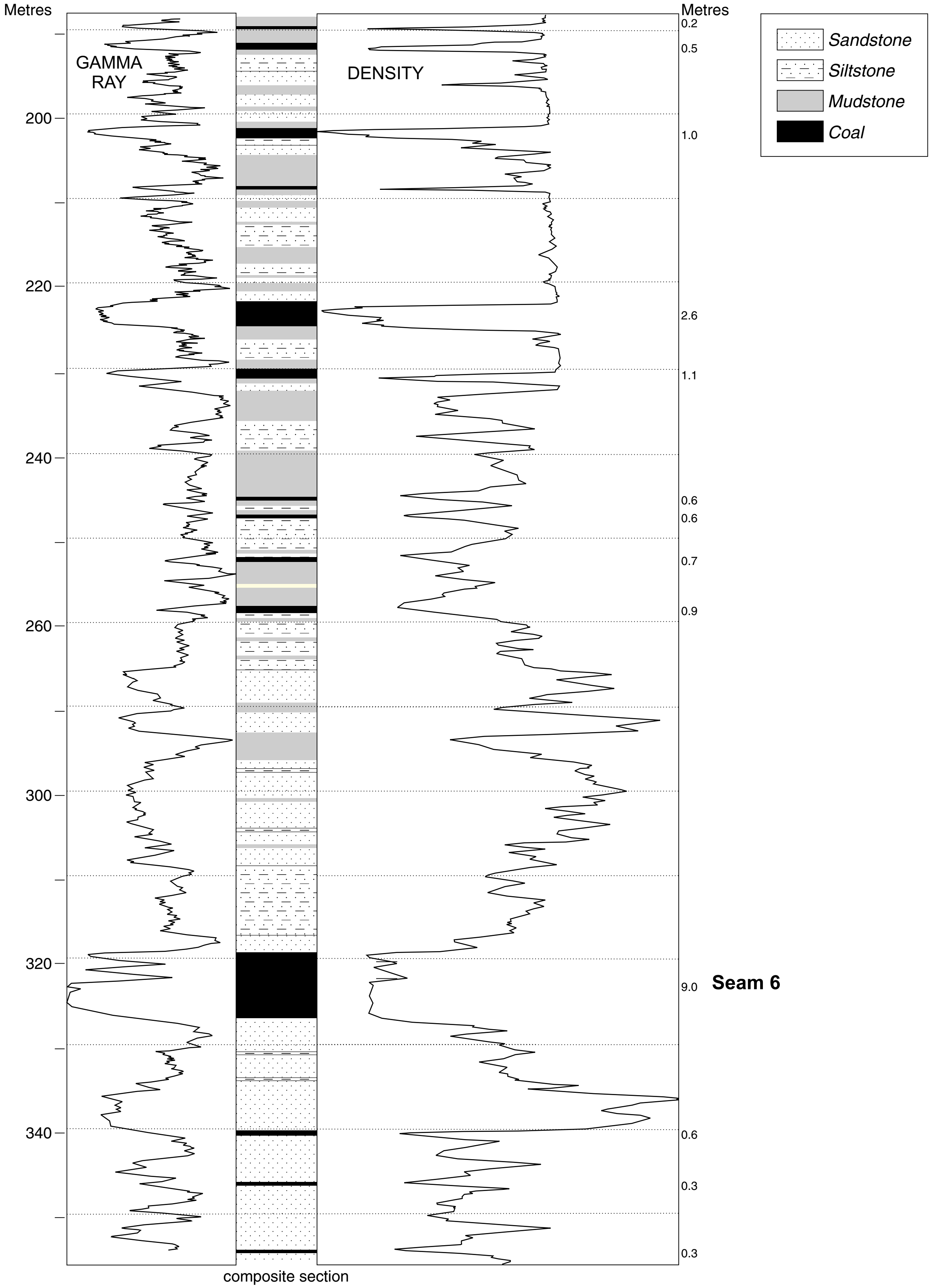


***Figure 57.*** *Detailed composite stratigraphic section of the Mist Mountain Formation coal measures encountered in the Canmore region.*

*Gas content.* Gas content data were collected for the Canmore 1, 2 and 3 wells and the Riverside 1 and 2 wells. Because a range of gas content data is available for the Canmore wells, it is unknown which specific seam was sampled. In the Riverside wells, eight canister tests were completed. The main coal seam targeted was the Wilson seam, which was intersected at depths ranging from 55 to 125 m. Gas content for the Riverside wells was widely variable but high, considering the depth of intersection. Results are given in Table 42.

It is not certain why the coal intersected at 125.5 m in Riverside No. 2 would have such a low gas content, considering the low ash value. A leak in the canister is suspected. The high gas content obtained from canister tests confirmed the observations in the underground mines, where gas outbursts were common. It is believed that these anomalously high values are because of the high overburden pressures resulting from the overthrusting associated with the Rundle Thrust Fault, and the topographic position of the coal below the regional water table of the Bow River valley.

*Coal quality.* The coals of the Cascade coal basin in the Canmore region are semi-anthracite in rank, having a vitrinite reflectance averaging 2.1% $Ro_{max}$. Ash content of the samples collected ranged from 5 to 36% a.d.b. and volatile matter was generally less than 11%. Maceral analysis was conducted on several samples and the coal appeared to be high in vitrinite. Because of the structural complexity of the region, the coal is highly friable and commonly sheared. This high degree of pulverization might explain the poor gas production relative to high gas content.

*Adsorption isotherms.* No adsorption isotherms were completed on the coal samples.

*Formation testing.* Several formation tests were conducted on the wells before stimulation and production. A summary of the formation tests performed on each well and seam are tabulated in Table 43.

Pump draw-down tests were conducted on the other Riverside wells to examine the connectivity and interference between wellbores. Lack of data interpretation prevented permeability measurements.

Following the formation testing, the wells were completed for limited production testing. The boreholes were back-filled to the target coal zone (seam No. 6 or the Wilson seam) and then production casing cemented into the borehole immediately above the coal. A slotted liner was installed in most wells to allow formation water to be produced from the inner tubing and gas in the outer annulus.

**Table 42**
**Summary of gas content data, Canmore region**

| Borehole | Depth (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content (%) (d.b.) |
|---|---|---|---|---|
| Canmore No. 1 | 234.9-288.2 | 14.6-24.0 | 16.6-25.2 | 8.10 |
| Canmore No. 2 | 196.7 | 10.10 | — | Unknown |
| Canmore No. 3 | 304.0 | 18.00 | 20.80 | 13.30 |
| Riverside No. 1 | 55.0 | 6.90 | 10.90 | 36.80 |
| | 56.0 | 7.10 | 10.00 | 28.80 |
| | 56.0 | 8.50 | 9.30 | 8.80 |
| | 57.8 | 4.10 | 6.00 | 31.50 |
| Riverside No. 2 | 124.0 | 14.50 | 16.00 | 9.50 |
| | 125.0 | 15.20 | 16.50 | 7.60 |
| | 125.5 | 4.10 | 4.30 | 5.00 |
| | 125 (chips) | 15.40 | 16.70 | 8.00 |

**Table 43**
**Summary of borehole testing, Canmore region**

| Borehole | Depth of test (m) | Test type | Permeability (mD) | I.S.I. pressure (kPa) | F.S.I. pressure (kPa) | Flow rate ($m^3$/day) | Recovery |
|---|---|---|---|---|---|---|---|
| Canmore No. 1 | 249 | DST | 0.9 | 1517 | 1172 | 5.20 | 24.4 m black water |
| Canmore No. 2 | 191-204 | DST | <0.5 | 600 | 455 | 0.07 | 12.2 m gas cut mud |
| | 230-240 | DST | <0.5 | 1482 | 1200 | 0.05 | 21.3 m gas cut mud |
| Canmore No. 3 | 304 | Injection | 0.9 | No data available | | | |
| Riverside No. 1 | 52.6 | Injection | 2 | No data available | | | |
| Riverside No. 4 | 42 | Injection | 2 | No data available | | | |

Gas production was undertaken from a number of wells. Completion methods varied from conventional hydraulic fracture stimulation to cavitation. Results of production from the wells are tabulated in Table 44. Although gas production was low for most of the wells, the depth of the coal reservoir was less than 250 m and reservoir pressures were low.

In all wells repeated mechanical problems hindered the uninterrupted dewatering of the seam. However, over the time period of gas production in all wells, irrespective of stimulation technique, there did not appear to be a significant increase in gas production rate as a result of lowering the water table. In a number of the wells, the water table was lowered to immediately above the coal seam. Lack of improvement in gas production, even when the reservoir was effectively de-watered, could be explained by the shallow depths of the coal seams. Reservoir pressures might be insufficient to allow gas to desorb freely. In addition, the coal seams were predominantly crushed or sheared and although gas content was high, overburden pressure made the reservoir permeability low. Lacking a well preserved cleat fabric, the coal behaved in a plastic manner and the natural fracture system, which might have been present, was closed.

*Technical assessment.* The Algas Canmore exploration and experimental production coalbed methane program was established a number of years before the widespread coalbed methane development in the United States. The understanding of the complexities of the coal, drilling techniques, borehole damage and stimulation methods were not clearly understood. In hindsight, numerous mistakes were made in the completion technology procedure that prevented achieving higher gas flows. However, even if there had been a 100% increase in gas production as a result of newer technological applications, gas volumes would still have been low (less than 100 Mcf/d). Volumes of 100 Mcf/d that can be achieved through modern technological advancements are probably not commercially significant under normal coalbed methane development economics. However, in Canmore, production wells are less than 500 m deep, completion costs are low and a production rate of 100 Mcf/d might be economically viable, particularly if economy of scale were achieved by drilling a large number of boreholes.

The Canmore region was an attractive coalbed methane exploration area in the early 1980s, when the mines were still operating. However, new housing development has sterilized most of the potential and has effectively removed any opportunity for coalbed methane development.

## Central region

### *Northridge Exploration Ltd.*

Northridge Exploration Ltd. conducted a formation test of a Mannville coal intersection in their Caroline well drilled during January 1992. The well is located in Township 33, Range 7 W5M (Fig. 58). The exploration target was a deeper Mannville conventional hydrocarbon interval, but interest in the coal was piqued as a result of a significant gas kick on the mud-log gas detector. No samples were collected and no further work was completed on the well.

*Data acquisition.* Coalbed methane data are limited from this exploration well as gas production from coal was realized after the drilling was completed. As a result, no coal material was collected and consequently no gas content or coal quality information exists. A formation test (drillstem test) was completed over the main coal zone. No further coalbed methane work was completed on the wellbore.

*Geology.* The coal measures intersected in the Northridge Caroline well at 3000 m belong to the Grande Cache

**Table 44**
**Summary of borehole production, Canmore region**

| Borehole | Depth (m) | Type of stimulation | Average gas production (Mcf/d) | Days produced | Peak gas production (Mcf/d) | Comments |
|---|---|---|---|---|---|---|
| Canmore No. 1 | 249 | Fracture | 18.6 | 431 | 49.8 | Numerous mechanical problems associated with pumping of wellbore |
| Canmore No. 2 | 195 | Fracture | 9.2 | 203 | 12.3 | Numerous mechanical problems associated with pumping of wellbore |
| Canmore No. 3 | 304 | Cavitation | 36 | 130 | 36 | Excessive plugging of pump because of fines production |
| Riverside No. 1 | 53 | Cavitation | <10 | Unknown | 22 | |
| Riverside No. 2 | 122 | Fracture | 48 | 320 | 65 | Precipitation in pipes, problems with gas locking of pump |
| Riverside No. 3 | 105 | Fracture | 35 | 423 | 55 | Frequent interruptions in pumping with gas locking of pump |
| Riverside No. 4 | 51 | Fracture | 0.6 | Unknown | Unknown | |

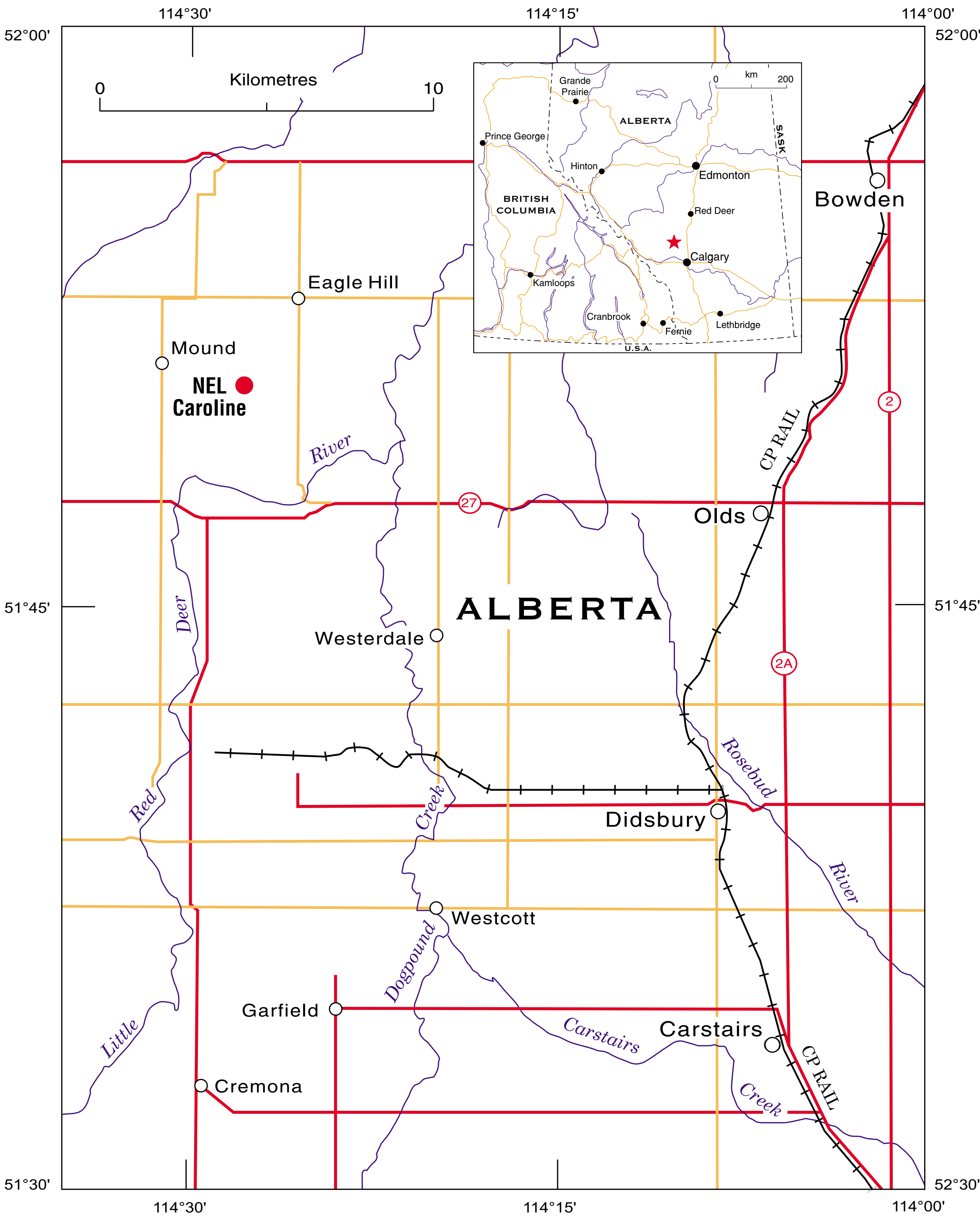


***Figure 58.*** *General location map of the Northridge Exploration Ltd. (06-23-33-07W5M) borehole.*

Member of the Gates Formation (Upper Mannville equivalent). The Gates Formation is about 300 m thick and the upper 165 m belong to the Mountain Park member. The underlying coal-bearing Grande Cache Member is about 115 m thick and, in the Northridge well, lies at a depth of 3015 to 3130 m. Five distinctive coal zones have been recognized with a cumulative thickness of 13.7 m. A summary of coal intersections is presented in Table 45. The seam designated as No. 3 (6.5 m thick) is the horizon that was tested in the wellbore.

A log response illustrating the stratigraphic section of the Grande Cache Member is presented in Figure 59.

*Gas content.* The wellbore was drilled to intersect a deeper hydrocarbon target, so no gas content samples were collected.

*Coal quality.* No coal samples were collected for proximate analyses. The geophysical log indicated that the No. 3 seam consisted of two plies, separated by a 1 m parting. The log signature suggested the coal plies were relatively clean with ash content estimated at between 15 and 20%. Grande Cache Member coals at a depth of 3000 m probably fall into a rank of low volatile bituminous, on the high end of the thermogenic window.

*Formation testing.* A conventional drillstem test was completed for Seams 3 and 4 to determine the coal gas producibility of the horizon. The test interval was from 3042.66 to 3075.00 m. Non-coal lithotypes in the test interval were mainly siltstone or silty sandstone and did not contribute significantly to the volume of gas or fluid recovered from the test. A small gas blow measuring 65 $m^3$/day (2.2 Mcf/d) was recorded, and gas flow was increasing at the time of final shut-in. Analysis of the drillstem test chart indicated low permeability. However, the test was carried out for only three hours. It is likely that the drillstem test data actually reflect the near wellbore damage, rather than the character of the formation.

*Technical assessment.* The Northridge Exploration Ltd. well intersected a thick (6.5 m) gassy coalbed at 3065 m. Although gas appeared to enter freely into the wellbore, the coal was at a depth where permeability barriers could have been high because of overburden pressure. Some tests of Fahler age coal in the deep basin of Alberta have produced gas from deep coal seams, but the volume has not been quantified. Drilling costs would be over $1,000,000 per well. There is also a high risk of borehole instability from coal caving into the borehole.

**Table 45**
**Summary of coal intersections, Northridge Exploration**

| Seam no. | Depth (top) (m) | Depth (base) (m) | Thickness (m) |
|---|---|---|---|
| 5 | 3016.0 | 3017.0 | 1.0 |
| 4 | 3052.0 | 3054.0 | 2.0 |
| 3 | 3065.7 | 3072.2 | 6.5 |
| 2 | 3085.3 | 3086.0 | 0.7 |
| 1 | 3117.0 | 3120.5 | 3.5 |
| Total | | | 13.7 |

### *Shell Ram River*

Shell Canada Resources Ltd. drilled an exploratory well (11-11-38-15W5M) in the Ram River area of western Alberta in January 1990 (Fig. 60). The well was drilled to a deeper oil and gas target, but core samples for desorption testing were cut in the Gates Formation coal. Gas content averaged 6.3 cc/g and appeared to be low with respect to coal rank.

*Data acquisition.* Two cores were cut to recover coal from the Grande Cache Member of the Gates Formation. Cut depths were 697.6 to 706.6 m and 711.8 to 716.2 m, and core recovery averaged 88%. Core was recovered by conventional means, so lost gas times were much longer (average 2 hours) than from wireline methods (10–15 minutes). Comparing the core intervals to coal intersections revealed that the main seam was not cored. Core interval No. 1 missed the entire seam and only 5 cm of coal was recovered. Core interval No. 2 recovered two thin seams, separated by a 1 m rock parting. Four core samples were collected and desorbed for about one month at the reservoir temperature (52°C). Initial readings were desorbed at 24°C, which would have negatively impacted the lost gas calculation. Following desorption of the samples, proximate analyses were completed and two adsorption isotherms run. No other tests were run on the borehole for coalbed methane testing.

*Geology.* The Grande Cache Member of the Gates Formation was intersected at 576.3 m. Strata consisted of thick, massive, quartzitic sandstone, interbedded dark to medium siltstone and dark mudstone and sparse coal seams. The Gates Formation is underlain by the mainly marine Blackstone Formation. A thrust fault repeats the Grande Cache Member at 1591 m. Six seams were intersected, the thickest (4.0 m) was designated Seam 6. Total cumulative coal thickness of all seams is 9.7 m over a 158 m stratigraphic interval. Regionally, the coal in the upper part of the Grande Cache Member is thin to thick and laterally discontinuous. The basal seam (Seam 6) commonly lies on a coarsening-upward sequence equivalent to the Glauconite zone in the Alberta-Plains-equivalent Mannville Group. This coal horizon appears to be more laterally contiguous but probably reflects the clastic transgression into the retreating Moosebar Sea toward the northwest. Stratigraphically, the basal seam intersected in the Shell Ram well is equivalent to the Jewel seam being mined in the Cadomin Luscar region to

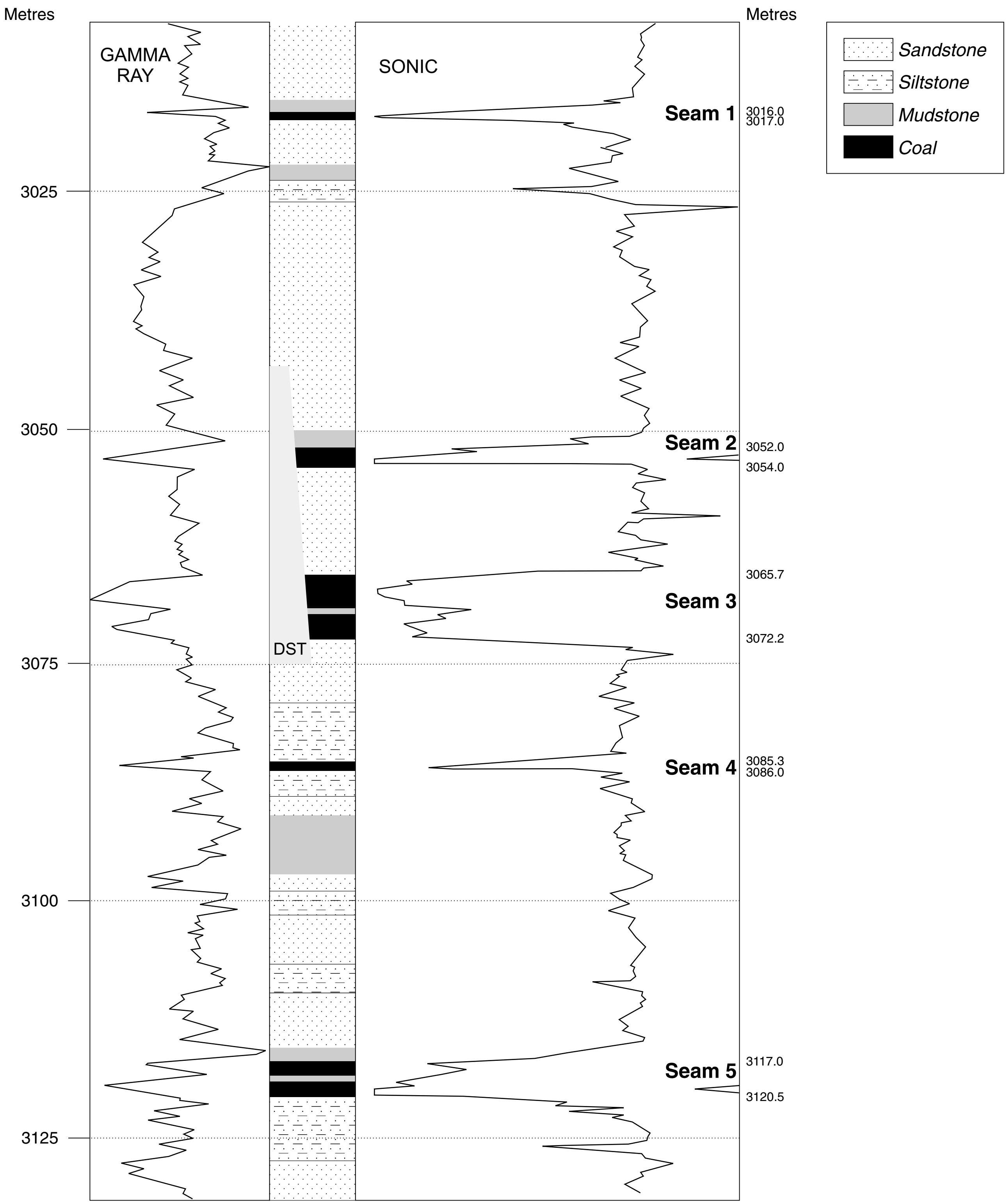


***Figure 59.*** *Detailed stratigraphic section of the Mannville coal zone for the Northridge Exploration Limited Caroline borehole.*

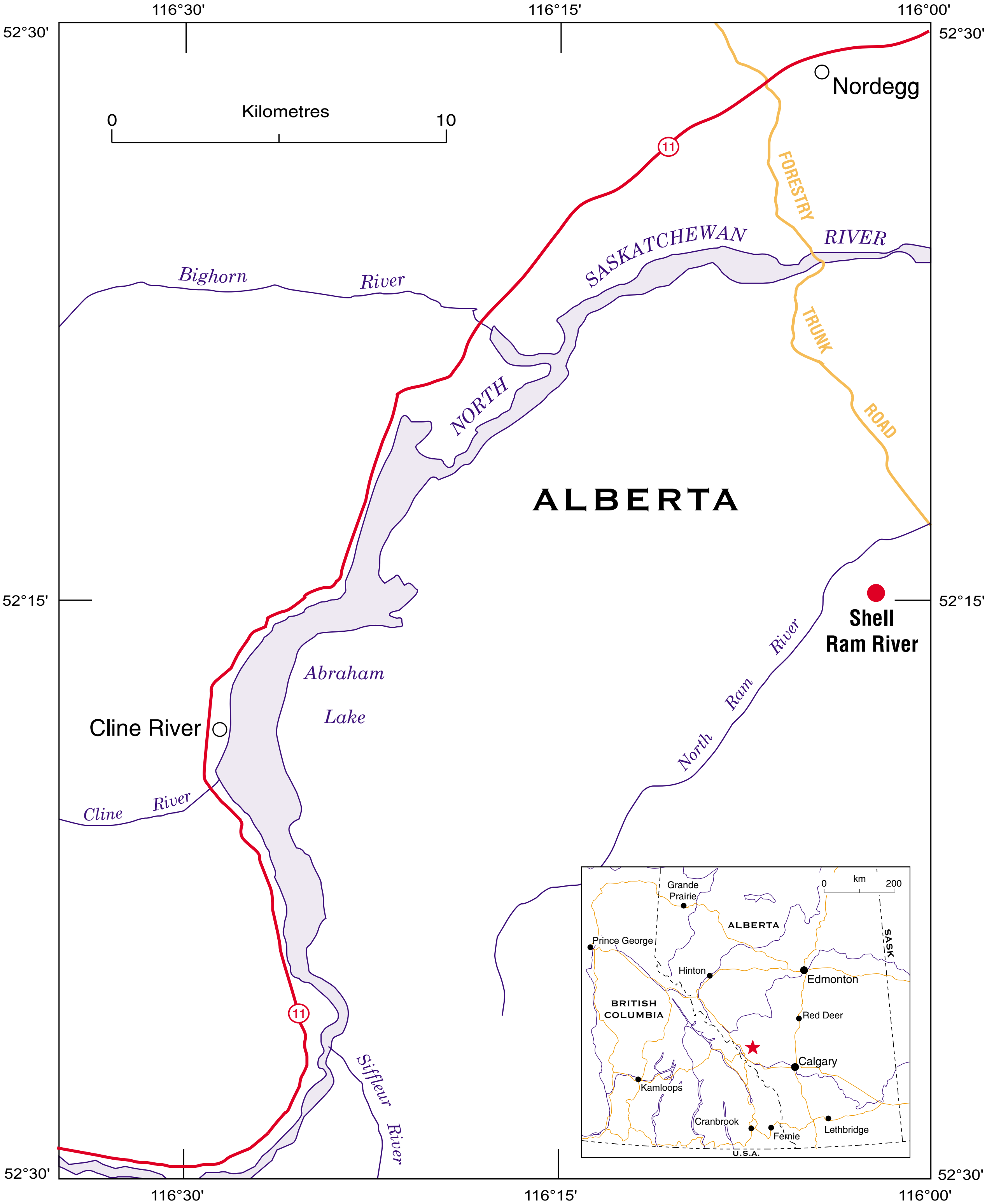


***Figure 60.*** *General location map of the Shell Ram River (11-11-38-15W5M) exploration borehole.*

the north. Both seams lie conformably on the Torrens member of the Gates Formation. In the Ram well, a secondary coal seam 3 m thick lies at the base of the Torrens Member (777 m depth), but is not included as part of the Grande Cache Member coal. Coal intersections and seam thicknesses are summarized in Table 46. Figure 61 gives a detailed stratigraphic section of the Grande Cache Member.

*Gas content.* Four desorption samples were collected from the two cored intervals. Samples were desorbed below reservoir temperature for 20 hours. The early desorption temperature was 23°C, about 30°C below reservoir temperature. This lower temperature resulted in an underestimation of the lost gas component. In addition, the time it took to trip the core barrel to surface averaged two hours. This lengthy delay in core recovery also resulted in an underestimation of lost gas.

Gas content ranged from 6.11 to 7.93 cc/g for the three samples from 712 m depth. The other sample collected at 697.8 m yielded a gas content of less than 2 cc/g, but the sample contained only 5 cm of coal. The dead space correction for this sample would have resulted in significant error. In the three deeper samples, lost gas volume estimate accounted for 26 to 29% of total gas desorbed. Accurate desorption curves at reservoir temperature would probably have boosted the lost gas component to over 40%. If this were the case, gas content would have risen marginally to between 7.2 and 8.6 cc/g .

*Coal quality.* Following completion of the desorption experiments, the canister samples were analyzed for proximate analysis. The three deeper canister samples were mixed. Ash content was 35.39%. Moisture on an "as-measured" basis was 1.13%. Rank determination from vitrinite reflectance was 1.12% $Ro_{max}$, making the coal high to medium volatile bituminous. The geophysical log response for the thick basal seam indicated that the coal has a much lower ash content than that analyzed from canisters 2, 3 and 4. A cleaner coal would have had a significant impact on the gas content.

*Adsorption isotherms.* Two adsorption isotherms were completed on the canister samples. The first isotherm was from the 5 cm sample of carbonaceous mudstone recovered in the shallower core interval. Ash content of this sample was 79%, indicating that it was not coal. The results from this isotherm are not believed to reflect the adsorptive capacity of the coal and are therefore not addressed in this report.

The second adsorption isotherm was made on the composite coal sample from the second core interval. The Langmuir formula for this sample is:

$$V=14.0*P/(P+1580)$$

where 14.0 is Langmuir volume (cc/g) and 1580 is Langmuir pressure (kPa).

Assuming a hydrostatic reservoir pressure of 9.817 kPa/m, reservoir capacity should be 11.4 cc/g. Actual average measured gas content was 7.0 cc/g, indicating that the coal reservoir was at 61% saturation. Caution must be exercised in using these numbers, as the sample appears to have a high ash content and does not adequately reflect the true desorption or adsorption characteristics of the Grande Cache Member coal.

*Formation testing.* No formation tests were completed over the coal intervals and the well was plugged and abandoned.

*Technical assessment.* The technical data gathered from this "piggyback" well was highly compromised by the core intervals chosen. Comparing core points to log intervals suggests that the core intervals were picked from drilling breaks and that a good borehole prognosis of coal seam intersections was not available. It is unfortunate that the main seam (No. 6) was completely ignored, even from a cuttings standpoint. As a result the coalbed methane results produced from the various tests performed do not reflect the true potential for coalbed methane in the region. There is a potential for finding coal gas in Seam 6 at shallow depth (700 m). Assuming an average seam thickness of 4 m and a gas content of 10 cc/g, the resource potential for this zone is 5.87 Bcf/section.

**Table 46**
**Summary of coal intersections, Shell Ram borehole**

| Seam no. | Depth (top) (m) | Depth (base) (m) | Total thickness (m) | Net coal thickness (m) |
|---|---|---|---|---|
| 1 | 581.9 | 583.8 | 1.9 | 1.9 |
| 2 | 632.0 | 632.5 | 0.5 | 0.5 |
| 3 | 697.5 | 697.7 | 0.2 | 0.2 |
| 4 | 711.1 | 714.0 | 2.9 | 2.0 |
| 5 | 719.0 | 719.5 | 0.5 | 0.5 |
| 6 | 733.5 | 739.8 | 6.3 | 4.6 |

## Northwest region

### *Conoco Canada project*

Conoco Canada Limited drilled a coalbed methane exploration borehole near the town of Coal Valley in west-central Alberta in October and November of 1994 (Fig. 62). The borehole targeted thick coal of the Tertiary age Coalspur Formation and the Upper Cretaceous Upper Brazeau Formation. Core samples were recovered for three major coal zones, Val D'Or, Mynheer and Brazeau.

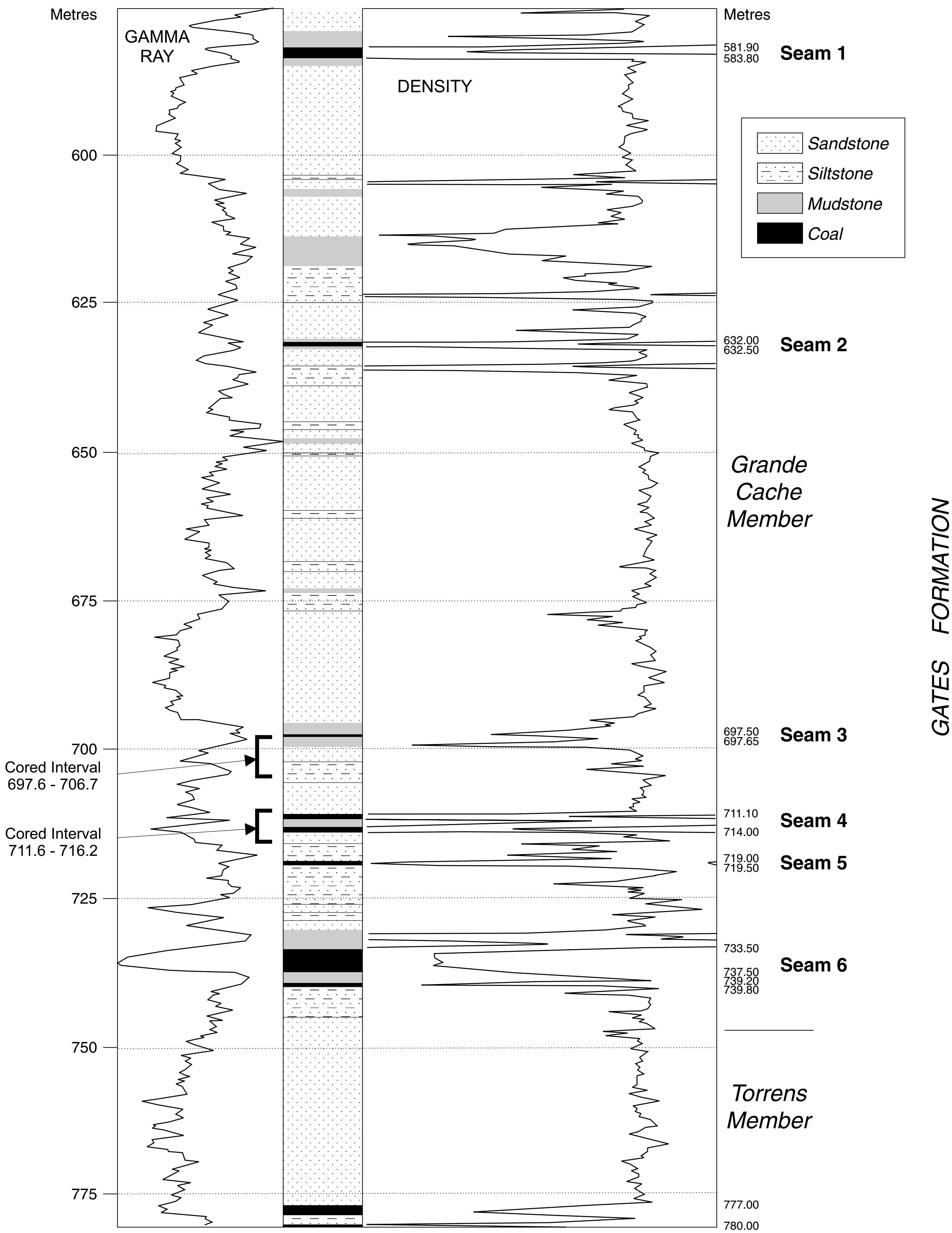


***Figure 61.*** *Detailed stratigraphic section of the Grande Cache Member of the Gates Formation for the Shell Ram borehole.*

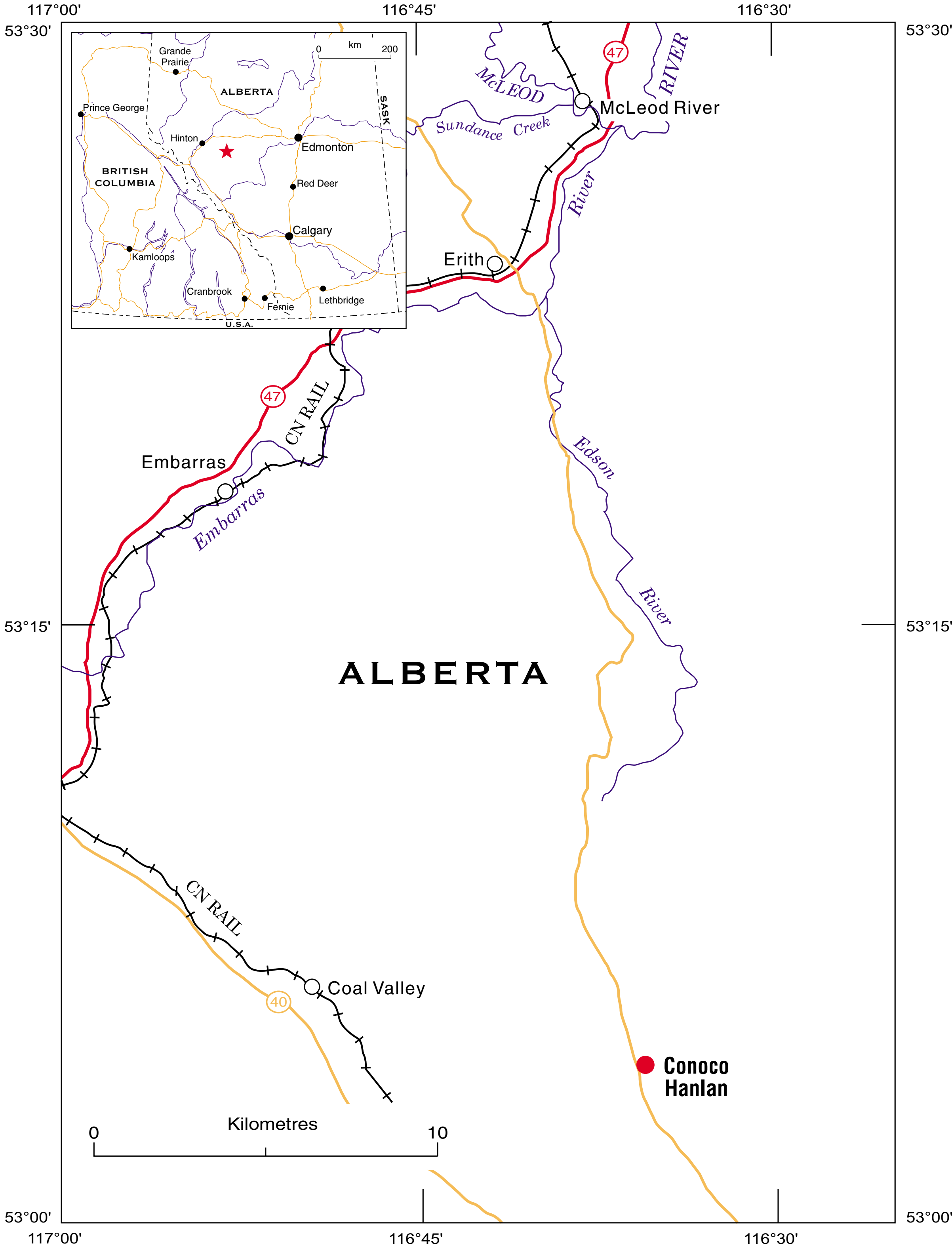


*Figure 62.* General location map of the Conoco Hanlan (11-20-47-18W5M) exploration borehole.

*Data acquisition.* The Conoco Hanlan borehole was drilled using a conventional oil and gas exploration drilling rig. Borehole diameter was 200 mm and drilling fluid was a polymer-based mud system. Upon reaching core point, the drill string was tripped out of the hole and a 9 m Christiansen core barrel with PVC liner was attached. The entire barrel was filled (9 m cored) then the drill string was tripped out of the hole.

Trip times were variable depending on depth, and ranged from 3.8 hours at 660 m to 6.5 hours at 880 m. Some operational difficulties occurred and the trip times achieved for the core from 850 m depth appeared to be extraordinarily long. At the surface, the PVC liner was retrieved from the barrel and cut to reveal the cored rock interval.

Desorption samples were collected for three coal intervals, Val D'Or (12 canisters), Mynheer (9 canisters) and Brazeau (2 canisters). The desorption results indicated that gas content values were relatively low, ranging from 0.20 to 2.31 cc/g. Lost gas calculations indicate that the lost gas component varied between 2 and 18% and averaged 7.5%.

*Geology.* The Conoco Hanlan well intersected the Coalspur coal measures at a depth of between 656 to 886.3 m, a thickness of 230.3 m. Five major coal zones were intersected, of which two were cored (Table 47).

Total cumulative zone thickness for the upper Coalspur Formation coal was 41.7m, of which total coal thickness was 19 m (Fig. 63). Total thickness of the upper Brazeau Formation coal zone is 1.99 m with a net coal thickness of 0.59 m.

The Val D'Or coal zone consists of an upper and lower seam about 1.4 and 4.3 m thick, respectively. A 0.79 m rock parting separates the two. The lower seam contains numerous rock partings. The Arbour, Marker, and Silkstone coal zones all consist of thin coal seams separated by thicker rock partings. The limited development of thick coal seams within these zones precluded further testing of the coalbed methane potential for these coal intervals.

**Table 47**
**Summary of coal intersections, Conoco Hanlan borehole**

| Seam | Depth (top) (m) | Depth (base) (m) | Total zone (m) | Total coal (m) |
|---|---|---|---|---|
| Val D'Or | 656.1 | 662.6 | 6.5 | 5.7 |
| Arbour | 696.2 | 703.3 | 7.1 | 2.1 |
| Marker | 745.4 | 756.1 | 10.7 | 3.0 |
| Silkstone | 833.8 | 844.5 | 10.7 | 3.3 |
| Mynheer | 879.8 | 886.5 | 6.7 | 4.9 |

The Mynheer zone consists of an upper seam 4.0 m thick and a lower seam 0.9 m thick, separated by a 1.6 m rock parting. In the upper seam, two intermediate partings are present and the overall geometry of the coal rock distribution appears to be similar to the Val D'Or zone.

*Gas content.* Measured gas content was highly variable, ranging from an average of 1.40 cc/g for the Val D’Or zone to 0.90 cc/g for the Mynheer and 0.24 cc/g for the Brazeau coal zone. The gas content appeared to be lower than expected. There also appeared to be an inverse relationship between increasing depth and measured gas content (Fig. 64).

A comparison of as-received gas content data for all samples reveals that the average for the Val D’Or zone is significantly higher than for the Mynheer zone, which is in turn higher than that for the Brazeau. Average gas content for the Val D’Or zone is 1.40 cc/g while that for the Mynheer and Brazeau is 0.90 and 0.24 cc/g, respectively. When the desorption data is corrected to a d.a.f. (dry ash free) basis, the trend of decreasing gas content with increasing depth is still present. This suggests that factors other than purely diluents, such as ash, are controlling the overall distribution of gas within the borehole.

There is no obvious data variability to explain the decreasing gas content with depth nor the difference in gas content data between the Val D’Or and Mynheer coal zones. Data from other boreholes have produced similar results.

*Coal quality*. Proximate analyses of the samples results in a range of ash values (11.14 to 49.08%), averaging 30% for the Val D’Or and Mynheer zones and 25% for the Brazeau zone. A comparison of quality data revealed that there is no significant difference in quality between coal from the three major coal zones. The Val D’Or zone had an as-received ash range of 11.14 to 47.5%, with an average of 30.95%. Similarly, the ash content for the Mynheer zone ranged from 15.23 to 49.08% with an average of 30.04%, and Brazeau coal averaged 25.4%. Volatile matter ranged from 36.49 to 46.19%, with an average of 40.94%, indicating the coal was high volatile bituminous B in rank. This value is consistent with the projected Ro value of 0.70% reflectance for coal at the intersected depth. Moisture content was variable. All samples except one had moisture contents of less than 4%, and averaged 2.85%. The primary reason the gas content was low is probably that the coal was insufficiently mature to reach the rank threshold where significant quantities of thermogenic methane could be generated. Even though the coal had the capacity to hold significant quantities of methane gas, it had not generated sufficient volumes to be adsorbed.

*Adsorption isotherms.* No adsorption isotherms were complete on the coal samples.

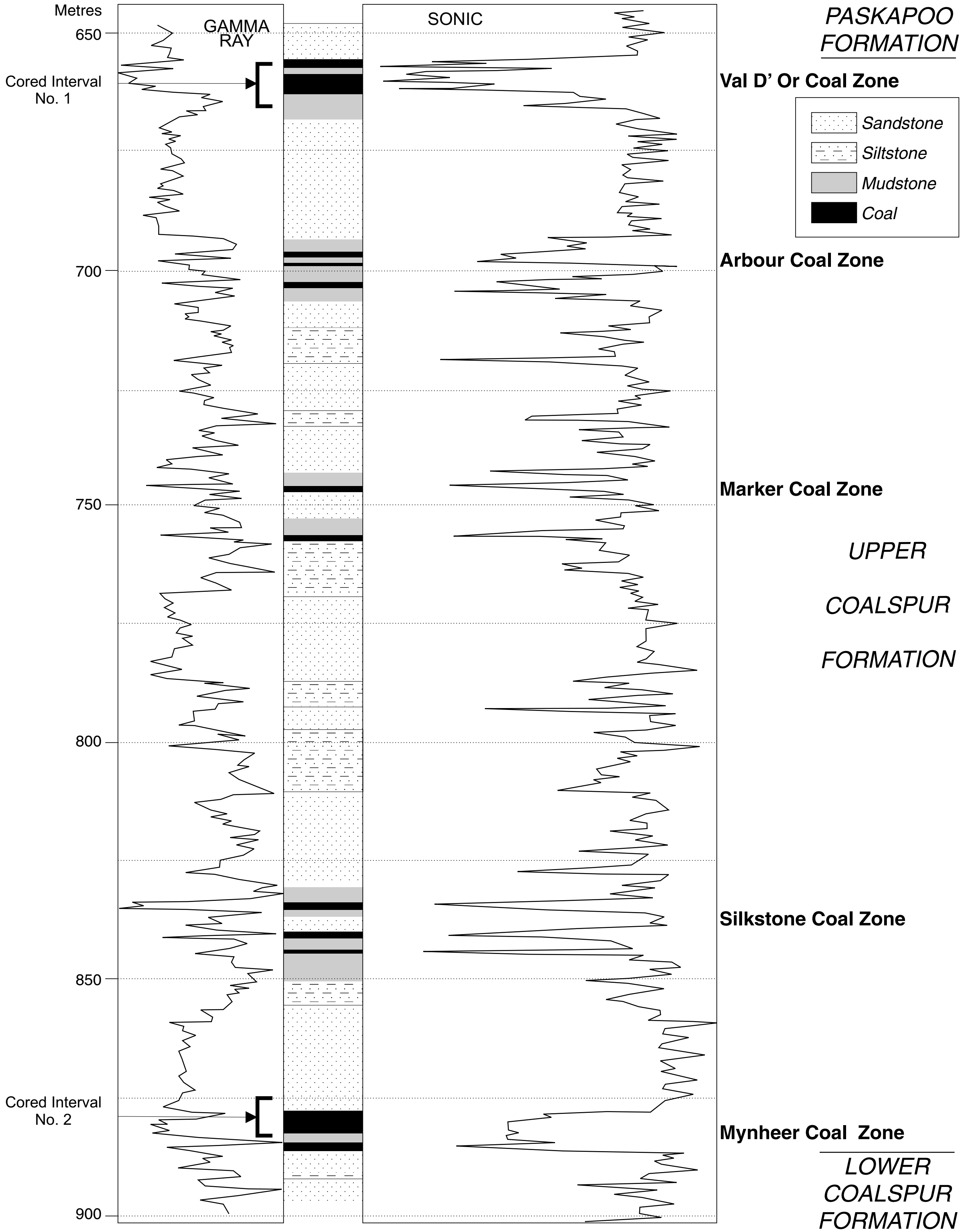


***Figure 63.*** *Detailed stratigraphic section of the upper Coalspur Formation illustrating the Val D'Or, Arbour, Silkstone, and Mynheer coal zones for the Conoco Hanlan borehole.*

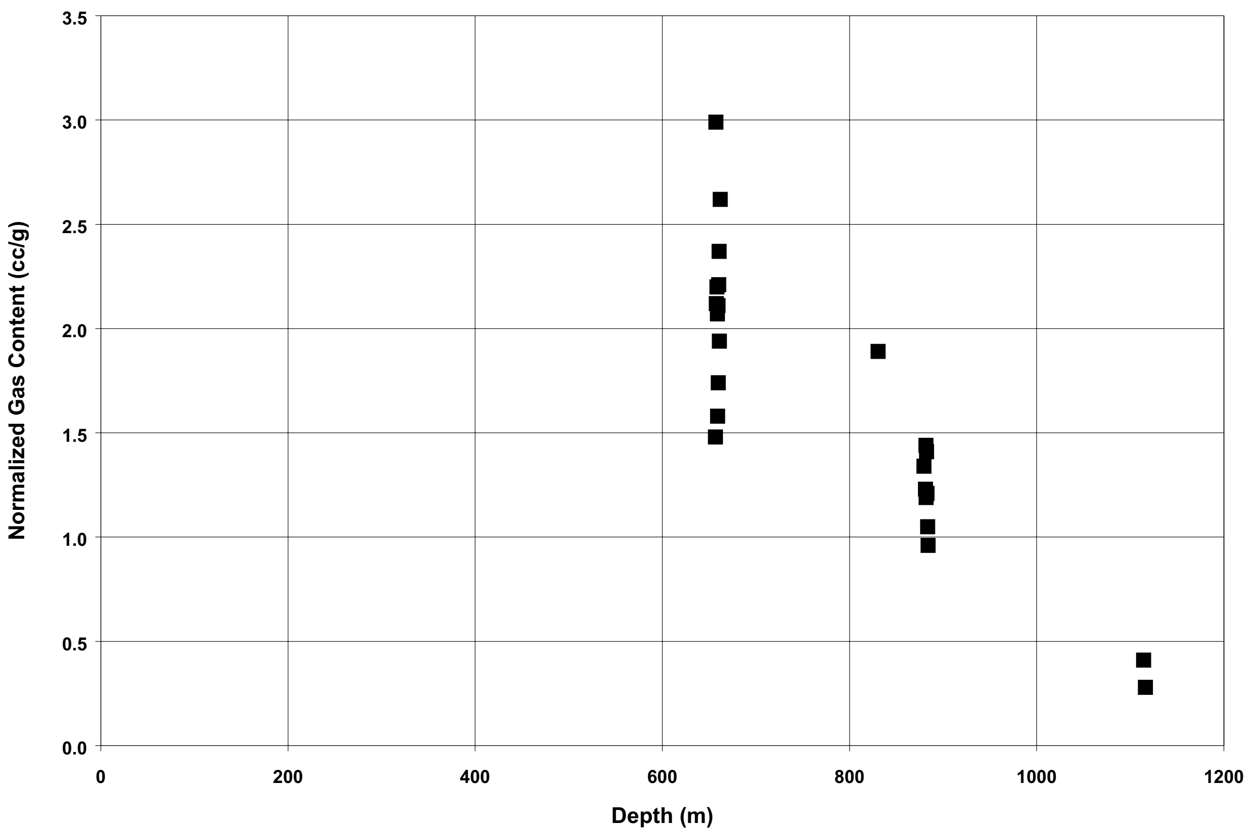


***Figure 64.*** *Normalized gas content versus depth for desorption samples collected from the Conoco Hanlan well.*

*Formation testing.* No formation tests were conducted on the wellbore.

*Technical assessment.* Gas content values for the Conoco Hanlan well appeared to be lower than anticipated, averaging 1.8 cc/g for the Val D'Or zone, 1.1 cc/g for the Mynheer zone and 0.25 cc/g for the Brazeau zone (see Table 48). The low gas content could be attributed to the high ash and mineral matter content of the coal samples (averaging 30%). Correcting the gas content to a dry ash-free basis (d.a.f.) yielded an average gas content of 2.1 cc/g for the Val D'Or, 1.2 cc/g for the Mynheer and 0.4 cc/g for the Brazeau zone. These gas content measurements were still lower than expected and appeared to be at least 30% lower than Coalspur Formation coal tests in other localities in west-central Alberta.

Lower than expected gas content values coupled with high ash content tended to downgrade the exploration viability of the Conoco Hanlan coalbed methane exploration target. Even though the Coalspur Formation had the potential for significant coal reserves [$73 \times 10^6$ tonnes per sq. mile ($1.89 \times 10^8$ tonnes/$km^2$)], in-place gas resources were low, averaging less than 3.5 Bcf/section ($9.9 \times 10^{-2}$ Bcm/section).

### *Mobil Oil Canada/Chevron Canada project 6-14-57-7-W6M*

Mobil Oil Canada, in conjunction with Chevron Canada undertook a coalbed methane test well near Grande Cache in 1991 (Fig. 65). The original plan for this well was to drill to the top of the Grande Cache Member coal and core the seams. Geological interpretation appears to have been incorrect, resulting in the coal seams being missed. Subsequent sidewall cores were completed for analyses.

*Data acquisition.* The coalbed methane well was drilled to 1025 m and penetrated coal-bearing strata of the Grande Cache Member of the Gates Formation as well as the Gething Formation.

The original target was the coal of the Grande Cache Member but because of geological misinterpretation, this coal was bypassed and only the Gladstone coal was cored. A number of sidewall cores were collected from the coal measures, but the quality of data is limited and of poor quality. Following completion of drilling, drillstem tests were completed on the No. 4 and No. 10 coal seams. A limited production test was undertaken on No. 10 seam and the well was abandoned because of poor production rates.


***Figure 65.*** *General location map of the Mobile Chevron Muskeg River (06-14-57-07W6M) exploration borehole.*

Several adsorption isotherms were completed on coal samples gathered from the Gladstone Formation and mechanical rock property tests were completed on Grande Cache Member core samples.

*Geology*. Grande Cache Member coal has been mined for many years in the Grande Cache region and farther south near Hinton and Cadomin. The coal-bearing sequence contains up to 14 coal zones within a stratigraphic interval of 155 m (Fig. 66). Seam thickness ranges from 0.5 m to more than 4.0 m. Cumulative coal thickness within the section is 15.8 m. Seam 12 lies at the top of the Grande Cache Member and Seam 3 lies at the base on top of the massive sandstone beds of the Torrens Member. Seams 4, 10 and 11 are the thickest units and appear to have the greatest potential.

In this borehole, seam No. 4 appears to be anomalously thin (1 m), with the upper 3 m having been shaled out. Regionally, the No. 4 seam has an average thickness of 4 to 5 m. Table 49 summarizes the coal zones intersected.

Beneath the Gates Formation lie the finer grained sediments of the Moosebar Formation. Two coarsening-upward cycles of strata, 65 m thick, can be recognized from the geophysical logs. The Moosebar Formation lies unconformably on top of the coal-bearing sediments of the Gething Formation. In the coalbed methane well, the Gething Formation is 90 m thick and contains up to four coal seams. Maximum thickness of the coal beds is 1.0 m and the average is 0.5 m. Cumulative coal thickness for the Gething Formation is 2.8 m.

**Table 48**
**Summary of measured gas content, Conoco Hanlan borehole**

| Sample no. | Seam name | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| 1 | Val D'Or | 656.80 | 1.02 | 1.42 |
| 2 | Val D'Or | 657.20 | 2.31 | 2.88 |
| 3 | Val D'Or | 657.60 | 1.04 | 1.98 |
| 4 | Val D'Or | 658.39 | 1.35 | 2.10 |
| 5 | Val D'Or | 658.73 | 1.77 | 1.99 |
| 6 | Val D'Or | 659.13 | 0.88 | 1.48 |
| 7 | Val D'Or | 659.45 | 1.60 | 2.02 |
| 8 | Val D'Or | 659.84 | 1.19 | 1.67 |
| 9 | Val D'Or | 660.24 | 1.42 | 2.11 |
| 10 | Val D'Or | 660.64 | 1.26 | 2.16 |
| 11 | Val D'Or | 661.00 | 1.37 | 1.85 |
| 12 | Val D'Or | 661.93 | 1.56 | 2.54 |
| 13 | Mynheer | 879.55 | 0.72 | 1.28 |
| 14 | Mynheer | 881.11 | 0.78 | 1.18 |
| 15 | Mynheer | 881.54 | 1.19 | 1.40 |
| 16 | Mynheer | 881.94 | 0.83 | 1.15 |
| 17 | Mynheer | 882.36 | 1.05 | 1.36 |
| 18 | Mynheer | 882.71 | 0.84 | 1.15 |
| 19 | Mynheer | 883.06 | 1.52 | 1.83 |
| 20 | Mynheer | 883.54 | 0.69 | 1.02 |
| 21 | Mynheer | 883.92 | 0.47 | 0.92 |
| 22 | Brazeau | 1114.30 | 0.29 | 0.39 |
| 23 | Brazeau | 1116.03 | 0.20 | 0.27 |

The borehole was located in the foothills region and the strata appear to dip gently to the west at less than 15°. The dip meter and formation micro-scanner logs show no indication of faulting within the borehole.

*Gas content.* Gas content data are limited for this borehole, as the coring undertaken in the Gething Formation intersected a minimal amount of coal (several interbands of shaly coal less than 10 cm thick), and the Grande Cache Member coal was not cored. A total of 10 sidewall cores were cut, five from Seam No. 3 of the Grande Cache Member and five from a seam in the Gething Formation. Core recovery was either poor or consisted mainly of shaly coal or coaly mudstone. The sidewall cores were placed in two canisters and desorbed. Gas content, as expected, was low. The samples were washed, and produced ash-free values of 16.8 and 9.4 cc/g.

Gas samples were collected from the sidewall cores and yielded methane content values of over 75%. As the analyses also reported some nitrogen within the sample, it is possible that the sample bomb was not completely purged of air. The methane content is probably significantly higher (> 90%).

*Coal quality.* As with the gas content data, samples of coal are limited to the sidewall samples from seam No. 3 and the Gething coal seam. Proximate analyses were performed on the coal and non-coal material separately. Ash content values of the coal from seam No. 3 and the Gething seam were 4.83 and 34.9%, respectively. Some cuttings were collected from seam No. 10 yielding an ash content of

**Table 49**
**Summary of coal intersections, Mobil/Chevron Muskeg River borehole**

| Seam number | Depth (m) | Total thickness (m) | Net thickness (m) |
|---|---|---|---|
| 12 | 559.0-560.0 | 1 | 1 |
| 11 | 565.8-567.0 | 1.2 | 1.2 |
| 11A | 584.9-586.0 | 1.1 | 1 |
| 10 | 600.0-605.0 | 5 | 4.6 |
| 9 | 617.0-618.4 | 1.4 | 1.2 |
| 7 | 648.0-649.3 | 1.3 | 1.3 |
| 6 | 654.5-655.0 | 0.5 | 0.5 |
| 5 | 673.0-673.5 | 0.5 | 0.5 |
| 4 | 679.0-683.0 | 4 | 1.0 |
| 3 | 702.0-702.5 | 0.5 | 0.5 |
| Total | | 16.5 | 12.8 |

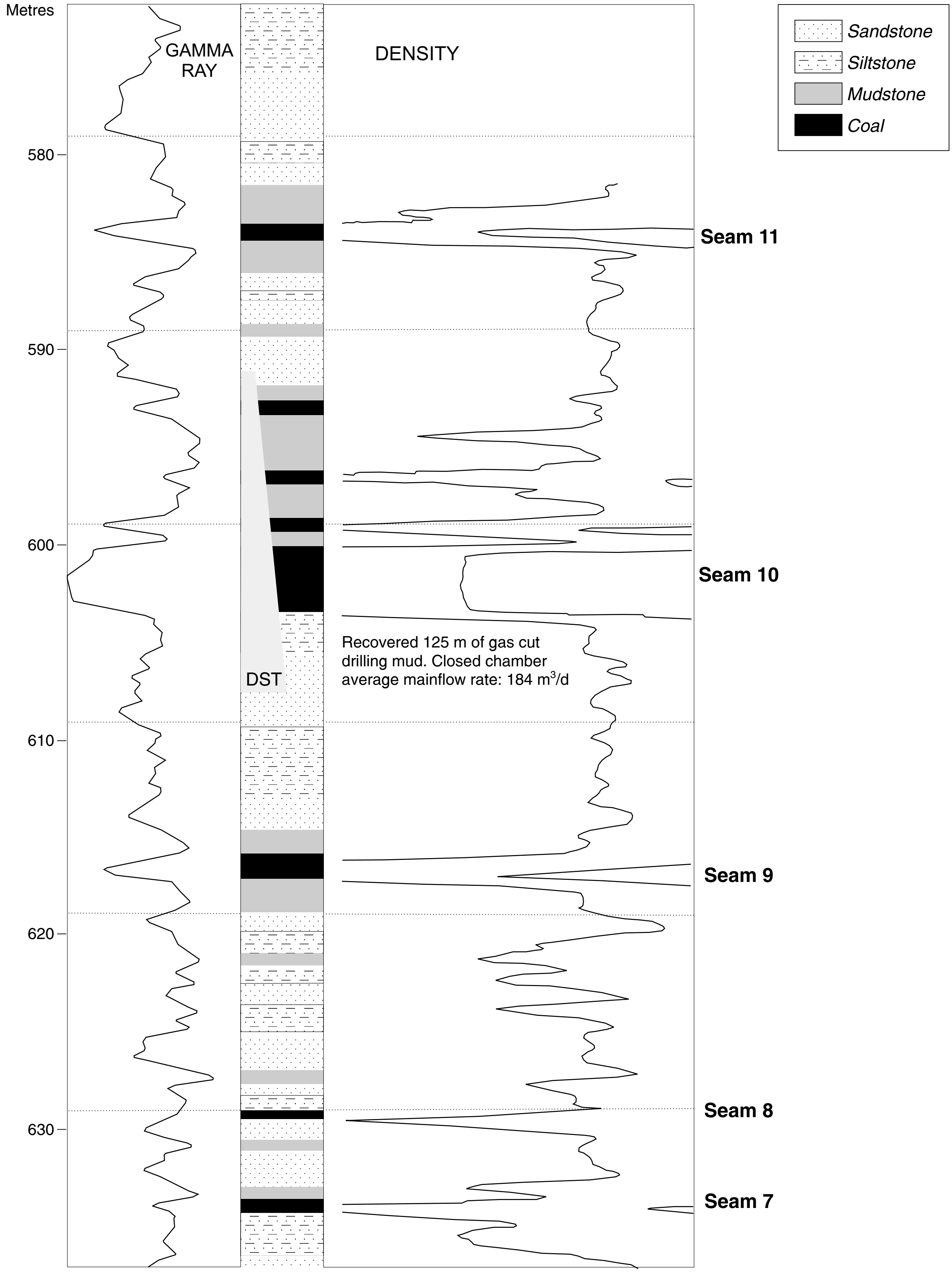


***Figure 66.*** *Detailed stratigraphic section of the Grande Cache Member of the Gates Formation in the Mobil/Chevron Muskeg River borehole.*

20.02%. Moisture content averaged 1.2%. Maceral analyses of the coal samples indicated that the coal was medium volatile bituminous in rank and had a vitrinite reflectance ranging from 1.13 to 1.22% $Ro_{mean}$. Vitrinite content averaged 75% for the limited number of samples collected (Seams 5 and 10).

*Adsorption isotherms.* Two adsorption isotherms were conducted on coal samples, one from cuttings collected from seam No. 10 of the Grande Cache Member, and the other from a coal seam in the Gething Formation. Tests were conducted at reservoir temperature and equilibrium moisture, but the results were significantly different. For the seam No. 10 sample, a Langmuir volume of 34.35 cc/g and a pressure of 6131 kPa were recorded. For the Gething test, the Langmuir volume was 17.9 cc/g and pressure was 2366 kPa. Ash content values for the samples were 20.02% and 30.71%, respectively. Comparative studies undertaken independently by the Geological Survey of Canada suggested that the lower volume might more accurately reflect the gas capacity of the Grande Cache Member coal.

*Formation testing.* Four drillstem tests and a limited production test were conducted in the wellbore. Three of the drillstem tests were completed on the No. 4 coal seam and the fourth test on the No. 10 seam. Results of the tests are summarized in Table 50. The drillstem test information indicated that the coal had low permeability. The closed chamber tests only allowed for a open flow period of 140 minutes, which might not be sufficient to adequately evaluate a low permeability reservoir. Interpretation of the drillstem test results by Mobil Oil staff indicated that the radius of investigation of the coal was limited to a maximum of 6 m and that the actual reservoir properties had not been assessed in this test procedure.

*Technical assessment.* The Mobil/Chevron coalbed methane exploration well was drilled in a structurally complex area and the prognosis of coal seam intersection was based on seismic reflectors. These reflectors were the Cadomin Formation and the actual coal measures were bypassed. Desorption samples obtained from sidewall cores contained a high percentage of drilling mud. Stimulation of the main seams of the Grande Cache Member produced reasonable gas flows. Production volumes were limited because the fracture stimulation was not completely successful. Further technical analysis should be conducted in the region to determine the existence of structures with permeability enhancement and trapping caprocks.

### *Mobil Oil Canada/Smoky River Coal - 3-91-02*

Smoky River Coal Limited drilled a coal exploration borehole during September 1991, as part of its continuing deep coal resource exploration program. The well was drilled in the mine permit area north of Sheep Creek, near the town of Grande Cache in northwest Alberta (Fig. 67). Mobil Oil Canada Limited participated in this well to undertake coalbed methane testing of the intersected coals. The well was being drilled for underground mine development. Total depth of the borehole was 304 m.

*Data acquisition.* The borehole was drilled using a mud-based fluid system to core point (224.7 m), upon which wireline coring was completed over an 8.8 m interval. Six core runs were made, and core recovery was widely variable (22-100%, averaging 78%). The borehole was subsequently deepened to the total depth of 304 m. Coal was placed into four canisters for desorption testing. The coal samples were desorbed at reservoir temperature (19°C) for about 3.5 hours, then the temperature was increased to 40°C to decrease the total desorption time. Following completion of the desorption tests, a composite sample from the four canisters was made for an adsorption isotherm test.

*Geology.* The coal intersected in the Smoky River exploration borehole belongs to the Grande Cache Member of the Gates Formation. The top of the Grande Cache member was intersected at 196.2 m and the base was not penetrated. Four coal horizons were intersected, of which two, (seams 10 and 11) are of significant thickness. The main seam (No. 4) is believed to lie at a depth of about 330 m. Table 51 summarizes the intersection and thickness of the coal units.

**Table 50**
**Summary of formation test data, Mobil/Chevron Muskeg River borehole**

| Coal Seam | DST | Depth (m) | Permeability (mD) | Initial Pressure (KPa) | Final Pressure (KPa) | Flow Rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|---|---|
| No. 4 | 1 | 675.0-691.5 | — | — | — | — | Misrun |
| No. 4 | 2 | 675.0-691.5 | — | — | — | — | Misrun |
| No. 4 | 3 | 675.0-691.5 | — | 2393 | 1400 | 10 | 10 m gassified drilling fluid, low rate of gas production |
| No. 10 | 4 | 592.0-608.5 | 0.08 | 3837 | 3378 | 145 | 125 m of gassified drilling fluid |

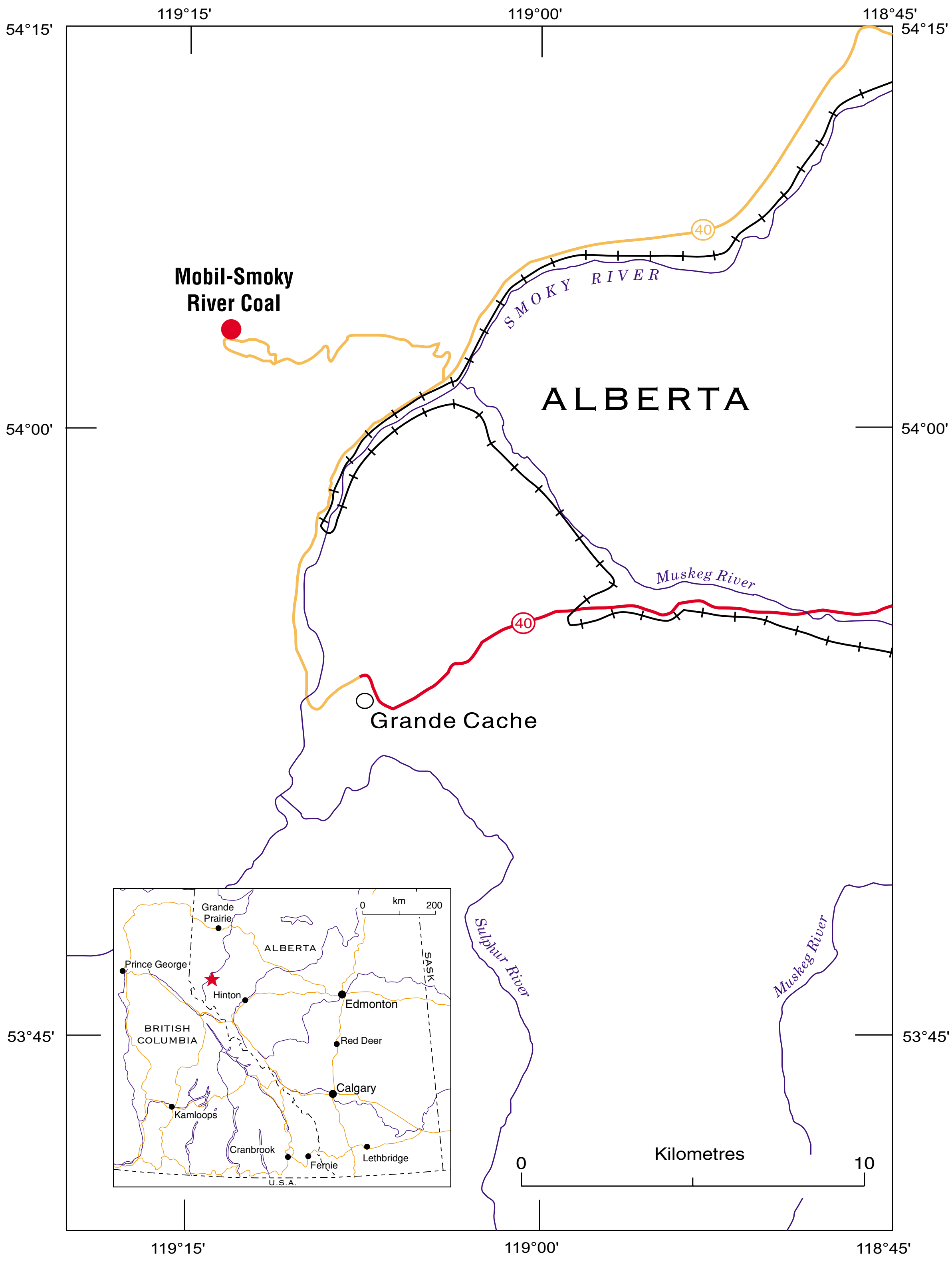


***Figure 67.*** *General location map of the Smoky River Coal exploration borehole.*

**Table 51**
**Summary of coal intersections, Smoky River borehole**

| Seam | Depth (m) | Total zone (m) | Net zone (m) |
|---|---|---|---|
| 12 | 196.2-196.4 | 0.2 | 0.2 |
| 11 | 223.3-227.1 | 3.8 | 2.7 |
| 11A | 230.5-231.5 | 1 | 0.8 |
| 10 | 250.3-256.8 | 6.5 | 4.4 |
| 8 | 279.8-280.3 | 0.5 | 0.5 |
| Total | | 12 | 8.6 |

Total coal zone intersected was 12.0 m and the cumulative net coal thickness was 8.6 m. The uppermost and lowest split of seam 11 (Fig. 68), were not recovered in the coring process. These thicknesses correspond to the Grande Cache Member coal intersections in the Mobil coalbed methane well 6-14-57-7-W6M.

The cored coal seam was predominantly crushed and sheared and dull to bright-banded. Cleat spacing, where retained, averaged 2–3 mm in the face cleat direction and 4–5 mm in the butt cleat direction. It is believed that much of the crushing and shearing of the coal resulted from coring procedures rather than geological conditions.

*Gas content.* Four gas canister samples were collected to determine gas content. All samples were collected from the seam 11 interval, with three from core and one from cuttings. Samples were collected only from the middle split of seam 11 and from the underlying seam 11A. Lost gas volumes were estimated at 15 to 27%. Gas content was low, ranging from 1 to 1.8 cc/g. Ash content was high and the normalized gas content ranged from 1.8 to 2.8 cc/g. Gas content was low because of the shallow depth where the samples were collected, as well as the high ash content of the coal.

*Coal quality.* Proximate analyses were conducted on the four canister samples, following completion of the desorption tests. Ash content was high, ranging from 31.56 to 60.6% (a.d.b.). Moisture content was low, averaging less than 1.0%. The equilibrium moisture for the samples was calculated at 2.2%. Vitrinite reflectance provided an $Ro_{mean}$ of 1.21%, indicating the coal was medium volatile bituminous in rank. Maceral analysis indicated that vitrinite content was 73% (m.m.f.b.).

*Adsorption isotherms.* The coal was blended to form a composite sample for an adsorption isotherm test. The sample test was conducted at 22°C with an equilibrium moisture content of 2.2%. Proximate ash analyses for the composite was 38.58%. Results from the adsorption isotherm test indicated a Langmuir volume of 11.7 cc/g and an ash-corrected Langmuir volume of 19.1 cc/g.

*Formation testing.* This wellbore was designed for underground mine exploration and was drilled to a maximum depth of 304 m. Therefore, no formation tests were conducted on the coal-bearing strata.

*Technical assessment.* The Smoky River/Mobil test well was drilled for purposes other than coalbed methane. Coal intersections were encountered at shallow depths and gas content values recorded were accordingly low (< 3 cc/g). Coal samples were limited to seam 11 only, with the most prospective seams (Nos. 4 and 10) either not penetrated or sampled.

## ALBERTA PLAINS

### PanCanadian Ewing Lake project

PanCanadian Petroleum Ltd. drilled PCP Ewing Lake in the winter of 1991/92. The well (7-1-37-21W4) was located about 40 km south of Stettler in south-central Alberta (Fig. 69). The target was the "Upper and Lower Mikwan" coal (i.e., Medicine River coal) in the Lower Cretaceous Mannville Group of the Alberta Plains. The seam was conventionally cored from 1352 to 1364 m, and desorption tests were completed on 38 samples representing the full seam intersection. Average gas content was 6.5 cc/g.

*Data acquisition.* The well was drilled to 1335.5 m using mud, then intermediate casing was set. Drilling continued, using an air hammer, to the top of the target coal at 1352 m. The seam was cored conventionally, using a water/soap mist to minimize damage to coal seam permeability. The seam was cored in two runs from 1352.0 to 1366.7 m, with full core recovery. Core recovery was by conventional standards and lost gas times were in the order of hours. Thirty-eight samples of core, generally 0.25 m in length, were desorbed and the total gas content determined. Desorption canisters were heated, although it is not known to what temperature.

A closed chamber drillstem test and an injection/fall-off test were performed over the cored interval. Resource Enterprises Inc. advised PanCanadian on formation testing procedures and Terra Tek Inc. supervised gas desorption and conducted isotherm testing.

*Geology.* The main coal zone within the upper Mannville Group is the Mikwan or Medicine River zone. This coal horizon lies at the base of the formation, immediately above the "Glauconite" sandstone. Other coal lies within the upper Mannville stratigraphic interval, but these seams are relatively thin (less than 1.5 m) and discontinuous. The GSC has completed a detailed coalbed methane study of a 16 township area that includes the Ewing Lake well. Several stratigraphically younger coal seams have been correlated

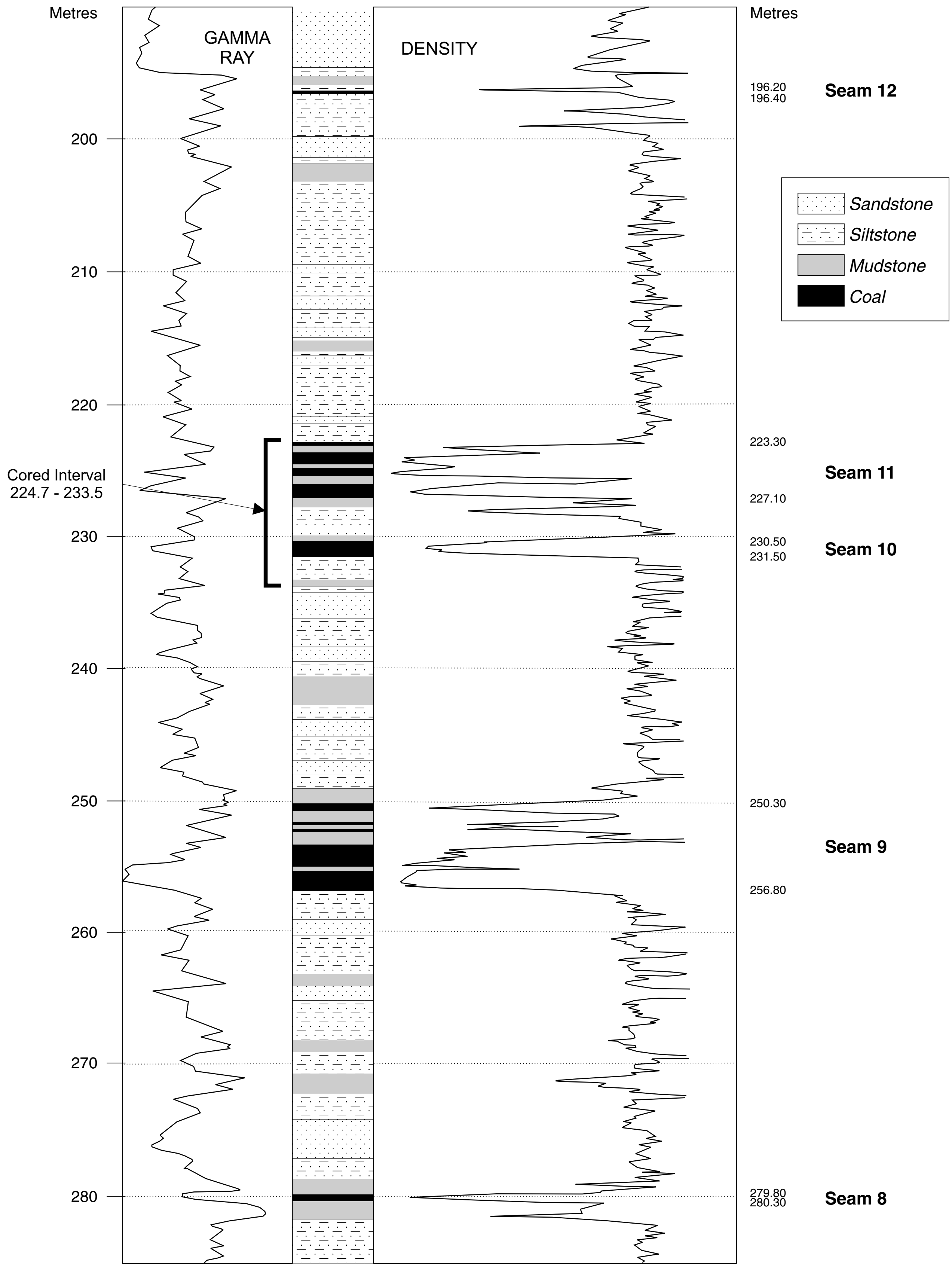


***Figure 68.*** *Detailed stratigraphic section of the coal seam intersections for the Smoky River Coal exploration borehole.*

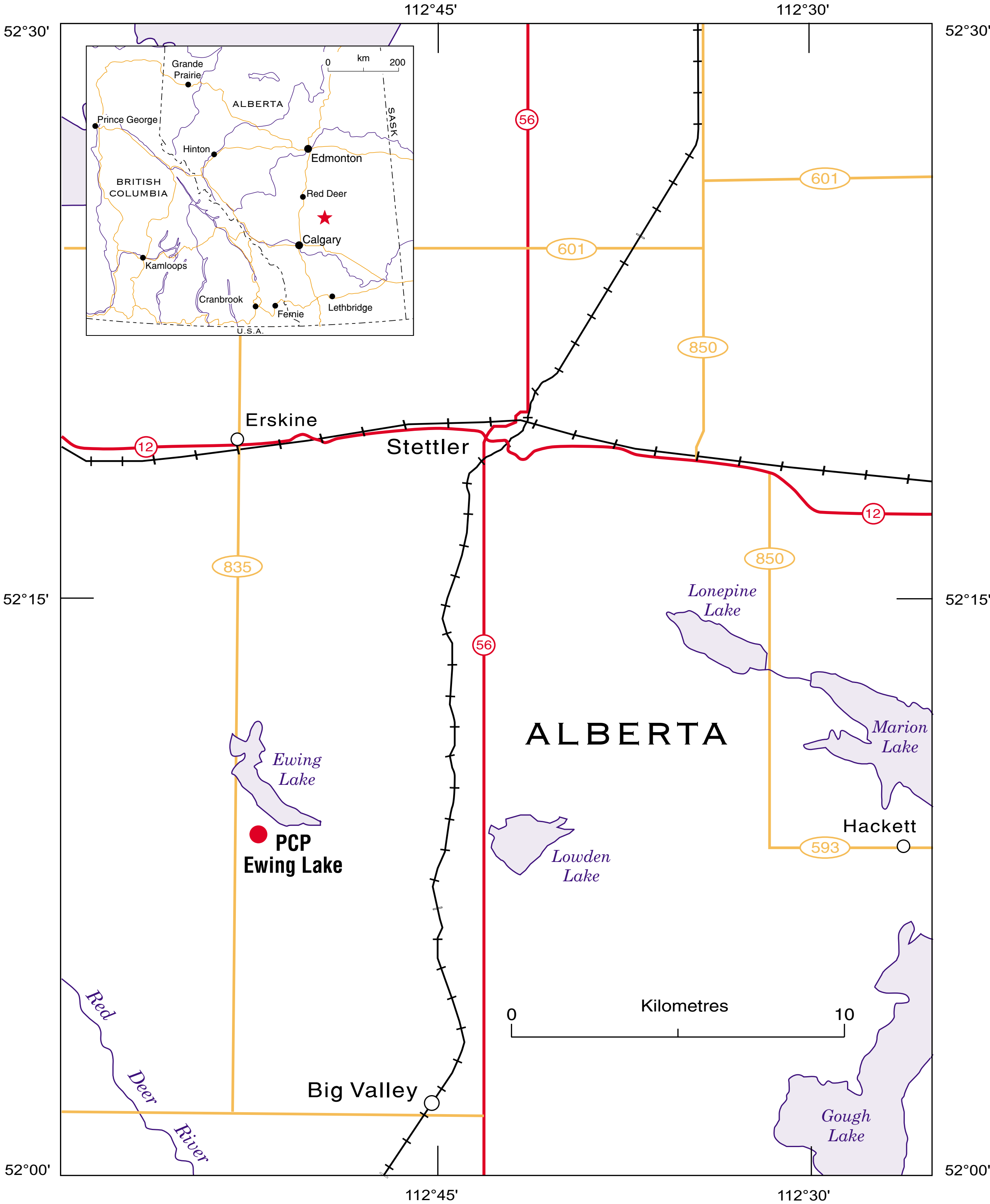


***Figure 69.*** *General location map of the PanCanadian Ewing Lake (07-01-37-21W4M) exploration borehole.*

and are referred to as the Twinning and Stettler horizons. No testing of coalbed methane potential has been undertaken on these units.

The target coal seams of the Ewing Lake well were the "Upper and Lower Mikwan" seams. Seam thickness profiles and log signatures for the coal-bearing interval in the upper Mannville Group are tabulated in Table 52 and illustrated in Figure 70. The coal was present in two splits; an upper unit 4.7 m thick from 1351.4 to 1356.1 m, and a lower unit 6.4 m thick from 1357.5 to 1363.9 m, separated by a 1.4 m parting. The parting is commonly carbonaceous claystone with abundant pyrite. Full core recovery was obtained. Cleats observed in the core appeared to be open.

*Gas content.* Gas content was relatively consistent, varying from 4.9 to 7.9 cc/g. The weighted mean value was 6.5 cc/g (Table 67). Coring to canister sealing time was about three hours. The supervisory team indicated that analysis of desorption data suggested no adverse effects on desorption as a result of this "lost gas " time interval. Lost gas, as a proportion of total gas content, varied from about 14 to 34%.

Ash content values were determined for two samples only and were low (2.3 and 2.9%, air-dried basis), so ash corrections to measured gas content values were negligible (Table 52). As coal rank would be constant over such a narrow depth interval, the variation in measured gas content values was probably a function of variable ash content between samples. Gas analyses on three samples indicated the methane content ranged from 83 to 88%.

*Coal quality.* Two vitrinite reflectance analyses indicated a rank of high volatile bituminous A/B (Ro 0.54 and 0.58%), lower than the theoretical peak methane generation level. Proximate analyses were performed on only two of the 38 desorption samples. Ash values were low (2.3 and 2.9%). The limited variation in gas content suggested that ash content was relatively uniform in the seam. Within the sample suite, variation in gas content is likely a function of variable ash.

*Adsorption isotherms.* Terra Tek Inc. conducted a series of tests designed to measure the effect of different frac fluids on the adsorption isotherm of coal core from the Ewing Lake well. The tests showed derived gas capacity was highest under methane sorption when de-ionized water was used as the testing fluid (11.06 cc/g) and lowest when Boragel was used (10.13 cc/g).

The isotherm test with no introduced fluid probably best approximates standard test procedures. The Langmuir equation for the test sample is:

$$V=17.1* P/(P+5633),$$

assuming a reservoir depth of 1359 m and a normal hydrostatic pressure of 9.727 kPa/m.

Results of the test indicated a theoretical gas capacity of 11.99 cc/g at a pressure equivalent to the depth of seam intersection. This is significantly higher than the gas content determined from core. The mean of the measured gas content was 6.5 cc/g, indicating that the reservoir was significantly undersaturated (54%). The ash content of the tested coal is

**Table 52**
**Seam intersections, coal quality and desorption data, PanCanadian Ewing Lake well**

| Sample no. | Top of sample (m) | Thickness (m) | Measured gas content (cc/g) | Ash content (a.d.b.) |
|---|---|---|---|---|
| EW-15 | 1352.61 | 0.26 | 6.4 | |
| 14 | 1352.87 | 0.27 | 5.2 | |
| 13 | 1353.14 | 0.27 | 6.7 | |
| 12 | 1353.41 | 0.27 | 7.0 | |
| 11 | 1353.68 | 0.27 | 7.0 | |
| 10 | 1353.95 | 0.27 | 6.9 | 2.9 |
| 9 | 1354.22 | 0.27 | 7.0 | |
| 8 | 1354.49 | 0.27 | 7.0 | |
| 7 | 1354.76 | 0.27 | 5.4 | |
| 6 | 1355.03 | 0.27 | 7.0 | |
| 5 | 1355.30 | 0.27 | 6.3 | |
| 4 | 1355.57 | 0.27 | 6.4 | |
| 3 | 1355.84 | 0.27 | 7.2 | |
| 2 | 1356.11 | 0.27 | 7.0 | |
| 1 | 1356.38 | 0.31 | 5.2 | |
| 38 | 1358.03 | 0.26 | 7.3 | |
| 37 | 1358.29 | 0.26 | 7.9 | |
| 36 | 1358.55 | 0.26 | 7.6 | |
| 35 | 1358.81 | 0.26 | 6.6 | |
| 34 | 1359.07 | 0.26 | 5.7 | |
| 33 | 1359.33 | 0.26 | 6.2 | |
| 32 | 1359.59 | 0.26 | 7.1 | |
| 31 | 1359.85 | 0.26 | 6.9 | |
| 30 | 1360.11 | 0.26 | 7.0 | |
| 29 | 1360.37 | 0.26 | 7.3 | |
| 28 | 1360.63 | 0.26 | 7.1 | |
| 27 | 1360.89 | 0.28 | 6.0 | 2.3 |
| 26 | 1361.17 | 0.26 | 5.6 | |
| 25 | 1361.45 | 0.33 | 4.9 | |
| 24 | 1361.78 | 0.24 | 5.4 | |
| 23 | 1362.02 | 0.26 | 6.3 | |
| 22 | 1362.28 | 0.26 | 6.2 | |
| 21 | 1362.54 | 0.26 | 5.7 | |
| 20 | 1362.80 | 0.26 | 7.5 | |
| 19 | 1363.06 | 0.26 | 7.3 | |
| 18 | 1363.32 | 0.26 | 5.5 | |
| 17 | 1363.58 | 0.26 | 6.3 | |
| 16 | 1363.84 | 0.26 | 5.4 | |
| | | Mean | 6.5 | |
| | | Max. | 7.9 | |

unknown but it is unlikely to be lower than the very low values found in two of the core samples and probably does not contribute to the discrepancy between theoretical and measured gas content. The isotherm tests were carried out at 45°C, which is close to reservoir temperature.

*Formation testing.* A closed chamber drillstem test was performed with packers set at 1359 m, about 2.5 m above the coal seam with 17 m of perforated pipe set to the bottom of the hole. A report by the testers (Halliburton) indicates that “due to single phase gas flow during the test the cleat permeability could not be determined. The test response is similar to that of an extremely tight (0.001-0.01 mD) reservoir”. The tests indicated that the interval is probably underpressured.

A report by REI notes permeability of <0.005 mD (Table 53). The final pressure was low and pressure was still building. Gas flow rates were 57 $m^3/d$ in the preflow stage and stabilized at 55 $m^3/d$ (1.94 Mcf/d) during the main flow period. The total test time, including two shut-in periods, was about 8.5 hours. The results suggest that “true formation pressure response has probably been masked”.

An injection/fall-off drillstem test was also performed on the well with packers set at 1330 m. The report (Halliburton) notes that as a result of inconsistencies in the testing, “ the results of the test should be seen as highly qualitative.” Further “it is expected that permeability calculated from the injection/falloff test would be higher than the ‘apparent’ permeability from the earlier closed chamber test”.

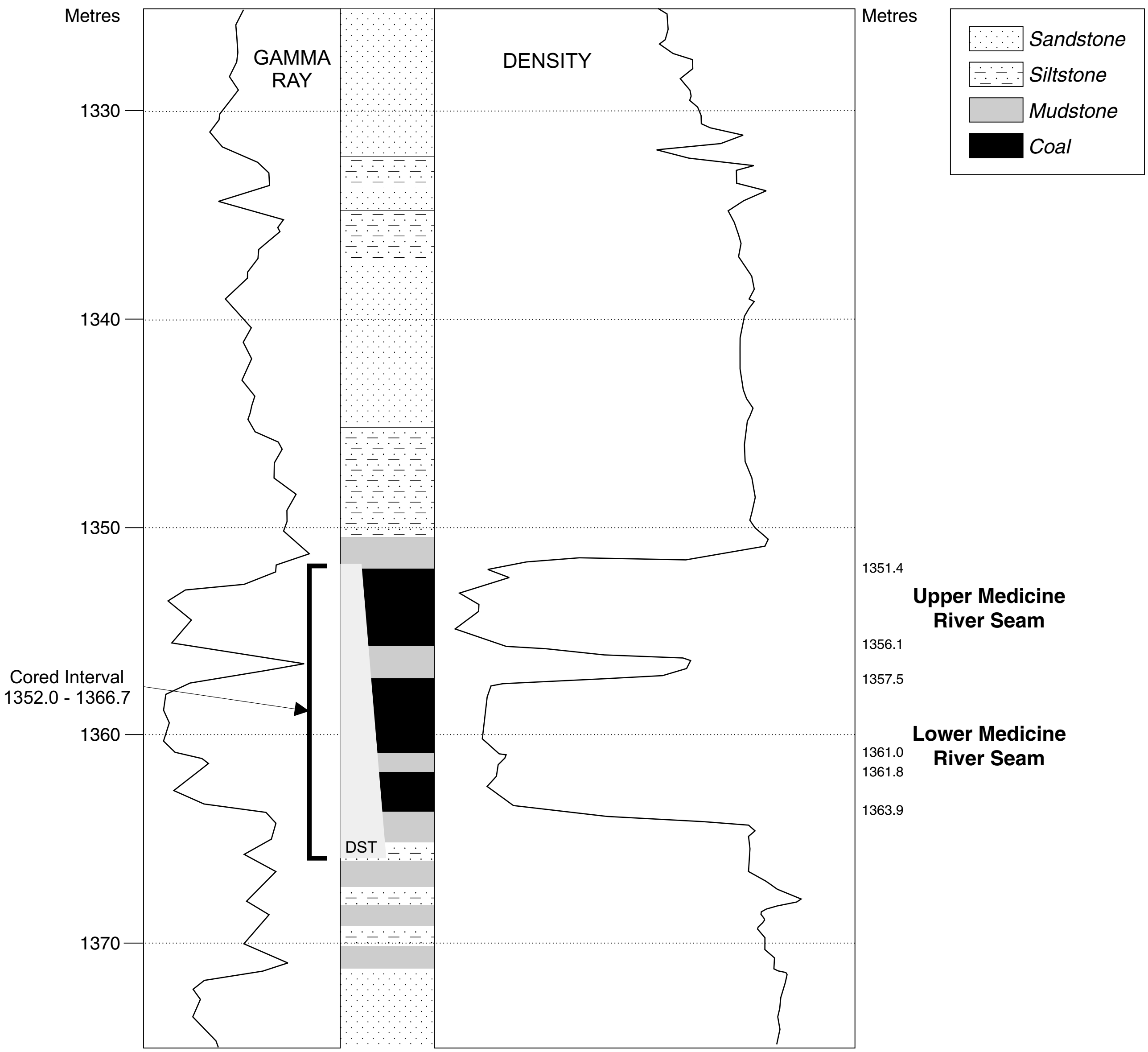


***Figure 70.*** *Detailed stratigraphic section of Mannville Group coal intersections of the PanCanadian Ewing Lake exploration borehole.*

A report by REI notes that the test interval could not hold the hydrostatic head of water in the drill string (13,268 kPa) and consequently the test was performed by pumping water into the string for one hour and then monitoring fall-off pressure for 10 hours. The interval that accepted fluid was apparently fractured by the injection. Absolute permeability was calculated at 2.1 mD, which is significantly higher than the permeability indicated by the closed chamber test. The injection test can be misleading, as it is likely that the cleat system is opened by injection, whereas during production, overburden pressure would likely decrease cleat aperture. The test indicates underpressuring of the interval.

*Technical assessment.* The well was drilled with air from the intermediate casing to the top of the coal and then with air/mist to core the seam. This approach should have minimized reservoir damage. The on-site team (REI) were experienced in coalbed methane testing, so sample collection and desorption testing were presumably satisfactory. Sample sealing times of over three hours are long, and lost gas of up to 34% of total gas is high. However, errors in lost gas estimation would not make a significant impact on measured gas content. Theoretical gas capacity was much higher than measured gas content indicating underpressuring or reservoir depletion.

Although formation testing had some problems, the reservoir was apparently underpressured, with low to very low permeability. Significantly, REI noted "during more than 30 drill stem tests of commercial and non-commercial coal zones we have never observed a test interval that appeared to be of low permeability that was eventually commercially produced, regardless of completion or stimulation techniques applied". It is concluded that although net coal thickness (11.8 m) was substantial and gas content was adequate, the reservoir permeability, pressure and fluid saturation might be inadequate for commercial development.

## PanCanadian Plains project

PanCanadian Petroleum Limited drilled a number of coalbed methane test wells in the Alberta Plains region between late 1989 and late 1991. Six boreholes were completed. All were drilled for deeper conventional hydrocarbon targets. The coalbed methane testing was a "piggyback" component of the drilling program. The target coal was from the Medicine River zone of the upper Mannville Group. Well locations were scattered, ranging from Township 24 Range 18 W4M to Township 45 Range 2 W5M. See Figures 71 to 73 for borehole locations. No production testing was performed.

*Data acquisition.* The six boreholes drilled to test the coalbed methane potential of the Mannville Group coal intersected the target zone at depths ranging from 1220 m in the PCP Seiu Lake well to greater than 1600 m in the Westerose wells. All wells were drilled using a conventional oil and gas drilling rig. Cores were cut using a conventional core barrel. The trip times for lost gas calculations were three to four hours. Cores were desorbed at reservoir temperature and following completion of the desorption testing, the coal was analyzed for coal quality. In some cases, adsorption isotherms were completed. Conventional drillstem wellbore tests were completed over the coal zones in some of the boreholes.

*Geology.* The target coal of the PanCanadian Plains drilling project was the Medicine River zone of the upper Mannville Group. This zone is laterally contiguous throughout much of central Alberta and ranges in thickness from less than 2 m to greater than 11 m. The zone commonly has two distinctive seams, designated as the upper and lower Medicine River seams. In the region of Fenn big Valley near Stettler, the two seams coalesce to form a horizon 11 m thick. Farther west, the Medicine River zone splits and thins so that in the region of Gilby and Sylvan Lake (Ranges 3 to 4, W5M), the Medicine River seam is less than 3 m thick and only one major seam is developed. The other coal seams in the upper Mannville Group are generally thin and discontinuous and are not considered to be prime coalbed methane exploration targets. Figures 74 to 79 illustrate the coal-bearing Mannville section intersected in each wellbore. Coal intersections and net coal thickness data are summarized in Table 54.

*Gas content.* Coal samples were collected from the core or cuttings and placed into desorption canisters. Measured gas content values ranged widely from 3.5 to 10.1 cc/g, reflecting the coal quality and the type of sample and canister desorption parameters. In Table 55, gas content values are averaged for each seam intersection. If the larger gas content values are eliminated, the average gas content for the Medicine River coal zone is 7.0 cc/g.

**Table 53**
**Drillstem test data, Ewing Lake well**

| Borehole | DST number | Depth (m) | Permeability (mD) | Initial pressure (kPa) | Final pressure (kPa) | Flow rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|---|---|
| Ewing Lake | 1 | 350-1367 | < 0.005 | 383 | 1463 | 55 | Nil |

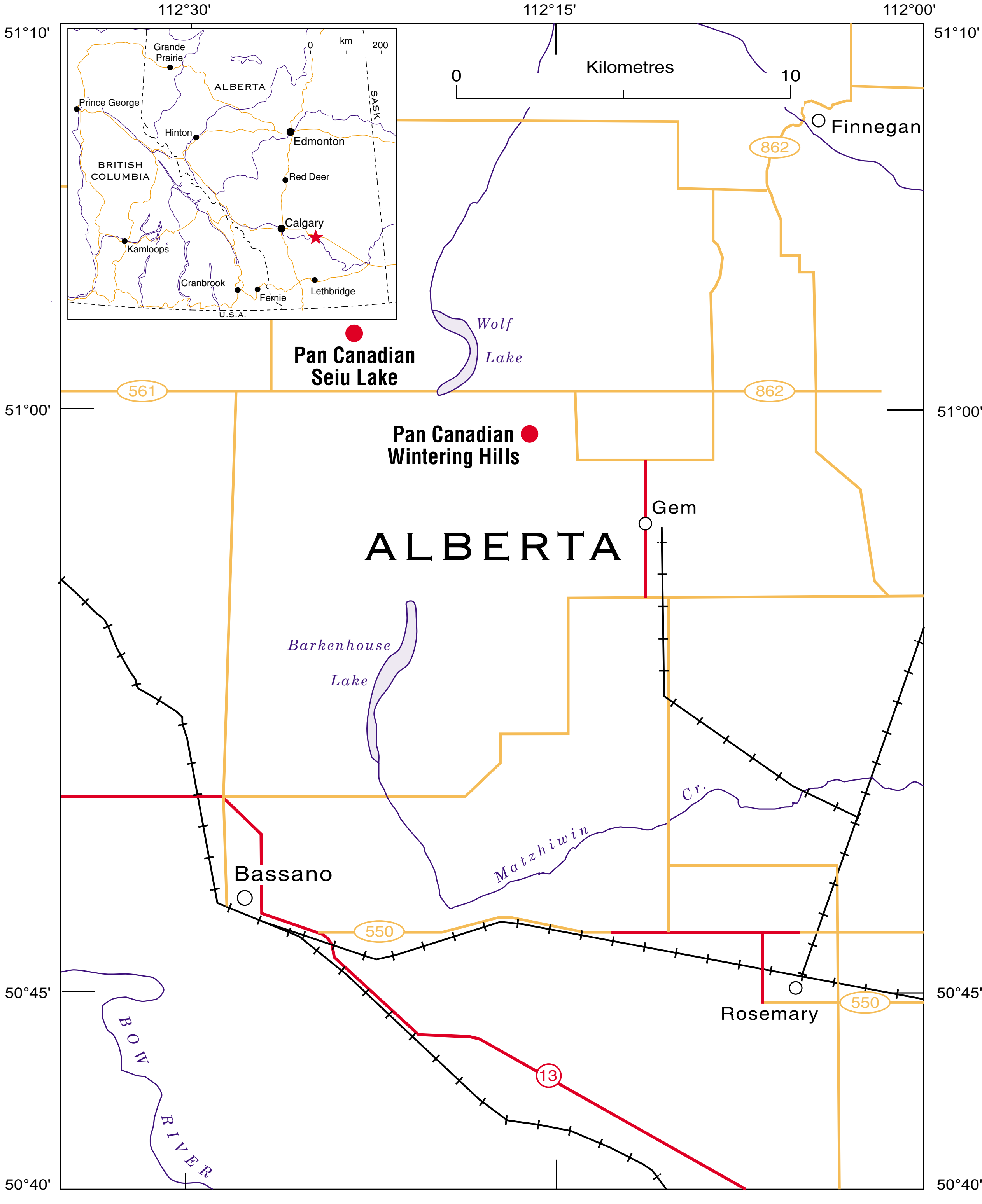


***Figure 71.*** *General location map of the PanCanadian W4M exploration boreholes: PanCanadian Seiu Lake (10-12-24-18W5); Pan Canadian Wintering Hills (11-26-23-17W5).*

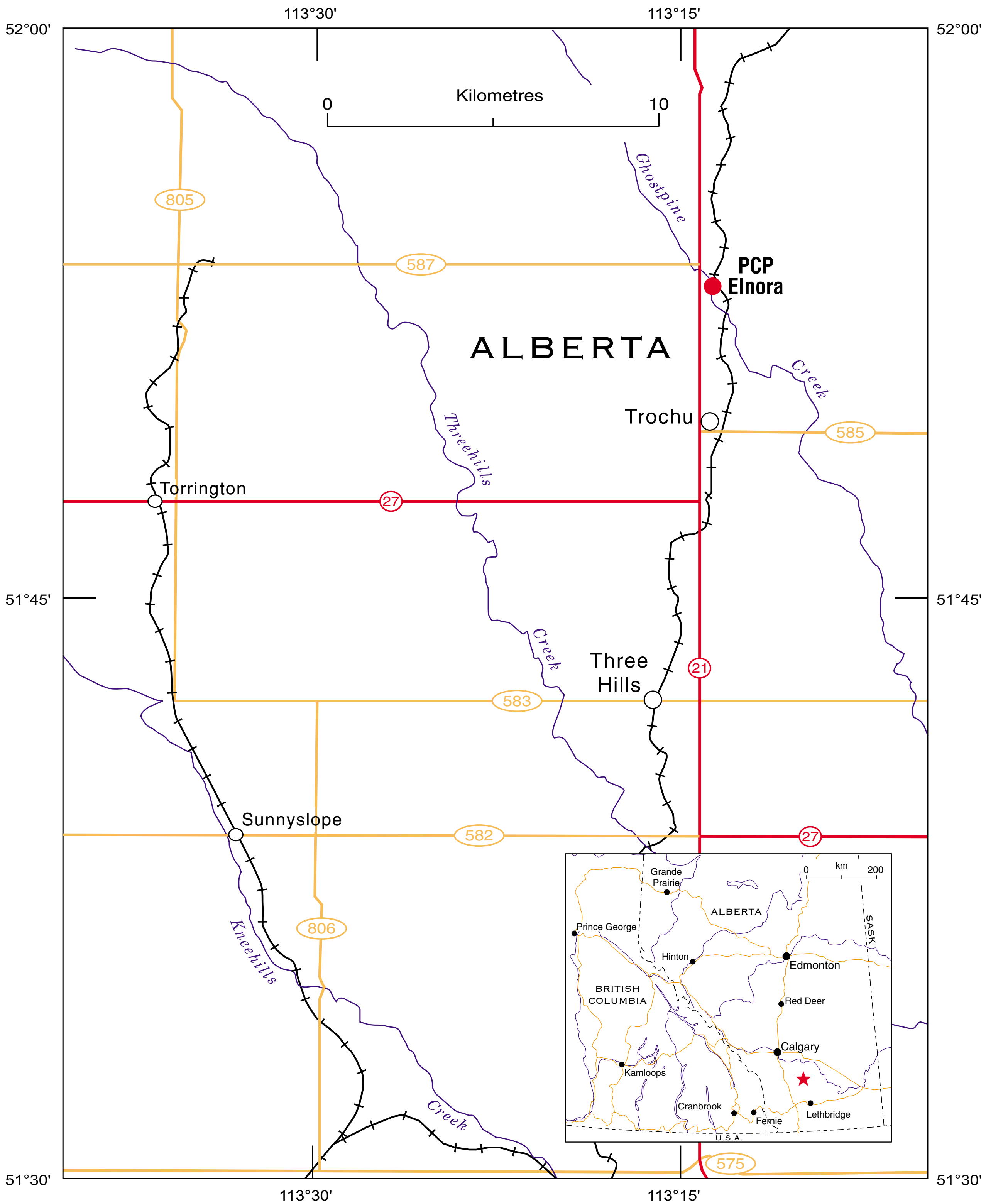


***Figure 72.*** *General location map of the PanCanadian Elnora (06-05-34-23W4M) exploration borehole.*

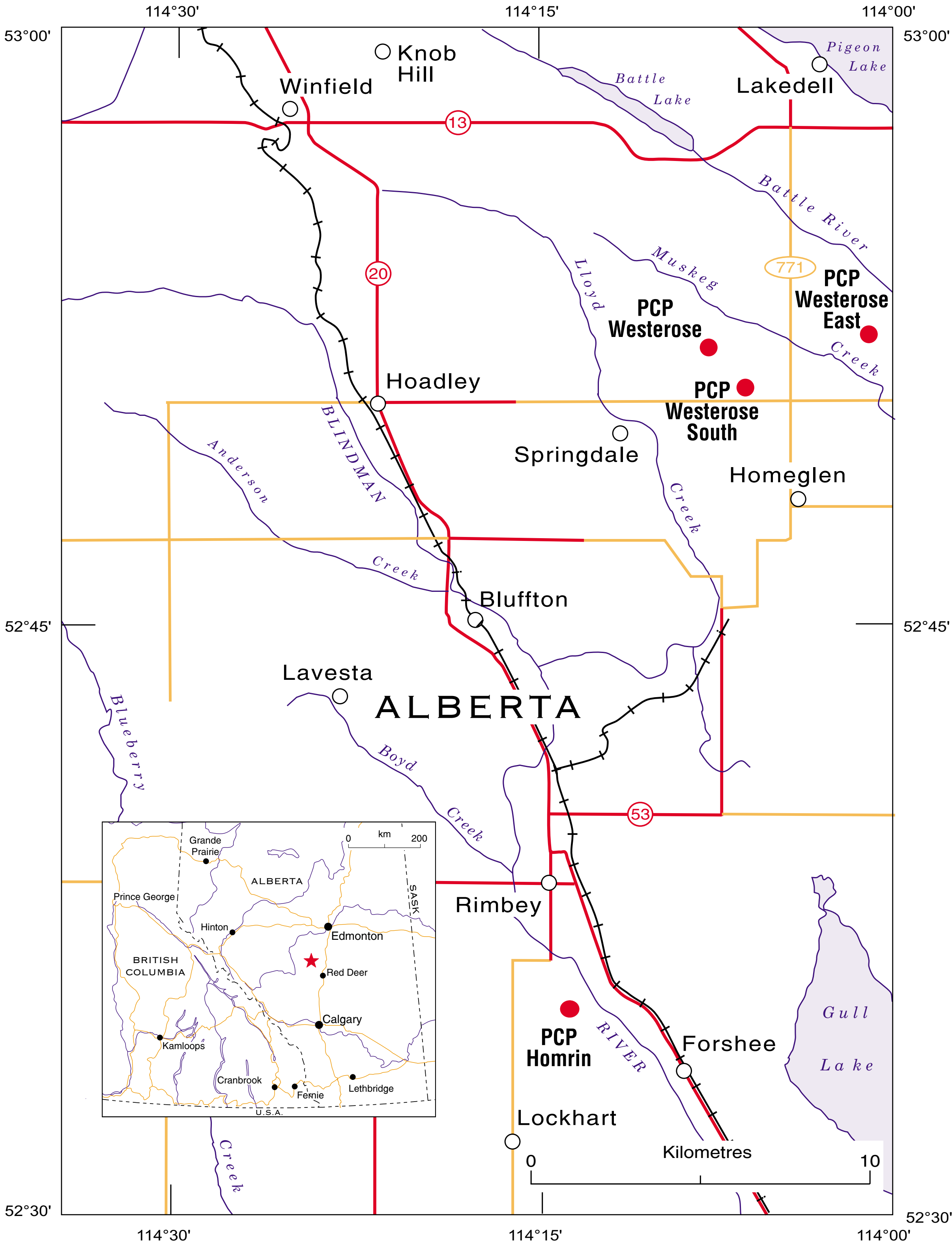


***Figure 73.*** *General location map of the PanCanadian W5M exploration boreholes: PCP Westerose (14-7-45-1W5M); PCP Westerose East (7-13-45-1W5M); PCP Westerose South (8-5-45-1W5M); PCP Homrin (8-4-42-2W5M).*

**Table 54**
**Coal intersections and net coal thickness data, PanCanadian Plains project**

| Borehole location | Depth of top Medicine River (m) | Depth of base Medicine River (m) | Number of seams | Total zone thickness (m) | Net coal thickness (m) |
|---|---|---|---|---|---|
| 10-12-24-18-W4M | 1220.8 | 1225.4 | 1 | 4.6 | 3.8 |
| 06-05-34-23-W4M | 1459.1 | 1493.2 | 4 | 34.1 | 8.5 |
| 08-04-42-02-W5M | 1843.4 | 1865.0 | 4 | 21.6 | 7.9 |
| 07-13-45-01-W5M | 1658.3 | 1669.2 | 3 | 10.9 | 8.5 |
| 08-05-45-01-W5M | 1759.9 | 1776.8 | 3 | 16.9 | 9.2 |
| 14-07-45-01-W5M | 1760.0 | 1773.5 | 4 | 13.5 | 8.8 |

**Table 55**
**Desorption data, PanCanadian Plains boreholes**

| Borehole location | Sample type | Number of canisters | Depth to top of samples (m) | Average measured gas content (cc/g) | Average normalized gas content (cc/g) | Average ash content (%) |
|---|---|---|---|---|---|---|
| 10-12-24-18-W4M | Core | 9 | 1219.5 | 6.1 | 7.6 | 18.4 |
| 06-05-34-23-W4M | Core | 3 | 1490.0 | 7.6 | 9.1 | 13.6 |
| 08-04-42-02-W5M | | Number of samples collected for desorption testing | | | | |
| 07-13-45-01-W5M | Core | 1 | 1659.0 | 10.1 | 10.4 | 2.6 |
| 08-05-45-01-W5M | Core | 3 | 1760.0 | 3.5 | 3.9 | 10.0 |
| 14-07-45-01-W5M | Sidewall and | 9 | 1771.5 | 6.6 | 9.5 | 23.65 |
| | cuttings | 3 | 1759.0 | 3.6 | 4.5 | 20.6 |

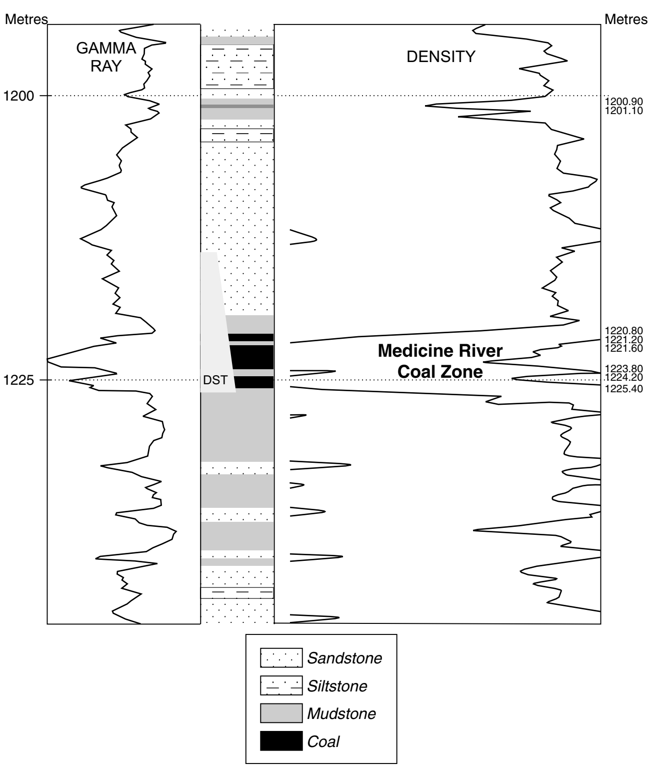


***Figure 74.*** *Detailed stratigraphic section of Medicine River coal zone, PanCanadian Seiu Lake borehole.*

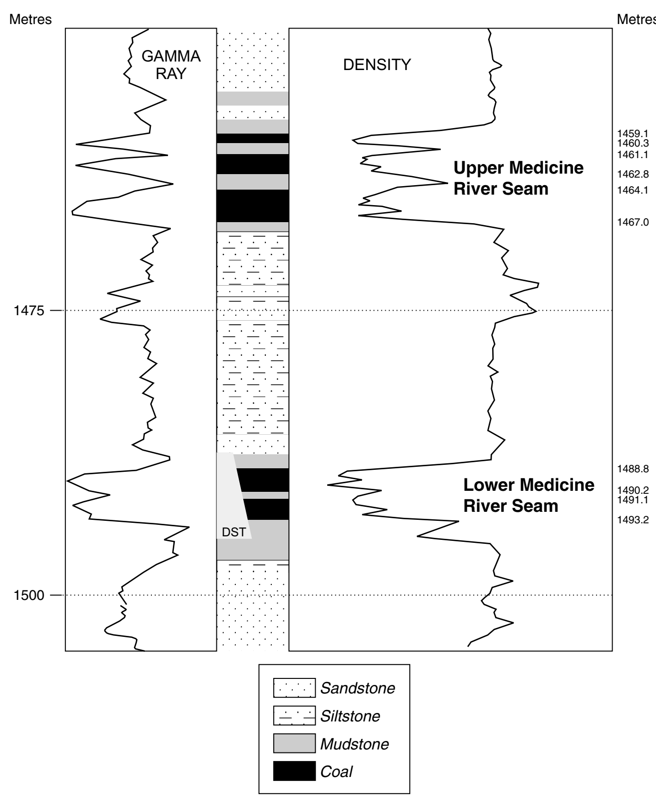


***Figure 75.*** *Detailed stratigraphic section of Medicine River coal zone, PanCanadian Elnora borehole.*

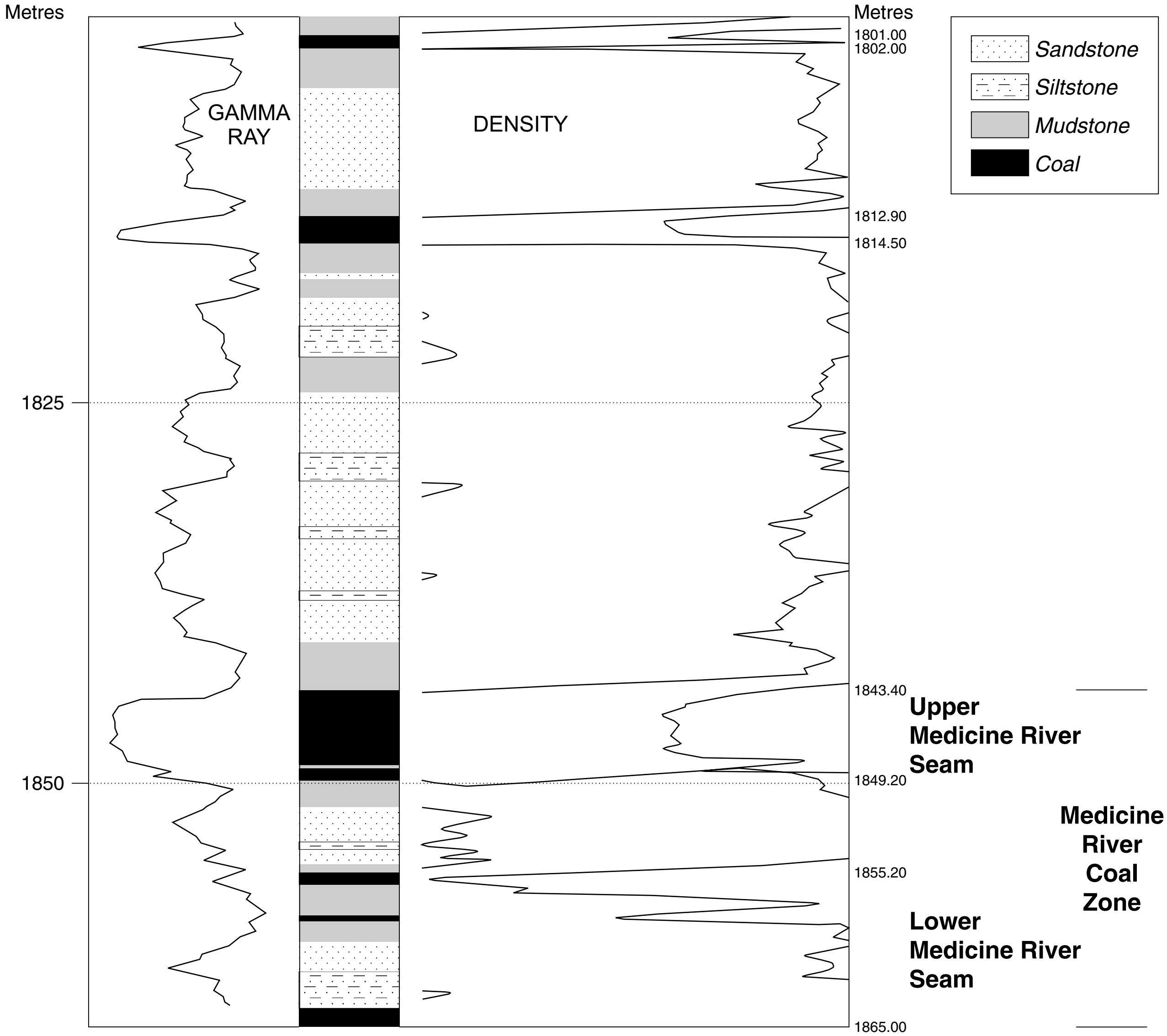


***Figure 76.*** *Detailed stratigraphic section of the Medicine River coal zone, PanCanadian Homrin borehole.*

Gas content values measured in the 7-13 well were higher than average, perhaps reflecting the longer time that the core barrel was on the bottom (eight hours). A recalculation was made to account for the bottom time and drilling mud density. Assuming drilling mud confining pressure equivalent to 340 m depth, no gas was desorbed until the core reached a depth of 340 m. Using this type of calculation, the lost gas component would be substantially less and total desorbed gas would be 7.8 cc/g. For this core sample, residual gas measurements were made. Residual gas accounted for 39% of the total desorbed gas. The canisters were desorbed for three months, but at a temperature of 22°C. This desorption temperature probably does not reflect the true reservoir temperature, so the volume of gas desorbed during the three month canister test would be lower than if the test had been conducted at true reservoir temperature.

In the adjacent 14-7 well, the coal samples were desorbed at 37°C. The gas content value obtained from the sidewall cores probably more accurately reflects the desorbed gas content value for the Medicine River coal zone.

There is no indication why the 8-5 well, which was drilled in the same area as the 14-7 and 7-13 wells, had low gas content. No proximate analysis was performed and the ash content was assumed to be 10%. It is possible that the coal samples had a high ash content, which would lead to a lower in situ gas content.

*Coal quality.* Following completion of desorption experiments, the coal samples were analyzed for quality and rank characteristics. These data are summarized in Table 56.

**Table 56**
**Proximate analyses, PanCanadian Plains boreholes**

| Borehole location | Moisture (%) | Ash (%) | Volatile matter (%) | Fixed carbon (%) | Sulphur (%) | Rank $Ro_{max}$ (%) |
|---|---|---|---|---|---|---|
| 10-12-24-18-W4M | 5.9 | 18.4 | 30.9 | 44.8 | — | 0.44 |
| 06-05-34-23-W4M | 2.0 | 13.6 | 31.7 | 52.7 | — | 0.72 |
| 08-04-42-02-W5M | | No proximate analyses conducted | | | | 0.85 |
| 07-13-45-01-W5M | 2.9 | 2.6 | 33.3 | 60.9 | — | 0.97 |
| 08-05-45-01-W5M | | No proximate analyses conducted | | | | |
| 14-07-45-01-W5M | 1.4 | 23.6 | 25.3 | 49.6 | — | — |

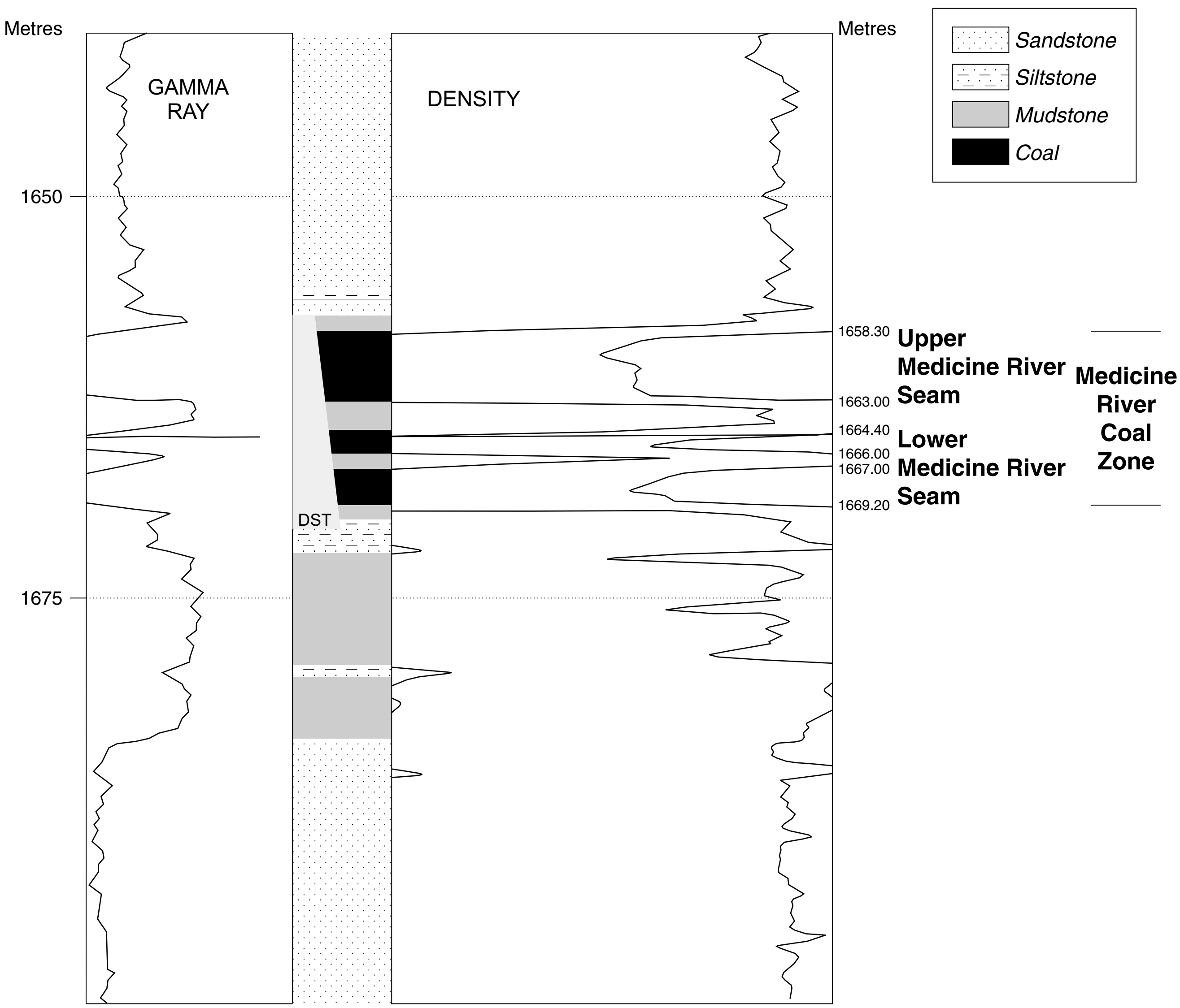


***Figure 77.*** *Detailed stratigraphic section of the Medicine River coal zone, PanCanadian Westerose East borehole.*

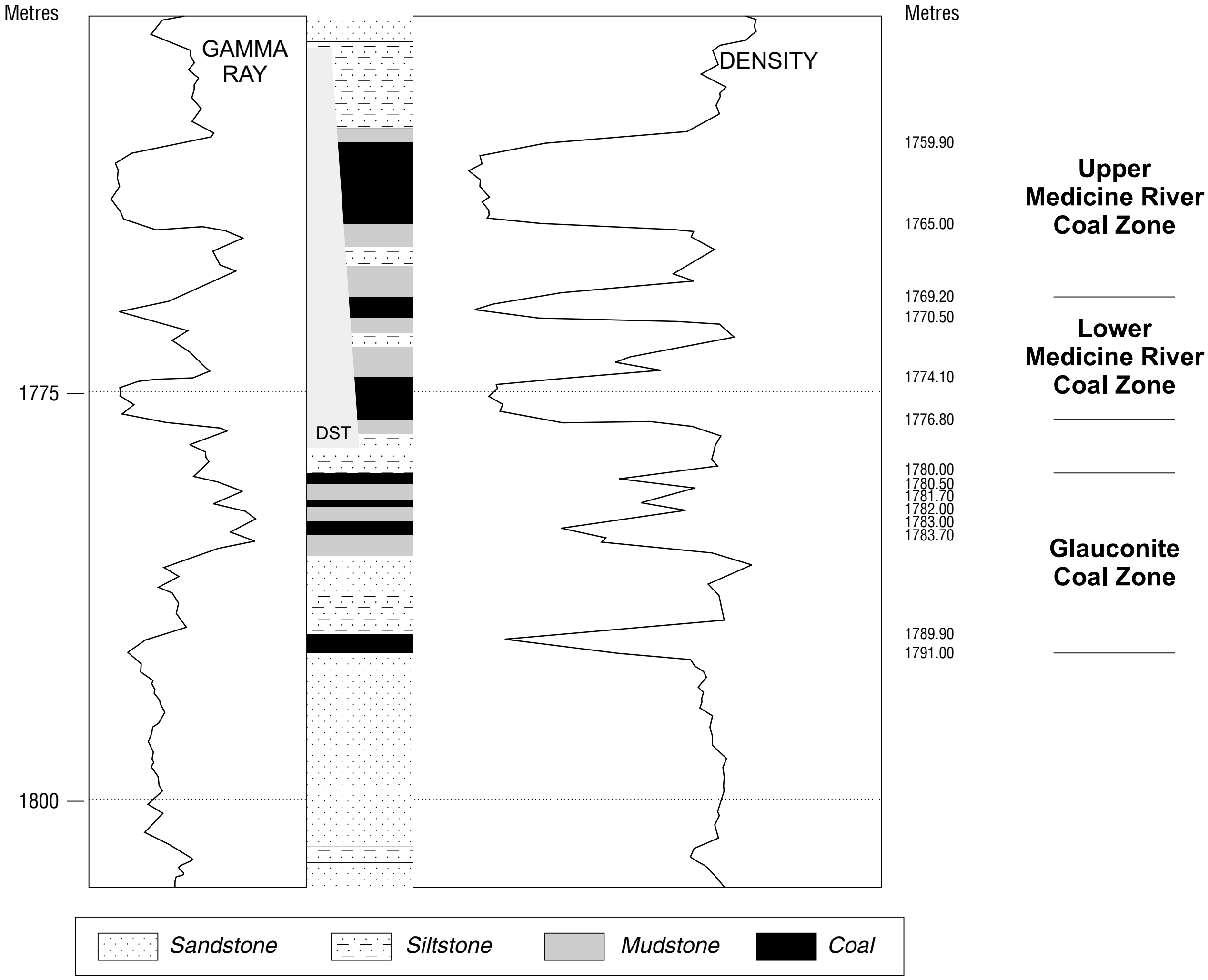


***Figure 78.*** *Detailed stratigraphic section of the Medicine River coal zone, PanCanadian Westerose South borehole.*

The reflectance measurements display a trend of increasing rank to the west into the deeper part of the western Canada basin. It is interesting to note that the gas content for the 10-12 well is 6.1 cc/g for a rank of coal that is supposedly not within the thermogenic gas generation window. This anomaly may be because of suppression of the true vitrinite reflectance value from hydrocarbon staining, or perhaps the gas content may be elevated because of some form of secondary biogenic gas generation.

*Adsorption isotherms.* Adsorption isotherms were completed on several coal samples following the termination of desorption testing. Comparing the gas capacity at reservoir conditions to actual measured gas content values will give some indication of the degree of gas saturation in the coal beds. Isotherm data are summarized in Table 57.

Reservoir pressure is based on an assumed gradient of 9.817 kPa/metre.

**Table 57**
**Adsorption isotherms, PanCanadian Plains boreholes**

| Borehole location | Depth (m) | Langmuir equation | Theoretical gas capacity (cc/g) | Measured gas content (cc/g) | Saturation (%) |
|---|---|---|---|---|---|
| 10-12-24-18-W4M | 1223 | V=13.0*P/(P+2970) | 10.4 | 6.1 | 59 |
| 08-05-45-01-W5M | 1760 | V=16.1*P/(P+7184) | 11.4 | 3.5 | 31 |

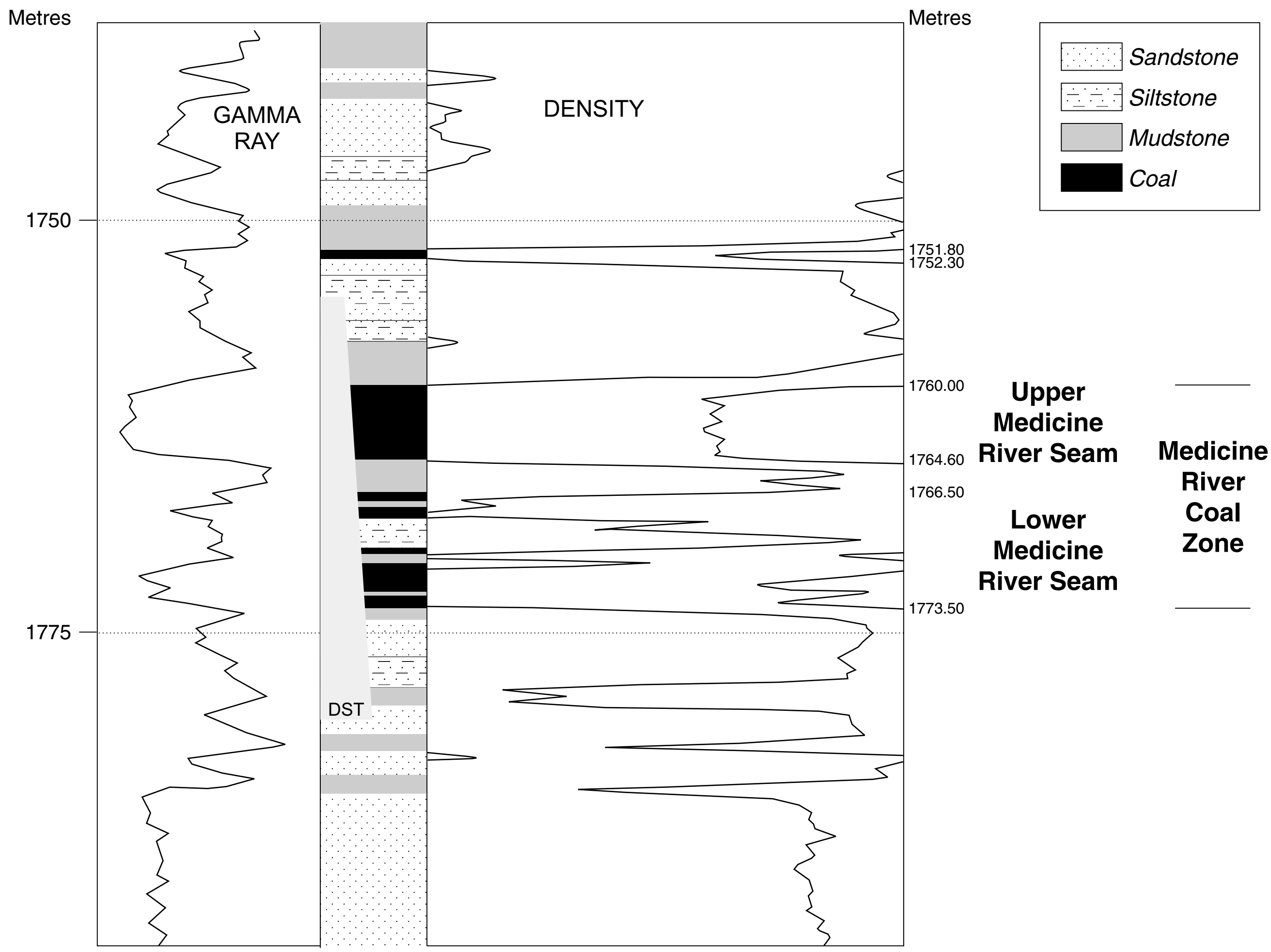


***Figure 79.*** *Detailed stratigraphic section of the Medicine River coal zone, PanCanadian Westerose borehole.*

For the two samples tested, the gas content appeared to be undersaturated relative to the gas capacity of the coal, as determined from the adsorption isotherm data. It must be noted that neither isotherm was performed at reservoir temperature (about 32°C). There would have been some difference in adsorptive capacity and thus saturation, but not of a significant magnitude.

Saturation levels might have been increased if one assumes that desorption time was insufficient to adequately desorb all of the gas from the sample. Residual gas could account for an additional 1 to 2 cc/g.

*Formation testing.* Formation testing was conducted on selected zones in a number of the boreholes. In all cases, the drillstem test results indicated the coal reservoir had low permeability. Most of the tests were conducted over time intervals that for a low permeability reservoir such as coal, would not evaluate past the wellbore damage and invasion zone. Recoveries consisted of water cut mud with limited gas flow. Drillstem test data are summarized in Table 58.

*Technical assessment.* The Plains drilling program conducted by PanCanadian from 1989 to 1991 was aimed at testing the coalbed methane potential of the Mannville "Medicine River coal zone". As part of a "piggyback" exploration program, coal test locations were dictated by the primary deeper oil and gas target and not optimum coalbed methane potential. Most of the coal tests were conducted on coal at depths greater than 1400 m, below the optimum range for gas storage and permeability retention. The results of the drillstem tests, while not totally indicative of formation reservoir characteristics, suggest the coal has low permeability and is not the most prospective target for coalbed methane exploration.

## Gulf Canada Fenn/Big Valley project

Gulf Canada Resources has undertaken a number of Plains exploration programs for coalbed methane. The foremost of these is the Fenn/Big Valley project, located about 35 km southwest of the town of Stettler in central Alberta (Fig. 80).

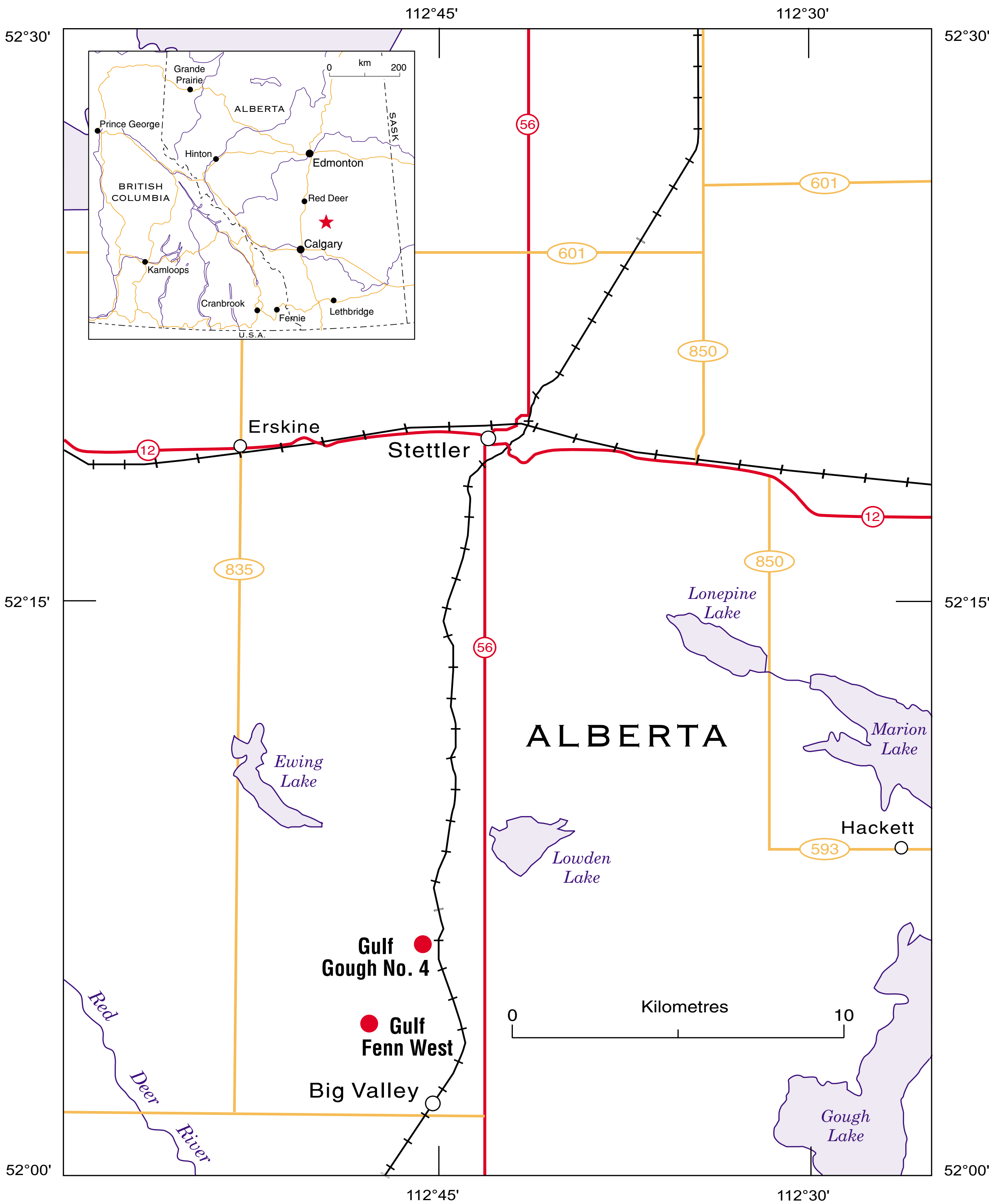


***Figure 80.*** *General location map of the Gulf Gough (04-23-36-20W4M) and the Gulf Fenn West (16-04-36-20W4M) exploration boreholes.*

**Table 58**
**Drillstem test data, PanCanadian Plains boreholes**

| Borehole location | Depth of test (m) | Initial S.I. pressure (kPa) | Final S.I. pressure (kPa) | Flow rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|
| 10-12-24-18-W4M | 1215-1227 | | | 7 | 20 m drilling mud |
| 06-05-34-23-W4M | 1487-1495 | 1675 | 2174 | 5 | 0.26 $m^3$ gas cut mud |
| 07-13-45-01-W5M | 1658-1672 | | | 17 | 0.12 $m^3$ drilling mud |
| 08-05-45-01-W5M | 1754-1778 | | | 23 | 45 m drilling mud |
| 14-07-45-01-W5M | 1756-1779 | | | 26 | 0.13$m^3$ drilling mud |

This area was chosen by Gulf for coalbed methane exploration because of the thick Medicine River coal zone present at a depth of about 1400 m, and the well developed infrastructure associated with the existing Big Valley oilfield. This field has been producing for many years and is now close to abandonment. Gulf's rationale was that if the existing facilities could be used during completion on the Mannville coal, low-cost well completions could be achieved. Two boreholes were drilled in the region, aiming at deeper conventional hydrocarbon targets. The Gulf CPR/ Gough well, located at 04-23-36-20-W4M did not recover any coal samples and only a falling-head injection test was performed. In the Fenn West well (16-4-36-20-W4M) coal samples were collected and numerous tests performed. Following the completion of these two wells, a number of stimulations were attempted on existing wellbores (8-11-36-20-W4M, 10-11-36-20-W4M and 4-23-36-20-W4M). Re-completions consisted primarily of perforating the casing across the Mannville coal zone and then hydraulically fracturing the coal. Several wells were brought on production, but gas yields have been disappointing.

*Data acquisition.* In the Gulf Fenn West well, two coal seams of the Mannville Group were cored using a split tube aluminum inner barrel. The core was retrieved to surface and 15 canister samples taken, seven from the upper seam and eight from the lower seam. The depth of the coal averaged about 1400 m and trip times for the wireline core retrieval system were 2.5 to 4 hours. Lost gas time ranged from 220 to 234 minutes. The core samples were desorbed at reservoir temperature and following completion of desorption measurements, analyzed for quality characteristics. One adsorption isotherm was completed on a sample from the lower seam. No other tests were performed on the Fenn West borehole. Numerical modelling was performed on the 8-11 well and pressure gradient tests on the 10-11 and 4-23 wells.

*Geology.* The principal targets of the Gulf Fenn/Big Valley coalbed methane program were the upper and lower Medicine River seams of the Lower Cretaceous Mannville Group. Depths of the Medicine River seam range from 1258.2 m in Gulf Gough to 1386.8 m in Fenn West. The two seams are separated by about 20 to 25 m. For the purpose of this assessment, the well from Fenn West was used as the type section (Fig. 81). The upper Medicine River seam is 4.1 m thick and was intersected at depths ranging from 1386.8 to 1390.9 m. The lower Medicine River seam was intersected at depths of 1411.6 to 1417.6 m and is 6.0 m thick. Both seams contain thin (< 0.2 m) partings and net coal thicknesses are 3.8 and 5.4 m, respectively. A third coal zone, considered too thin for coalbed methane purposes, lies at the top of the Mannville at 1350.3 to 1352.7 m.

*Gas content.* Fifteen canister samples were collected from the two cored intervals. Lost gas times were more than 200 minutes and the lost gas component accounted for 24 to 41% of the total desorbed gas volume. Gas content values are summarized in Table 59.

**Table 59**
**Desorption data, Gulf Fenn/Big Valley project**

| Sample no. | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content (%) (a.r.) |
|---|---|---|---|---|
| 1 | 1387.15-1387.55 | 8.90 | 10.20 | 3.64 |
| 2 | 1387.55-1387.95 | 10.00 | 10.90 | 9.40 |
| 3 | 1387.95-1388.27 | 10.00 | 11.40 | 4.76 |
| 4 | 1388.65-1389.05 | 11.50 | 11.70 | 15.84 |
| 5 | 1389.05-1389.45 | 8.10 | 8.40 | 20.38 |
| 6 | 1389.50-1389.90 | 8.80 | 9.50 | 9.74 |
| 7 | 1389.90-1390.30 | 9.20 | 13.60 | 3.35 |
| 8 | 1412.00-1412.40 | 10.70 | 10.90 | 17.40 |

**Table 59 (cont.)**
**Desorption data, Gulf Fenn/Big Valley project**

| Sample no. | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content (%) (a.r.) |
|---|---|---|---|---|
| 9 | 1412.40-1412.80 | 10.60 | 11.90 | 6.56 |
| 10 | 1412.80-1413.20 | 8.40 | 12.40 | 44.01 |
| 11 | 1413.20-1413.60 | 10.90 | 12.30 | 5.67 |
| 12 | 1413.60-1413.97 | 11.00 | 12.30 | 7.26 |
| 13 | 1413.97-1414.37 | 10.90 | 12.30 | 5.03 |
| 14 | 1414.37-1414.78 | 10.10 | 11.50 | 6.18 |
| 15 | 1414.78-1415.24 | 9.60 | 10.00 | 13.29 |

Normalized gas content values were calculated on a dry m.m.f.b. Average gas content for the seams was 9.5 cc/g for the upper seam and 10.3 cc/g for the lower seam.

*Coal quality.* Proximate analyses were completed on all samples. Ash content was low, averaging less than 10%, and the volatile matter ranged from 19.31 to 36.08%. Based on volatile matter content, the coal is high volatile bituminous B. Reflectance measurements were 0.55 and 0.58% Ro, supporting this rank determination. It is interesting to note that the gas content values are high for coal of this maturity. In theory, coal of low rank has not entered the thermogenic gas generation window, so gas content should be substantially lower. It is possible that biogenic methane accounts for the additional coal gas that is adsorbed onto the coal matrix surface. Coal quality data are given in Table 60.

*Adsorption isotherms.* One adsorption isotherm was completed on the sample from 1414.37 m. The test produced a Langmuir volume of 14.66 cc/g and a Langmuir pressure of 8519 kPa. At a reservoir depth of 1414 m, assuming a normal hydrostatic pressure gradient of 9.817 kPa/m, gas saturation would be 9.1 cc/g. This suggests that most of the samples were oversaturated. The equilibrium moisture

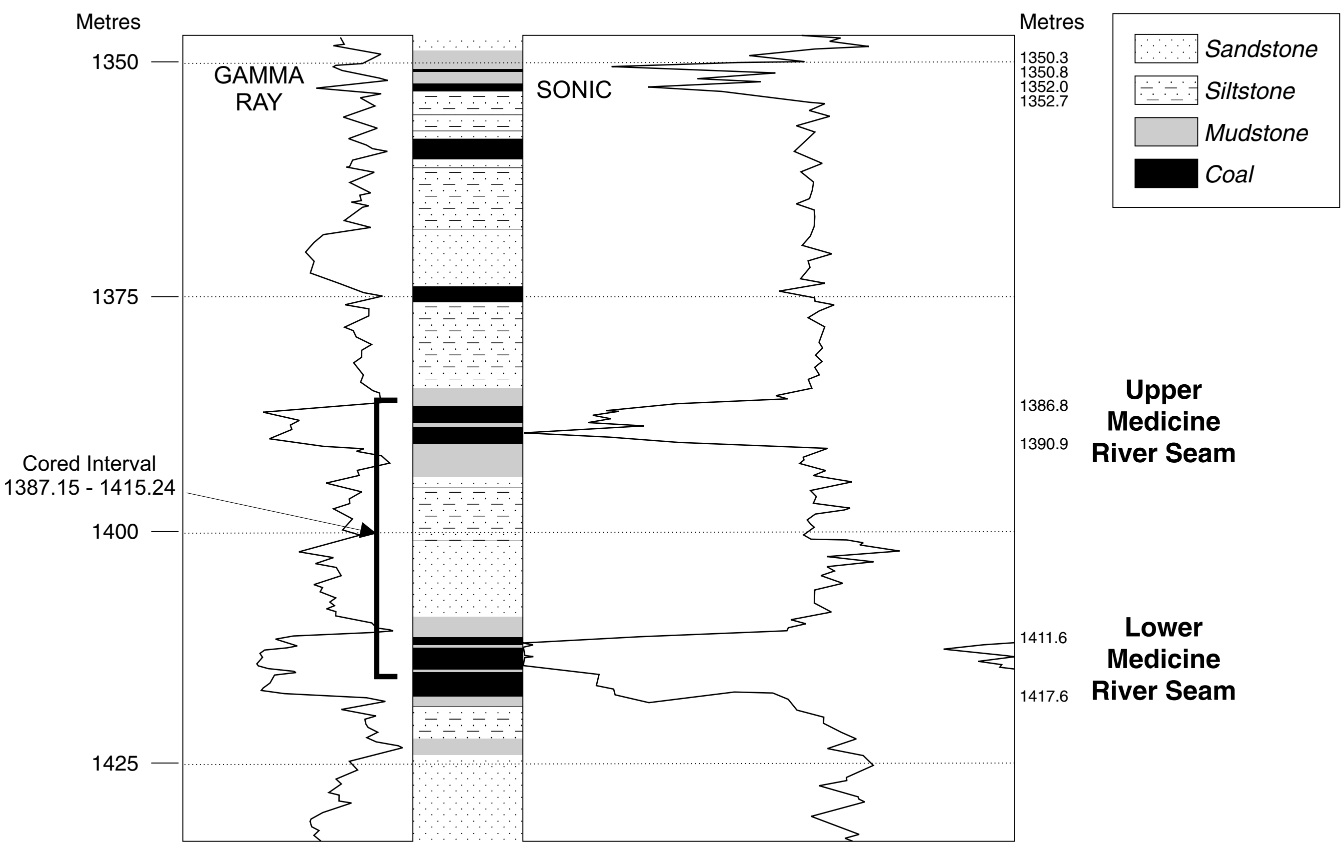


***Figure 81.*** *Detailed stratigraphic section of the Medicine River coal zone, Gulf Fenn West exploration borehole.*

Table 60
**Proximate analyses, Gulf Fenn/Big Valley project**

| Sample depth (m) | Moisture a.r.b. (%) | Ash (%) | Volatile matter (%) | Fixed carbon (%) |
|---|---|---|---|---|
| 1387.15-1387.55 | 6.87 | 3.64 | 35.36 | 54.13 |
| 1387.55-1387.95 | 5.79 | 9.40 | 35.31 | 49.50 |
| 1387.95-1388.27 | 6.39 | 4.76 | 29.84 | 59.01 |
| 1388.65-1389.05 | 4.87 | 15.84 | 31.24 | 48.05 |
| 1389.05-1389.45 | 4.89 | 20.38 | 25.68 | 49.05 |
| 1389.50-1389.90 | 5.71 | 9.74 | 30.52 | 54.03 |
| 1389.90-1390.30 | 6.74 | 3.35 | 34.76 | 55.15 |
| 1412.00-1412.40 | 5.67 | 17.40 | 28.58 | 48.35 |
| 1412.40-1412.80 | 5.41 | 6.56 | 32.34 | 55.69 |
| 1412.80-1413.20 | 3.04 | 44.01 | 19.31 | 33.64 |
| 1413.20-1413.60 | 5.97 | 5.67 | 33.60 | 54.76 |
| 1413.60-1413.97 | 5.47 | 7.26 | 32.15 | 55.12 |
| 1413.97-1414.37 | 5.60 | 5.03 | 35.62 | 53.75 |
| 1414.37-1414.78 | 4.96 | 6.18 | 36.08 | 52.78 |
| 1414.78-1415.24 | 5.45 | 13.29 | 31.19 | 50.07 |

content used for the test was assumed to be 7.4%, which could be high for the rank of coal, although the coal was prepared at equilibrium moisture. Another possible explanation is that the lost gas component might not be as high as calculated. The Mannville coal tends to have slow diffusion rates, and with an extended lost gas time, it is possible to overestimate the lost gas volume.

*Formation testing.* Injection/fall-off tests were conducted on the 4-3 well, to determine reservoir properties. A value of 0.1 mD was obtained from the test. In the 8-11, 10-11 and 4-23 wells, pressure tests were performed to determine reservoir pressure. Pressures ranged from 6000 to 8900 kPa.

In the 16-4 well, the coal zone was perforated and hydraulically stimulated before a limited production and shut in test. Data were analyzed by Resource Enterprises, who determined that the permeability of the reservoir was 0.98 mD, with limited formation damage. Maximum flow rate was 78 Mcf/d and 9 bbls/day of fluid. A reservoir pressure of 6.2 kPa/m suggests that the formation was underpressured.

*Technical assessment.* The Gulf Canada coalbed methane project was designed to produce coal gas from existing wellbores in the Fenn/Big Valley region. The actual exploration target was Medicine River coal draped over a structural high that might have led to enhanced permeability. The elevated gas content obtained from the core samples might be explained by free gas in the fracture system, although with a lost gas time of more than 220 minutes, most of the easily desorbed free gas should have escaped from the core.

Gulf had hoped that the coal being draped over the underlying Paleozoic high would have resulted in higher permeability values, but reservoir tests confirmed that the coal only had permeabilities of less than 1 mD. Production attained from the test wells has generally been poor, usually less than 50 Mcf/d. The most productive well was stimulated with a $CO_2$ frac, but production results are not available for this well. It is believed that initial production rates from this well were over 250 Mcf/d, but declined rapidly to less than 100 Mcf/d. All of the recompletion attempts by Gulf have occurred in existing wellbores where cement and drilling mud damage of the near wellbore is assumed to be high. To date, no undamaged zone has been stimulated. The production rates attained from the Medicine River tests are consistent with other Mannville coal zone tests that have been completed in the Alberta Plains (Lionheart and Ewing Lake) and suggest that the Medicine River coal seams have low permeability unless there is some form of structural enhancement. Draping over the underlying Paleozoic highs might not be sufficient to produce the degree of permeability enhancement necessary to achieve reservoir permeabilities of 10 to 30 mD.

## Enron Twining project

Enron Oil Canada Ltd. drilled two wells (8-14-32-25W4 and 16-23-33-25W4) in the winter of 1991/92, both located about 10 to 15 km west of the town of Trochu (Fig. 82). In both wells, the “Mikwan” coal was cored with high recovery and 12 samples were desorbed for gas content. The Mikwan is considered equivalent to the Medicine River coal of the Lower Cretaceous Mannville Group. The seams were intersected at depths of 1634 and 1593 m, respectively. Measured gas content values ranged from 2.6 to 8.6 cc/g, with the 16-23 well recording the higher gas content.

*Data acquisition.* The wells were drilled with gel-chem fluid. The cored intervals were 1634.0 to 1640.2 m in the 8-14 well and 1593.0 to 1594.4 m in the 16-23 well. Times taken to recover cores to surface were typically two to three hours, indicating that conventional coring equipment was used. On-site Core Laboratories personnel conducted measurements. Samples were desorbed at 32$^{o}$C, which is lower than the recorded reservoir temperature in the drillstem test.

Closed chamber drillstem tests were performed in each well, although some problems were encountered in the 16-23 well.

*Geology.* The target zone for the two exploration wells was the Mikwan or Medicine River coal of the upper Mannville Group. In the 8-14 well, the zone was intersected at a depth of 1634.6 m. Total seam thickness was 2.73 m and net coal thickness was 2.3 m. Thin rider seams were present in the

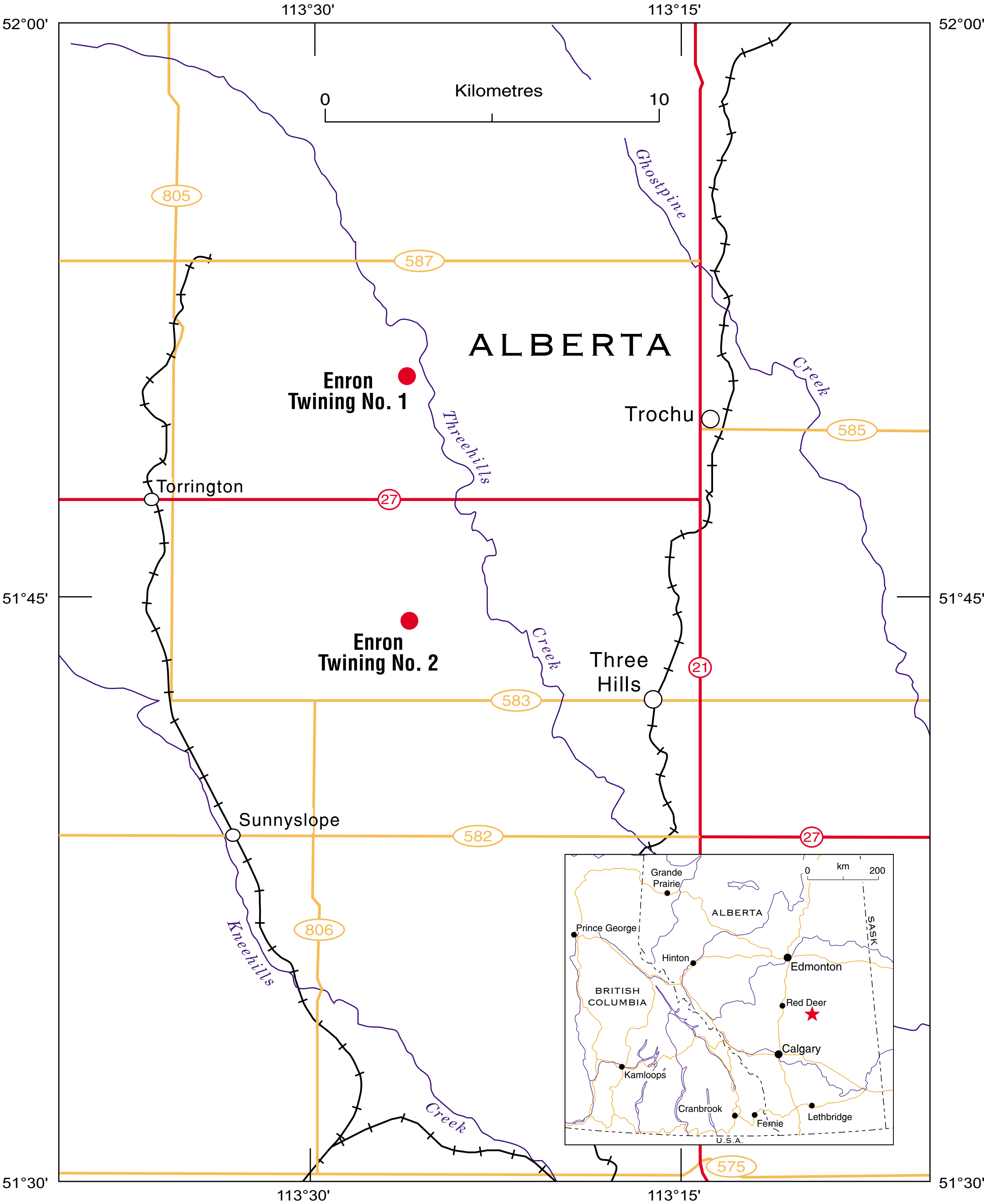


***Figure 82.*** *General location map of the Enron Twining boreholes: Enron Twining (08-14-32-25W4M); Enron Twining (16-23-33-25W4M).*

upper strata of the upper Mannville Group, but these seams tended to be thin (less than 1.5 m) and discontinuous, and are not considered to be prime coalbed methane exploration targets. In the 16-23 well, the Mikwan seam was intersected at a depth of 1593 m. Total zone thickness was 7.8 m and net coal thickness was 7.1 m (Fig. 83). In this well, the Mikwan seam appears to have split into several individual plies, separated by mudstone partings.

*Gas content.* Desorption data for the two wells are shown in Table 61. In the 8-14 well, as-received gas content ranged from 2.6 to 7.8 cc/g, as a result of variable ash content (7 to 65%). Gas content was somewhat higher (6.7 to 8.6 cc/g; as-received) in the 16-23 well, probably as a result of lower ash content. Weighted mean gas content (as-received) was 6.4 and 7.6 cc/g, respectively. Normalized gas content was more consistent in both wells (6.3 to 10.0 cc/g). The inverse relationship between measured gas content and ash is shown in Figure 84.

The coal was desorbed at reservoir temperature (36°C). Lost gas times were generally 2 to 3 hours and calculated lost gas ranges from 5 to 10% of the total gas content. Lost gas curves had relatively low gradients, however, suggesting that the rapid desorption period following depressurizing at the surface was not captured, and lost gas could be higher than calculated. Gas composition was determined for two samples from each well. Methane content ranged from 81 to 90% (air free), with higher values recorded in the 8-14 well.

*Coal composition.* Vitrinite reflectance values of 0.64 to 0.68% indicate ranks of high volatile bituminous C, below the level of peak gas generation/retention. Ash content of the sampled coal was variable (Table 61). Figure 84 shows the relationship between measured gas content and the ash component.

The coal in both wells was generally described as dull with minor brighter sections and poor cleat development. Core photographs show long sections of “stick” core indicating a high proportion of dull components and a lack of fractures in the 8-14 well. Canisters 1 and 6 in well 16-23 were fractured, probably by drilling.

*Adsorption isotherms.* An adsorption isotherm test was performed on a composite sample of all canistered coal from each well at a constant temperature of 55°C. Results are summarized in Table 62. Theoretical gas capacity values are higher than those measured in the sample set. This could be the result of an underpressured reservoir or gas depletion from the coal. The isotherm temperature is similar to estimated reservoir temperatures. The ash content of the composite sample in the 8-14 well is high (30.5%), which might account for the slightly lower ash-free theoretical gas capacity.

*Formation testing.* A closed chamber drillstem test was performed on the coal seams in each well. A summary of the results is shown in Table 63. In both cases, total duration of the tests, which included two flow periods, was on the order of 7 to 10 hours.

The drillstem test in the 8-14 well was considered “mechanically successful” and yielded low gas flow rates of 3 $m^3$/d. In the 16-23 well the packer seat was lost during pre-flow. However, the test was considered successful. Gas was

**Table 61**
**Desorption data, Enron Twining project**

| Well | Canister no. | Top (m) | Thickness (m) | Gas content (cc/g) | Ash (%) | Normalized gas content (cc/g) | Normalized gas content (scf/t) |
|---|---|---|---|---|---|---|---|
| 8-14-32-25W4 | 1 | 1634.17 | 0.40 | 2.6 | 65 | 7.3 | 234 |
| | 2 | 1634.62 | 0.40 | 7.2 | 8 | 7.8 | 250 |
| | 3 | 1635.09 | 0.40 | 7.4 | 7 | 8.0 | 256 |
| | 4 | 1635.53 | 0.43 | 3.1 | 51 | 6.3 | 203 |
| | 5 | 1635.96 | 1.50 | 7.8 | 19 | 9.7 | 309 |
| Mean 6.4 | | | | | | | |
| 16-23-32-5W4 | 1 | 1593.00 | 1.40 | 6.7 | 23 | 8.6 | 277 |
| | 2 | 1594.40 | 1.40 | 7.8 | 5 | 8.1 | 260 |
| | 3 | 1595.97 | 0.39 | 8.5 | 10 | 9.5 | 303 |
| | 4 | 1596.36 | 0.37 | 8.5 | 10 | 9.5 | 303 |
| | 5 | 1596.73 | 0.37 | 7.1 | 27 | 9.7 | 310 |
| | 6 | 1598.20 | 0.40 | 8.4 | 16 | 10.0 | 321 |
| | 7 | 1598.60 | 0.40 | 8.6 | 5 | 9.0 | 289 |
| Mean 7.6 | | | | | | | |

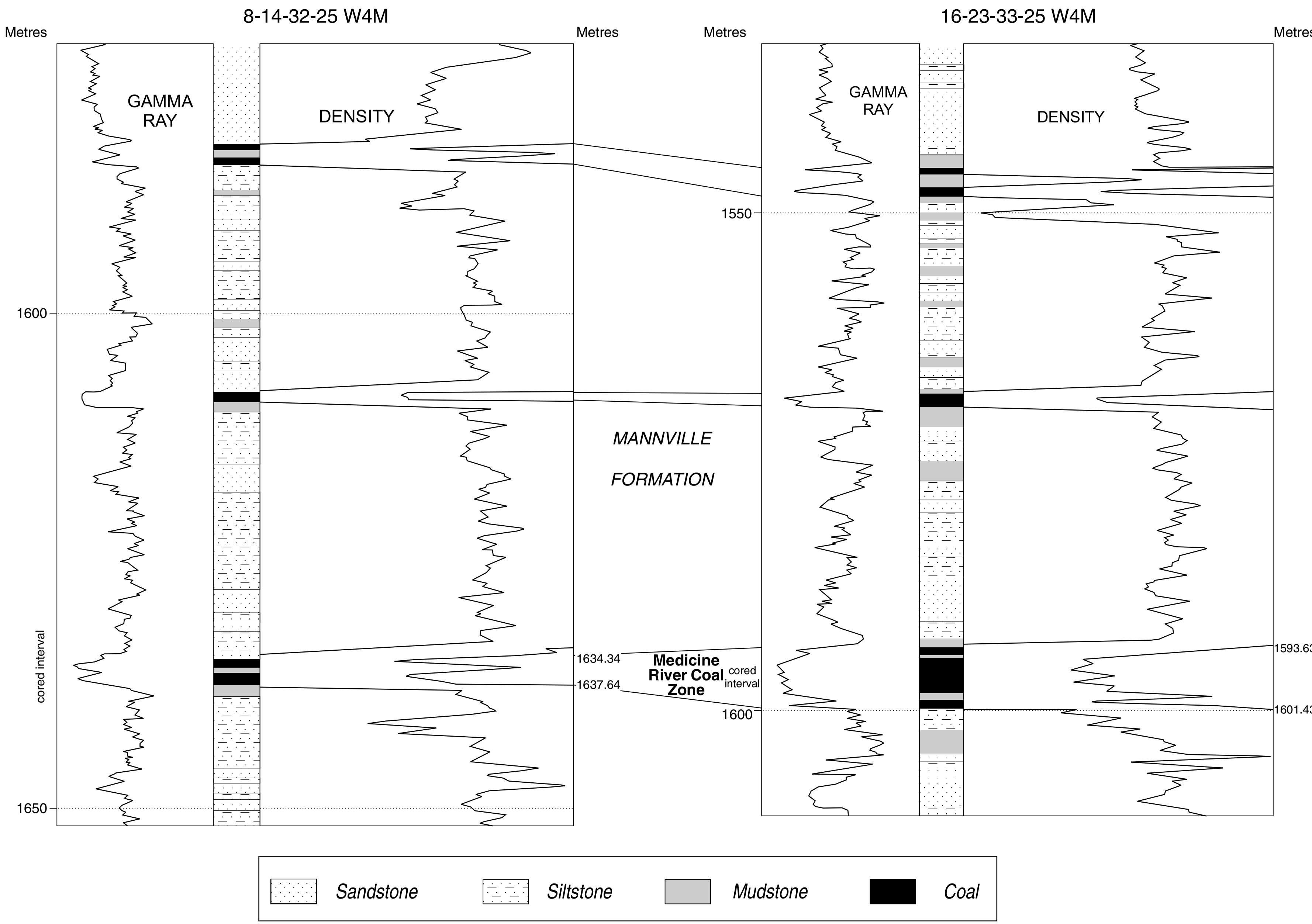


***Figure 83.*** *Detailed stratigraphic sections of the coal measures, Enron Twining 8-14 and 16-23 boreholes.*

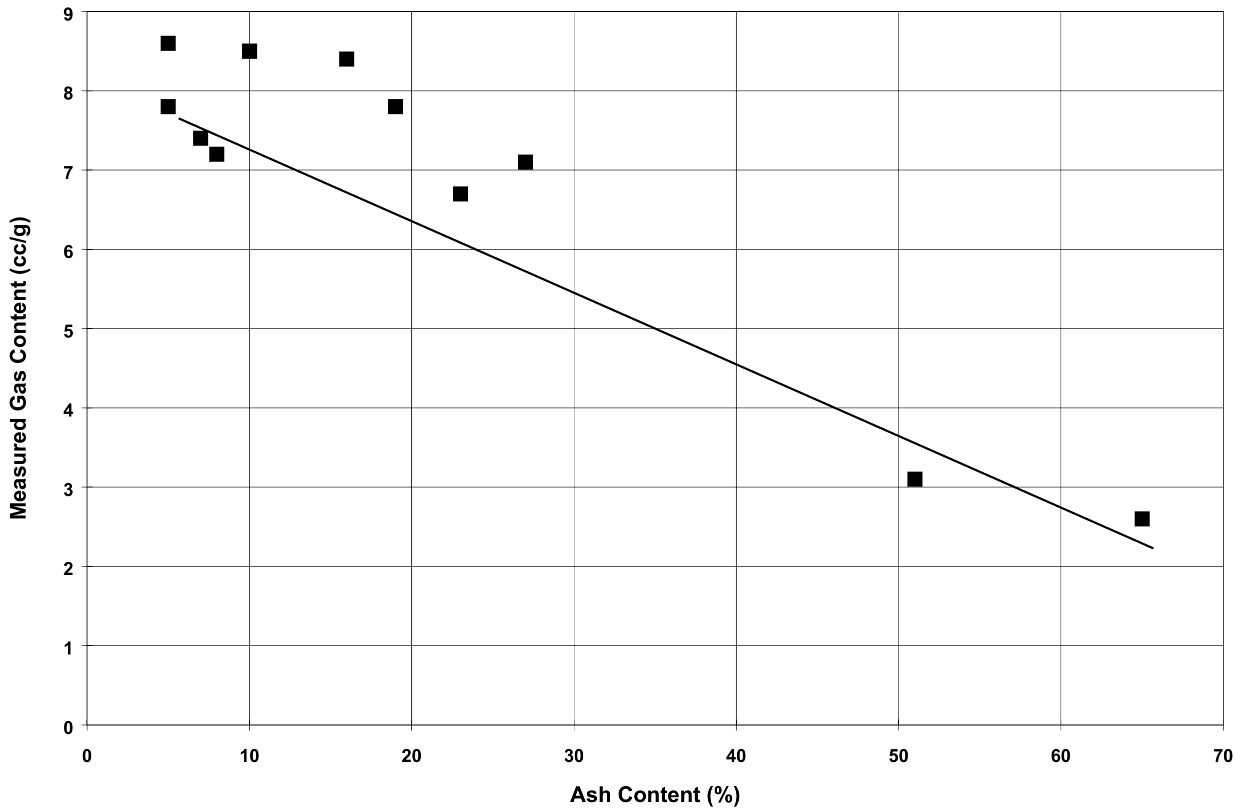


***Figure 84.*** *Measured gas content versus ash for the Enron coal samples.*

produced at low and erratic rates initially because of the presence of a mud column arising from the packer seat loss. Results indicated a zone with relatively high secondary porosity or permeability close to the wellbore. A somewhat stabilized gas flow rate of 6.5 $m^3$/d was achieved for the remainder of the test. No estimation of permeability in either well was provided in the test reports.

*Technical assessment.* Core recovery was high and the on-site desorption personnel were experienced in coalbed methane testing. Lost gas times were relatively long, which might have resulted in underestimation of the lost gas component. However, this would probably not result in significant underestimation of total gas. Desorption was carried out at a lower temperature than in the reservoir. However, as the desorption period was about eight months, this should have affected only the diffusion rate and not the total gas content.

Seam thickness is favorable for gas exploitation and although gas content values were relatively low, permeability is probably adequate for significant flow rates. However, drillstem tests indicate relatively low flow rates, and the physical nature of the coal core suggests low fracture permeability. Drillstem tests of just a few hours duration do not provide adequate testing of the permeability or gas flow from a coal reservoir. However, experience in both commercial and unsuccessful coalbed methane projects suggests that the low flow rates recorded here do not offer good economic potential.

**Table 62**
**Adsorption isotherms, Enron Twining borehole**

| Well | Depth (m) | Ash (%) (a.d.b.) | Moisture (eq. %) | Langmuir volume (cc/g) | Langmuir volume (a.f.b.) (cc/g) | Langmuir pressure (kPa) | Gas capacity (a.f.b.) at reservoir pressure |
|---|---|---|---|---|---|---|---|
| 8-14 | 1635 | 30.5 | 2.3 | 14.1 | 20.3 | 10,767 | 12.1 |
| 16-23 | 1595 | 14.1 | 3.1 | 11.6 | 13.5 | 7694 | 13.6 |

**Table 63**
**Drillstem test data, Enron Twining project**

| Well | Depth (m) | Initial pressure (kPa) | Final pressure (kPa) | Flow rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|
| 8-14 | ~1634 | 4619 | 5515 | 3.0 | Drilling mud |
| 16-23 | ~ 1593 | 5929 | 4566 | 6.5 | Gassified drilling mud |

## Lionheart Consortium project

The Lionheart Energy Corporation coalbed methane project entailed two phases of exploration in the Chigwell area of central Alberta (Fig. 85). In Phase 1, cuttings were collected for desorption from the upper and lower Medicine River coal seams of the Attock 5-3-41-25-W4M borehole drilled in February 1995. This well was drilled to intersect a deeper hydrocarbon target, so only cuttings were recovered.

Following the completion of this well, no further fieldwork was initiated until late 1996 and early 1997, when Lionheart Energy entered into a consortium agreement with several oil and gas companies to attempt a re-completion on the Mannville coal horizon in Chigwell 15-36-41-25-W4M. The well was perforated, hydraulically fractured and put on test production for three months.

*Data acquisition.* Coal gas content data was acquired from a controlled rotary drilling program that allowed cuttings to be collected from individual coal seams. When it was thought a coal seam had been penetrated, drilling was stopped and a sample retrieved. After verification of the coal intersection, the hole was conditioned and then circulated for 0.5 to 1 hour. The coal seam was then drilled and the cuttings collected off the shale shaker. In theory, if the borehole is relatively free of caving, coal cutting samples should be representative of the intersected seam. The cuttings were quickly washed to eliminate drilling mud and then sealed in a desorption canister. In the case of the Attock well, abundant caving material contaminated the sample and back calculations of in situ gas content values had to be made after the desorption process was completed. Coal chip samples were washed with a liquid of 1.8 specific gravity (SG) to eliminate the rock material that had contaminated the sample. The weight of the 1.80 SG split was assumed to be the source of all the coal gas in the canister, and gas content values were calculated by dividing this weight into the cumulative gas desorbed.

*Geology.* Coals that were tested in the Lionheart Chigwell project belong to the upper Mannville Group (Fig. 86). Two main seams were intersected in the Attock well: the lower Medicine River seam between 1542.2 and 1546.5 m, and the upper Medicine River seam between 1530.0 and 1534.2 m. Cumulative net coal thickness for the Medicine River zone is 8 m over a stratigraphic interval of 12.5 m. Other seams higher in the section are thin and discontinuous and not considered suitable exploration targets.

*Gas content.* Four canister samples of coal cuttings were collected, two from each of the Medicine River coal seams. Samples were desorbed at 25°C. Gas content averaged 6.2 cc/g for the upper seam and 5.6 cc/g for the lower seam. Ash content was high because of contamination and, as a result, the gas content was determined from the weight of the 1.80 float fraction. Normalized gas content averaged 8.0 and 7.0 cc/g, respectively.

*Coal quality.* Proximate analyses were completed on the four canister samples following completion of the desorption process. Ash content on an as-received basis was greater than 50%. The ash content of the 1.80 SG float averaged 17%. Petrographic determination of rank indicates that the coal has an $Ro_{max}$ of 0.81%, suggesting that the coal is high volatile bituminous A.

*Adsorption isotherms.* No adsorption isotherms were conducted on the coal samples.

*Formation testing.* No formation testing was done on the Attock well. After nearly one year, Lionheart Energy Corporation entered into a joint venture consortium project to recomplete an existing well in the Chigwell field. Several companies joined forces to undertake the experimental recompletion of Chigwell 15-36-41-25-W5M. This well was chosen in anticipation of encountering enhanced permeability within the coal seam, because of the coal draping over the underlying Paleozoic high. Originally, the plans called for the well to be cavitated, but the final completion techniques consisted of a hydraulic stimulation. It was felt that the cement bond over the coal zones was of insufficient strength and that a conventional fracture stimulation would access the coal zone beyond the immediate wellbore radius. The well was stimulated in December of 1996 and placed on pump. Initially, large volumes of water were produced and extremely cold operating conditions resulted in the pump freezing and the wellbore having to be shut-in. Production was resumed the following February. Gas production diminished steadily from a peak of 25 Mcf/d in the early stages to less than 10 Mcf/d after 50 days of production. It is unclear whether

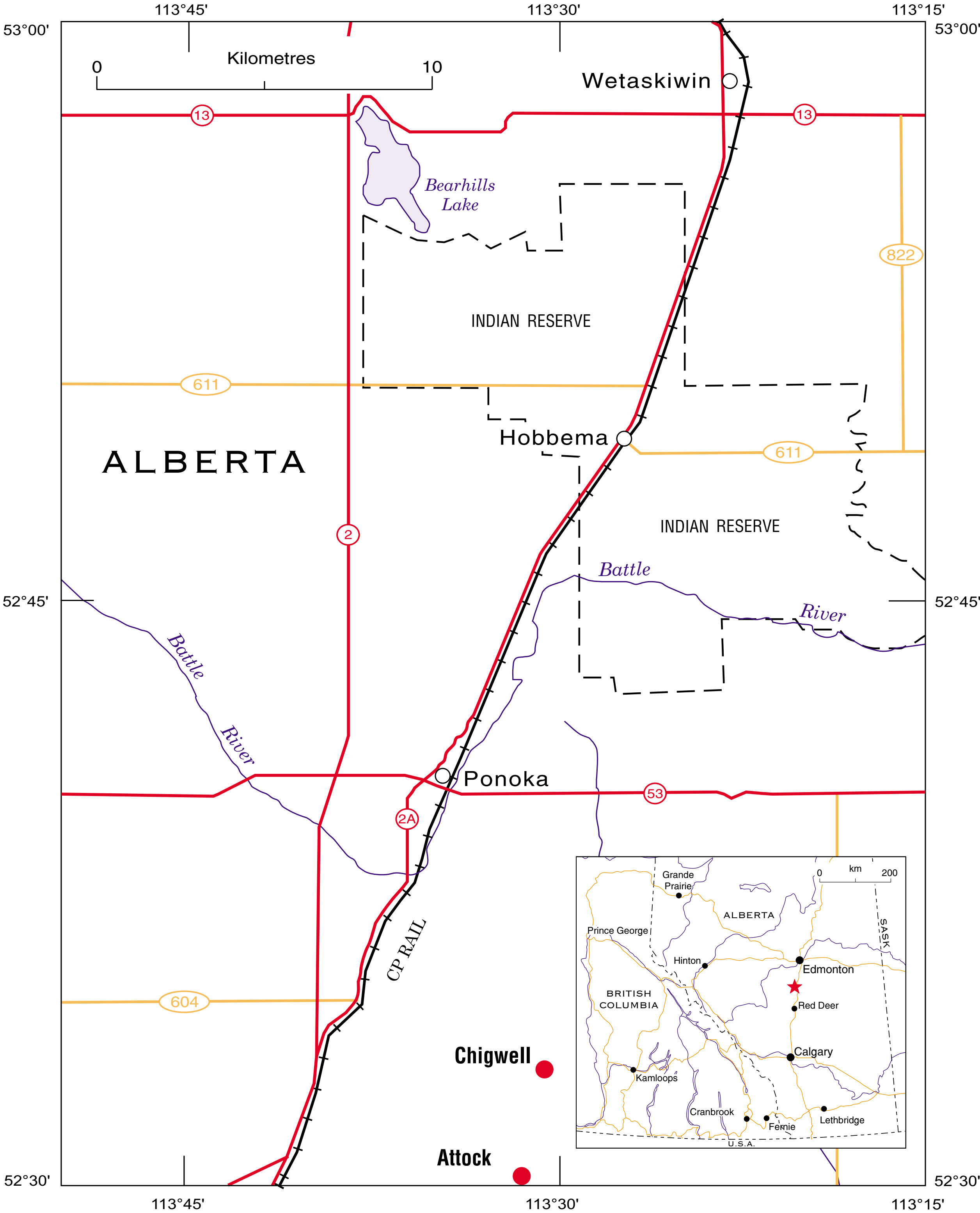


***Figure 85.*** *General location map of the Lionheart Attock (05-03-41-25W4M) and the Lionheart Chigwell (15-36-41-25W4M) recompletion boreholes.*

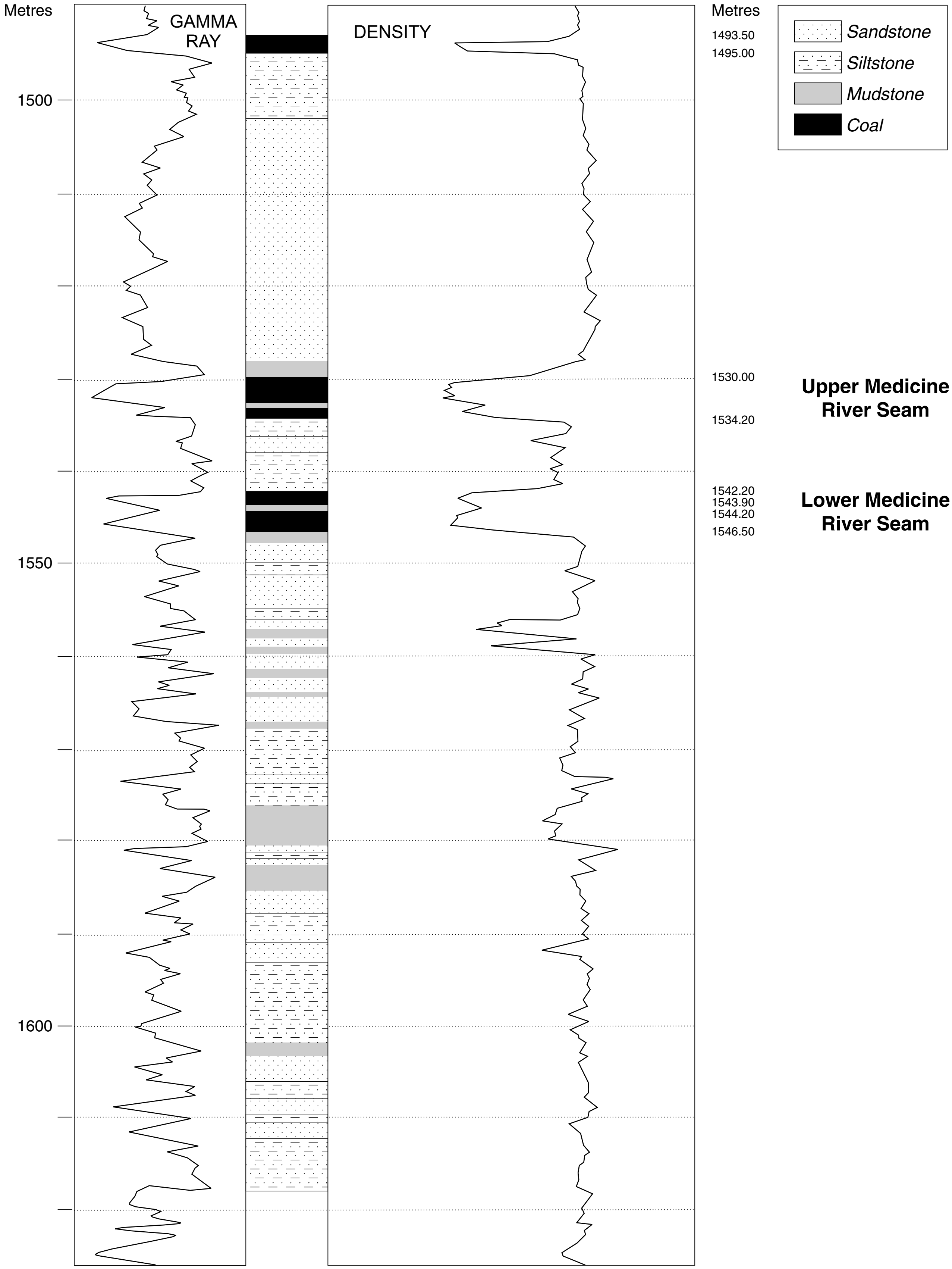


***Figure 86.*** *Detailed stratigraphic section of the Medicine River coal zone, Lionheart Attock borehole.*

the fracture was originally connected to the wellbore, or whether the coal had subsequently been squeezed in the immediate vicinity of the well, closing off communication between the fracture and the wellbore. It is also possible that cement damage from the original drilling was much more extensive than initially thought.

*Technical assessment.* The exploration procedure followed by the Lionheart consortium was to test the coal of the Mannville Group in a recompletion borehole where the coal might have undergone permeability enhancement due to its draping over an underlying structural high. The Chigwell 15-36 wellbore was chosen for this purpose. It is apparent from the low production rates achieved after fracture stimulation that the hydraulic fracture was not connected to the natural fracture system of the coal, assuming such a system was present. If one assumes that the fracture stimulation was successful, significantly more gas should have been liberated if the natural fracture system of the coal had been developed and accessed. The early dewatering problems would have had some negative impact on gas production, particularly if the down time of pumping were long enough to allow water to re-invade the fracture and pore structure of the area of coal matrix previously desorbed. Gas production rates continue to decline and it is doubtful whether economically attractive rates can be achieved from this wellbore.

## Alberta Energy Company Plains project

Limited coalbed methane-related analyses have been performed in four wells drilled for conventional hydrocarbon purposes by Alberta Energy Company on the Alberta Plains. The wells are located in southern Alberta, south of the Red Deer River and close to the Saskatchewan boundary (Fig. 87).

The tested coal is the Medicine River equivalent in the Upper Cretaceous lower Mannville Group. A coal core was cut in AEC Suffield 13-1, but in the other wells only cuttings were collected. The coal is of low rank, and gas content was also relatively low.

*Data acquisition.* In most cases, coalbed methane tests were ancillary to the primary, conventional hydrocarbon goals of these wells. Coal cuttings were collected for desorption tests and/or limited other analyses.

In Suffield 13-1, a core was cut from 956.60 to 959.87 m. Three core and two cuttings samples were desorbed. An adsorption isotherm test was run and gas samples analyzed.

*Geology.* The sampled coal is most likely the equivalent of the Medicine River coal of the Lower Cretaceous Mannville Group of the Alberta Plains.

In the Jenner well, two seams were intersected between 886.7 and 921.3 m. Net coal thickness was about 1.2 m (Fig. 88). In the Suffield 13-1 well, coal was intersected between 917 and 960 m. Net coal thickness was about 3.8 m (Fig. 89).

*Gas content.* Gas content determined on desorbed cores are probably the most representative of in-situ gas volumes. In Suffield 13-1, three cores gave measured gas content values ranging from 1.9 to 6.1 cc/g. This is a relatively wide range that is in part a function of highly variable ash content (14.6 to 79.5%; Table 64). Normalized gas content values were more consistent, but still rather variable (4.7 to 9.3 cc/g) for coal of the same rank, indicating that desorption tests have not accurately assessed gas content in all cases.

Cuttings samples yielded a wide range of gas content values (1.3 to 6.8 cc/g as-received), again reflecting variable ash content (Table 64). Normalized gas content values ranged from 2.5 to 8.9 cc/g.

Lost gas times were about 75 minutes for cores and 45 minutes for cuttings. The lost gas component is generally high (30 to 50% of total gas) except for canister 3 in well 13-1 (17%), which also yielded the highest gas content.

**Table 64**
**Desorption data, Alberta Energy Company, Plains project**

| Borehole | Coal zone | Canister number | Interval (m) | Sample type | Measured gas (a.r.) (cc/g) | Ash (%) (d.b.) | Normalized gas (a.f.b.) (cc/g) |
|---|---|---|---|---|---|---|---|
| 13-1-20-8W4 | 1 | 1 | 952.25-959.87 | Cuttings | 1.3 | 54.4 | 2.9 |
| | 2 | 3 | 956.60-957.24 | Core | 1.9 | 79.5 | 9.3 |
| | 2 | 2 | 957.24-958.75 | Core | 6.1 | 14.6 | 7.1 |
| | 2 | 1 | 958.75-959.87 | Core | 2.9 | 38.3 | 4.7 |
| | 2 | 4 | 956.00-962.00 | Cuttings | 6.8 | 23.7 | 8.9 |
| 7-34-19-8W4 | 1 | 1 | ~ 950m [1] | Cuttings | N/A | N/A | 2.5 |
| 13-23-20-9W4 | 2 | 1 | ~923 | Cuttings | 2.2 | 50.7 | 4.6 |

Note: 1- Suffield 7-34 was drilled horizontally.

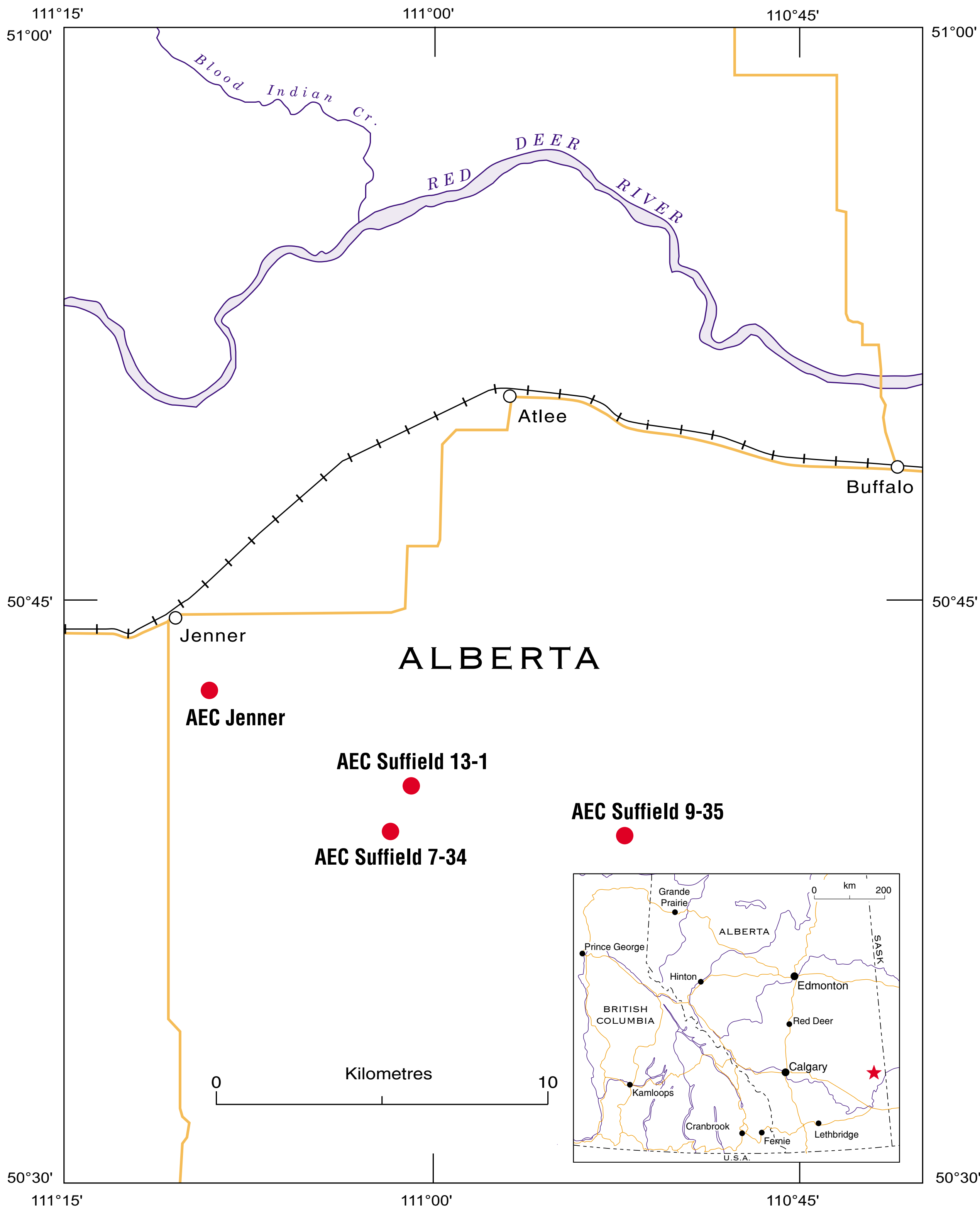


***Figure 87.*** *General location map of the Alberta Energy Suffield exploration boreholes: AEC Jenner (13-23-20-09W4M); AEC Suffield (07-34-19-08W4M); AEC Suffield (09-35-19-07W4M); AEC Suffield (13-01-20-08W4M).*

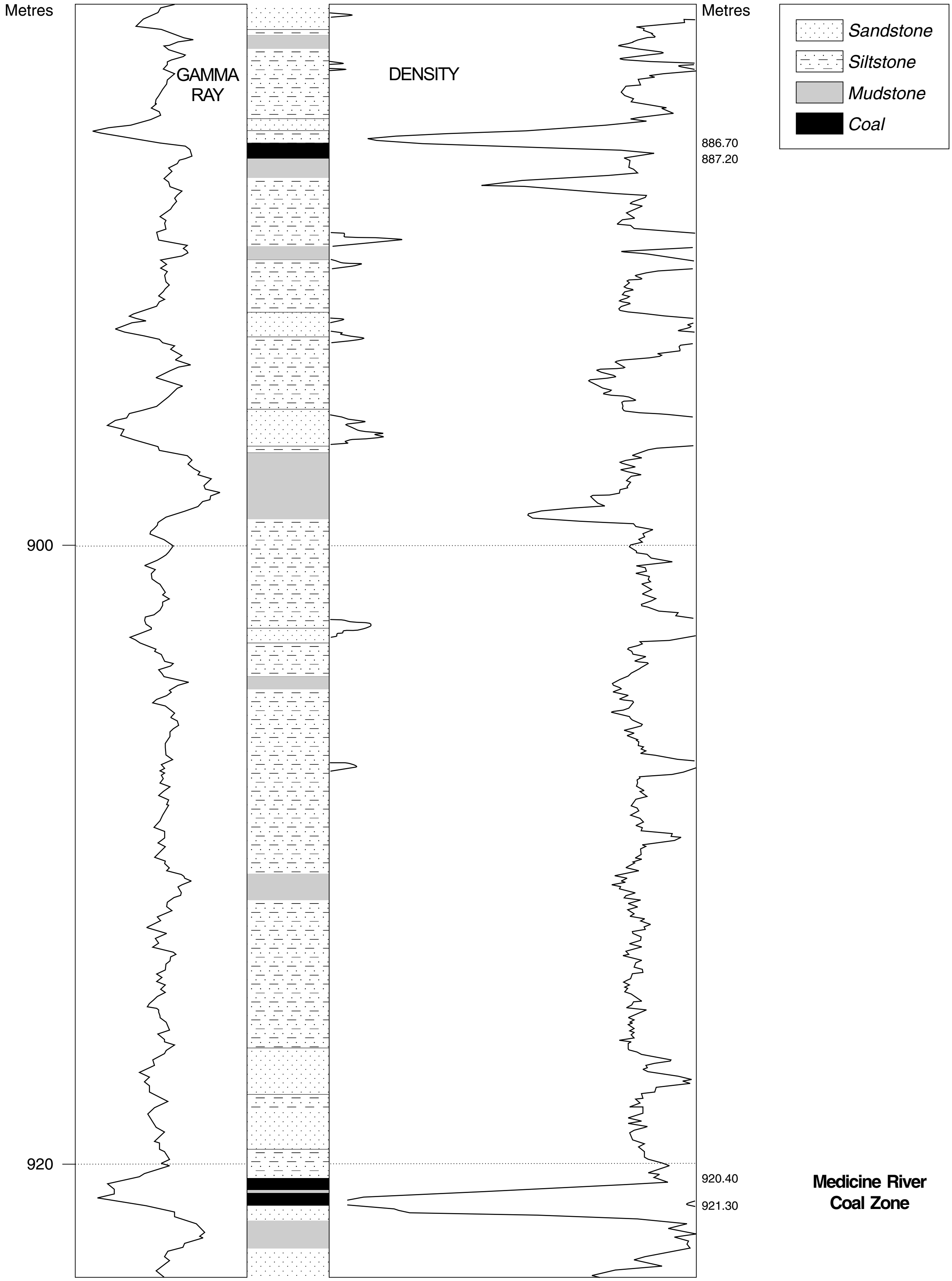


***Figure 88.*** *Detailed stratigraphic section of the AEC Jenner borehole.*

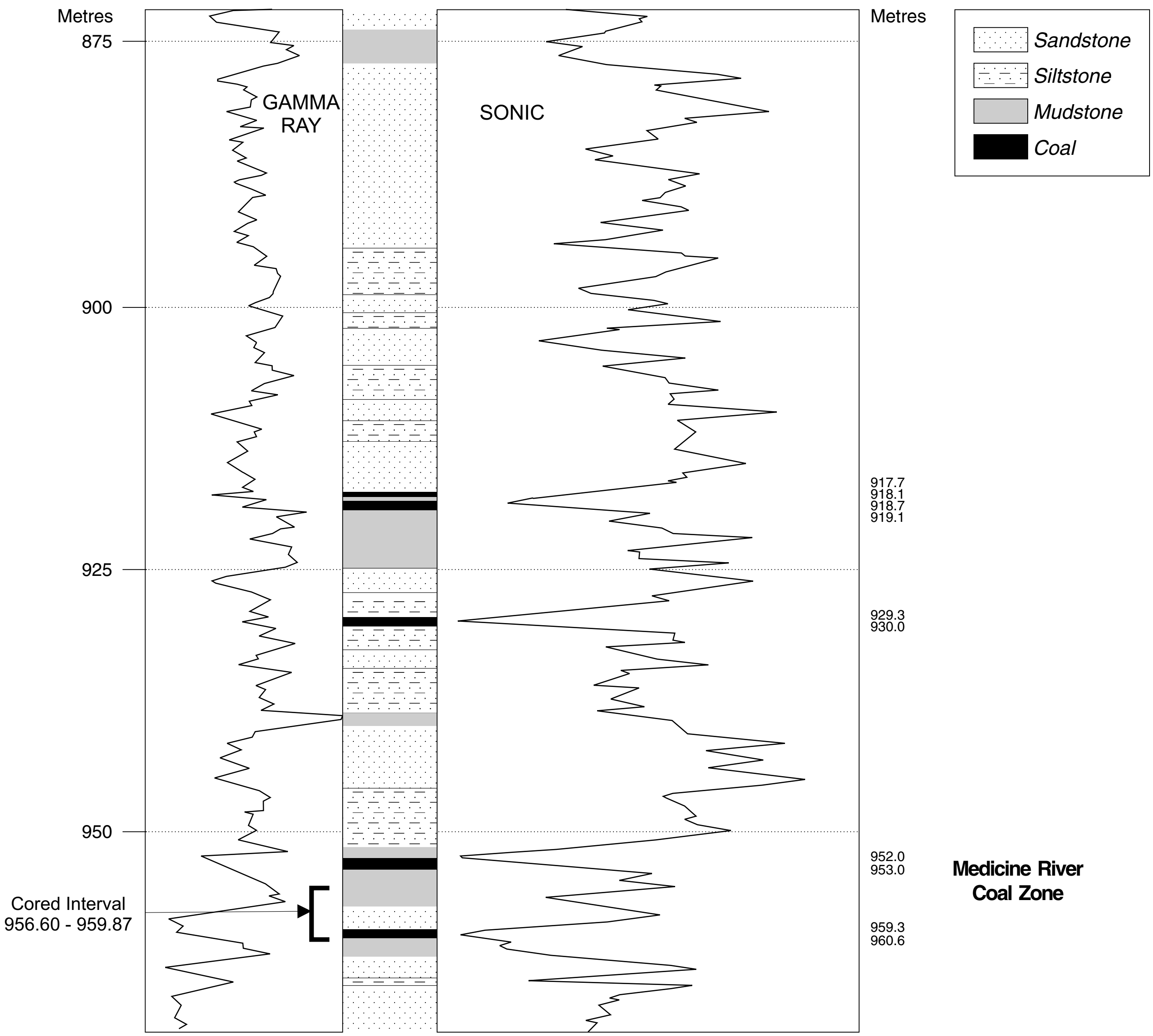


***Figure 89.*** *Detailed stratigraphic section of the AEC Suffield 13-01 borehole.*

The higher gas content (e.g., 8.9 and 9.3 cc/g normalized) in these samples is higher than expected at the rank indicated by vitrinite reflectance. Core description in the 13-1 well report states “oil stained sandstones”, so it is possible that reflectance has been suppressed.

Gas analyses from Suffield 13-1 gave methane contents ranging from 57 to 76%. All gas samples are considered to be contaminated with air.

*Coal quality.* Vitrinite reflectance ranges from 0.41 to 0.46%, indicating a sub-bituminous C to B rank. Volatile matter content suggests higher rank (up to high volatile A/B), and it is possible that reflectance has been suppressed by oil staining.

*Adsorption isotherms.* An adsorption isotherm test was conducted on a cored sample from 959 m in the Suffield 13-1 well (Table 65). The sample was adsorbed at 25°C and indicated a reservoir capacity of 12.3 cc/g at hydrostatic pressure at reservoir depth. Based on the mean normalized gas contents of the two core samples with lowest ash in this well, it appears that the reservoir is only 67% saturated, indicating depletion of gas or underpressuring of the reservoir.

**Table 65**
**Adsorption isotherm, AEC Suffield 13-01 borehole**

| Borehole | Depth (m) | Langmuir equation | Reservoir capacity (a.f.b.) (cc/g) | Normalized gas content (cc/g) | Reservoir saturation (%) |
|---|---|---|---|---|---|
| 13-1-20-8W4 | 959.1 | V=19.2*P/(P+5298) | 12.3 | 8.2* | 67 |

*mean of canisters 2 and 3, zone 2 in Suffield 13-1

*Formation testing.* No formation tests were conducted in any of the Suffield-area boreholes. Laboratory testing of core samples from the 13-1 well yielded a very high range of horizontal permeability (3.5 to 1540 mD). High values probably result from testing along fractures and/or bedding planes. Vertical permeability ranged from 1.1 mD to 4.1 mD.

*Technical assessment.* In AEC Suffield 13-1, a core was cut in coal for specific coalbed methane evaluation. In the other wells, cuttings were collected and limited tests applicable to coalbed methane evaluation were conducted.

Gas content was relatively low, although perhaps higher than might be expected at the low rank (sub-bituminous B/C) of the coal tested. In most cases, cuttings samples yielded lower gas content values than cores, as should be expected.

The isotherm test yielded an ash-free reservoir capacity of 12.3 cc/g (normalized), which could be a marginally economic gas content in saturated reservoirs with low-ash coal. Under typical conditions of moderate- to high-ash coal, undersaturated reservoir coal of higher rank (and gas capacity) would be required to provide economic coalbed methane potential.

## Gulf Gilby/Sylvan Lake project

Gulf Canada Resources Limited undertook a limited coalbed methane exploration program to assess the potential of the Tertiary age Ardley coal zone of the Scollard Formation and the lower Cretaceous Medicine River coal zone of the Mannville Group in the Gilby/Sylvan Lake region of western Alberta (Fig. 90). Two wells were drilled in 1990 (14-15-38-3-W5M and 8-13-41-4-W5M) and coal samples consisted of cuttings. The wells were not drilled specifically for coalbed methane purposes.

*Data acquisition.* In the Gulf Sylvan Lake well, the Scollard Formation coal was intersected at a depth of 422 m. Two samples were collected and desorbed in canisters at reservoir temperature. No other tests were performed on the well.

In the Gilby well, the Medicine River coal zone was intersected at a depth of 2056 m and two cuttings samples were collected. As with the Sylvan Lake well, no other work was completed.

*Geology.* The Scollard Formation was intersected in the Sylvan Lake well at a depth of 396 m. Five coal zones were penetrated, with the thickest being the Upper Silkstone coal at 422.7 m. Non-coal lithotypes consist of interbedded sandstone, siltstone and mudstone. In other boreholes intersecting the Scollard Formation, the upper boundary of the formation is overlain by thick massive sandstone of the overlying Paskapoo Formation. In the Sylvan Lake well, the contact is more gradational and rock types are interbedded siltstone and mudstone, with no distinctive break. Coal intersections are tabulated in Table 66 and illustrated in Figure 91.

In the Gilby well, the Medicine River coal zone of the Mannville Group was intersected at a depth of 2056 m and attains a thickness of 4 m. Two subsidiary coal seams lie below the Medicine River zone and are defined as the Glauconite horizon (2067.9 to 2068.6 m and 2069.9 to 2070.3 m). These seams are thin and discontinuous and not considered prospective for coalbed methane. Figure 92 illustrates the detailed coal section for the Mannville Group.

*Gas content.* Gas content values were derived from cuttings samples. It is unknown whether the canisters were desorbed at reservoir temperature; no proximate analyses were completed. For the Sylvan Lake well, gas content averaged 1.25 cc/g from the Silkstone coal zone at a depth of 422 m.

In the Gilby well, gas content of the Medicine River zone averaged 4 cc/g from a depth of 2058 m. In both sets of samples, the gas content appeared to be substantially lower than expected for the rank and depth of intersection of the coal. These anomalously low values are probably a result of the type of sample collected.

**Table 66**
**Coal intersections, Gulf Sylvan Lake borehole**

| Coal zone | Depth (top) (m) | Depth (base) (m) | Total coal thickness (m) | Net coal thickness (m) |
|---|---|---|---|---|
| Val D'Or | 396.00 | 398.70 | 2.70 | 1.70 |
| Arbour | 410.50 | 412.07 | 1.57 | 1.57 |
| Upper Silkstone | 422.70 | 429.00 | 6.30 | 4.30 |
| Lower Silkstone | 438.50 | 440.80 | 2.30 | 1.50 |
| Mynheer | 469.40 | 470.80 | 1.40 | 1.40 |

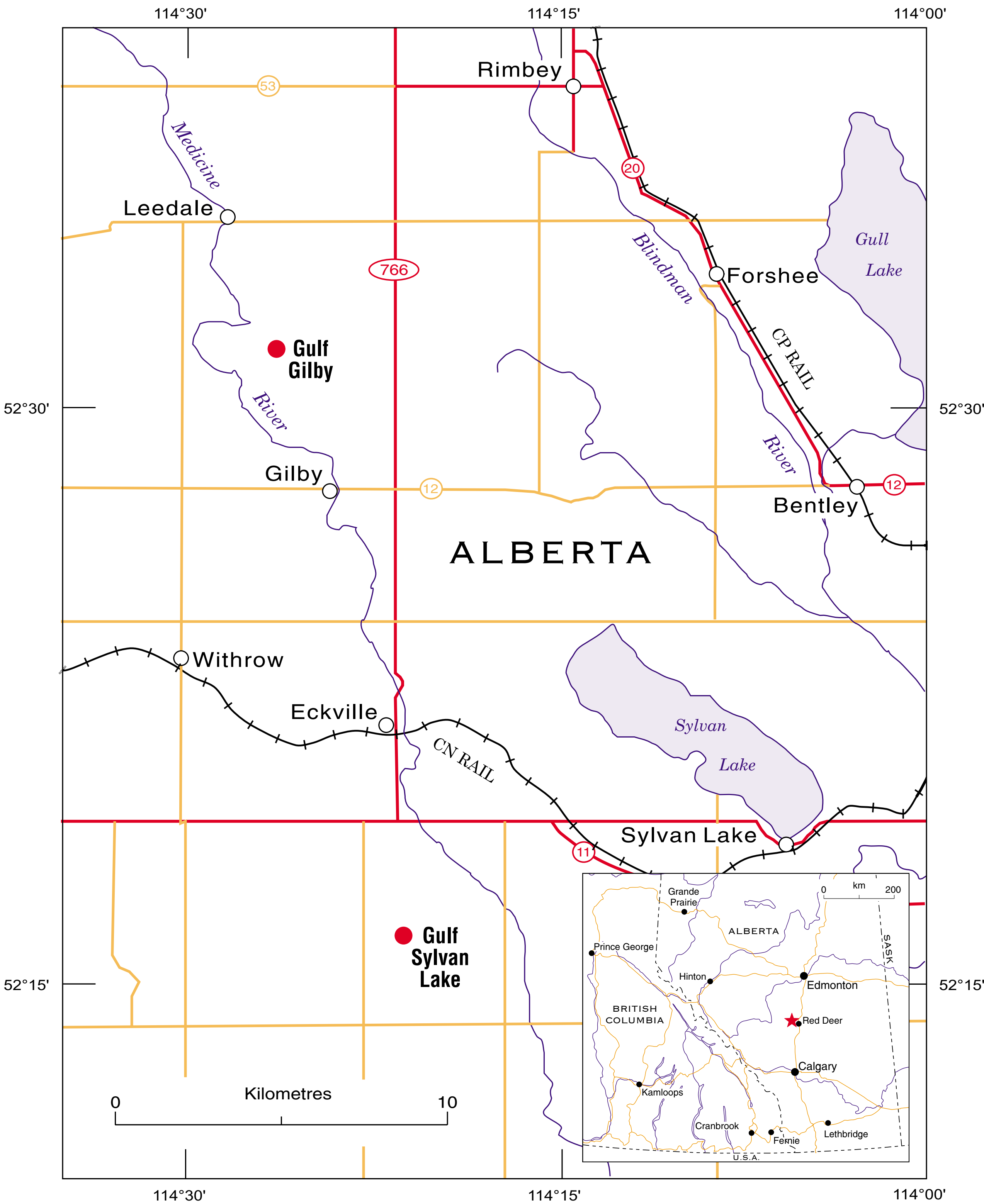


***Figure 90.*** *General location map of the Gulf Sylvan Lake (14-15-38-03W5M) and the Gulf Gilby (08-13-41-04W5M) exploration boreholes.*

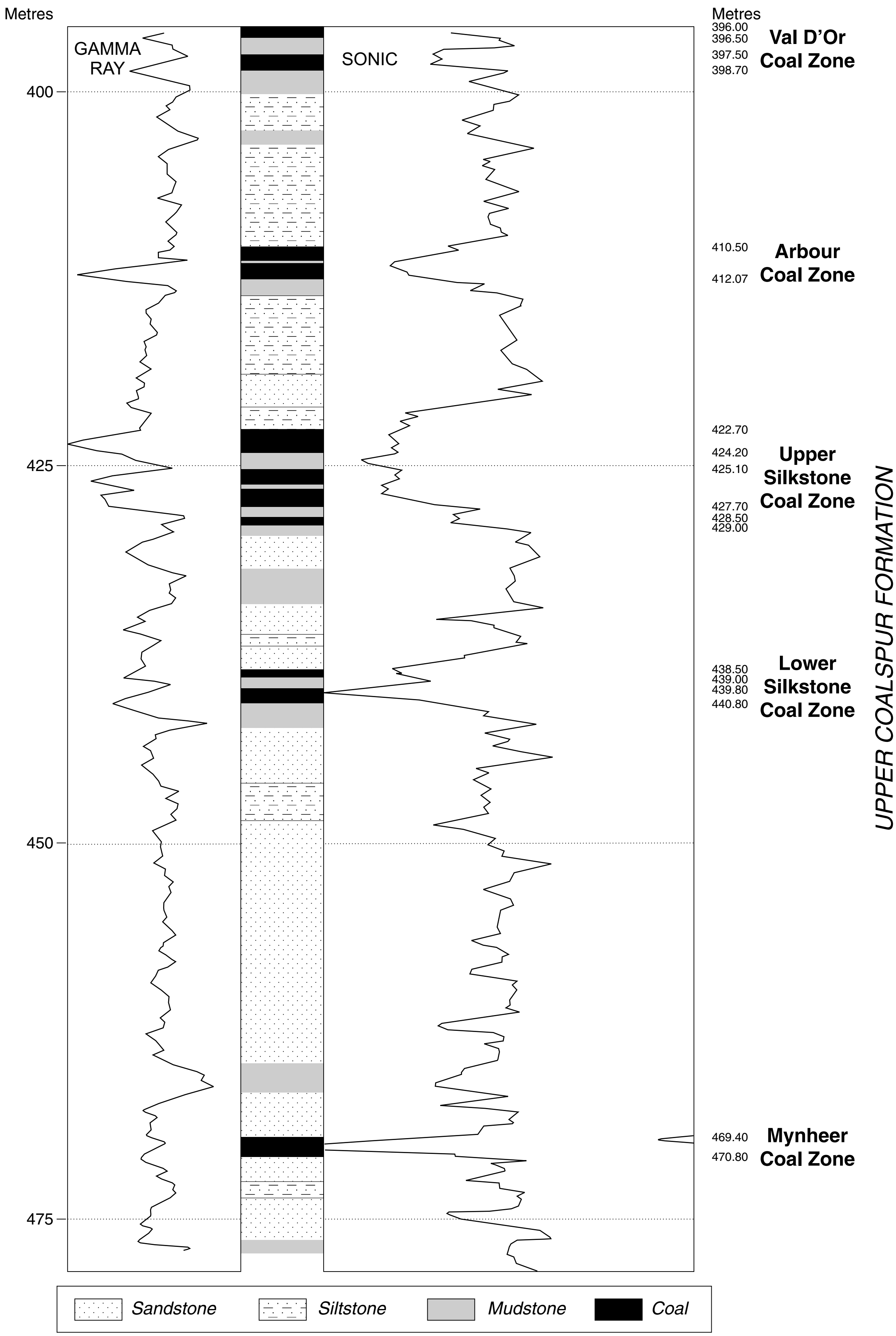


***Figure 91.*** *Detailed stratigraphic section of the Scollard Formation, Gulf Sylvan Lake borehole.*

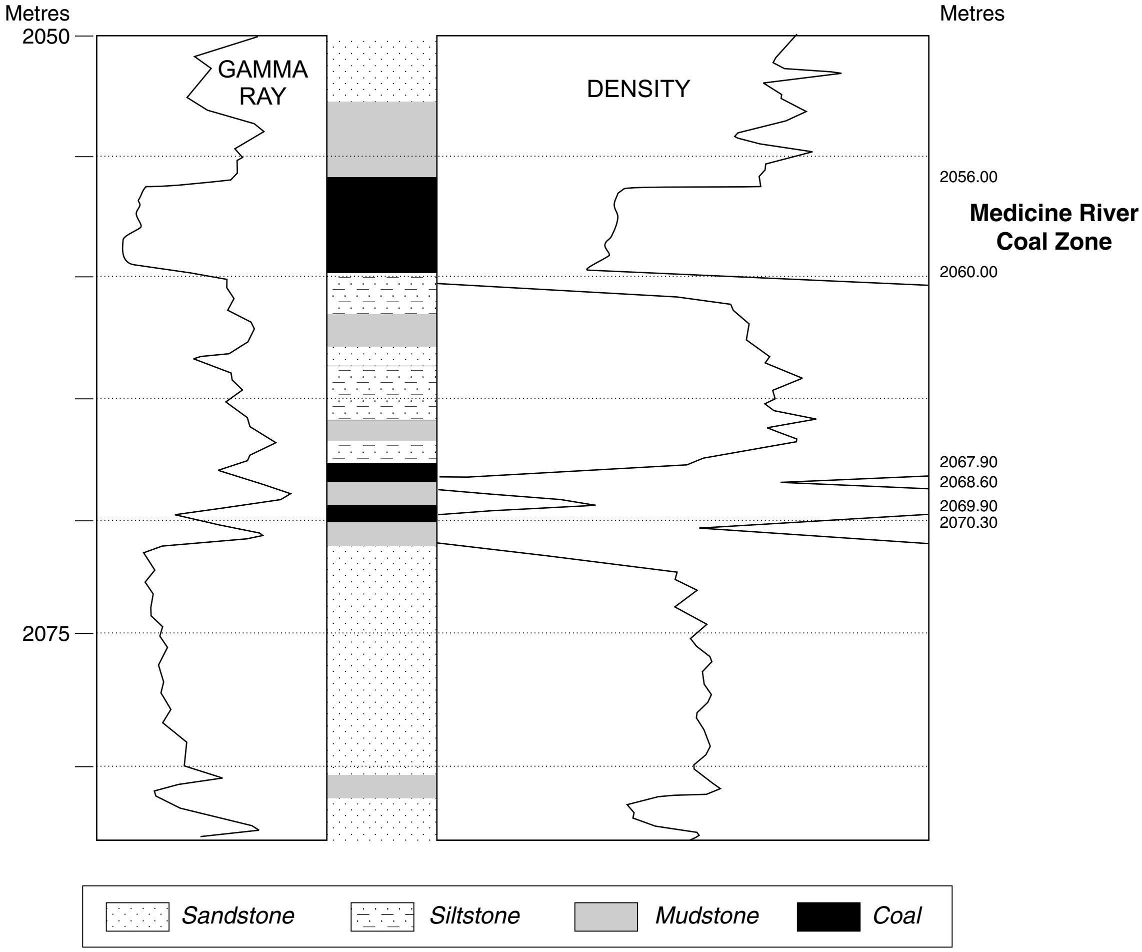


***Figure 92.*** *Detailed stratigraphic section of the Mannville Group, Gulf Gilby borehole.*

*Coal quality.* No coal quality data are available for the samples collected.

*Adsorption isotherms.* No adsorption isotherms were performed on the coal samples.

*Formation testing.* No formation tests were completed on the wellbore.

*Technical assessment.* In the two Gulf Canada Resources wellbores, coal samples were taken from shallower horizons to test for coalbed methane potential. The method of sampling and the number of tests performed indicated that Gulf personnel did not have a well defined coalbed methane exploration play in mind, and that the samples were a means of collecting data at relatively low cost to the company. No assessment of the potential can be made as the data are too limited.

## PetroCanada Gilby project 6-15-41-3-W5M

PetroCanada Resources Limited drilled a coalbed methane exploration well in the Gilby region of central Alberta in the fall of 1992 (Fig. 93). The well was drilled for a deeper conventional hydrocarbon target and was twinning an existing location. Two coal horizons were targeted for evaluation: the Ardley coal of the Scollard Formation, at a depth of about 476 m, and the Medicine River coal zone of the Mannville Group, at a depth of 2053 m.

*Data acquisition.* The borehole was drilled using a conventional oil and gas exploration drill rig. In the Ardley coal zone intersection, cuttings samples were collected from the shale shaker. The Medicine River zone was cored using a conventional core barrel with plastic inner liner. The top of the Medicine River seam was first touched with the conventional rock bit, and the drill string was then replaced

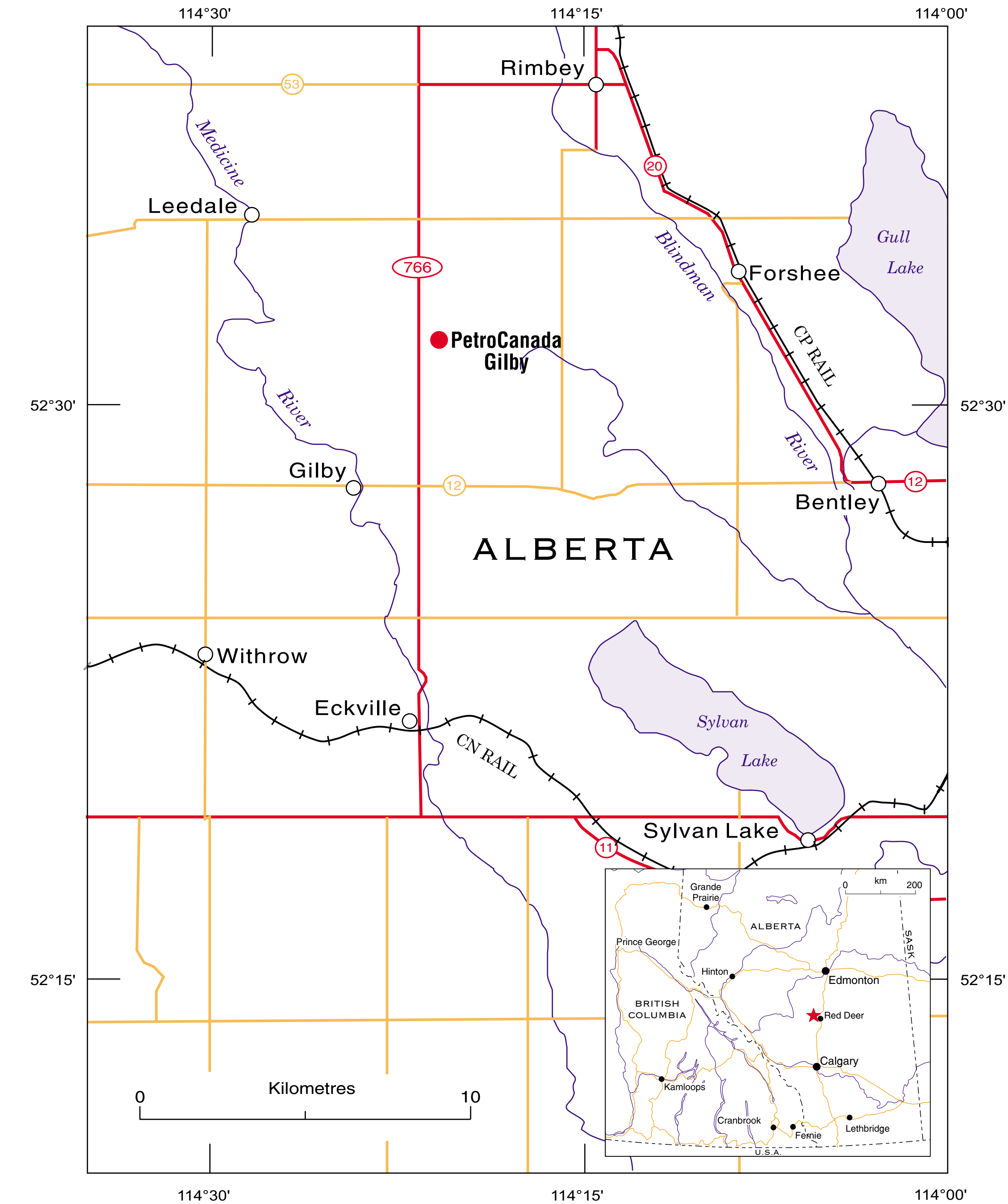


*__Figure 93.__ General location map of the PetroCanada Gilby (06-15-41-03W5M) exploration borehole.*

with the core barrel. Trip time for the retrieval of the cored interval was about 2 hours.

Nine canister samples were collected, two of which were cuttings samples. The canisters were desorbed at reservoir temperature (20°C for the Ardley sample and 54°C for the Mannville samples). Following desorption, the coal was analyzed for proximate analysis. No other tests were performed on the coal measures.

*Geology*. The Ardley coal zone of the Tertiary Scollard Formation was intersected at a depth of 422 m. The contact with the overlying Paskapoo Formation is sharp and consists of a medium- to coarse-grained, buff coloured sandstone lying on top of finer grained interbedded siltstone and mudstone.

The Lower Cretaceous Mannville Group was intersected at a depth of 2008 m. A thin, discontinuous coal seam was intersected in the upper section of the group at a depth of between 2008.7 and 2009.4 m. The principal exploration target was the Medicine River coal zone, lying between 2022.3 and 2058.6 m. Two seams were developed: the upper at 2022.3 to 2024.3 m and the lower at 2053.0 to 2058.6 m. Total combined net coal thickness was 8.3 m. Figure 94 shows a Mannville Group detailed stratigraphic section.

*Gas content*. Gas content data were obtained from cuttings cores. Only the lower Medicine River seam was cored; cuttings were collected for the main Ardley seam and the upper Medicine River seam. Gas content data include an estimate of residual gas. Data are summarized in Table 67.

Gas content values for the Medicine River seam are consistent and average 10.99 cc/g as measured. There is a discrepancy between cuttings and core, which can be attributed to the diffusion rate and the size of the sample material as it desorbs.

**Table 67**
**Desorption data, PetroCanada Gilby**

| Sample interval (m) | Sample type | Measured gas content (cc/g) | Normalized gas content (cc/g)* | Ash content (a.r.b.) (%) |
|---|---|---|---|---|
| 476.0-483.0 | Cuttings | 1.95 | 2.78 | 14.88 |
| 2022.0-2024.5 | Cuttings | 8.29 | 9.60 | 8.0 |
| 2053.0-2053.4 | Cuttings | 8.84 | 10.67 | 10.32 |
| 2053.4-2054.3 | Core | 10.97 | 12.81 | 7.85 |
| 2054.3-2055.2 | Core | 12.08 | 13.85 | 6.33 |
| 2055.2-2056.0 | Core | 10.67 | 12.64 | 10.04 |
| 2056.0-2056.9 | Core | 11.59 | 12.81 | 5.24 |
| 2056.9-2057.7 | Core | 10.29 | 11.81 | 6.61 |
| 2057.7-2058.6 | Core | 10.33 | 12.01 | 6.35 |

* Normalized gas content is calculated on a dry mineral matter free basis.

*Coal quality*. Following completion of the desorption testing, the coal samples underwent proximate analysis. The cuttings samples were washed in a liquid of 1.6 specific gravity, and the float material was analyzed. The weight of the float material was then used to calculate the gas content for these samples. Coal quality data are presented in Table 68.

*Adsorption isotherms*. No adsorption isotherms were performed.

*Formation testing.* No formation testing was undertaken over the coal intervals for the wellbore.

*Technical assessment*. The PetroCanada Resources test borehole at Gilby was designed to assess the coalbed methane potential of the Medicine River coal zone. The samples collected indicate that the gas content of the coal averaged nearly 11 cc/g at a depth of about 2058 m. No

**Table 68**
**Proximate analyses, PetroCanada Gilby**

| Sample interval (m) | Sample type | Moisture content (%) (a.r.b.) | Ash content (%) (a.r.b.) | Volatile matter (%) (a.r.b.) | Fixed carbon (%) (a.r.b.) | Sulphur (%) (a.r.b.) |
|---|---|---|---|---|---|---|
| 476.0-483.0 | Cuttings | 4.15 | 14.88 | 29.17 | 51.80 | 0.50 |
| 2022.0-2024.5 | Cuttings | 1.68 | 8.0 | 31.49 | 58.83 | 0.50 |
| 2053.0-2053.4 | Cuttings | 3.31 | 10.32 | 28.03 | 58.34 | 0.50 |
| 2053.4-2054.3 | Core | 5.39 | 7.85 | 29.89 | 56.87 | 1.78 |
| 2054.3-2055.2 | Core | 4.52 | 6.33 | 28.59 | 60.56 | 1.02 |
| 2055.2-2056.0 | Core | 4.30 | 10.04 | 29.09 | 56.57 | 1.80 |
| 2056.0-2056.9 | Core | 3.59 | 5.24 | 27.28 | 63.89 | 0.86 |
| 2056.9-2057.7 | Core | 4.93 | 6.61 | 28.49 | 59.97 | 2.35 |
| 2057.7-2058.6 | Core | 5.08 | 6.35 | 31.50 | 57.07 | 4.63 |

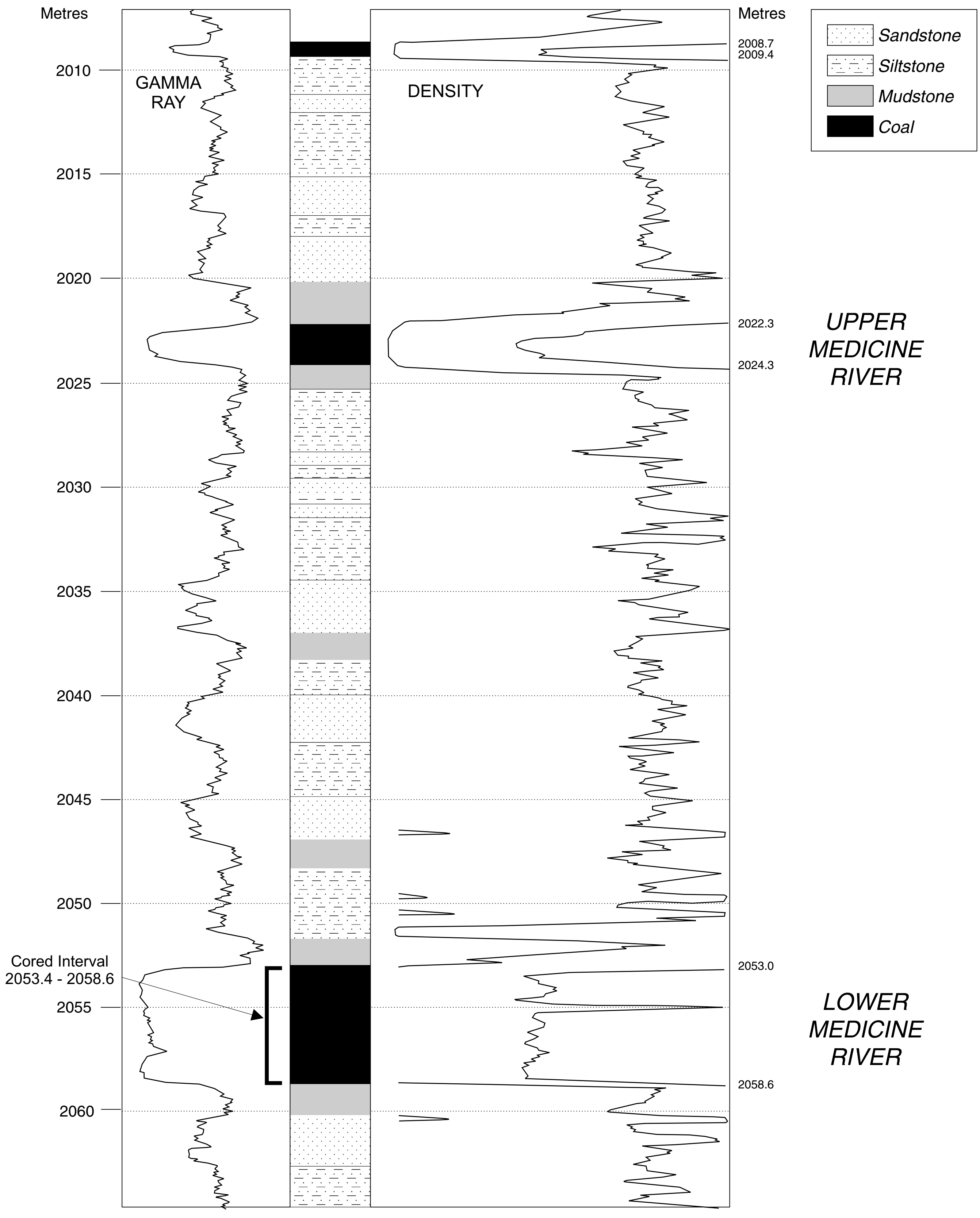


***Figure 94.*** *Detailed stratigraphic section of the Medicine River coal zone, PetroCanada Gilby borehole.*

adsorption isotherms were completed to determine the degree of reservoir saturation. Using the Ryan equation to determine the theoretical gas capacity of the coal at reservoir depth produces a value of 15.1 cc/g, suggesting that the coal has a 73% saturation. This value is comparable to other Mannville coal in the region. Assuming an average seam thickness of 7 m, in situ resources are estimated at 8 Bcf per section.

No reservoir properties were determined from the wellbore and permeability is unknown. Description of the core indicates that the coal is competent, with occasional bright, well cleated bands. The predominant lithotype is dull coal with limited cleating. Using similar visual descriptions of Mannville Group coal from other borehole intersections, and considering the depth of the coal, the permeability is expected to be low, probably less than 1 mD.

Following completion of the Gilby well, PetroCanada Resources proceeded to continue its coalbed methane exploration efforts by undertaking a regional study in the Battle Lake region, located in Townships 45 and 46, Ranges 1 and 2, W5M (Fig. 95). The focus of the regional study was understanding the subsurface SP geophysical response of the Medicine River coal zone. The results of the study suggested that the Medicine River coal seam was draped over an underlying Paleozoic high associated with a Devonian reef complex. On the edges of the reef, maximum draping of the coal might have lead to an extensional stress regime. This could have produced an enhanced natural fracture system that would lead to higher permeability. In conjunction with Baytex Energy Ltd., a core of the Medicine River seam at 6-6-46-1-W5M was retrieved. Coal samples were desorbed by Norwest Resource Consultants, but the only information available is a composite gas content value of 17.2 cc/g. This value appears to be anomalous, considering the depth of intersection and the ash content. No further assessment of the gas content can be made. PetroCanada, in response to the favourable gas content and permeability estimates, applied to the Alberta government for an experimental pilot project. After extensive public hearings, the project was finally approved, but by this time, PetroCanada had abandoned the project and placed the entire property for sale.

A conventional drillstem test was performed on the lower Medicine River seam and a permeability value of 3.9 mD calculated. During the drillstem test, the tool had to be opened, allowing drilling fluid into the test chamber. The permeability value estimated is based on fluid recovery because gas flow was too small to measure. Given that the total recovered fluid was estimated at 17 m within the drill column and not the 32 m used in the permeability calculation, it is believed that the permeability value of 3.9 mD is an overestimate of the true reservoir properties.

### PetroCanada Redwater project

PetroCanada Inc. drilled the Redwater well (10-21-57-21 W4) in the winter of 1990/91 in the Redwater oilfield immediately northeast of Edmonton (Fig. 96). The intention was to test for coalbed methane to assess the potential of establishing gas production upsection of oil production horizons, to extend the life of the field, and fully use the existing infrastructure.

The target was the Medicine River coal of the Lower Cretaceous Mannville Group. Three oriented cores were cut in the interval 648.0 to 670.6 m. Two seams, 0.35 and 1.53 m thick, were cored at 650 and 664 m, respectively. Ten core samples were desorbed for gas content, which ranged between 2.2 and 5.5 cc/g (as-received). Values were in accordance with the low rank of the coal.

*Data acquisition*. The well was drilled with a petroleum rig to a total depth (TD) of 814 m. Flocculated water was used as drilling fluid to the top of the coal and then gel-chem was used during conventional coring. Three cores were cut:

- Core 1: 648.0–651.0 m (full recovery)
- Core 2: 651.0–658.0 m (98.6% recovery)
- Core 3: 662.0–670.6 m (full recovery)

Core 1 was relatively unsuccessful, with the core “jamming off” at 651 m. Recovered material was rubble and primarily shale, as found in the top of Core 2.

TerraTek Inc. supervised collection and desorption testing of ten coal core samples. Desorption was at a 22$^{o}$C, which is close to the bottom-hole temperature of 27.5$^{o}$C.

*Geology*. The Medicine River coal in the Lower Cretaceous Mannville Group was the target for the PCI Redwater well. The Mannville Group sediments in the area dip gently to the southwest. Coal seams are commonly draped over residual Nisku topography on the Paleozoic unconformity.

Petroleum well data indicate that within the Redwater field, the Medicine River coal zone occurs at depths of between 675 and 700 m. Before drilling, two main seams were identified in this zone: the upper seam, with a thickness of 2 to 3 m throughout the field, and the lower seam, 2.0 to 2.7 m thick, developed in the eastern part of the field. Both seams have thin overlying “riders”. Coal rank is high volatile bituminous B based on a reflectance of 0.46%, a low value for potential gas generation/retention.

Drilling results indicate that only one of the identified main seams and its “rider” was cored (Fig. 97). The well was

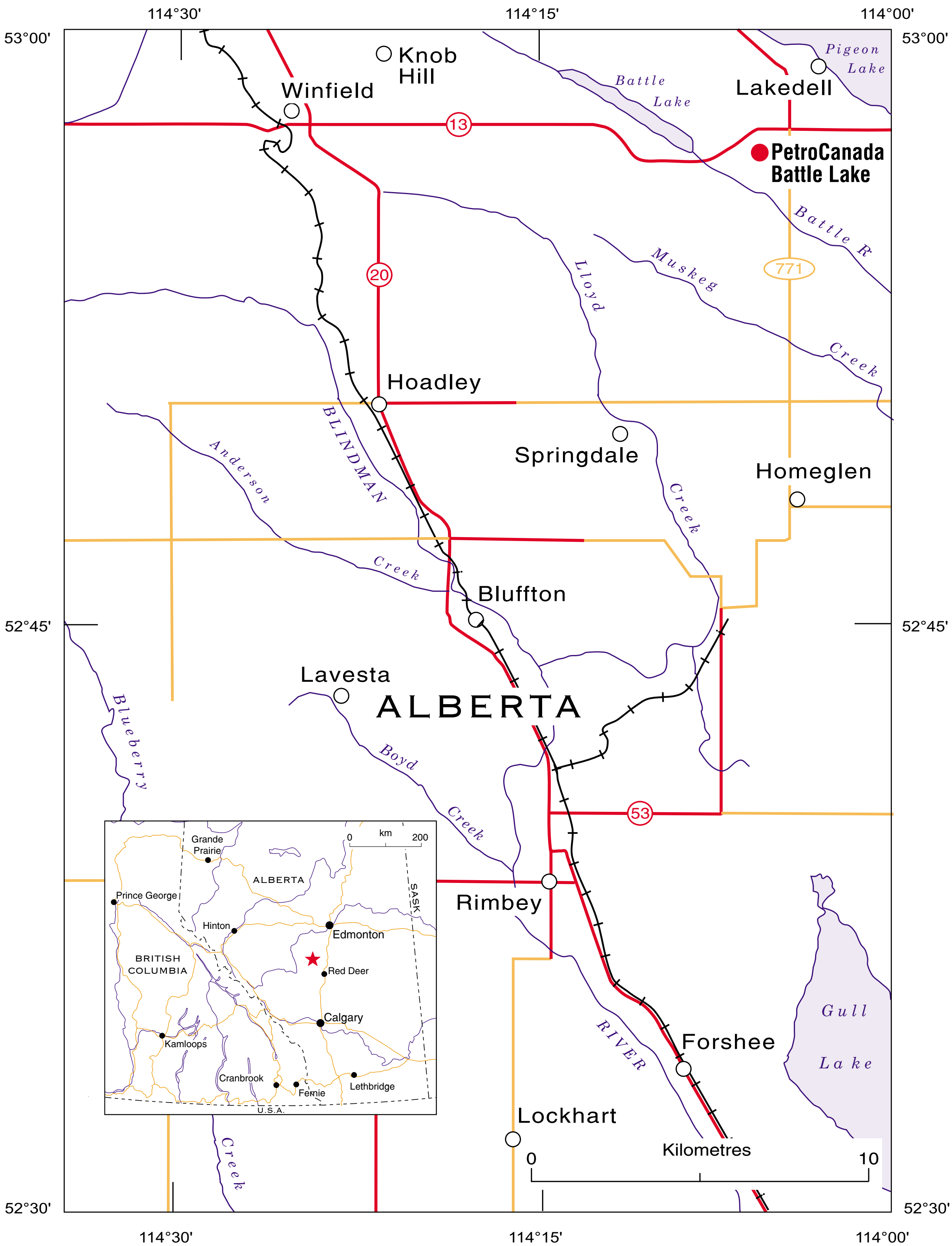


***Figure 95.*** *Location map of the Battle Lake exploration target area for PetroCanada Resources.*

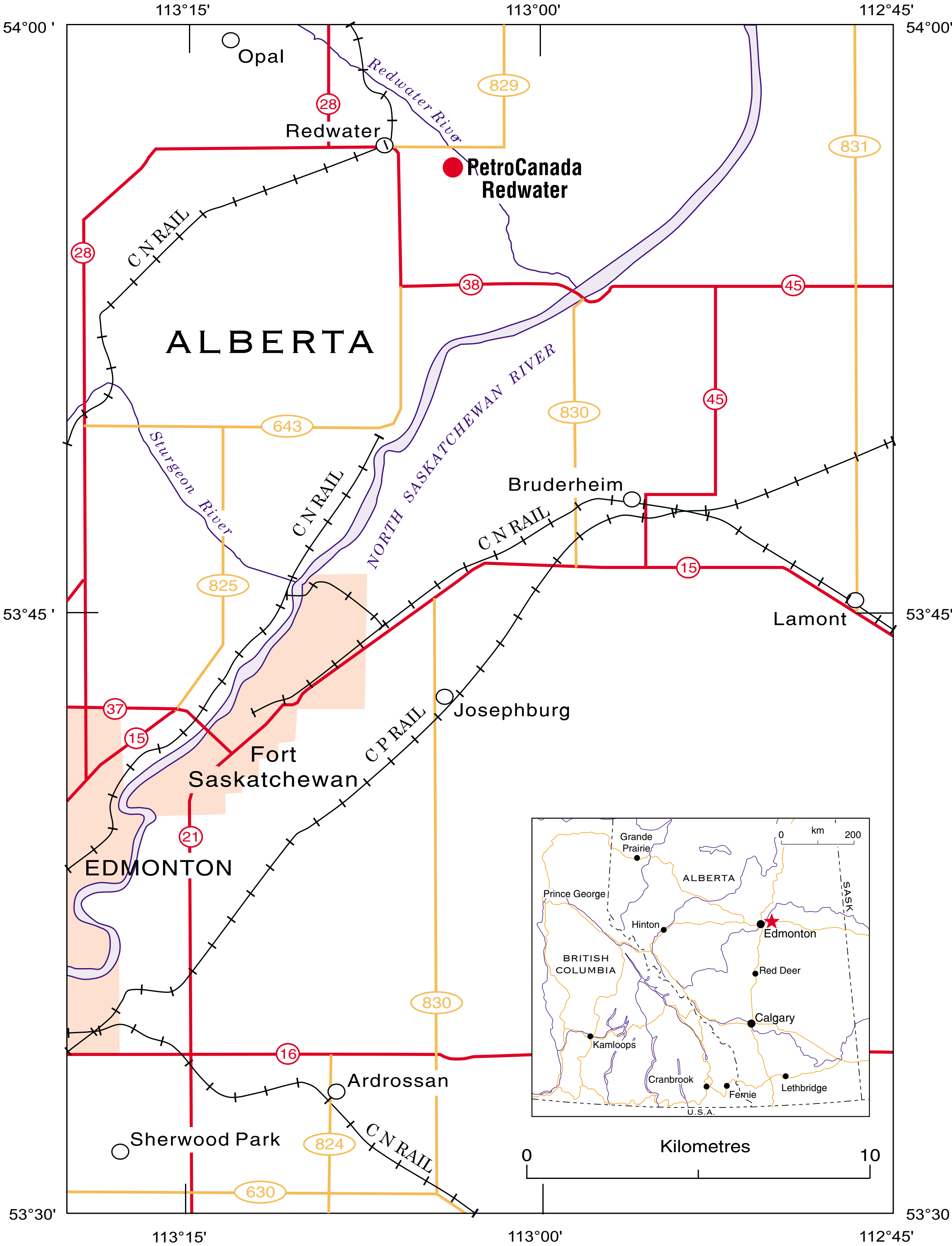


***Figure 96.*** *General location map of the PetroCanada Redwater (10-21-57-21W4M) coalbed methane exploration borehole.*

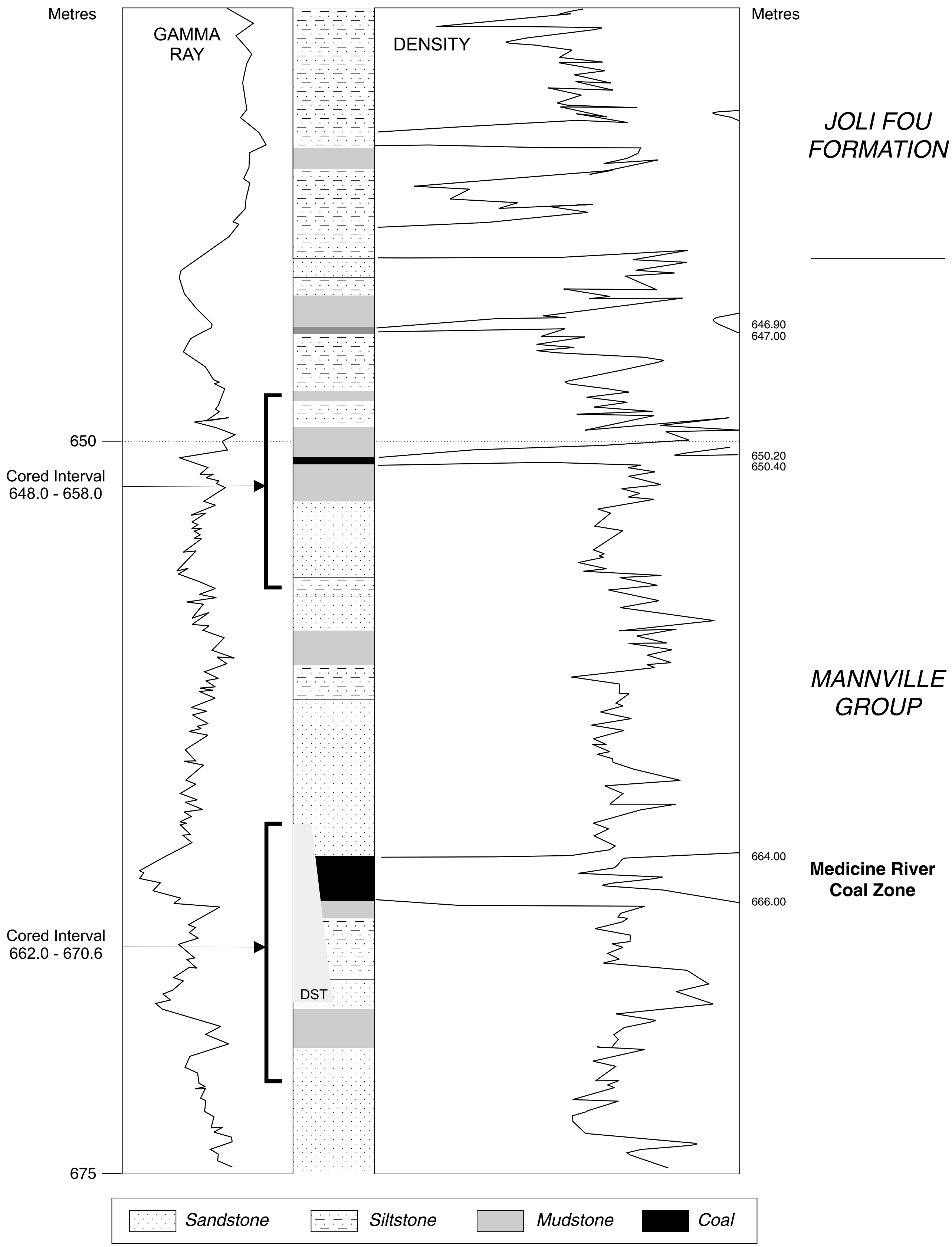


***Figure 97.*** *Detailed stratigraphic section of the Mannville coal measures intersected in the PetroCanada Redwater borehole.*

spudded in the central part of the Redwater field and it is not clear whether it was expected that both seams would be intersected. Core descriptions indicate the seams are exclusively coal, although this seems unlikely and it is possible that non-coal partings were not identified. Logs indicate that no other significant seams were intersected.

*Gas content.* Ten coal samples were desorbed and results are shown in Table 69. As-received gas content values ranged from 2.18 to 5.50 cc/g. Ash content was variable and the relationship between ash and gas is shown in Figure 98. There is a broad linear relationship between all samples except Canister 1, which appears to have an anomalously high gas content. Normalized (dry ash free) gas content values are consistent (4.21 to 4.75 cc/g), again except for Canister 1 (7.44 cc/g). Sample 1 was a small sample (0.06 m) and it was placed in the same sized canister as other samples (0.3 m). This might have led to erroneous corrections for air volume inside the canister, which would have resulted in anomalous gas content. Lost gas times were about 2 to 3 hours.

Theoretical considerations of "maximum producible methane" indicate values of about 7 cc/g for high volatile bituminous B coal at depths of 700 m.

*Coal quality*. The sampled coal is of relatively low rank and, consequently, low coalbed methane potential. Four vitrinite reflectance analyses averaged 0.45%, which indicates sub-bituminous B rank. Proximate analyses indicated higher rank (high volatile bituminous A). Ash contents ranged from 3.84 to 36.84% (Table 69).

**Table 69**
**Desorption data, PCI Redwater**

| Sample | Top (m) | Thickness (m) | Ash (%) | Total Gas a.r. (cc/g) | Total Gas d.a.f. (cc/g) |
|---|---|---|---|---|---|
| 2 | 652.15 | 0.25 | 3.84 | 3.67 | 4.61 |
| 1 | 652.40 | 0.06 | 13.77 | 5.50 | 7.44 |
| 10 | 665.35 | 0.30 | 20.10 | 2.84 | 4.34 |
| 9 | 665.65 | 0.20 | 4.63 | 3.26 | 4.21 |
| 8 | 665.85 | 0.20 | 4.32 | 3.71 | 4.76 |
| 7 | 666.05 | 0.15 | 5.13 | 4.03 | 5.15 |
| 6 | 666.20 | 0.20 | 36.84 | 2.18 | 4.23 |
| 5 | 666.40 | 0.25 | 4.99 | 3.70 | 4.69 |
| 4 | 666.65 | 0.20 | 13.37 | 3.04 | 4.28 |
| 3 | 666.85 | 0.25 | 23.67 | 2.96 | 4.75 |

Core descriptions indicated gross and net coal thickness to be the same (i.e., 0.35 and 1.53 m in two seams). Core photographs are unclear but it appears that in-seam partings were thin and rare.

*Adsorption isotherms*. An adsorption isotherm was determined at 22.2$^{o}$C on a 0.15 m coal sample from the main seam. Results indicate a theoretical gas capacity at seam depth and under hydrostatic pressure of 6.6 cc/g for 5% ash coal (Table 70). Desorption results for coal of similar ash content (canisters 5, 7, 8, 9; Table 69) indicate lower gas content (3.3 to 4.0 cc/g), suggesting an underpressured reservoir or depletion of gas from the seam.

*Formation testing*. A closed chamber drillstem test was conducted over the main seam in the depth interval 662 m to 667.5 m (Table 71). Total test time was five hours, with two shut-ins. Gas flow was negligible, with rates of 1 $m^3$/d recorded in both the first and second flow periods. Liquid inflow recorded as watery drilling mud was 5.1 $m^3$/d in the preflow and 3.8 $m^3$/d in the main flow.

The initial and final shut-in pressures are similar, indicating reasonable permeability, as the reservoir returned to original pressure within the final three-hour shut-in. Measured hydrostatic pressures indicate minor overpressuring.

Four plug samples were taken in sandstones above and below the main seam for porosity/permeability analyses. Porosities ranged between 14 and 25% and horizontal permeability between 0.5 and 50 mD.

*Technical assessment*. Although two coal seams have been identified in the Redwater field, only one with a thin rider seam was cored in PCI Redwater. The well appears to have been spudded in an area in which the second seam was not developed.

**Table 70**
**Adsorption isotherm data, PCI Redwater**

| Depth (m) | Langmuir pressure (kPa) | Langmuir volume (cc/g) | Theoretical gas capacity (cc/g) |
|---|---|---|---|
| 666.05-666.20 | 3320 | 10 | 6.6 |

**Table 71**
**Drillstem test data, PCI Redwater**

| DST no. | Depth (m) | First shut-in (kPa) | Second shut-in (kPa) | Gas flow rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|
| 1 | 662.0-667.5 | 5907 | 6010 | 1 | Watery drilling mud |

Adsorption isotherms indicate undersaturation of the coal. Core photographs show sandstone roof and floor to the main seam and testing shows relatively high porosity and permeability. It is possible that seam gas has leaked into the enclosing sandstone. It is also possible that many years of hydrocarbon production in the Redwater field has lead to gas depletion in the coal seams.

Drillstem tests reported little gas flow, although moderate permeability was indicated. Some permeability might have been impeded by the use of gel-chem as drilling fluid. The drillstem tests were carried out over too short a period to accurately assess the permeability of a coal reservoir.

Gas content was as expected from coal of this relatively low rank and was probably too low to support economic coalbed methane extraction.

## Amoco Canada Plains project

Amoco Canada drilled the Blackstone (16-11-44-16W5) and Brazeau River (10-28-45-14 W5) wells in the latter part of 1991. These were coalbed methane wells to test the coal of the upper Coalspur Formation of the Cretaceous–Tertiary Saunders Group in western Alberta (Fig. 99). In both wells, the major coal seams were cored, and 15 samples were desorbed, primarily in 1.5 m canisters. Gas contents (as-received) ranged from 1.7 to 2.9 cc/g in the Brazeau well and were higher (4.3 to >5.8 cc/g) in the Blackstone well, where the target coal was deeper and of slightly higher rank.

Abundant coal occurs in both wells. In Blackstone, the main split of the Val D'Or C, the Val D'Or D, and the Arbour coal zones appear most attractive, with net coal thicknesses of 2.05, 3.67 and 4.92 m, respectively, with minor proportions of interburden (Fig. 100; Table 72).

In the Brazeau well, coal thickness is significantly reduced in most zones (Fig. 101; Table 72). The most attractive target appears to be the Arbour zone, with a net coal thickness of 4.89 m in a 14.79 m section. The lower split contains 1.43 m net coal thickness in a 1.74 m section.

*Gas content.* Coal samples were selected from the core runs and were desorbed in large canisters (1.5 m) at 30$^{o}$C. Lost gas times were about 1.5 to 2 hours. Desorption data are summarized in Table 73. Desorption was apparently terminated prematurely in both wells as residual gas content was high as a proportion of total gas content.

Gas content values (as-received) in the Blackstone well ranged from 1.9 to 3.7 cc/g and when normalized, ranged from 4.3 > 5.8 cc/g (Table 73). These values are consistent with the low rank of the coal.

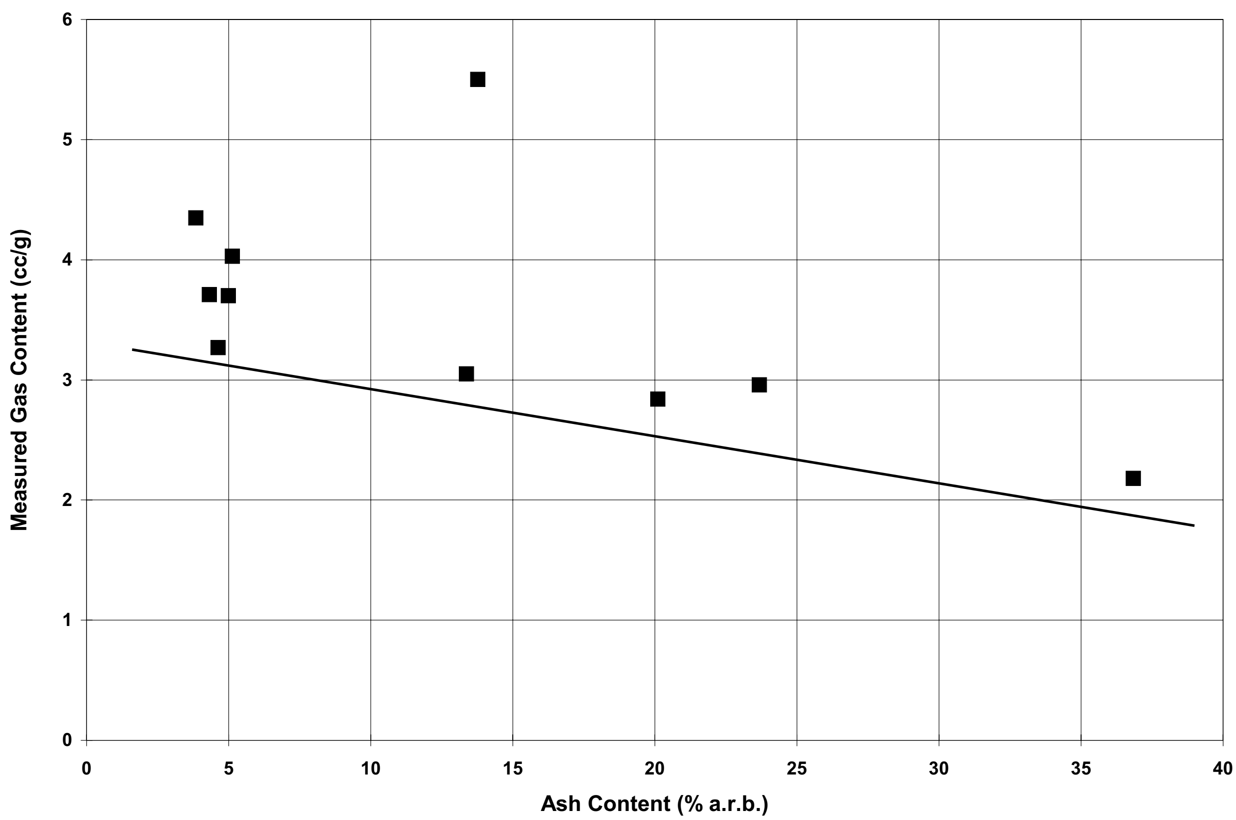


***Figure 98.*** *Measured gas content versus ash content for the Redwater desorption samples.*


***Figure 99.*** *General location map of the Amoco Blackstone (16-11-44-15W5M) and the Amoco Brazeau River (10-28-45-14W5M) exploration boreholes.*

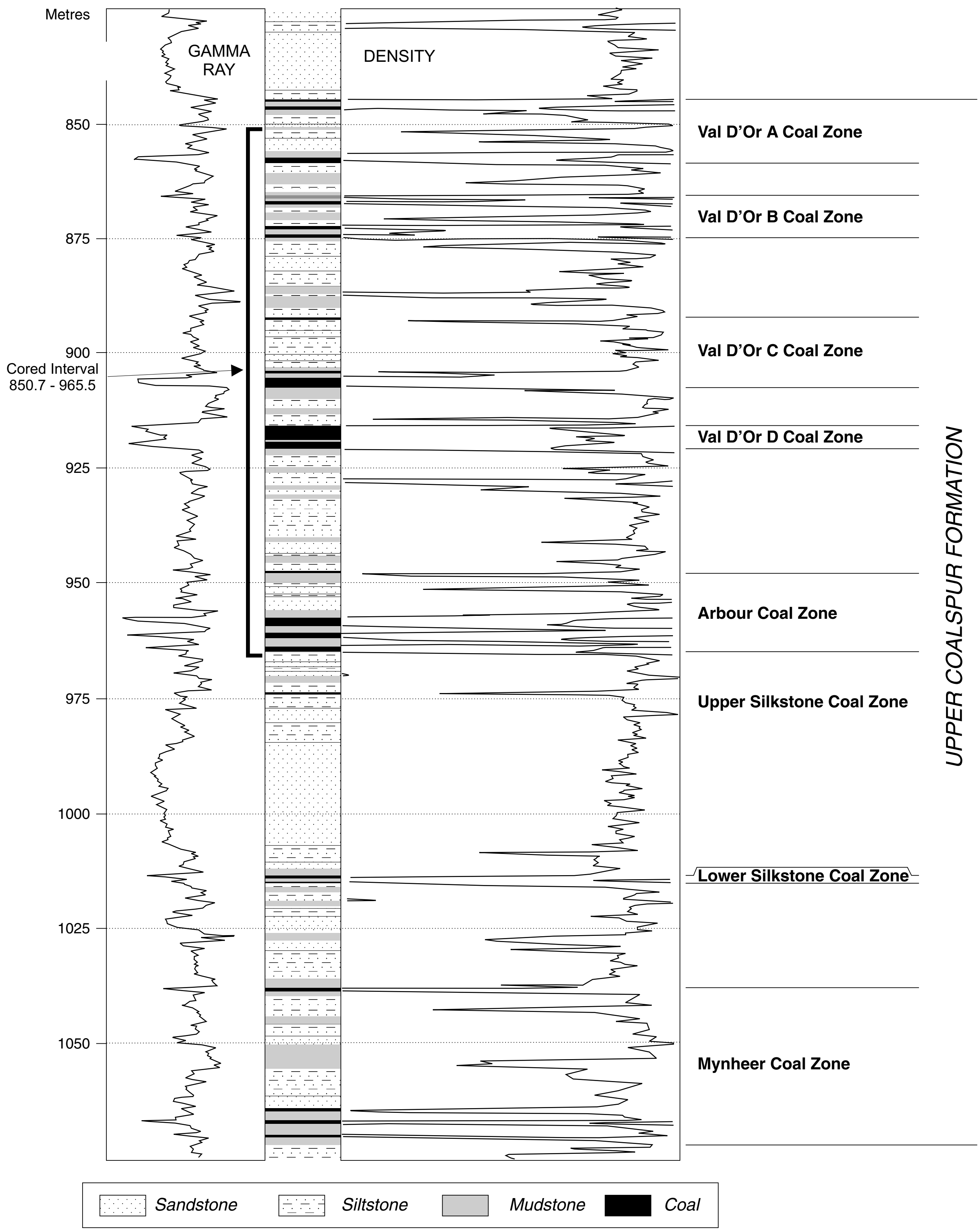


***Figure 100.*** *Detailed stratigraphic section of the Amoco Blackstone borehole.*

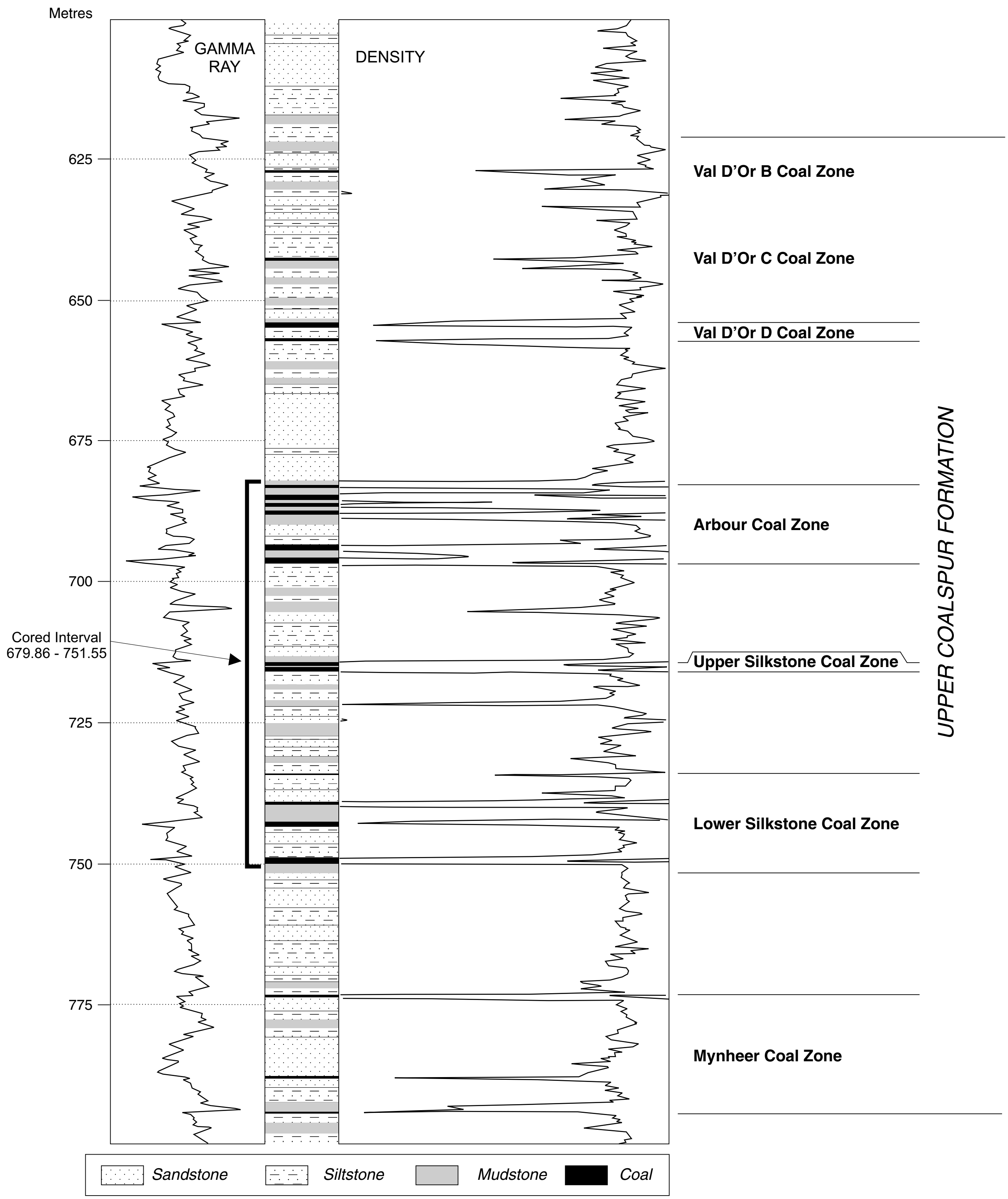


***Figure 101.*** *Detailed stratigraphic section of the Amoco Brazeau River exploration borehole.*

In the Brazeau well, coal was of slightly lower rank and intersected at shallower depths. Consequently gas content values are lower, ranging from 1.7 to 2.9 cc/g (as-received). Samples generally have moderate to high ash contents (19.5 to 35.5%) and normalized gas contents are higher, between 3.1 and 4.3 cc/g (Table 73).

Gas content values showed a general increase with depth on both as-received and normalized bases (Fig. 102). At this low rank, the rate of increase in gas content with depth was relatively low.

In the Blackstone well, 8 of 10 gas samples showed a range in methane content of 76 to 93%. The other two samples had very low methane content and anomalous nitrogen content. However, oxygen content in the canisters indicates no air contamination. Air contamination was common in gas samples from the Brazeau well, with only one of six samples having a valid methane content of 87%.

*Coal quality.* Vitrinite reflectance analyses ranged from 0.49 to 0.59% $R_o$ in the Brazeau well and were higher (0.60 to 0.64%) in the Blackstone well. All values indicated coal rank of high volatile bituminous C, which is below peak levels for potential gas generation and storage. Ash content was moderate to high (13 to 58%; Table 73). There was a broad inverse relationship between ash content and as-received gas content (Fig. 103).

**Table 72**
**Seam intersections, Amoco Blackstone and Brazeau River**

| Coal zone | Amoco Blackstone Interval (m) | Amoco Blackstone Thickness (m) | Amoco Blackstone Net coal (m*) | Amoco Brazeau Interval (m) | Amoco Brazeau Thickness (m) | Amoco Brazeau Net coal (m*) |
|---|---|---|---|---|---|---|
| Val D'Or A | 844.80 - 858.30 | 13.50 | 2.68† | | | |
| B | 865.60 - 874.80 | 9.20 | 2.50** | 626.80 - 627.10 | 0.30 | 0.30** |
| C | 892.80 - 907.31 | 14.51 | 2.74†† | 642.70 - 643.0 | 0.30 | 0.30** |
| D | 915.75 - 920.90 | 5.15 | 3.67†† | 654.20 - 657.30 | 2.10 | 1.00** |
| Arbour | 947.40 - 964.81 | 17.41 | 4.92† | 682.24 - 697.05 | 14.79 | 4.89†† |
| U. Silkstone | 973.00 - 973.40 | 0.40 | 0.40†† | 714.07 - 715.80 | 1.73 | 1.38†† |
| L. Silkstone | 1013.50-1015.20 | 1.70 | 0.80** | 733.90 - 749.77 | 15.87 | 2.36†† |
| Mynheer | 1038.20-1074.20 | 36.00 | 2.20** | 773.40 - 795.30 | 21.90 | 1.30** |

*Net coal interpreted from geophysical logs and detailed brightness log of core; **not cored; †cored in part; ††cored

**Table 73**
**Gas content, Amoco Blackstone and Brazeau River**

| Core no. | Interval (m) | Thickness (m) | Coal zone | Measured gas content (a.r.b.) (cc/g) | Ash (%) (d.b.) | Normalized gas content (a.f.) (cc/g) |
|---|---|---|---|---|---|---|
| **Blackstone** | | | | | | |
| 2 | 856.93 - 858.28 | 0.35 | Val D'Or A | 2.3 | 14.8 | 4.3 |
| 3 | 905.00 - 906.11 | 1.11 | Val D'Or C | 1.9 | 58.0 | 4.9 |
| 3 | 906.11 - 907.06 | 0.95 | Val D'Or C | 3.7 | 13.0 | 4.4 |
| 4 | 915.65 - 916.00 | 0.35 | Val D'Or D | >2.8 | 37.5 | > 4.5 |
| 4 | 916.00 - 917.40 | 1.40 | Val D'Or D | 2.7 | 22.9 | 4.8 |
| 5 | 917.43 - 918.63 | 1.20 | Val D'Or D | 2.0 | 54.1 | 5.8 |
| 5 | 918.63 - 920.01 | 1.38 | Val D'Or D | 2.7 | 31.5 | 4.3 |
| 6 | 957.09 - 957.77 | 0.68 | Arbour | >2.6 | 54.2 | >5.8 |
| 6 | 957.77 - 959.22 | 0.45 | Arbour | 3.2 | 21.5 | 4.7 |
| 7 | 960.77 - 962.20 | 1.43 | Arbour | 2.6 | 26.7 | 5.4 |
| **Brazeau** | | | | | | |
| 1 | 682.30 - 683.40 | 1.10 | Arbour | 2.3 | 19.5 | 3.6 |
| 2 | 684.45 - 686.81 | 1.56 * | Arbour | 1.7 | 35.5 | 3.1 |
| | 693.70 - 694.62/ | | | | | |
| 3 | 696.00 - 696.50 | 1.42 | Arbour | 2.8 | 31.4 | 4.3 |
| 4 | 714.45 - 715.35 | 1.20 | U. Silkstone | 2.7 | 28.5 | 4.1 |
| 6 | 742.50 - 743.30 | 0.80 | L. Silkstone | 2.9 | 19.8 | 4.0 |

*Sampled interval includes 0.8 m core loss.
Residual gas data are not available for samples in which gas contents are preceded by >.

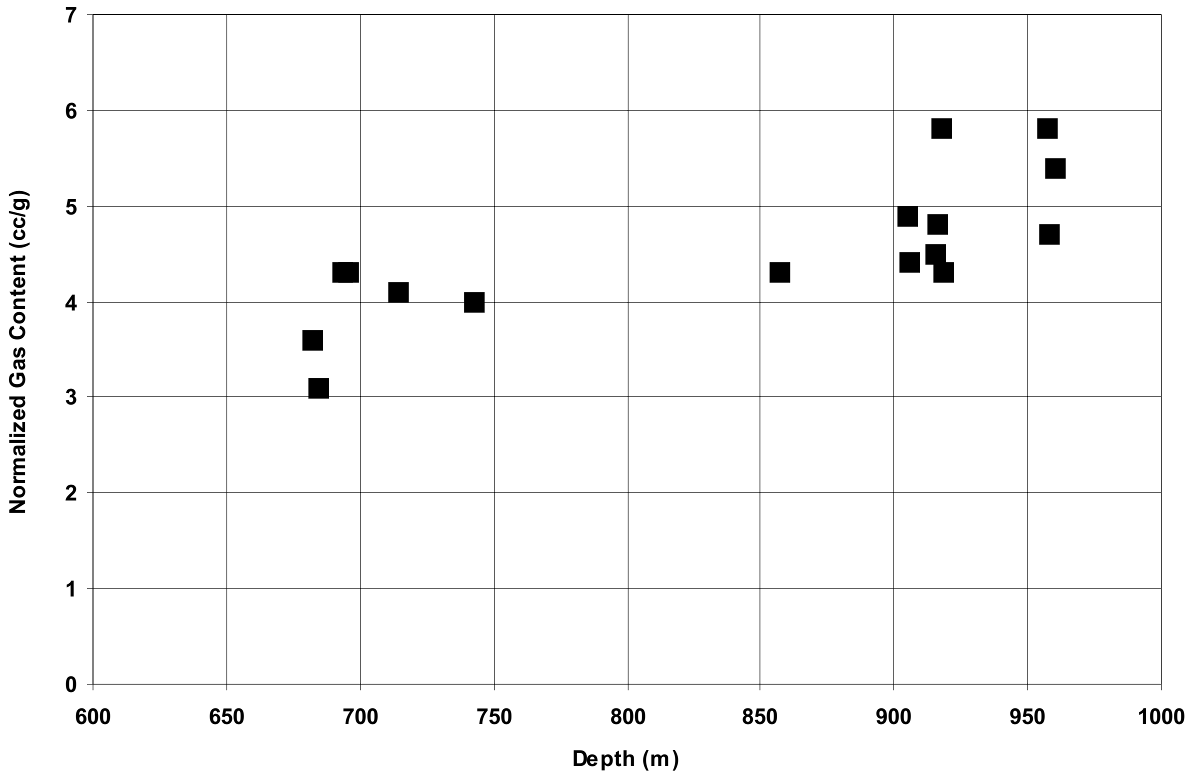


***Figure 102.*** *Normalized gas content versus depth of intersection, Amoco plains boreholes.*

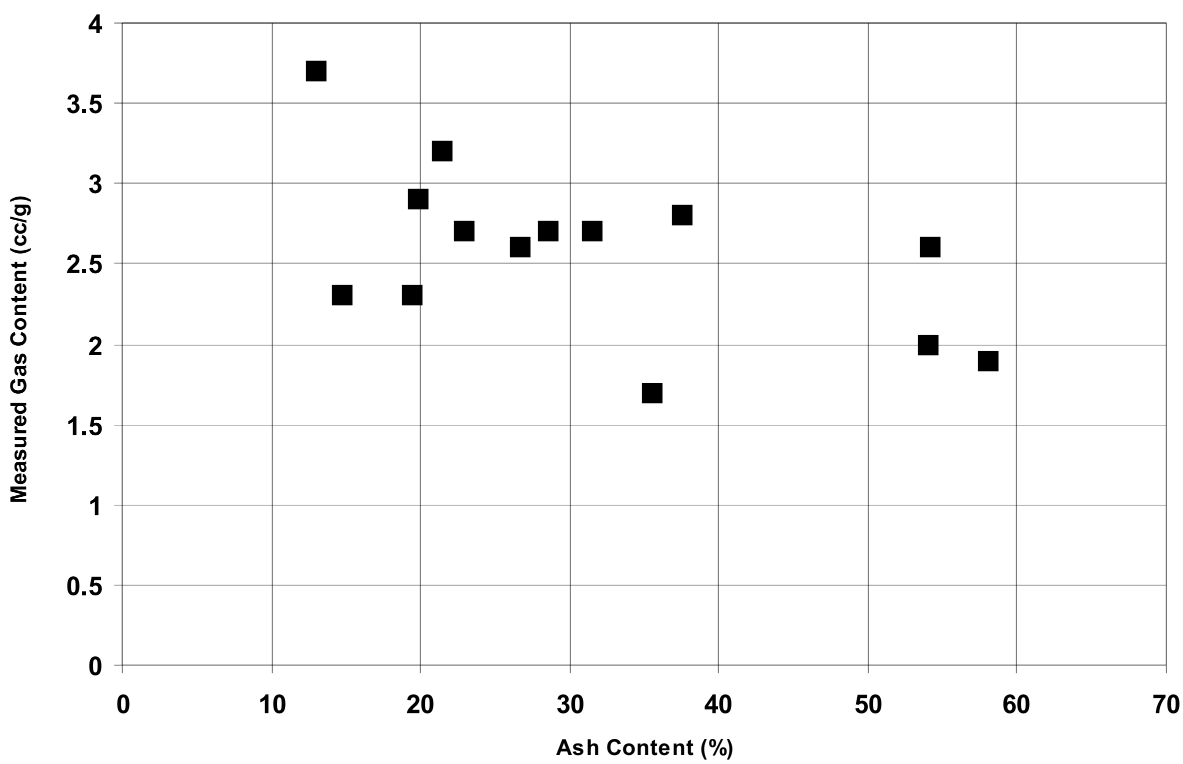


***Figure 103.*** *Measured gas content versus ash content, Amoco plains boreholes.*

*Adsorption isotherms.* No adsorption isotherms were completed.

*Formation testing.* No formation tests were performed on the test wells.

*Technical assessment.* Gas desorption was conducted by Core Laboratories staff who are experienced in coalbed methane testing. Lost gas times were relatively short and desorption temperature approximated reservoir temperature. Desorption was probably terminated prematurely as residual gas constitutes a generally high proportion of total gas. However, it is unlikely that longer desorption times would have resulted in any significant increase in gas content.

Coal rank was relatively low (high volatile bituminous C) and gas content was accordingly low. Even with successful reservoir stimulation, it is unlikely that this coal would offer economic coalbed methane potential.

## Norcen Plains project

Norcen Energy Resources undertook a regional coalbed methane exploration program to assess the potential of the Mannville and Scollard coals in north-central Alberta during 1990. Locations of the boreholes are illustrated in Figures 104 to 111. Most of the boreholes were drilled for conventional oil or gas targets, and the coalbed methane research was part of a “piggyback” project. As data are limited for each well, the boreholes have been combined into one section in this report.

*Data acquisition.* The boreholes were part of Norcen’s ongoing conventional oil and gas exploration program. No specific drilling methods were applied and most of the samples were in the form of drill cuttings with an occasional core cut through the Medicine River coal zone. Samples were desorbed at reservoir temperatures and proximate analyses completed. Other tests included gas analyses and vitrinite reflectance for rank determination.

*Geology.* Scollard Formation coal lies at depths of between 400 and 600 m, and are referred to as the Ardley coal zone. Individual seams are laterally contiguous, but vary in thickness. The base of the coal measures is marked by the Cretaceous–Tertiary boundary. The Scollard Formation coal was intersected in all boreholes, but samples were taken from only two. Table 74 gives a summary of coal intersections.

Detailed stratigraphic sections are presented in Figures 112 and 113. The Scollard coal is equivalent to the Coalspur coal, drilled by BHP in the Pine Creek and Pembina regions.

The Mannville Group coal encompasses a series of laterally contiguous coal seams that vary in thickness over an average stratigraphic interval of 90 m. Up to six zones are present. the thickness of each zone is highly variable and, unlike the Medicine River zone to the south, no particular coal horizon is dominant. For the purpose of this compilation of individual tests of Norcen wells, no correlation has been attempted. Table 75 summarizes the main coal intersections

**Table 74**
**Scollard coal intersections, Norcen Plains project**

| Borehole location | Depth to top of coal measures (m) | Depth to base of coal measures (m) | No. of seams | Thickest coal zone (m) | Net coal thickness (m) |
|---|---|---|---|---|---|
| 3-29-47-6-W5M | 321.2 | 389.0 | 6 | 4.5 | 13.5 |
| 9-23-57-25-W5M | 454.8 | 522.0 | 10 | 3.1 | 16.5 |

**Table 75**
**Coal intersections, Medicine River zones**

| Borehole | Top of coal measures (m) | Base of coal measures (m) | No. of seams | Net coal thickness (m) | Top of thickest zone (m) | Base of thickest zone (m) | Net coal thickness thickest zone (m) |
|---|---|---|---|---|---|---|---|
| 16-24-60-20-W5M | 1951.1 | 2044.5 | 8 | 11 | 1986.0 | 1991.5 | 4.5 |
| 9-23-57-25-W5M | 2856.0 | 2916.8 | 4 | 8.9 | 2887.1 | 2890.9 | 3.8 |
| 2-14-58-21-W5M | 2255.2 | 2301.8 | 4 | 7.0 | 2255.2 | 2258.3 | 3.1 |
| 9-22-58-24-W5M | 2580.3 | 2664.0 | 5 | 8.9 | 2661.0 | 2664.0 | 3.0 |
| 15-21-60-19-W5M | 1985.1 | 2082.0 | 7 | 8.2 | 2043.1 | 2047.0 | 2.9 |
| 16-15-57-02-W5M | 996.6 | 1036.1 | 5 | 5.3 | 1004.0 | 1006.0 | 2.0 |
| 12-17-52-06-W5M | 1557.0 | 1616.0 | 5 | 13.0 | 1571.0 | 1576.5 | 4.5 |
| 3-36-46-2-W5M | 1571.1 | 1673.6 | 5 | 8.5 | 1650.1 | 1653.8 | 3.7 |
| 9-34-61-26-W5M | 2422.0 | 2532.0 | 10 | 16.0 | 2469.0 | 2475.0 | 5.1 |


***Figure 104.*** *General location map of the Norcen Colt (09-22-58-24W5M) borehole.*


***Figure 105.*** *General location map of the Norcen Plains exploration boreholes: Kaybob S, 15-21-60-19W5M; Kaybob S, 16-24-60-20W5M; Por Fir, 02-14-58-21W5M.*

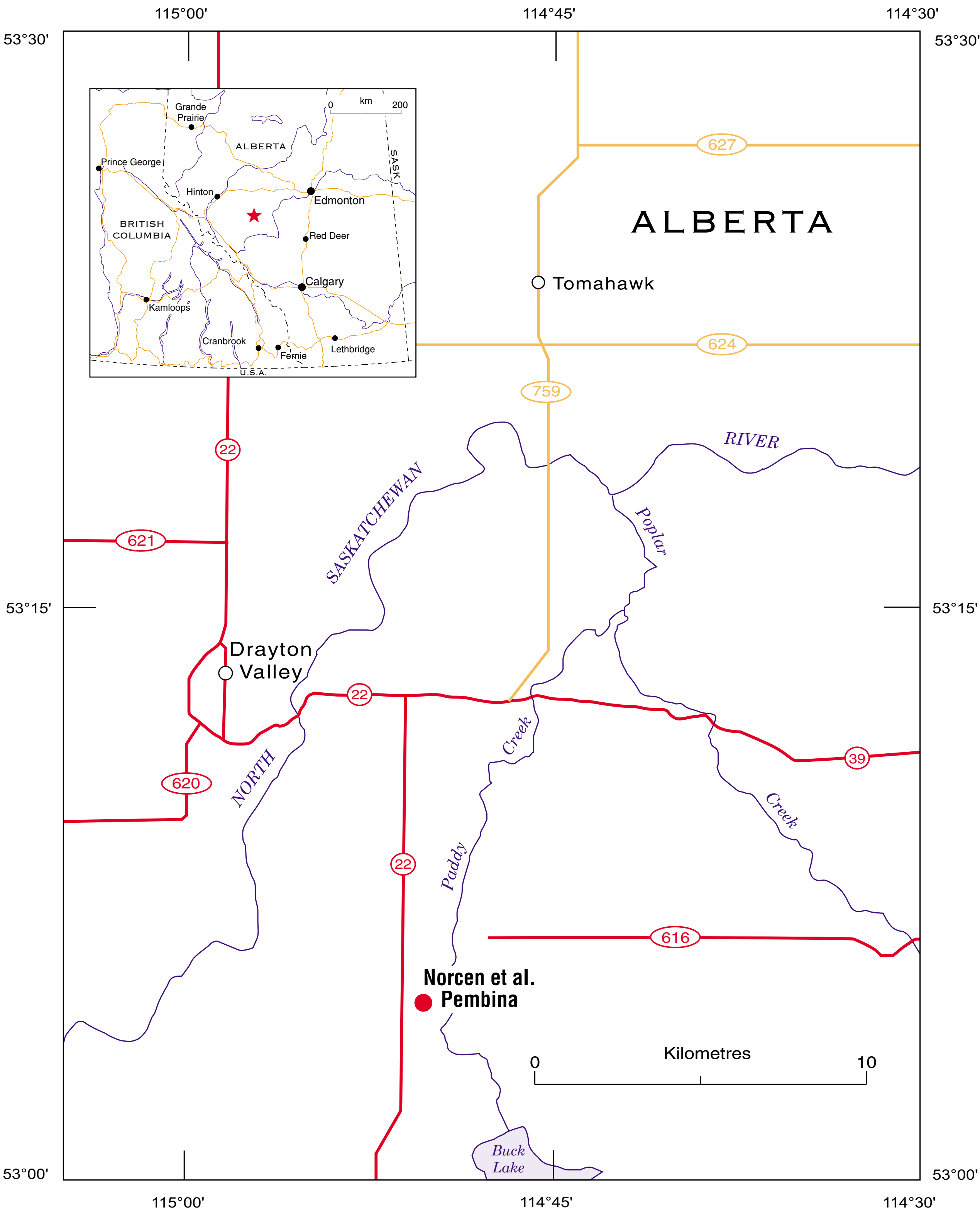


***Figure 106.*** *General location map of the Norcen Pembina (03-29-47-06W5M) borehole.*

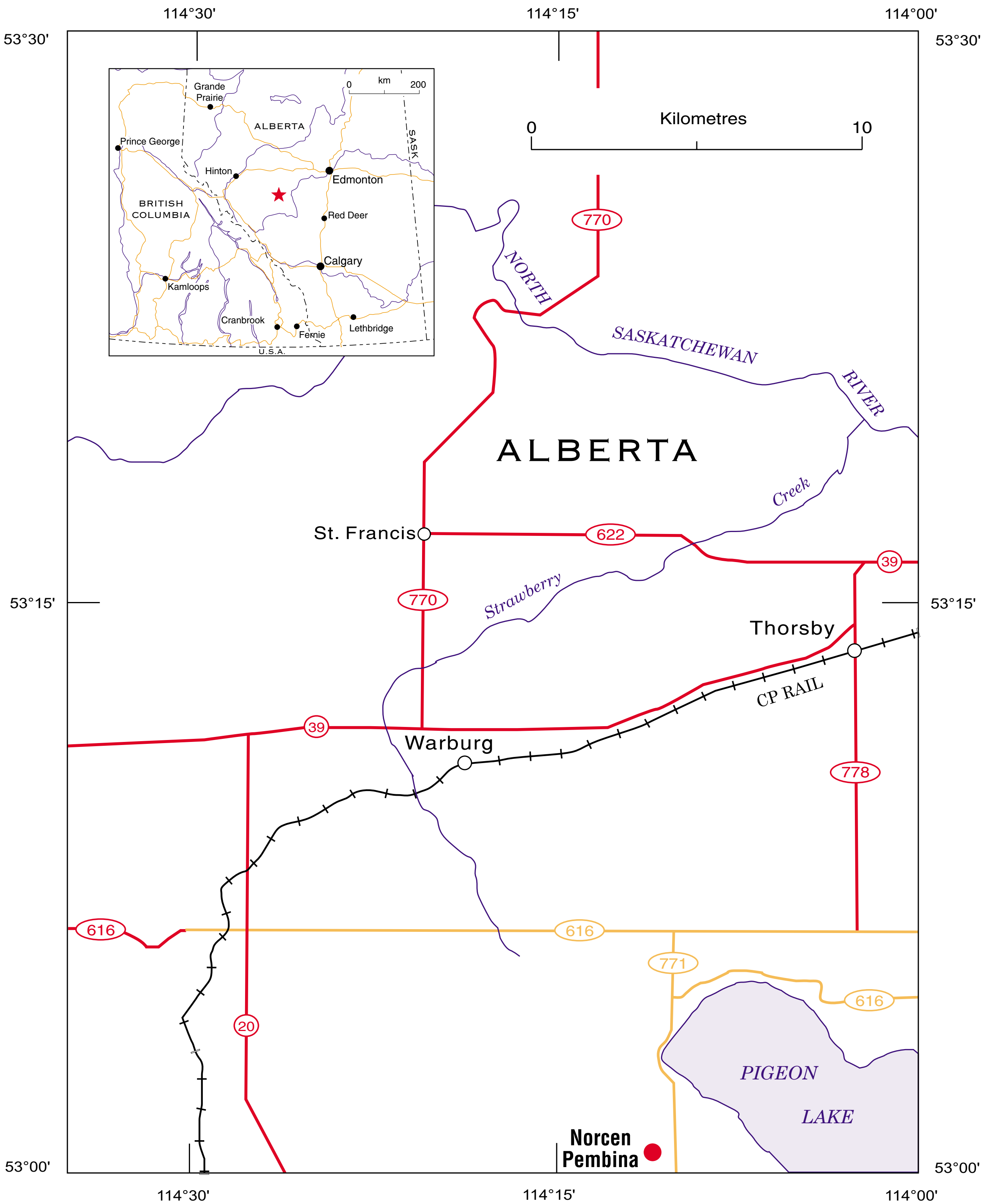


***Figure 107.*** *General location map of the Norcen Pembina (03-36-46-02W5M) borehole.*

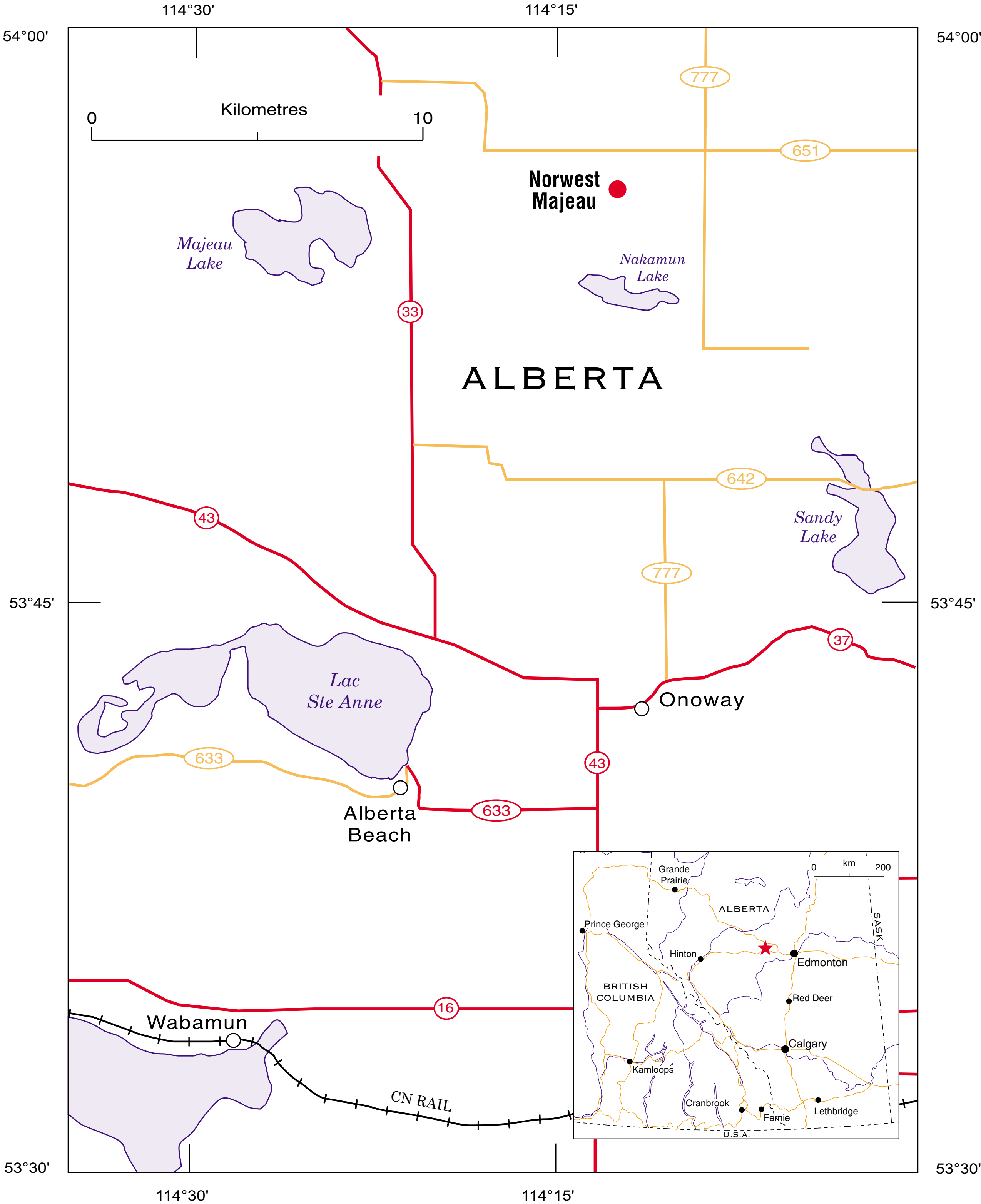


***Figure 108.*** *General location map of the Norwest Majeau (16-15-57-06W5M) borehole.*

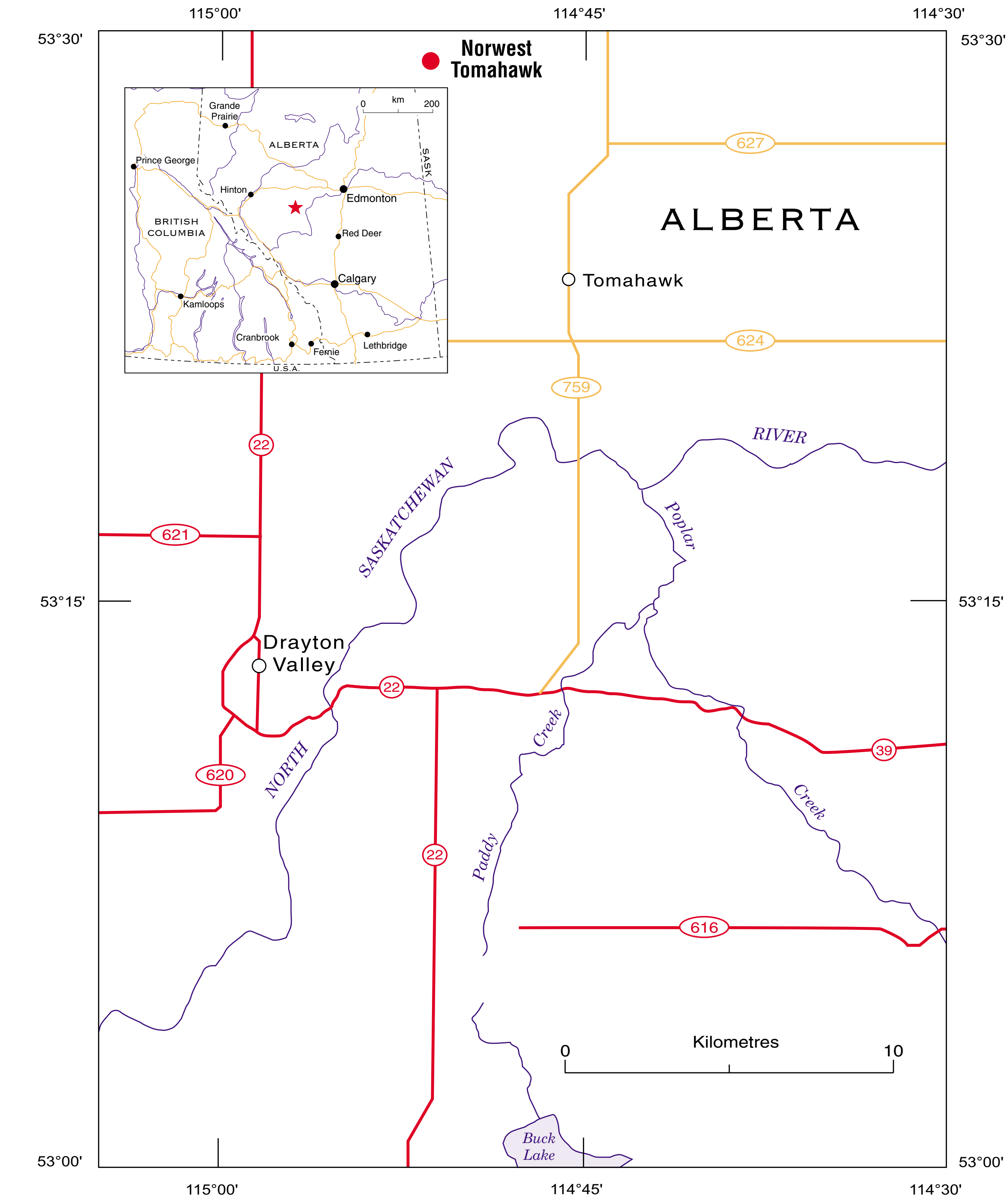


***Figure 109.*** *General location map of the Norwest Tomahawk (12-17-52-06W5M) borehole.*

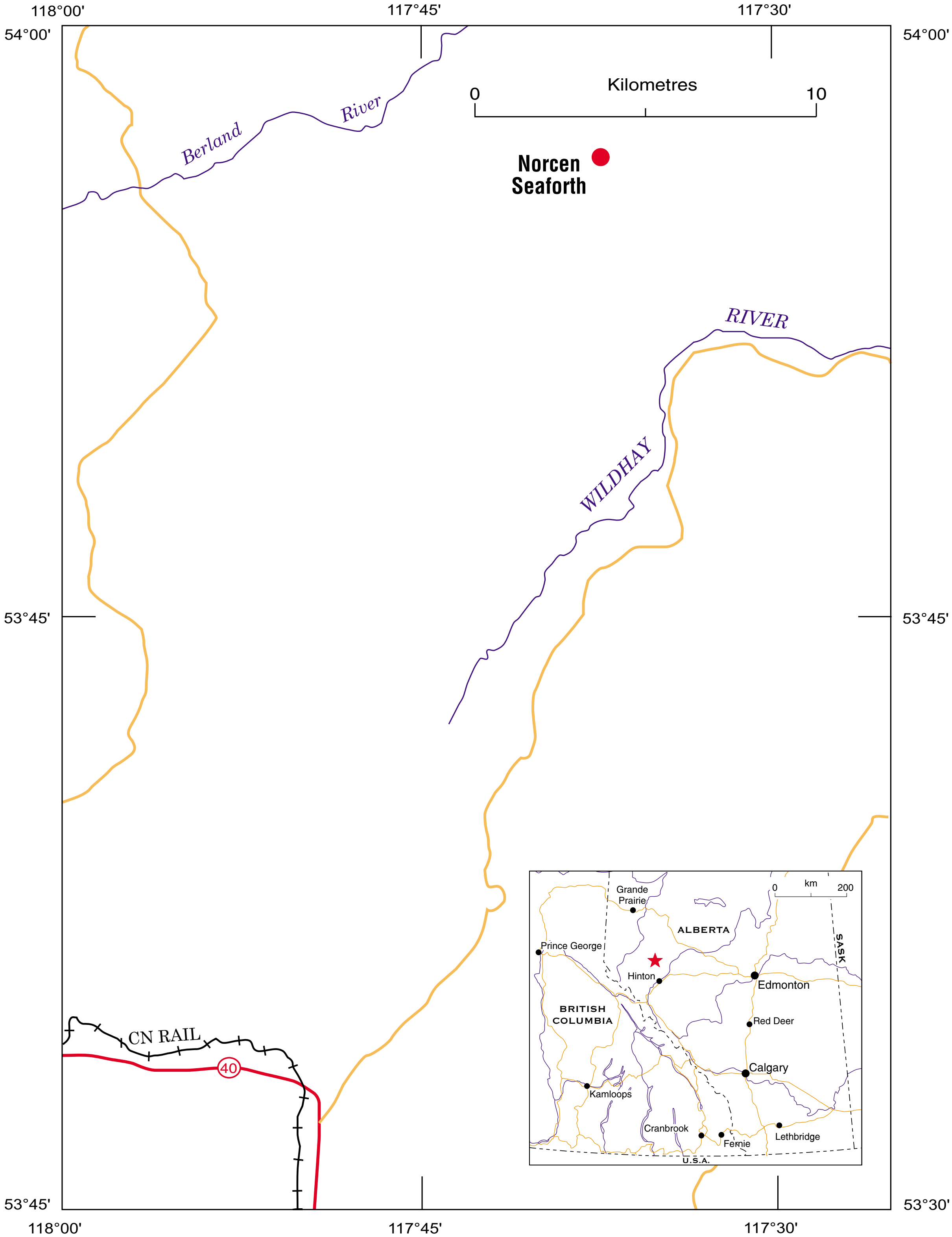


***Figure 110.*** *General location map of the Norcen Seaforth (09-23-57-25W5M) borehole.*


***Figure 111.*** *General location map of the Norcen Simonette (09-34-61-26W5M) borehole.*

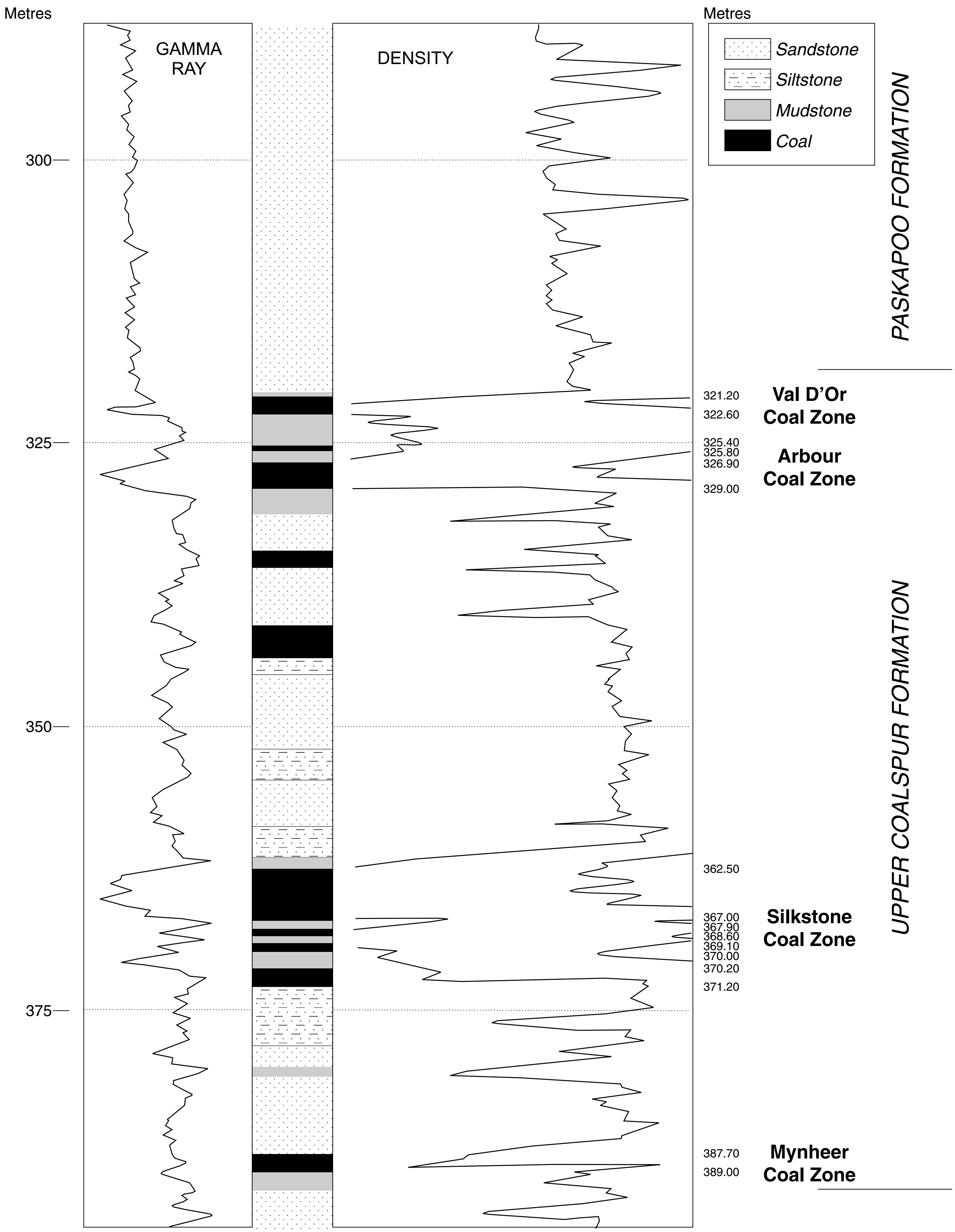


***Figure 112.*** *Detailed stratigraphic section of the Norcen Pembina 3-29 borehole.*

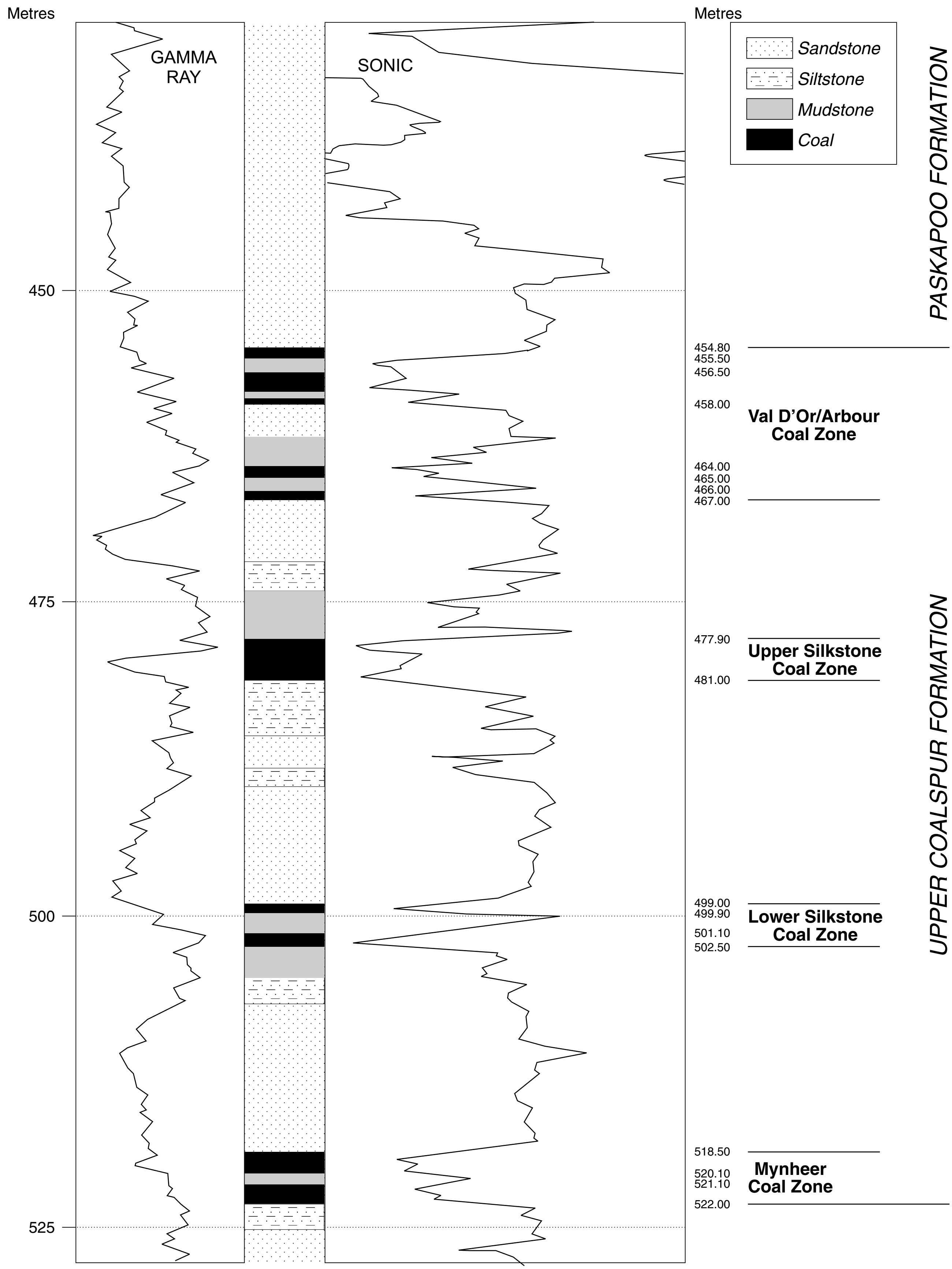


***Figure 113.*** *Detailed stratigraphic section of the Coalspur Formation, Norcen Seaforth borehole.*

in each well. Figures 114 to 122 present the detailed stratigraphy within the Mannville Group for each well.

*Gas content*. Canister tests for the Scollard Formation coal were derived from cuttings. In wellbore 9-23, two samples were collected, from 330 and 372 m. Gas content values were 4.7 and 1.1 cc/g, respectively. Ash content was 20 and 47%. The gas content of 4.7 cc/g is thought to be representative of the Scollard Formation coal and is similar to values obtained from the BHP exploration program.

In wellbore 9-23, one sample from the Val D'Or seam at 455 m was collected. Gas content was low (0.9 cc/g) but no lost gas measurement was made.

Gas content data for the Mannville coal samples were widely variable as a result of the sample type (core versus cuttings), depth of sample, coal rank, and ash content (Table 76). A plot of measured gas content versus ash illustrates a general trend of decreasing gas content with increasing ash (Fig. 123).

A plot of normalized gas content versus rank (Fig. 124) for samples of similar type does not display an obvious trend, but this might be the result of the lack of data points. Although there are only two core samples, they appear to have a higher gas content than cuttings samples for coal of similar rank, probably reflecting the inaccuracies of the lost gas calculations. As coal rank depends on depth, one can conclude that as Mannville coal deepens to the west, in situ gas content will increase for coal of similar rank and quality.

*Coal quality*. For most of the samples collected from the Norcen Plains drilling project, proximate analyses and rank determination were performed. As would be expected, the quality results were widely variable, particularly from the cuttings samples. In general, cuttings samples had significantly higher ash content than core intervals. Rank determinations and volatile matter content indicated that Mannville Group coal ranged from high volatile sub-bituminous C to medium volatile bituminous in rank. Some of the coal samples with high gas content and low reflectance values could reflect the vitrinite suppression that is common in the Mannville Group coal. Coal quality data are summarized in Table 77.

**Table 76**
**Desorption data, Mannville coal, Norcen Plains**

| Borehole location | Depth of sample(m) | Reflectance $Ro_{max}$ (%) | Sample type | Average measured gas content (cc/g) | Average ash content (%) (a.d.b.) | Average normalized ash content (cc/g) |
|---|---|---|---|---|---|---|
| 16-24-60-20-W5M | 2040.5 | 0.89 | Cuttings | 1.5* | 69.9 | 5.0 |
| 9-23-57-25-W5M | 2886.0 | 1.18 | Cuttings | n.m. | 39.5 | n.m. |
| 2-14-58-21-W5M | 2257.0 | 1.25 | Cuttings | 15.6 | 19.4 | 19.4 |
| 9-22-58-24-W5M | 2662.6 | 1.16 | Cuttings | 3.0 | 29.7 | 4.3 |
| 15-21-60-19-W5M | 2040.0 | 0.74 | Cuttings | 4.5 | 42.7 | 7.9 |
| 16-15-57-02-W5M | 1036 | 0.51 | Cuttings | 1.4 | 45.5 | 2.6 |
| 12-17-52-06-W5M | 1607.7 | 0.62 | Core | 10.2 | 14.6 | 11.89 |
| 3-36-46-2-W5M | 1650.8 | 0.66 | Core | 7.8 | 24.7 | 10.56 |
| 9-34-61-26-W5M | 2472.0 | 0.75 | Cuttings | 3.8 | 52.7 | 8.0 |

*Gas content values for sample does not include lost gas component. Assuming a lost gas contribution of 30% from cuttings, measured gas content was estimated to be about 2.5 cc/g.

**Table 77**
**Proximate analyses, Mannville coal, Norcen Plains**

| Borehole location | Depth (m) | Moisture (%) (a.d.b.) | Ash (%) (a.d.b.) | Volatile matter (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Sulphur (%) (a.d.b.) | Reflectance $Ro_{max}$ (%) |
|---|---|---|---|---|---|---|---|
| 16-24-60-20-W5M | 2040.5 | 1.1 | 69.9 | 14.6 | 14.4 | 0.58 | 0.89 |
| 9-23-57-25-W5M | 2886.0 | 0.7 | 39.7 | 16.1 | 56.5 | 0.55 | 1.18 |
| 2-14-58-21-W5M | 2257.0 | 18.3 | 19.4 | 19.4 | 42.9 | | 1.25 |
| 9-22-58-24-W5M | 2662.6 | 0.8 | 29.7 | 20.3 | 48.7 | | 1.16 |
| 15-21-60-19-W5M | 2040.0 | 1.5 | 42.7 | 20.4 | 35.2 | 0.7 | 0.74 |
| 16-15-57-06-W5M | 1036 | 4.3 | 45.5 | 21.6 | 28.4 | 0.7 | 0.51 |
| 12-17-52-06-W5M | 1607.7 | 4.8 | 14.6 | 33.8 | 46.8 | 1.0 | 0.62 |
| 3-36-46-2-W5M | 1650.8 | 3.1 | 24.7 | 30.2 | 58.0 | 1.0 | 0.66 |
| 9-34-61-26-W5M | 2472.0 | 1.3 | 52.7 | 17.3 | 28.5 | 0.65 | 0.75 |

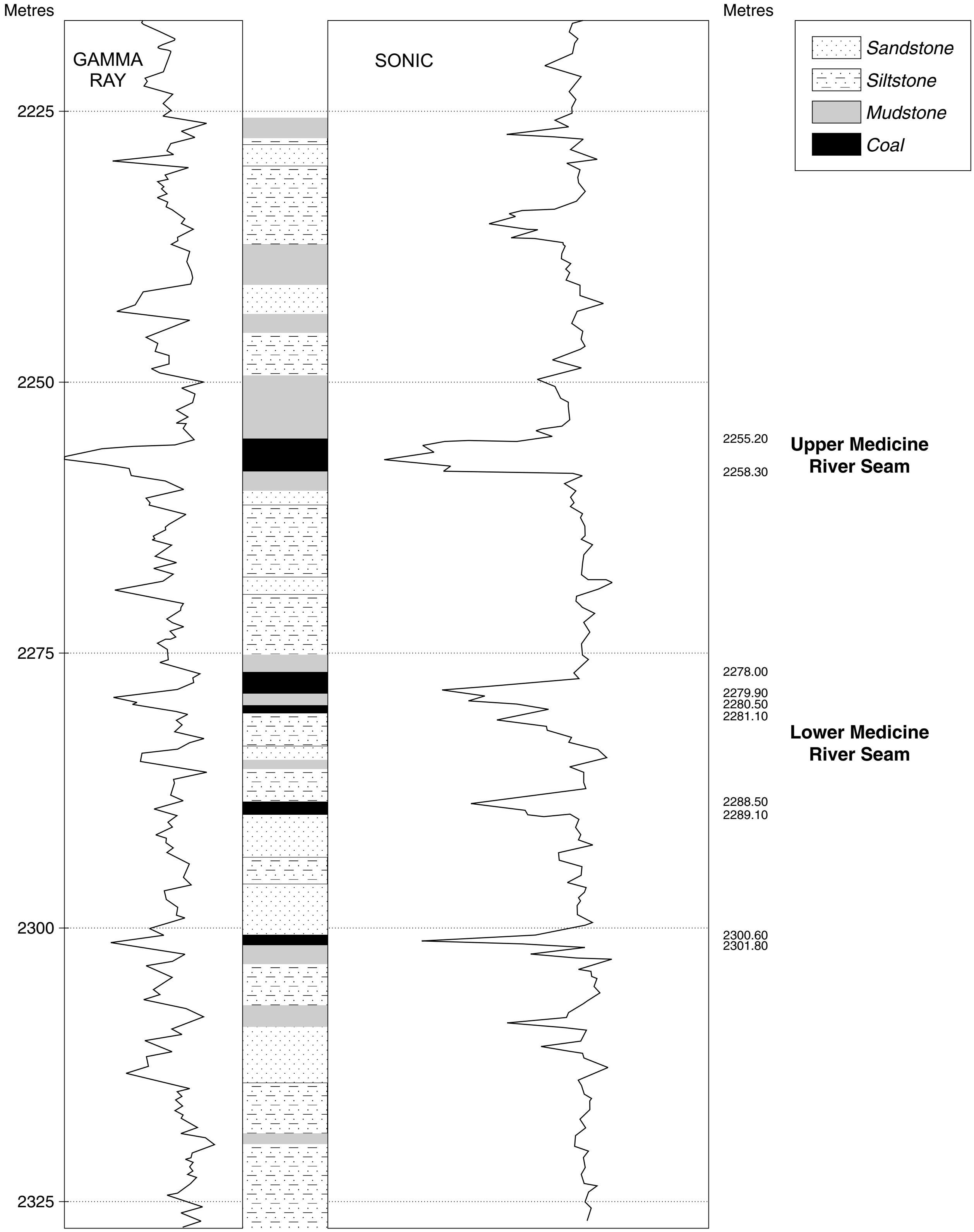


***Figure 114.*** *Detailed stratigraphic section of the Norcen Por Fir borehole.*

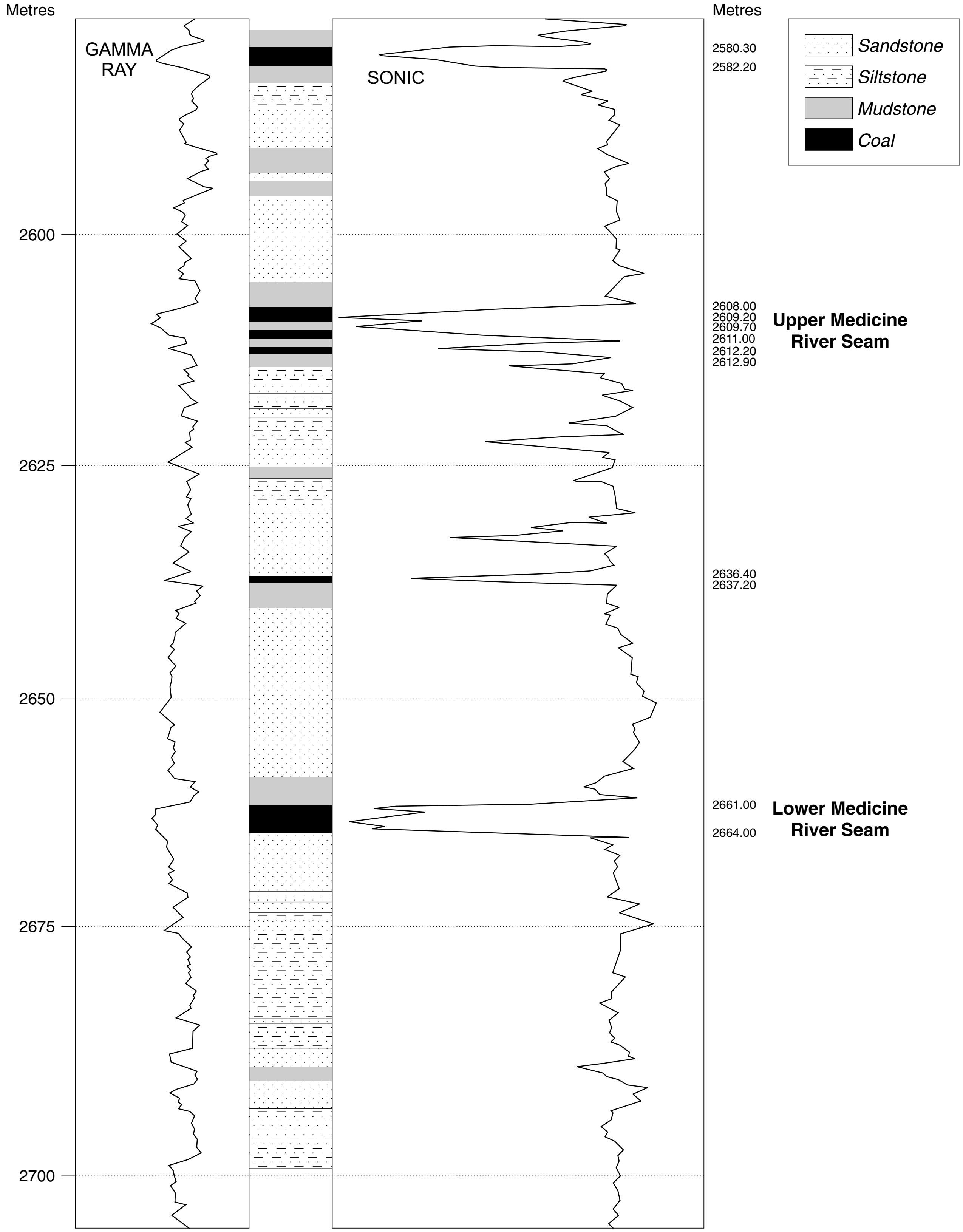


***Figure 115.*** *Detailed stratigraphic section of the Norcen Colt borehole.*

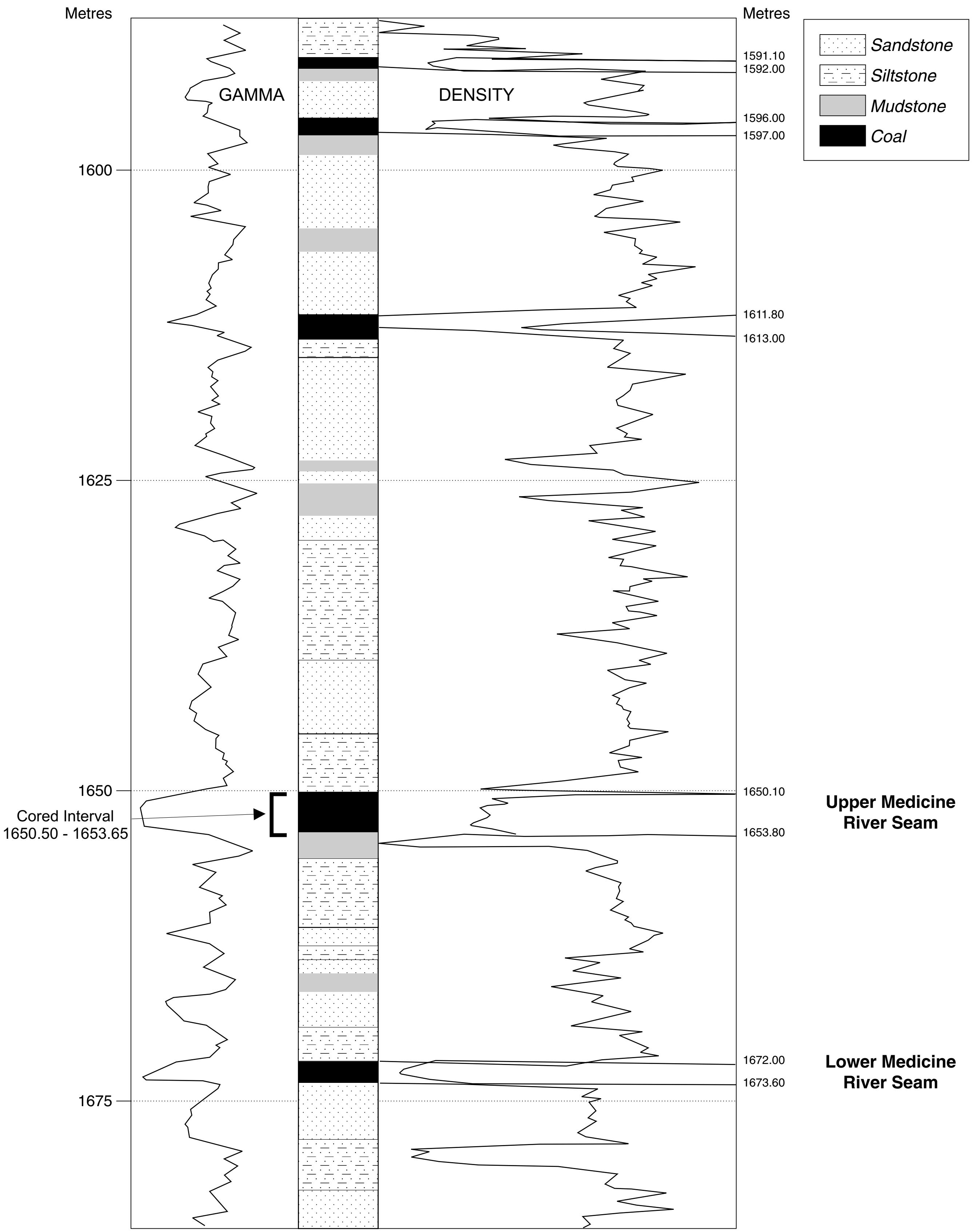


***Figure 116.*** *Detailed stratigraphic section of the Norcen Pembina 3-36 borehole.*

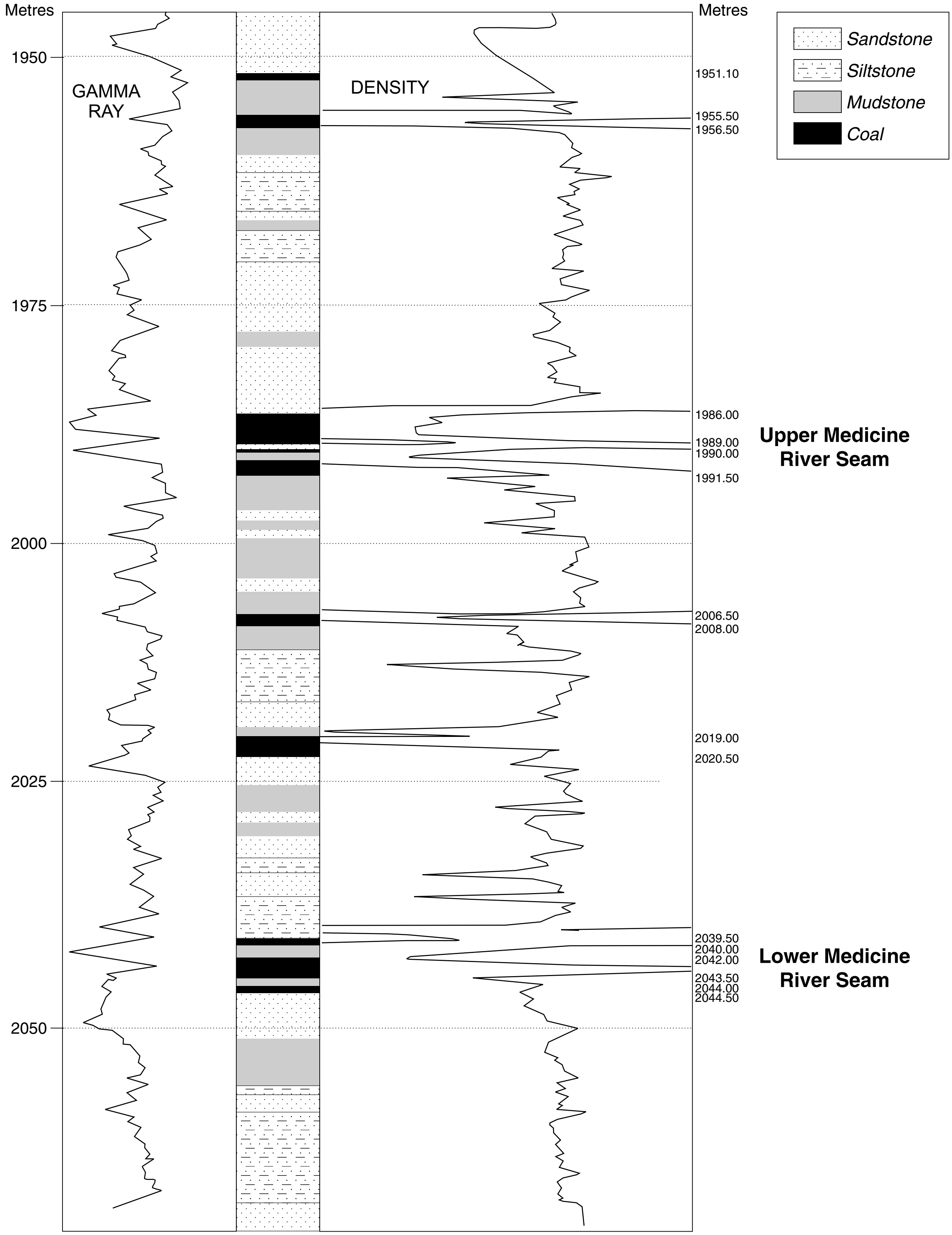


***Figure 117.*** *Detailed stratigraphic section of the Norcen Kaybob South 16-24 borehole.*

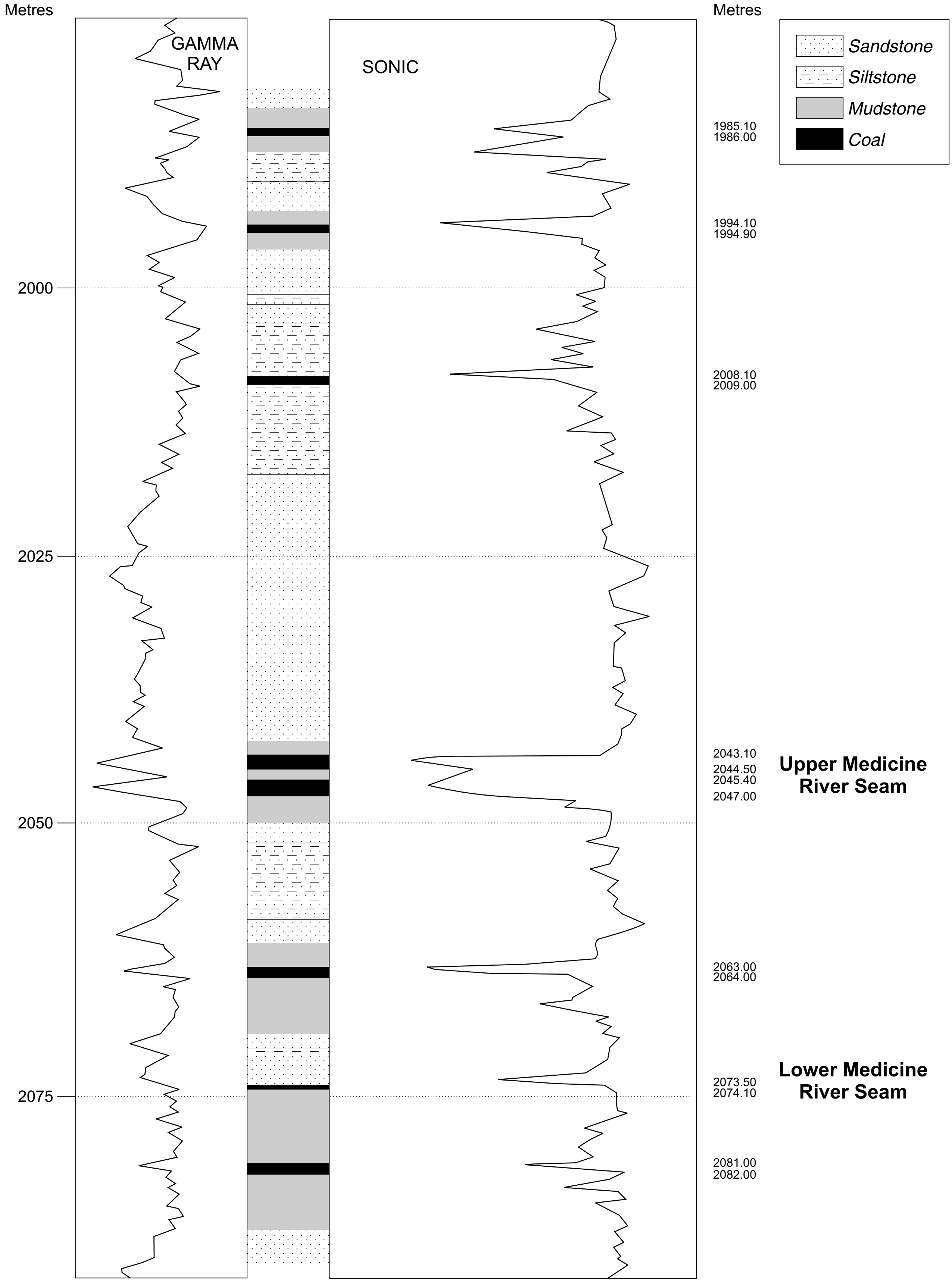


***Figure 118.*** *Detailed stratigraphic section of the Norcen Kaybob South 15-21 borehole.*

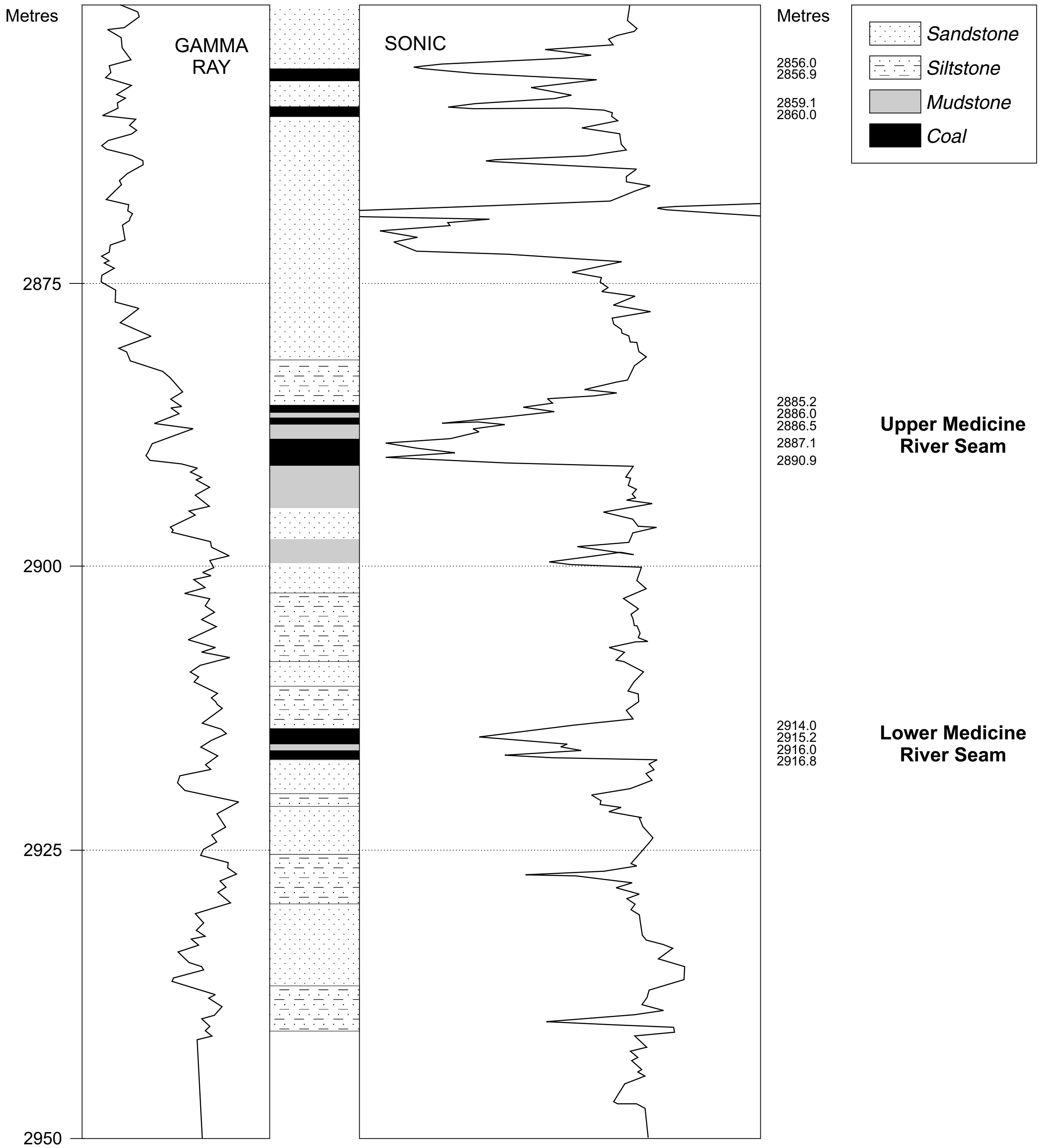


***Figure 119.*** *Detailed stratigraphic section of the lower Norcen Seaforth borehole.*

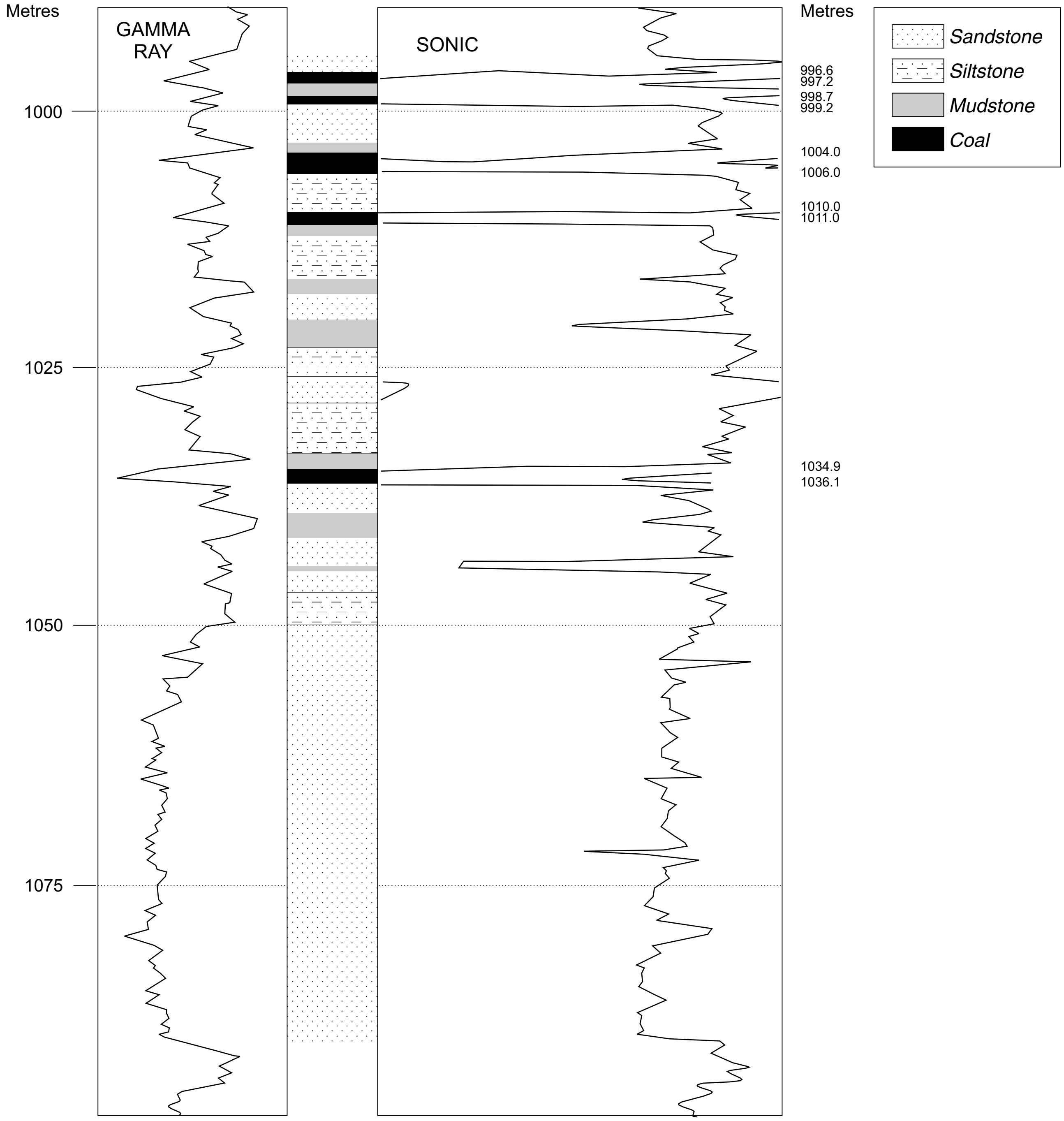


***Figure 120.*** *Detailed stratigraphic section of the Norwest Majeau borehole.*

*Adsorption isotherms.* Two adsorption isotherms were completed for the series of Norcen test samples. A comparison of measured gas content to gas capacity indicated that the coal was undersaturated, which in comparison with other Mannville Group coals of the Alberta Plains appears to be typical.

Data from these isotherms are summarized in Table 78.

*Formation testing.* No formation tests for coalbed methane were performed on any of these wellbores.

*Technical assessment.* The evaluation program undertaken by Norcen was designed to provide a regional assessment of the coalbed methane potential of Scollard and Mannville coal in the Alberta Plains. By being implemented as part of the conventional oil and gas program that Norcen was

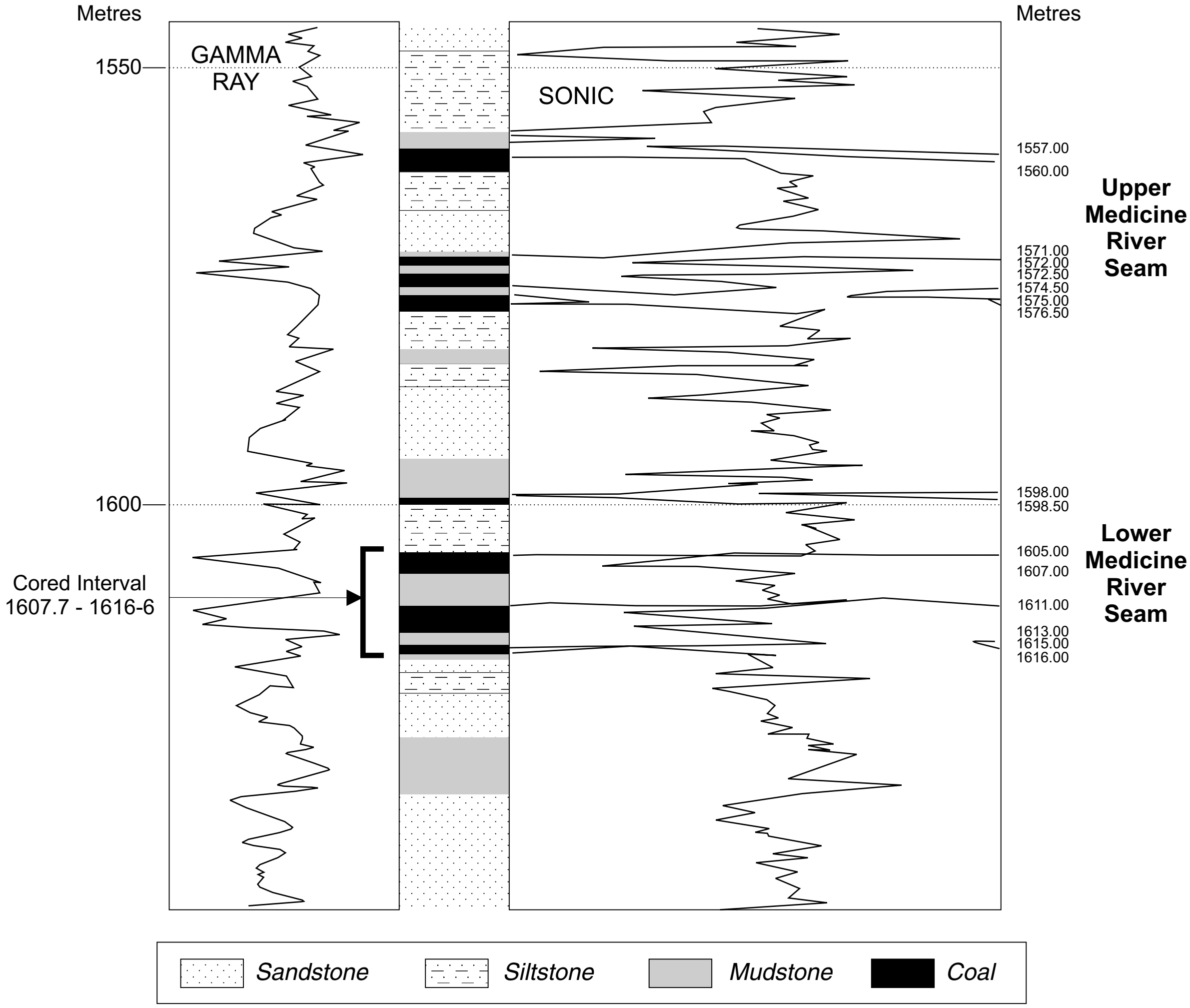


***Figure 121.*** *Detailed stratigraphic section of the Norwest Tomahawk borehole.*

**Table 78**
**Adsorption isotherm data, Norcen Plains**

| Borehole location | Depth (m) | Langmuir equation | Reservoir capacity (a.f.b.) (cc/g) | Normalized gas content (cc/g) | Reservoir saturation (%) |
|---|---|---|---|---|---|
| 12-17-52-06-W5M | 1613 | V=33.1*P/(P+11719) | 19 | 11.89 | 63 |
| 03-36-46-02-W5M | 1650 | V=25.6*P/(P+2229) | 22.5 | 10.56 | 47 |

conducting, significant cost savings were made in acquiring the data. Results appeared to be consistent with data gathered from coalbed methane programs conducted by other companies for the same coal measures. It appears that Norcen did not believe that the data collected warranted further exploration, although the high gas content obtained in 2-14-58-21-W5M should be examined further.

## Wascana Energy Brazeau project

Wascana Energy drilled a conventional oil and gas exploration borehole in west-central Alberta in February 1991. It was decided to test the coalbed methane potential of the upper Coalspur and Mannville Group coals (Fig. 125). This wellbore is classified as a “piggyback well”, because

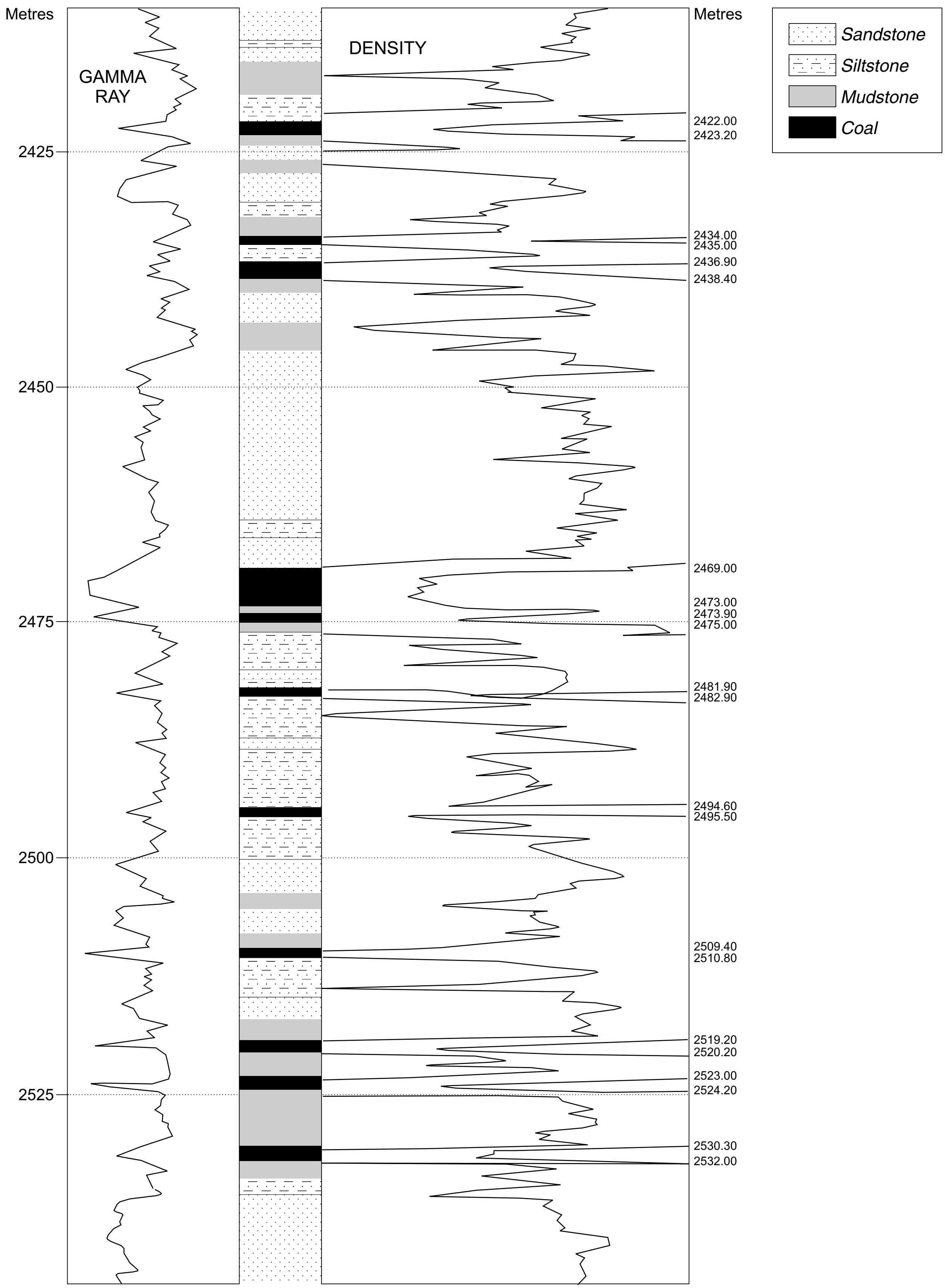


***Figure 122.*** *Detailed stratigraphic section of the Norcen Simonette borehole.*

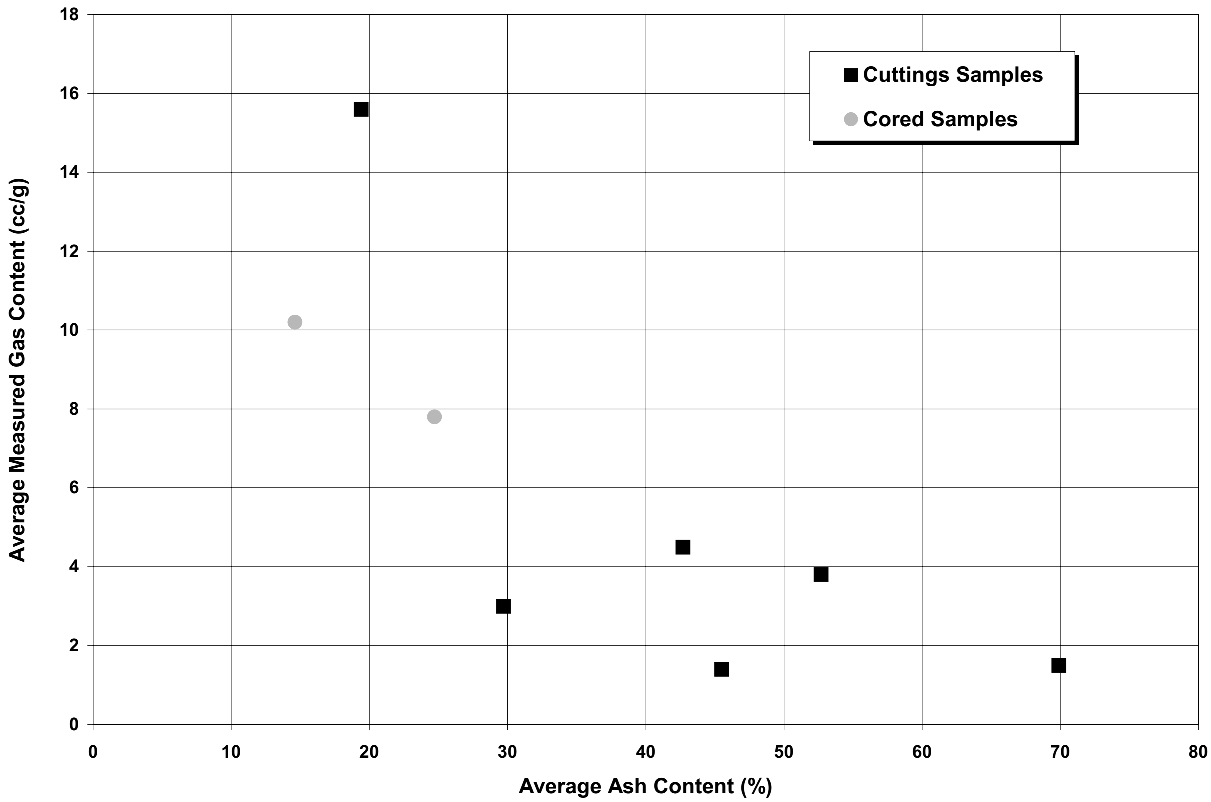


***Figure 123.*** *Measured gas content versus ash content for the Mannville coal intersections.*

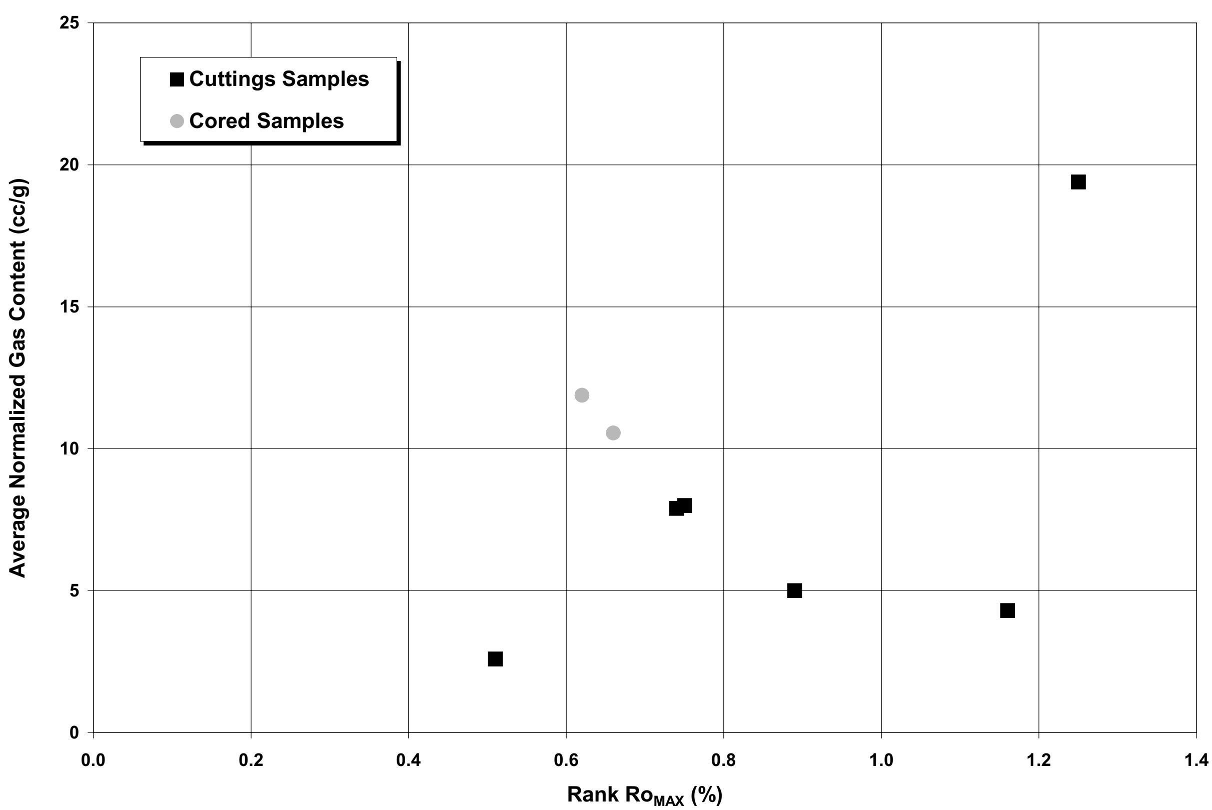


***Figure 124.*** *Normalized gas content versus rank for Mannville coal intersections.*


***Figure 125.*** *General location map of the Wascana Brazeau (08-05-48-11W5M) exploration borehole.*

the primary hydrocarbon target was another horizon, separate from coalbed methane potential reservoirs.

*Data acquisition.* The wellbore was drilled to a total depth of 2568 m. The upper Coalspur Formation coal was intersected at a depth of about 466.2 m. Coal from the Medicine River zone of the Mannville Group was intersected at a depth of 2310 m. Cuttings were collected from each zone and desorbed to determine gas content. Subsequently, proximate, petrographic and gas composition analyses and adsorption isotherms were completed on the coal samples. Following completion of the wellbore to total depth, a drillstem test was completed over the Medicine River coal zone. No production tests were completed because of the low permeability results of the drillstem test.

*Geology.* Two major coal zones were targeted for examination within this borehole. At a depth of about 540 m, the Tertiary age coal of the Coalspur Formation was intersected (Fig. 126). The major coal zones are the Val D'Or, Arbour, Marker, and Silkstone. Table 79 summarizes the upper Coalspur Formation coal intersections for this borehole. Total thickness of the coal-bearing interval is 93.7 m, and cumulative net coal thickness is 19.2 m. The thickest coal zone (the Silkstone) has a total thickness of 12.4 m and a cumulative net coal thickness of 7.3 m. Partings, predominantly kaolinitic or carbonaceous claystone, are common in all seams.

The Medicine River coal zone of the Lower Cretaceous Mannville Group was intersected at depths ranging from 2310.3 to 2316.6 m. Within the Mannville Group, two coal zones are present, the thickest and most laterally continuous being the Medicine River zone.

**Table 79**
**Coal intersections, Wascana Brazeau**

| Seam | Depth (m) | Total zone thickness (m) | Net coal thickness (m) |
|---|---|---|---|
| Val D'Or | 466.2-470.0 | 3.7 | 3.6 |
| Arbour | 472.6-473.8 | 3.8 | 3.2 |
| Marker | 497.6-506.1 | 8.3 | 2.2 |
| Silkstone | 543.8-551.1 | 12.4 | 7.3 |
| Mynheer | 553.0-561.2 | 2.9 | 2.9 |
| Total coal | 466.3-560.0 | 93.7 | 19.2 |

This zone contains three seams with a cumulative net coal thickness of 3.8 m (Fig. 127). Lying 12 m stratigraphically below the Medicine River zone are thin Glauconite zone coal seams. Three seams are present, with a cumulative net coal thickness of 2.0 m over a 12.4 m stratigraphic interval.

*Gas content.* Coal cuttings were collected from the Silkstone zone of the upper Coalspur Formation and the Medicine River zone of the Mannville Group. However, gas content determinations were only made on the Medicine River coal. Three samples were desorbed and the results are summarized in Table 80.

Gas content values are consistent in all samples and probably reflect an optimistic value of gas content for the Medicine River coal zone. The choice of floating the coal at a SG of 1.60 may not accurately reveal the total contribution of gas from the entire rock mass. Studies by the Gas Research Institute have shown that rock material with a SG as high as 1.85–1.90 can contribute significant quantities of gas to the overall volume of gas desorbed.

*Coal quality.* Proximate and ultimate analyses and maceral analyses were performed on the coal cuttings samples. The coal was floated at 1.60 SG and average ash content ranged from 11.6 to 12.8% for the Coalspur Formation coal, and 5.0 to 8.97% for the Medicine River coal. Equilibrium moisture was calculated at 2.1% for the Medicine River samples. Vitrinite reflectance analyses indicated that the Medicine River coal is high volatile bituminous with an $Ro_{max}$ of 0.99 to 1.01%. Vitrinite content ranged from 35 to 66%.

*Adsorption isotherms.* Two adsorption isotherms were completed, one on a Coalspur Formation coal, and the other on Medicine River Sample 1. Samples were run at two separate temperatures and at moisture content slightly above equilibrium. Results of the tests are tabulated in Table 81.

No Coalspur Formation canister samples were collected, but similar desorption tests on the BHP Pembina well yielded gas content values ranging from 3.5 to 4.5 cc/g, similar to values calculated from the adsorption isotherms.

**Table 80**
**Desorption data, Wascana Brazeau**

| Sample number | Depth interval (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) | Ash content* (%) (a.d.b.) |
|---|---|---|---|---|
| 1 | 2310.3-2311.3 | 11.78 | 13.32 | 9.9 |
| 2 | 2311.8-2312.3 | 12.38 | 13.39 | 5.58 |
| 3 | 2312.3-2312.6 | 11.57 | 12.5 | 6.09 |

* Ash content is obtained from the proximate analysis of the 1.60 S.G. float material.

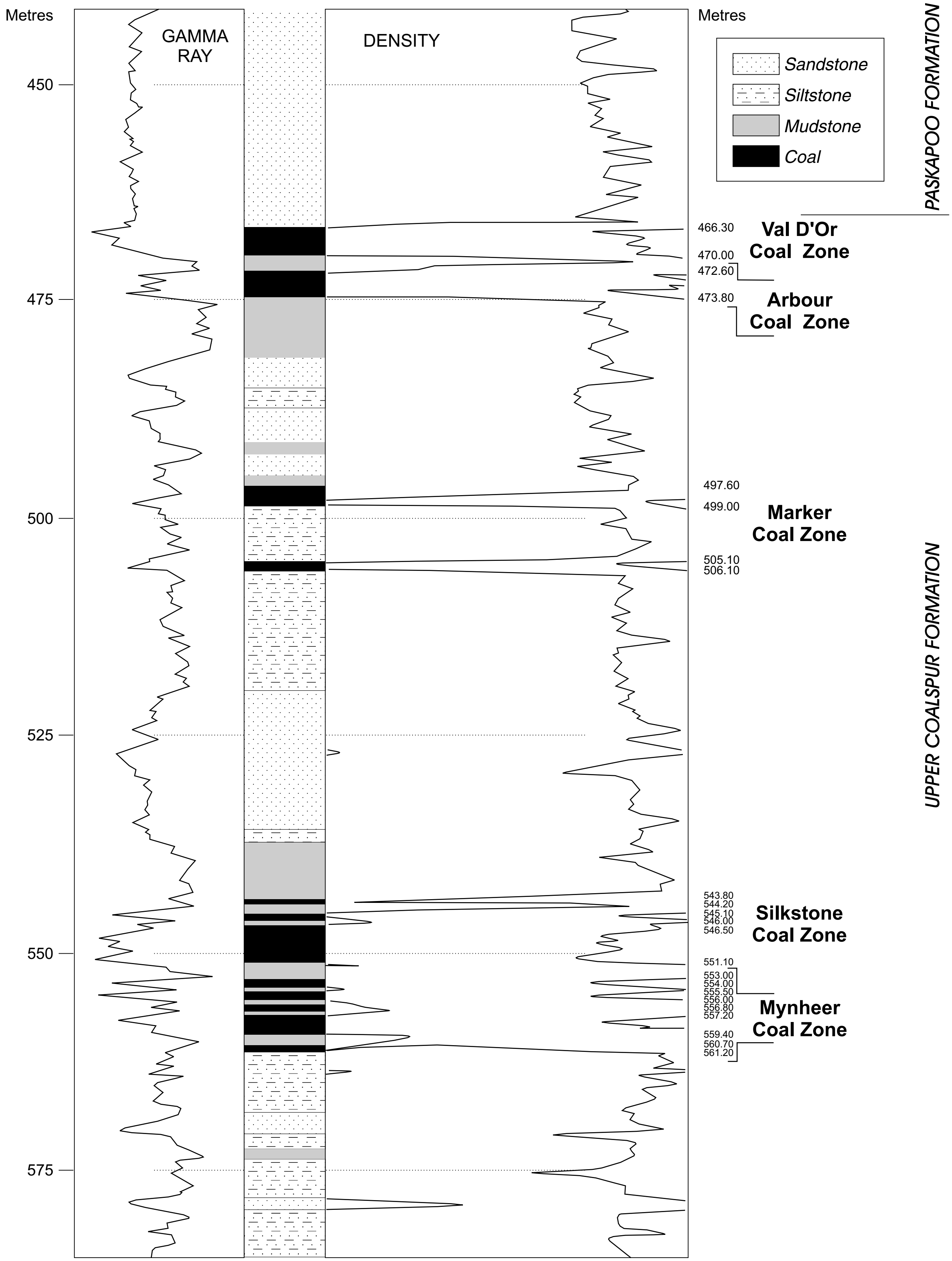


***Figure 126.*** *Detailed stratigraphic section of the Coalspur Formation coal measures intersected in the Wascana Brazeau borehole.*

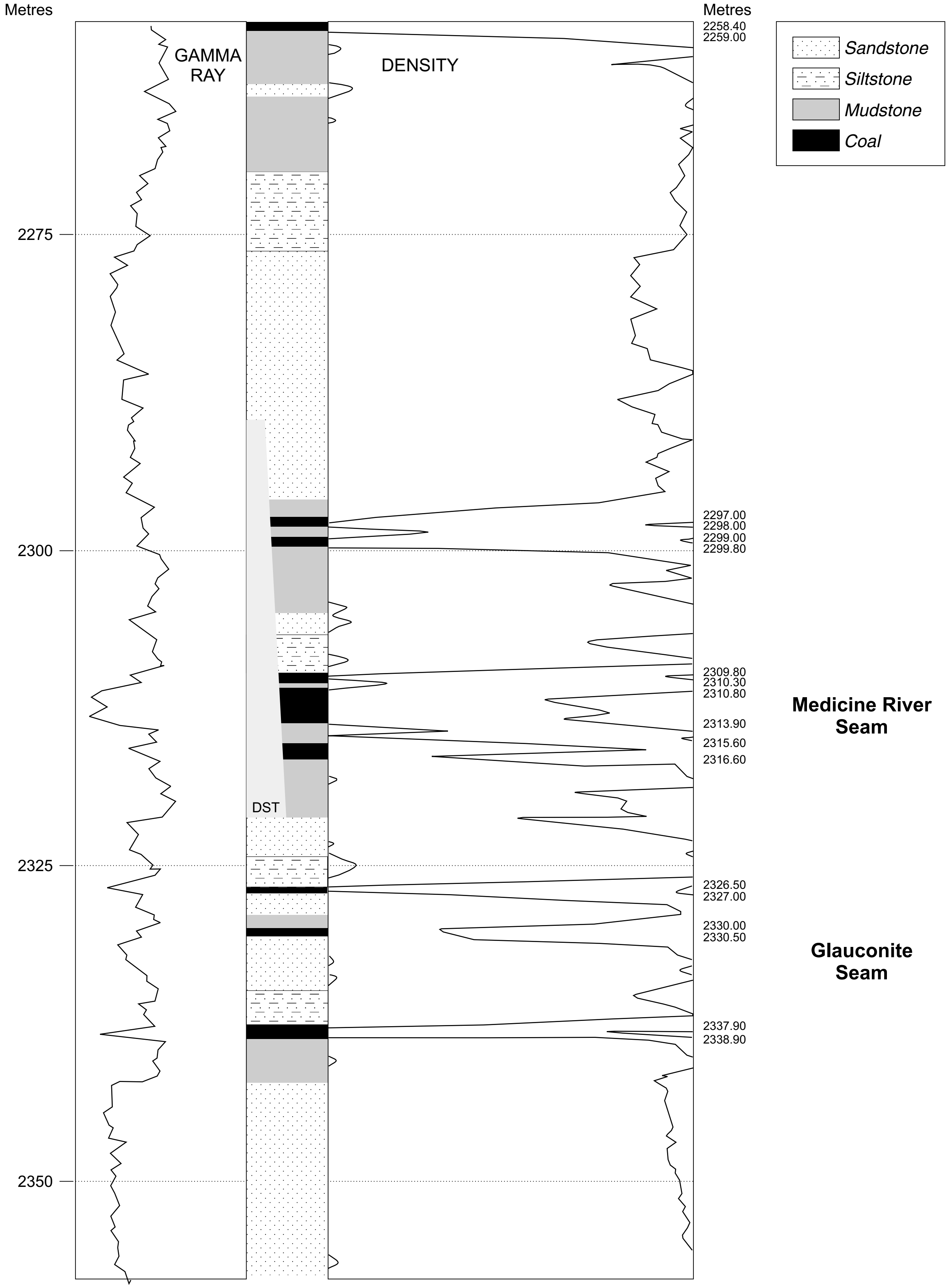


***Figure 127.*** *Detailed stratigraphic section of the Mannville Group coal measures intersected in the Wascana Brazeau borehole.*

**Table 81**
**Adsorption isotherm data, Wascana Brazeau**

| Sample depth (m) | Langmuir equation | Temperature (°C) | Reservoir capacity (cc/g) | Measured gas content (cc/g) | Saturation (%) |
|---|---|---|---|---|---|
| 540-570 | V=10.28*P/(P+7761) | 25 | 4.21 | — | — |
| 2308-2311 | V=10.58*P/(P+3934) | 63 | 9.02 | 11.78 | 130 |

The reservoir capacity of the Medicine River samples was determined from an adsorption isotherm run on coal floated at a SG of 1.60. Independent research by GSC (Calgary) demonstrated that the Langmuir gas capacity volume of the coal can be suppressed by as much as 30% by the immersion fluid. If the reservoir capacity value is increased by 30% and then compared to the actual measured capacity, the saturation would be 100%. In addition, a float of 1.60 SG represents a conservative volume of coal contributing to the supply of gas to the sample. If a higher SG were used, such as 1.85 or 1.90, the measured gas content would be significantly lower and saturation would be less than 100%.

*Formation testing.* One drillstem test was completed on the Medicine River coal zone. The bottom hole inflate test was run over an interval spanning 2289 to 2322 m. Results from the test indicated that the coal had a low permeability, although there was an initial gas surge in the main flow period. It was interpreted that the initial gas surge came from free gas stored in the natural fractures in immediate proximity to the wellbore. After the initial surge (4200 $m^3$/day) gas flowed at a steady rate of 100 $m^3$/day for the duration of the test. The test was run for a total of eight hours and might not adequately reflect the true nature of the reservoir. Analyses of data from the Horner plots suggested a reservoir permeability of 0.004 mD. However, these analyses were calculated from the initial shut-in pressures, because the final shut-in pressure had not been established at the end of the test.

*Technical assessment.* The Wascana Brazeau test well was drilled specifically to demonstrate the presence of methane gas within the Coalspur Formation and Medicine River coal zones. Gas content was measured from cuttings in the Medicine River coal only. Although the gas content appeared to be acceptable, the fact that the desorption measurements were made from cuttings and the final gas content values calculated from a 1.60 SG float raises questions about the validity of the numbers. It is highly likely that actual “in situ” gas content values would be lower than the numbers reported.

The wellbore test (drillstem test) indicated that the reservoir permeability of the Medicine River coal was 0.004 mD. Although the test was probably taken in insufficient time to properly measure the characteristics of the reservoir except in the immediate vicinity of the wellbore, permeability values were so low that even an increase of 100 times would still have given a reservoir permeability of less than 1 mD.

## BHP Petroleum Pembina project

The BHP Petroleum Pembina well was drilled 50 km southwest of Drayton Valley in west-central Alberta (Fig. 128). In the Pembina area, the coal-bearing upper Coalspur Formation lies at depths ranging from 480 to 700 m. The formation thickens to the west. Average thickness is 80 m. Four correlative coal zones have been identified and are defined stratigraphically from shallowest to deepest as the Val D’Or, Arbour, Silkstone, and Mynheer. Total zone thickness for each coal horizon is widely variable. Net coal thickness (the coal components of the total zone) is variable as well. The Val D’Or ranges from 1 to 4 m, the Arbour from 1 to 6 m, the Silkstone from 1 to 8 m and the Mynheer from 1 to 5 m. Cumulative net coal thickness for the coal measures ranges from 18 to 42 m.

Structural features within the Pembina study area are subdued, consisting of several gentle rolls superimposed on a regional dip to the south and west. Smaller scale structural features appear to be associated with sand bodies that were deposited within the interseam or interzone beds. The coal measures are commonly draped over these depositional features as a result of differential compaction and might provide areas of permeability enhancement.

*Data acquisition.* The borehole was drilled open hole to a depth of 486 m, after which a wireline-retrievable drill string was used. Core was obtained using a strata-pack coring bit linked to a wireline retrievable, 3-m long, Christiansen split tube barrel. Borehole diameter was 159 mm and core diameter was 76 mm. Maximum core interval per run was 3.0 m. Most runs averaged 2.8 m. Thirty-five core runs were required to drill the interval from 486.31 to 581.35 m; then the borehole was deepened to 745 m. A total of 95 m was cored, of which 94.05 m were recovered, producing an average 99% recovery for the entire interval. Once the coring was completed, the borehole was reamed, drilled to final depth, and geophysically logged. Log profiles in conjunction with core descriptions were used to determine intervals for

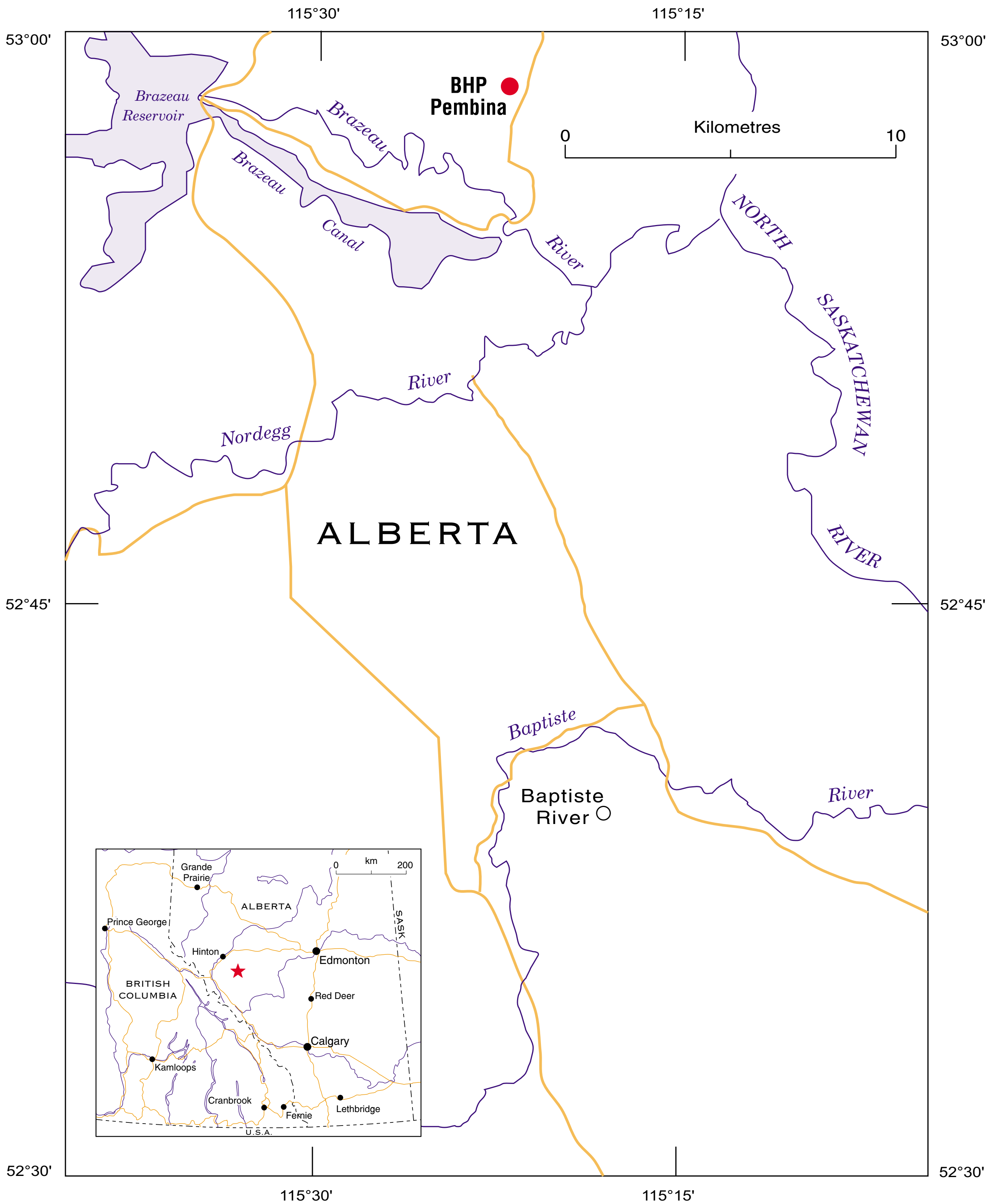


***Figure 128.*** *General location map of the BHP Pembina (14-15-46-10W5M) borehole.*

drillstem tests. Drillstem tests were completed over the Silkstone and Arbour coal zones and the wellbore was subsequently cased, hydraulically fractured, and suspended.

*Geology*. The BHP Pembina well intersected the upper Coalspur Formation between 502.40 and 579.30 m, a thickness of 76.9 m (Fig. 129). Four major coal zones were intersected and core recovery averaged 99%. Depths of intersection along with zone and net coal thicknesses are summarized in Table 82.

In the Pembina appraisal well, and subsequent open hole completion well (11-10-46-10-W5M), the Arbour/Silkstone/Mynheer A interval represents the thickest coal development and was designated as the zone for completion and limited production testing.

Thin rock partings are common and usually consist of bentonitic or carbonaceous claystone and mudstone. The bentonitic partings are generally less than 5 cm thick. The carbonaceous claystone and mudstone bands range in thickness from 5 to 20 cm.

*Gas content*. Gas content was variable, ranging from 4.73 cc/g in the Val D'Or zone to 1.02 cc/g in the Mynheer zone. Twenty-four gas canister tests were completed. Average gas content for the coal measures was 3.70 cc/g. The lost gas component varied between 1 and 10% of the total gas and averaged 4%. Thus, any errors in lost gas estimation probably would not contribute significantly to errors in total gas estimation.

A comparison of as-received gas content data versus depth of intersection for all samples revealed low gas content for the Mynheer B seam compared to the other coal zones (Fig. 130; Table 83). The gas content value for Mynheer B samples averaged 2.3 cc/g compared with 4.35, 3.27, 3.72 and 3.0 cc/g for the Val D'Or, Arbour, and Silkstone zones,

**Table 82**
**Coal intersections, BHP Pembina**

| Seam name | Depth (top) (m) | Depth (base) (m) | Total zone (m) | Total coal thickness (m) |
|---|---|---|---|---|
| Val D'Or | 502.40 | 508.50 | 6.10 | 3.85 |
| Arbour | 526.36 | 539.72 | 13.36 | 5.16 |
| Silkstone | 540.73 | 549.06 | 8.33 | 7.21 |
| Mynheer | 549.44 | 579.30 | 29.86*(5.16) | 3.65 |

*The 29.86 m zone thickness for the Mynheer zone includes a 24.7 m rock parting separating Mynheer A seam from Mynheer B seam. If this interval is excluded, the total zone thickness is 5.16 m.

**Table 83**
**Desorption data, BHP Pembina**

| Seam name | Sample number | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Val D'Or | 65 | 502.51 | 4.53 | 5.00 |
| Val D'Or | 66 | 504.00 | 4.39 | 4.92 |
| Val D'Or | 67 | 504.47 | 4.01 | 4.91 |
| Val D'Or | 68 | 504.87 | 4.10 | 5.12 |
| Val D'Or | 69 | 508.60 | 4.73 | 5.35 |
| Arbour | 70 | 526.34 | 3.66 | 4.71 |
| Arbour | 71 | 530.16 | 1.02 | 1.32 |
| Arbour | 72 | 530.72 | 3.55 | 4.33 |
| Arbour | 73 | 531.44 | 3.75 | 4.60 |
| Arbour | 74 | 532.19 | 3.42 | 4.33 |
| Arbour | 75 | 532.59 | 3.89 | 4.73 |
| Arbour | 76 | 533.23 | 2.68 | 3.05 |
| Arbour | 77 | 534.06 | 4.20 | 4.89 |
| Silkstone | 78 | 540.91 | 3.65 | 4.19 |
| Silkstone | 79 | 542.25 | 4.17 | 4.80 |
| Silkstone | 80 | 542.78 | 4.43 | 4.69 |
| Silkstone | 81 | 544.38 | 2.65 | 3.35 |
| Silkstone | 82 | 545.62 | 4.05 | 4.68 |

**Table 83 (cont.)**
**Desorption data, BHP Pembina**

| Seam name | Sample number | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Silkstone | 83 | 547.76 | 3.99 | 4.42 |
| Silkstone | 84 | 548.66 | 3.09 | 4.26 |
| Mynheer | 85 | 549.52 | 3.77 | 4.31 |
| Mynheer | 86 | 576.67 | 1.16 | 1.68 |
| Mynheer | 87 | 577.37 | 2.78 | 3.79 |
| Mynheer | 88 | 579.08 | 2.95 | 3.58 |

and Mynheer A seam, respectively. After normalization of gas content data to an ash-free basis, most coal samples had gas content values ranging from 3.27 to 4.18 cc/g and averaging 3.83 cc/g. There is apparently no relationship between depth and coal zone (Fig. 131). The Mynheer B coal samples ranged from 1.52 to 2.96 cc/g and averaged 2.39 cc/g. These values are higher than those for Coalspur Formation coal tested in other west-central Alberta localities.

Ash content values are in the same range for all samples, and a plot of ash versus gas content reveals a general trend of decreased gas content with increased ash (Fig. 132). The Mynheer zone appears to have an overall higher ash content, which might explain the lower gas content. This phenomenon of lower gas content for the Mynheer B seam has been observed in the other BHP appraisal wells.

*Coal quality*. A comparison of quality data revealed no significant difference between the major coal zones (Table 84). Volatile matter ranged from 24.80 to 35.16% (as-received) and, when recalculated to a dry-ash-free basis, from 34 to 44%, with most samples indicating rank in the high volatile bituminous A to C range. The as-received ash range was 5.59 to 31.10%, with an average value of 17.07%. The wide range of values suggested that where ash content

**Table 84**
**Proximate analyses, BHP Pembina**

| Seam name | Sample number | Depth of intersection (m) | Moisture content (%) (a.d.b.) | Ash content (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Volatile matter (%) (a.d.b.) |
|---|---|---|---|---|---|---|
| Val D'Or | 65 | 502.51 | 7.20 | 9.33 | 52.16 | 31.31 |
| Val D'Or | 66 | 504.00 | 7.83 | 10.80 | 50.92 | 30.45 |
| Val D'Or | 67 | 504.47 | 7.18 | 18.35 | 44.66 | 29.81 |
| Val D'Or | 68 | 504.87 | 7.02 | 19.89 | 43.59 | 29.60 |
| Val D'Or | 69 | 508.60 | 7.05 | 11.64 | 49.29 | 32.02 |
| Arbour | 70 | 526.34 | 5.96 | 22.30 | 43.24 | 28.50 |
| Arbour | 71 | 530.16 | 6.37 | 22.58 | 43.59 | 27.46 |
| Arbour | 72 | 530.72 | 6.99 | 17.98 | 45.50 | 29.53 |
| Arbour | 73 | 531.44 | 6.83 | 18.44 | 45.38 | 29.35 |
| Arbour | 74 | 532.19 | 5.85 | 21.08 | 45.85 | 27.22 |
| Arbour | 75 | 532.59 | 6.16 | 17.72 | 46.00 | 30.12 |
| Arbour | 76 | 533.23 | 6.37 | 12.06 | 50.03 | 31.54 |
| Arbour | 77 | 534.06 | 6.32 | 14.07 | 48.30 | 31.31 |
| Silkstone | 78 | 540.91 | 6.59 | 12.80 | 52.02 | 28.59 |
| Silkstone | 79 | 542.25 | 6.40 | 13.11 | 50.15 | 30.34 |
| Silkstone | 80 | 542.78 | 6.48 | 5.59 | 55.36 | 32.57 |
| Silkstone | 81 | 544.38 | 6.73 | 20.96 | 45.01 | 27.30 |
| Silkstone | 82 | 545.62 | 6.93 | 13.51 | 45.64 | 33.92 |
| Silkstone | 83 | 547.76 | 7.87 | 9.65 | 51.95 | 30.53 |
| Silkstone | 84 | 548.66 | 6.18 | 27.43 | 39.87 | 26.52 |
| Mynheer | 85 | 549.52 | 6.43 | 15.23 | 47.06 | 31.28 |
| Mynheer | 86 | 576.67 | 6.11 | 31.10 | 38.80 | 23.99 |
| Mynheer | 87 | 577.37 | 6.80 | 26.68 | 39.25 | 27.27 |
| Mynheer | 88 | 579.08 | 6.30 | 17.59 | 42.85 | 33.26 |

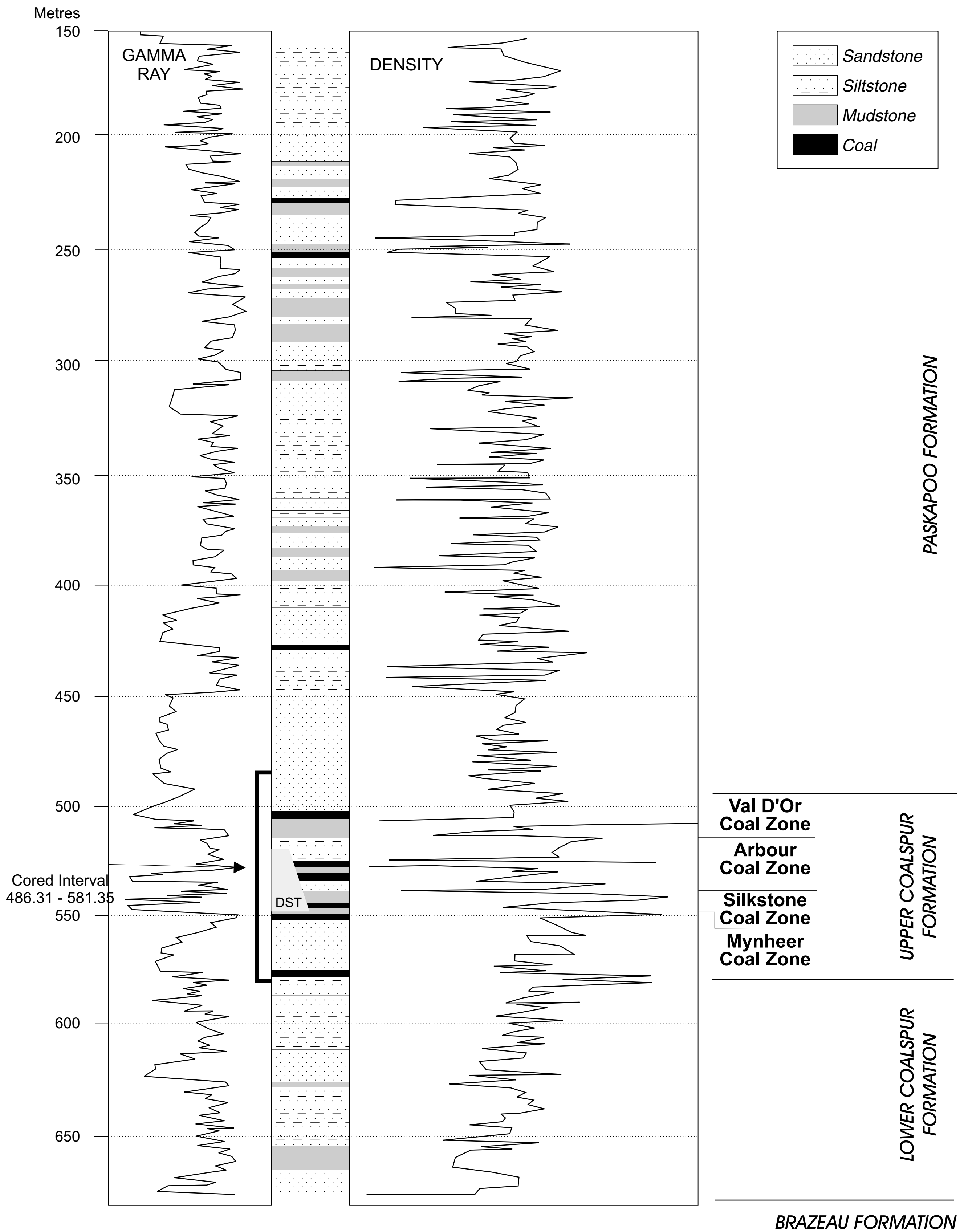


***Figure 129.*** *Detailed stratigraphic section illustrating the four major coal zones intersected in the BHP Pembina borehole.*

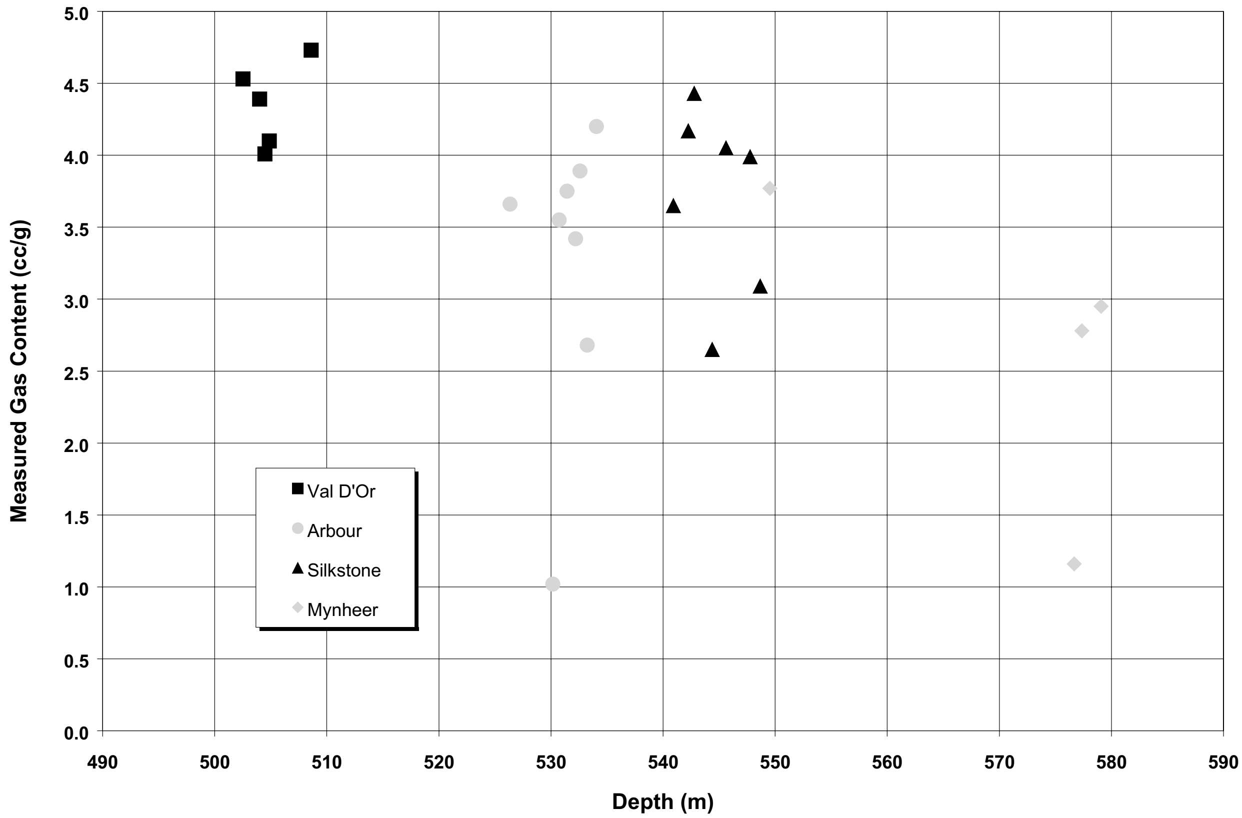


***Figure 130.*** *Measured gas content versus depth, BHP Pembina samples.*

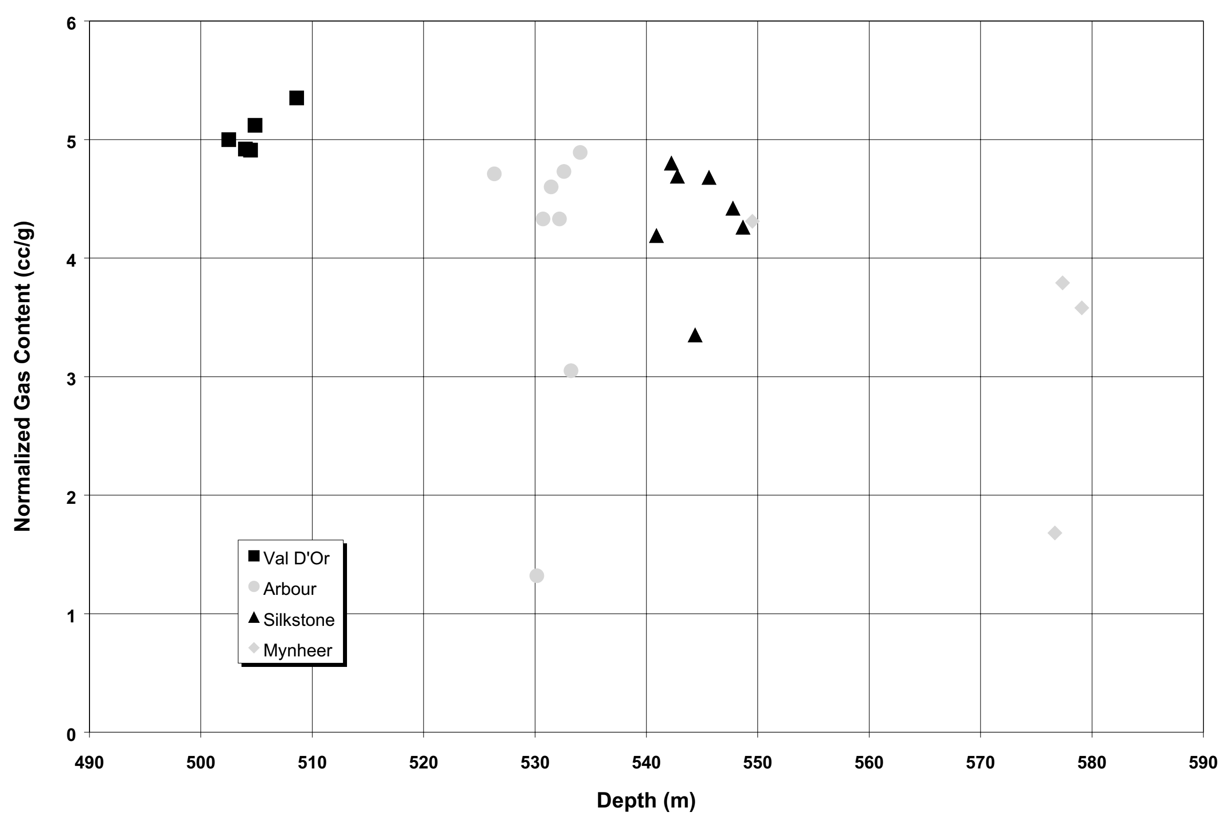


***Figure 131.*** *Normalized gas content versus depth, BHP Pembina samples.*

was high, thin inorganic partings were included in the samples placed in desorption canisters. This is inevitable when lengths of continuous core are the preferred samples for desorption testing. Moisture content was primarily in the 4 to 5.8% range. Hard grove grindability indices were similar for most samples and generally ranged from 49 to 55. Sulphur content (air-dried basis) was generally quite low, ranging from 0.16 to 0.41%. Gas analyses for two samples indicated that methane (C1-4) accounted for greater than 98% of the gas composition.

*Formation testing.* The Pembina appraisal well was drilled on the southern end of a structural high, which might account for the well-developed cleat within the coal and the reasonable permeability values determined from the on-site drillstem tests (4 to 7 mD). A limited production test was conducted on the well after fracture stimulation and the well produced at a maximum rate of 45 Mcf/d. Production declined to 35 Mcf/d after 28 days of production testing. Following the test, the well was plugged and abandoned.

BHP Petroleum drilled an offset well at 11-19-46-10-W5M in an attempt to cavitate the Silkstone coal zone. The borehole was drilled to the top of the upper Silkstone coal and production casing cemented. The coal was then cavitated for 24 hours. The presence of coal fragments in the sump pit suggested that the cavitation was successful. Initial gas production was over 100 Mcf/d during cavitation. The drilling crew had difficulty removing the fines from the borehole. The sump pit was not deep enough to accommodate all the excess cuttings produced by the cavitation process. To facilitate removing the fines, additives (soap based) were mixed with the drilling fluid. Within 24 hours, gas production dropped from 100 Mcf/d to less than 25 Mcf/d. Logging the borehole also revealed that within the 9 m cavitated zone, only the upper 3 m was exposed to drill-fluid dewatering, the remaining 6 m covered by cuttings. This well was deemed a technical failure and subsequently plugged and abandoned.

*Technical assessment.* The purpose of the BHP Plains coalbed methane exploration program was to find thick, laterally extensive coal of the Tertiary Coalspur Formation with gas content values in the 6 to 8 cc/g range. The exploration philosophy was based on BHP's experience in the San Juan Basin, where coal of low rank has high gas content (6 to 8 cc/g), and gas production of greater than 350 Mcf/d had been achieved.

Although the continuity of the coal was demonstrated, the gas content was substantially lower than anticipated. The reason for the difference in gas content for coal of essentially

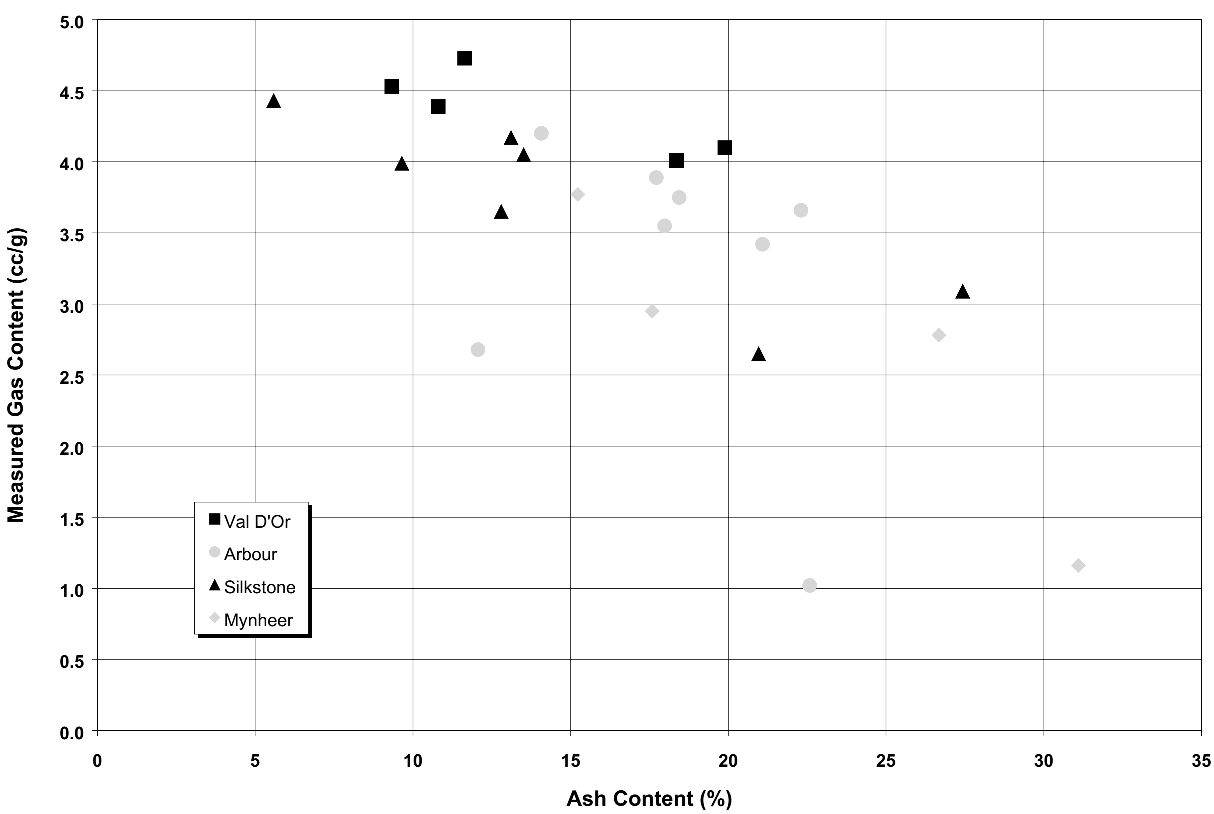


***Figure 132.*** *Measured gas content versus ash content (a.d.b.), BHP Pembina samples.*

similar rank and maturity appears to be coal composition. The coal of the Fruitland Formation in the San Juan Basin is high in resin and liptinite, in contrast to the relatively liptinite-poor coal of the Coalspur Formation. Thermogenic gas generation can occur at lower maturation levels in coal that is high in hydrogen (resin or liptinite rich). These conclusions, developed during joint research conducted by the GSC, might have significant implications for the definition of future shallow, low rank exploration targets (similar to the Powder River Basin play).

It also became apparent that although the cavitation of the second BHP Pembina well was successful, the additives used severely inhibited gas production. Also, the inadequate depth of the sump pit for fines removal resulted in only one third of the coal actually contributing to the gas production attained during the limited production test. Results from the cavitation well should be discounted, because the degree of success of the tests was compromised by on-site drilling and completion decisions made by BHP personnel.

## BHP Petroleum Peco project

BHP Petroleum Canada Limited undertook the drilling of a coalbed methane appraisal well [BHP (Can) Brazeau 10-16-48-14-W5M well (referred to as Peco)] in the spring of 1995. The well was located 60 km southwest of the town of Drayton Valley (Fig. 133).

The Peco exploration well encountered a cumulative net coal thickness of 20.35 m in four major coal zones. The most prospective coal horizon is the Val D'Or zone, containing greater than 7.35 m of coal. The Arbour, Silkstone and Mynheer zones contained 1.41, 4.55, and 7.04 m of net coal, respectively. Measured gas content was variable, ranging from 3.05 cc/g in the Val D'Or zone, to 1.67 cc/g in the Mynheer zone. Twenty-one gas canister tests were completed, and average gas content for the coal measures was 2.5 cc/g . Coal quality was variable, with ash content ranging from 7.19 to 39.44%, and averaging 19.97 %.

Within the Peco area, the coal-bearing upper Coalspur Formation lies at depths ranging from 700 to 800 m. Four correlative coal zones were identified and defined stratigraphically, from shallowest to deepest, as the Val D'Or, Arbour, Silkstone, and Mynheer. Total zone thickness for each coal horizon varied widely. Cumulative net coal thickness for the coal measures ranged from 18 to 42 m.

Structural features within the Peco study area consisted of gentle rolls and swales superimposed on a regional dip to the south and west. All coal zones appeared to have similar structural features, suggesting that regional flexures observed in the structural contour maps are post-depositional. Smaller scale structural features appeared to be associated with sandbodies deposited within the interseam or interzone beds. The coal measures are commonly draped over these depositional features because of differential compaction, and can provide areas of permeability enhancement.

*Data acquisition.* The borehole was drilled open hole to a depth of 707 m then a wireline-retrievable drill string was used. Core was obtained using a strata-pack coring bit linked to a wireline retrievable, 3-m long, Christiansen split tube barrel. Borehole diameter was 159 mm and core diameter was 76 mm. Maximum core interval per run was 3.0 m, with most runs averaging 2.8 m. Forty-five core runs were required to drill the interval from 707.74 to 825.77 m deep. A total of 118 m was cored, of which 116.82 m was recovered.

After core retrieval, the barrel was placed in the laboratory trailer and core photographs were taken of each interval. The core was logged and reconciled to driller's depth intervals to determine core loss. Coal samples were selected for desorption and micropermeability tests and the remaining core was boxed for shipment to the core repository in Calgary. Two drillstem tests were completed, from 780.4 to 785.4 m in the Mynheer coal zone and from 711.20 to 723.20 m in the Val D'Or coal zone. The borehole was subsequently cased and suspended.

*Geology.* The BHP Brazeau well intersected the Coalspur coal at depths ranging from 711.70 to 820.67 m, a thickness of 109 m. Four major coal zones were intersected and core recovery averaged 99%. Depths of intersection along with zone and net coal thickness are summarized in Table 85.

The Val D'Or coal zone consists of an upper and lower seam about 1.4 m thick and 4.3 m thick, respectively, separated by a 0.65 m rock parting. The lower seam contains numerous thin (less than 5 cm) rock partings observable in core that are not apparent from the geophysical log response, which indicated solid coal seams. Thin bed effects and the limitations of the source/detector spacing of the logging tools could explain this discrepancy.

The Arbour coal zone consists of three thin coal seams separated by rock partings. Total zone thickness is 2.03 m, and net coal thickness is 1.41 m. The underlying Silkstone

**Table 85**
**Coal intersections, BHP Peco**

| Seam name | Depth (top) (m) | Depth (base) (m) | Total zone (m) | Net coal thickness (m) |
|---|---|---|---|---|
| Val D'Or | 711.7 | 722 | 10.3 | 7.35 |
| Arbour | 745.48 | 747.51 | 2.03 | 1.41 |
| Silkstone | 776.35 | 783.98 | 7.63 | 4.55 |
| Mynheer | 809.19 | 820.67 | 11.48 | 7.04 |

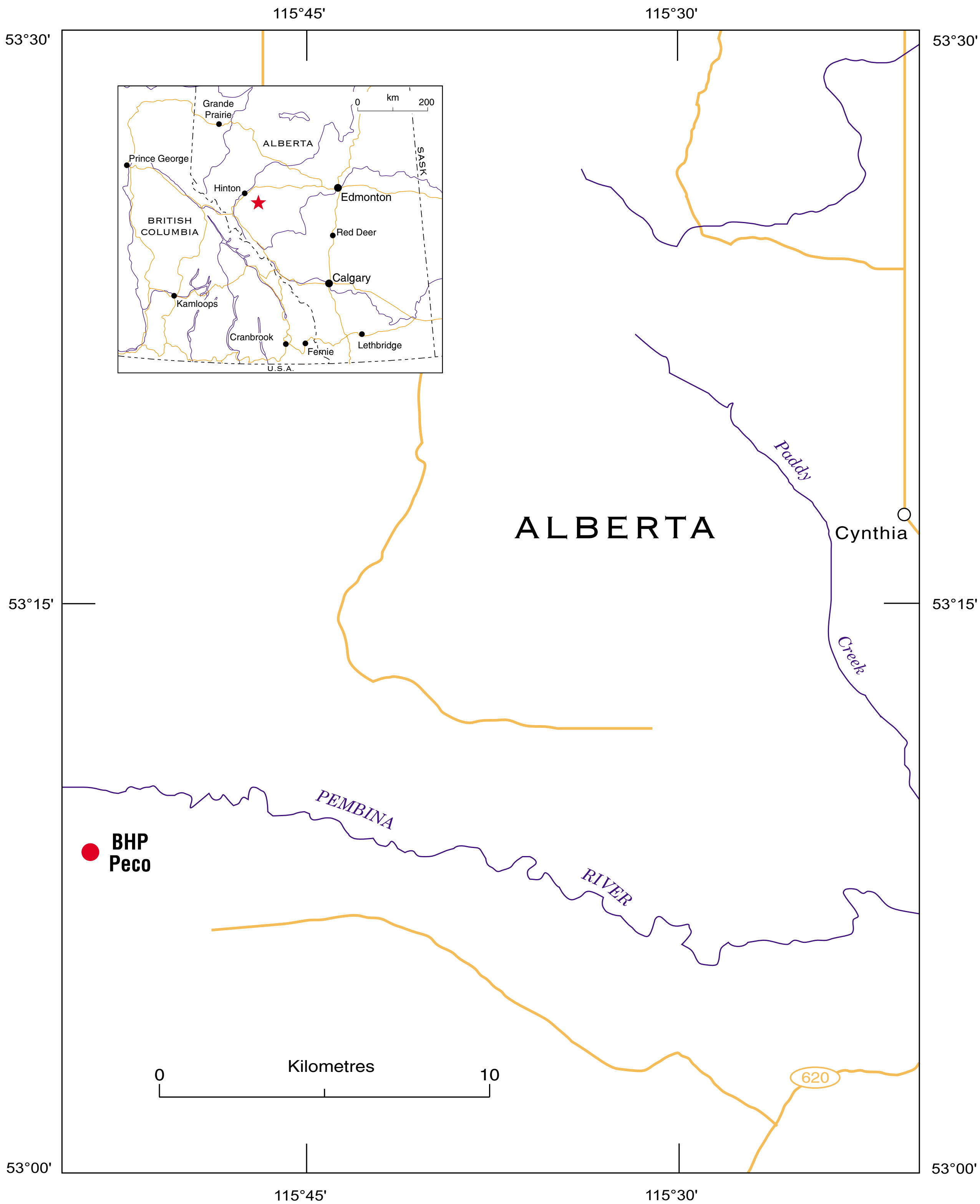


***Figure 133.*** *General location map of the BHP Peco (10-16-48-14W5M) borehole.*

zone contains four distinct coal seams (net coal 4.55 m) over a 7.63 m interval. The limited development of thick coal within these zones precluded further testing of the coalbed methane potential of these coal intervals.

The Mynheer zone consists of an upper seam 1.44 m thick, a middle seam 4.52 m thick, and a 0.7 m thick lower seam. In the middle seam, two intermediate partings are present and the overall geometry of the coal/rock distribution appears to be similar to the Val D'Or zone. Total zone thickness is 11.48 m with a net coal thickness of 7.04 m. Proximate analyses of the canister samples reveal high "as-received" ash contents, which reflect this high degree of interbedding (Fig. 134).

*Gas content.* Desorption samples were collected for four coal intervals, the Val D'Or, Arbour, Silkstone, and Mynheer. Twenty-one valid desorption samples were taken: six from the Val D'Or zone and two, five, and eight samples from the other zones, respectively. As measured gas content values were relatively low, ranging from 1.25 to 3.72 cc/g and averaging 2.50 cc/g. The lost gas component varied between 1 and 8% of the total gas and averaged 3%. Consequently, any errors in the lost gas estimation probably would not contribute significantly to errors in estimation of total gas.

A comparison of as-received gas content data versus depth of intersection for all samples revealed low gas content for the Mynheer zone compared with the other coal zones (Fig. 135; Table 86). The Mynheer sample averaged 1.67 cc/g compared to the average gas content of 3.05, 2.5, and 3.18 cc/g for the Val D'Or, Arbour, and Silkstone zones, respectively. Normalized gas content for the Val D'Or, Arbour, and Silkstone coal zones ranged from 3.27 to 4.18 cc/g and averaged 3.83 cc/g with no apparent influence from depth or coal zone (Fig. 136). The Mynheer coal samples ranged from 1.52 to 2.96 cc/g and averaged 2.39 cc/g.

*Coal quality.* A comparison of coal quality data revealed no significant differentiation among the major coal zones (Table 87). Volatile matter ranged between 24.80 and 35.16% (as-received) and, when recalculated to a dry-ash-free basis, ranged between 34 and 44% with most samples indicating rank in the high volatile bituminous A to C range. The as-received ash content range was 7.19 to 39.44%, with an average value of 19.97%. The wide range of values suggested that where ash content was high, thin inorganic partings had been included in the samples placed in desorption canisters. This is inevitable when lengths of continuous core are the preferred samples for desorption testing. Moisture content is primarily in the 4 to 5.8% range. Hardgrove grindability indices were similar for most samples and generally ranged from 49 to 55. Sulphur content (air-dried basis) was generally low, ranging from 0.16 to 0.41%. Gas composition was predominantly methane (>85%) with lesser amounts of nitrogen (14%) suggesting that the sample was slightly contaminated with air. $CO_2$ content was less than 1%.

**Table 86**
**Desorption data, BHP Peco**

| Seam name | Sample no. | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Val D'Or | 42 | 712.53 | 3.07 | 3.57 |
| Val D'Or | 44 | 714.36 | 2.34 | 3.19 |
| Val D'Or | 45 | 714.74 | 3.20 | 3.64 |
| Val D'Or | 46 | 715.84 | 3.00 | 3.89 |
| Val D'Or | 47 | 718.45 | 2.58 | 3.38 |
| Val D'Or | 48 | 721.36 | 3.72 | 4.01 |
| Arbour | 50 | 745.48 | 1.83 | 3.02 |
| Arbour | 51 | 747.06 | 3.15 | 3.58 |
| Silkstone | 52 | 776.35 | 2.70 | 3.38 |
| Silkstone | 53 | 778.13 | 3.46 | 3.93 |
| Silkstone | 54 | 781.26 | 3.20 | 3.48 |
| Silkstone | 55 | 782.14 | 3.30 | 3.76 |
| Silkstone | 56 | 783.58 | 3.22 | 3.62 |
| Mynheer | 57 | 809.39 | 2.43 | 2.78 |
| Mynheer | 58 | 809.71 | 1.25 | 1.53 |
| Mynheer | 59 | 813.90 | 1.28 | 1.44 |
| Mynheer | 60 | 815.32 | 1.94 | 2.76 |
| Mynheer | 61 | 816.13 | 1.42 | 2.20 |
| Mynheer | 62 | 817.55 | 1.42 | 2.01 |
| Mynheer | 63 | 818.02 | 1.96 | 2.77 |
| Mynheer | 64 | 818.42 | 1.64 | 2.60 |

*Formation testing.* No formation test data were available for the Peco wellbore.

*Technical assessment.* The Peco well was the third in a four-hole program initiated by BHP Petroleum to assess the potential of the thick, laterally continuous coal of the Coalspur Formation. Although the borehole did intersect thick coal seams, gas content was below the minimum threshold established by BHP. The project was eventually abandoned after it was determined that gas production rates of 150 Mcf/d were not attainable from coal that had an in situ gas content of 3 to 4 cc/g.

## BHP Petroleum Pine Creek project

BHP Petroleum (Canada) Inc. drilled a coalbed methane exploration borehole (BHP Pine Creek) about 37 km northwest of the town of Edson, in west-central Alberta, in January–February, 1995 as part of a four-well appraisal program (Fig. 137). The borehole targeted the thick coal of the Tertiary Coalspur Formation. The Val D'Or/Arbour, Upper and Lower Silkstone, and Mynheer coal zones were cored and sampled for gas content, gas composition, coal quality and micropermeability.

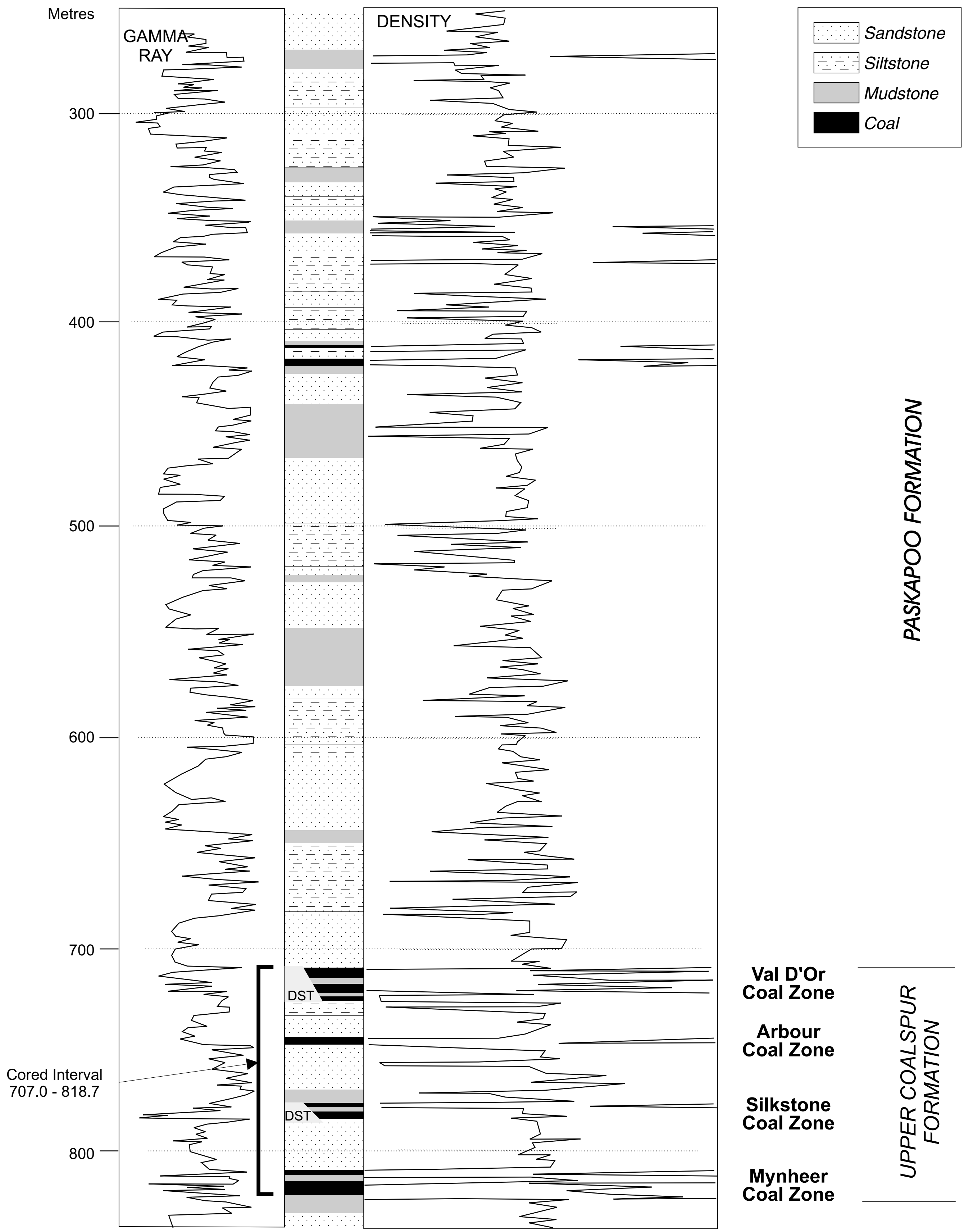


***Figure 134.*** *Detailed stratigraphic section illustrating the four major coal zones intersected in the BHP Peco borehole.*

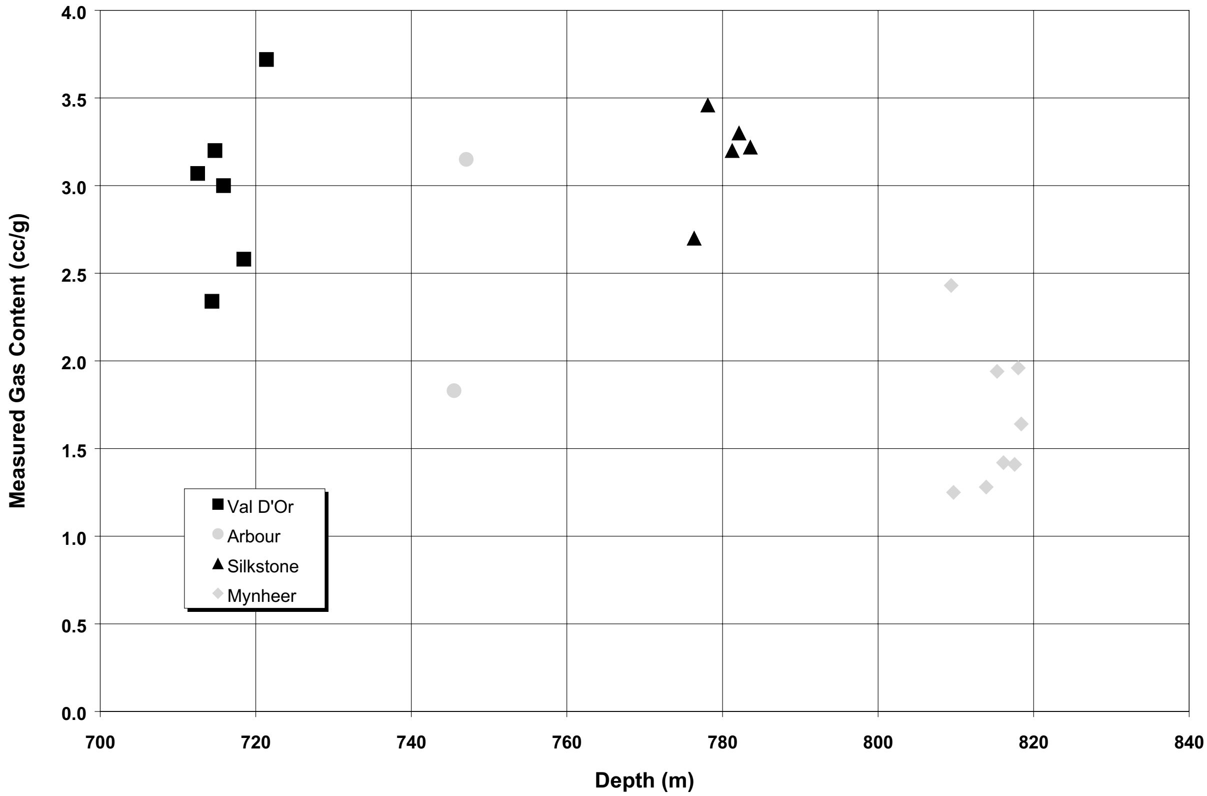


***Figure 135.*** *Measured gas content versus depth of intersection, BHP Peco samples.*

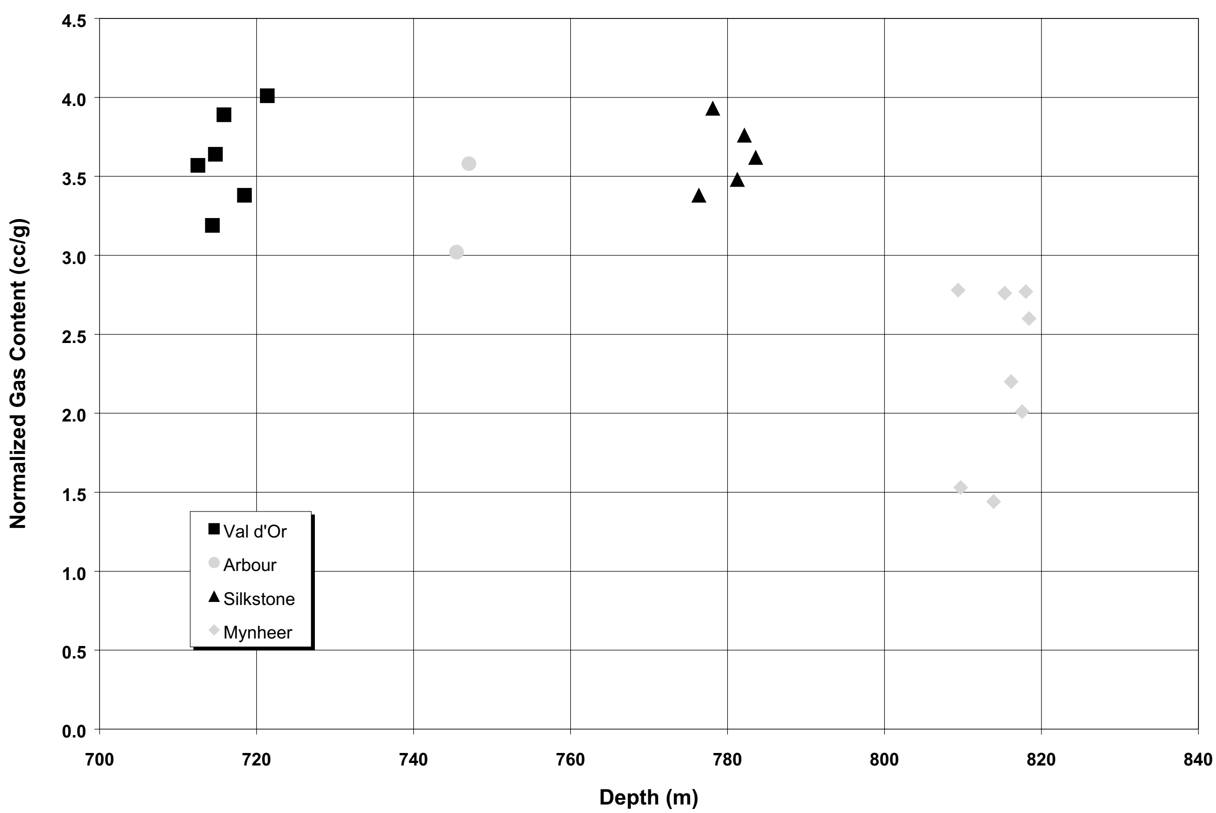


***Figure 136.*** *Normalized gas content versus depth of intersection, BHP Peco samples.*

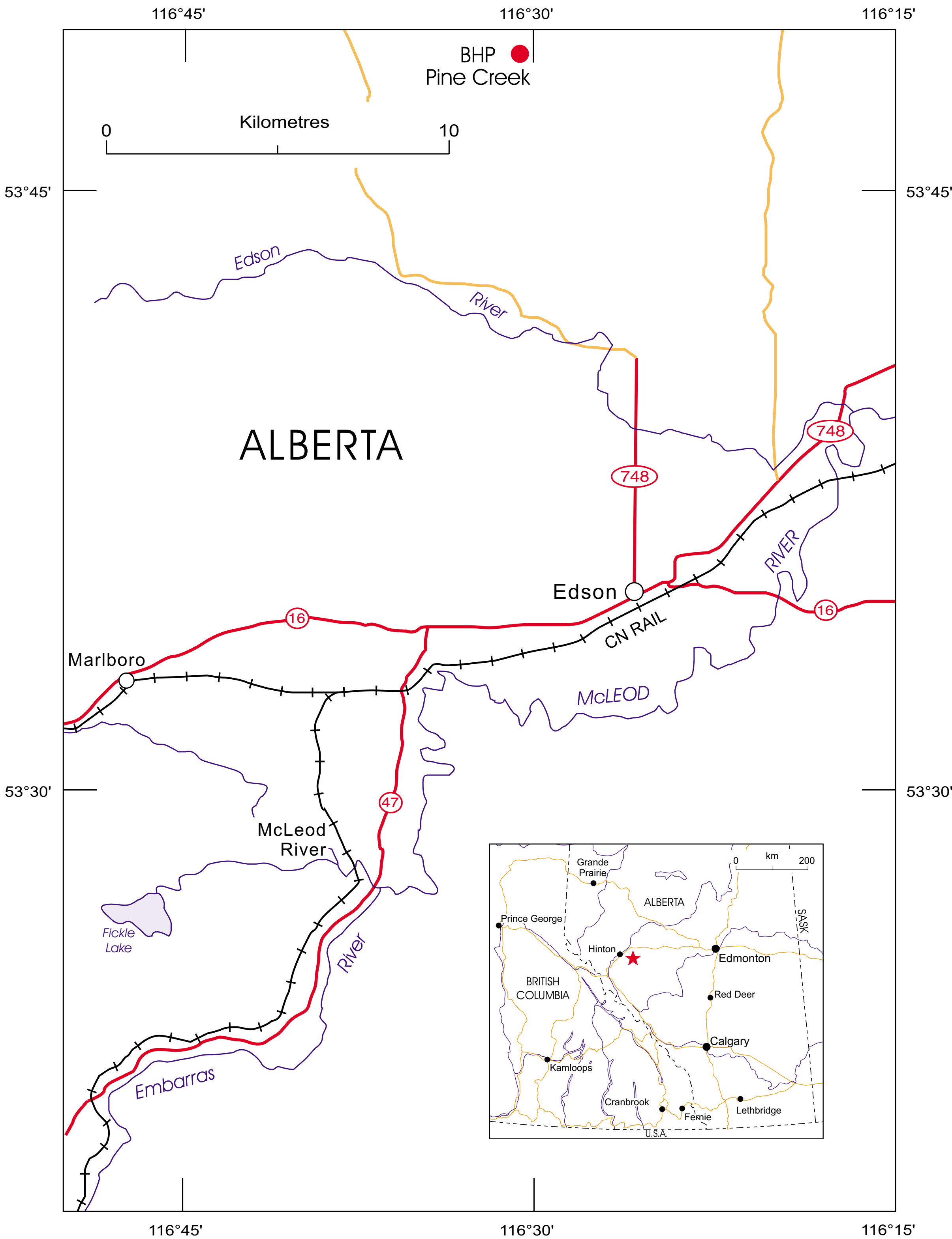


***Figure 137.*** *General location map of the BHP Pine Creek (11-06-56-19W5M) borehole.*

**Table 87**
**Proximate analyses, BHP Peco**

| Seam name | Sample number | Depth of intersection (m) | Moisture content (%) (a.d.b.) | Ash content (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Volatile matter (%) (a.d.b.) |
|---|---|---|---|---|---|---|
| Val D'Or | 42 | 712.53 | 4.05 | 13.94 | 48.71 | 33.30 |
| Val D'Or | 44 | 714.36 | 4.60 | 26.74 | 42.46 | 26.20 |
| Val D'Or | 45 | 714.74 | 4.33 | 12.19 | 51.30 | 32.18 |
| Val D'Or | 46 | 715.84 | 4.03 | 22.82 | 42.15 | 31.00 |
| Val D'Or | 47 | 718.45 | 4.42 | 23.75 | 43.77 | 28.06 |
| Val D'Or | 48 | 721.36 | 3.57 | 7.19 | 54.08 | 35.16 |
| Arbour | 50 | 745.48 | 4.72 | 39.44 | 31.04 | 24.80 |
| Arbour | 51 | 747.06 | 5.14 | 12.06 | 51.59 | 31.21 |
| Silkstone | 52 | 776.35 | 5.40 | 20.12 | 46.65 | 27.83 |
| Silkstone | 53 | 778.13 | 5.44 | 11.85 | 52.73 | 29.98 |
| Silkstone | 54 | 781.26 | 5.80 | 8.12 | 54.10 | 31.98 |
| Silkstone | 55 | 782.14 | 5.15 | 12.32 | 51.89 | 30.64 |
| Silkstone | 56 | 783.58 | 5.51 | 11.08 | 51.05 | 32.36 |
| Mynheer | 57 | 809.39 | 5.36 | 12.64 | 51.27 | 30.73 |
| Mynheer | 58 | 809.71 | 4.92 | 13.50 | 51.08 | 30.50 |
| Mynheer | 59 | 813.90 | 4.94 | 10.84 | 51.89 | 32.33 |
| Mynheer | 60 | 815.32 | 4.19 | 29.61 | 39.28 | 26.92 |
| Mynheer | 61 | 816.13 | 3.91 | 35.44 | 35.08 | 28.57 |
| Mynheer | 62 | 817.55 | 3.72 | 29.71 | 37.92 | 28.65 |
| Mynheer | 63 | 818.02 | 3.52 | 29.17 | 39.59 | 27.72 |
| Mynheer | 64 | 818.42 | 4.37 | 36.81 | 32.42 | 26.40 |

*Data acquisition.* The BHP Pine Creek borehole was drilled using a conventional oil and gas exploration drilling rig. Borehole diameter was 200 mm and drilling fluid was a polymer based mud system. The borehole was drilled open hole to 704 m and then a continuous core was taken of the upper Coalspur Formation, including the Val D'Or/Arbour, Silkstone and Mynheer coal zones, to a total depth of 790 m. Twenty coal samples were sealed in canisters and desorbed for a period of 100 days.

Upon reaching core point, the drill string was tripped out of the hole and replaced with a wireline string. A 3-m long core barrel with a split inner tube was used for coring. The use of a wireline string and several inner tubes minimized trip times and consequently minimized the time between coring of coal and sealing samples in desorption canisters. The average trip time was 14 minutes and a further 25 minutes were required for core description and sampling.

*Geology.* The BHP Pine Creek well intersected the Upper Coalspur coal measures at a depth spanning 710.9 m to 787.7 m, a thickness of 76.8 m. Four coal zones were intersected; all of which were cored (Table 88). Total coal thickness in each zone includes coal interpreted from geophysical logs in intervals where core was lost.

The coal cored in the BHP Pine Creek well had a wide range of volatile matter content, indicating rank in the high volatile bituminous A-C range.

A thick (21.5 m) coal zone between 720.7 and 742.2 m has been assigned to the Val D'Or/Arbour zone. To the southeast (e.g., in the Peco and Pembina study areas) these two coals can be correlated as separate units, but in Pine Creek there is no clearly definable boundary. The zone contains 14.1 m of coal with common, fine-grained clastic interbeds, such as carbonaceous bentonitic and kaolinitic claystone and mudstone, as well as less common siltstone. Thirteen coal samples were taken for desorption testing and five for micropermeability analyses (Fig. 138).

The most common coal lithotype is "dull and bright", representing beds with 40–60% bright bands. Brighter lithotypes are common in the upper 8 m but rare elsewhere. In general, the brighter coal lithotypes are well cleated with distinct face cleat at a spacing of 10 to 20 mm in the upper part of the zone and more closely spaced in lower portions. Butt cleat is less common and less distinct with wider spacing. Cleat is commonly not apparent in duller lithotypes.

**Table 88**
**Coal intersections, BHP Pine Creek**

| Seam name | Top depth (m) | Base depth (m) | Total zone (m) | Net coal thickness (m) |
|---|---|---|---|---|
| Val D'Or/Arbour | 720.7 | 742.2 | 21.5 | 14.1 |
| U Silkstone | 748 | 757.8 | 9.8 | 6.4 |
| L Silkstone | 768.5 | 770.2 | 1.7 | 1.3 |
| Mynheer | 784.1 | 787.6 | 3.5 | 2.5 |

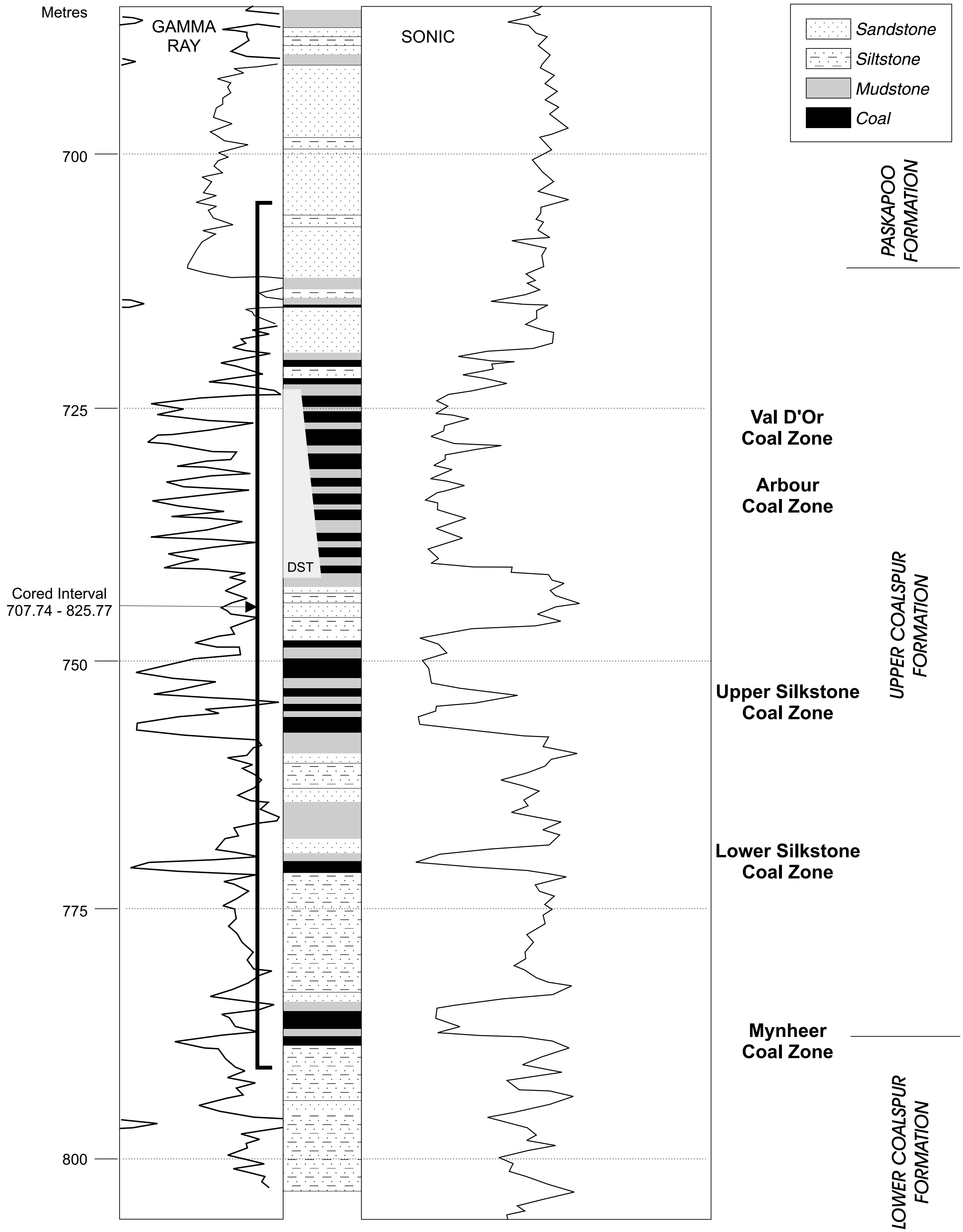


***Figure 138.*** *Detailed stratigraphic section illustrating the four major coal zones intersected in the BHP Pine Creek borehole.*

Core recovery was poor in the upper Silkstone zone, with a 2.25 m loss in the central part of the seam and two loss zones of 0.64 m each in the lower portion. Lithology was interpreted from geophysical logs, which indicated that most of the material lost in the middle of the seam was good quality coal and elsewhere comprised both coal and clastic partings. The coal was relatively dull and cleat was observed only in the top 0.6 m. Three desorption samples and three micropermeability samples were taken from this seam. The lower Silkstone zone is thin and only one sample was taken for gas desorption testing. A relatively bright coal bed at the base was well cleated with face cleat at a spacing of 5 to 10 mm.

The Mynheer zone is apparently poor quality with 1.75 m of relatively dull coal and shaly coal interbedded with common bentonitic and carbonaceous claystone. Two desorption samples were taken in this zone.

*Gas content*. Desorption samples were collected for four coal intervals, Val D'Or/Arbour, Upper and Lower Silkstone, and Mynheer. Total number of valid desorption samples was 19; 13 from the Val D'Or/Arbour zone and 3, 1 and 2 samples from the other zones, respectively. As measured gas content values are relatively low, ranging from 0.56 to 2.74 cc/g. Data are summarized in Table 89.

A comparison of as measured gas content data for all samples revealed little relationship between gas content and either coal zone or depth (Fig. 139). After "normalization" of gas content data (i.e., recalculation to an ash-free basis) most coal samples had gas contents in the 2.5 to 3.3 cc/g range, with no apparent influence from depth or coal zone (Fig. 140). The cored interval was only 70 m thick, however, and no significant rank change would be expected. Normalized gas content values for the BHP Pine Creek well were higher than at BHP Embarras, averaging 2.6 cc/g for the Val D'Or/Arbour zone, 2.6 cc/g for the Upper Silkstone, 3.1 cc/g for the Lower Silkstone (one sample only), and 2.8 cc/g for the Mynheer zone. These gas content values are consistent with Coalspur Formation coal tested in other localities in west-central Alberta. The lost gas component varied between 1 and 12% of the total gas and averaged 3%.

*Coal quality*. Coal quality data indicated that the coal of all zones averaged 40% volatile matter (dry ash free basis), which indicated a rank of high volatile bituminous B. The primary reason the gas content was low is probably that the coal was of insufficient maturity to have reached the rank window where significant quantities of thermogenic methane are generated (peak generation at about 31% volatile matter). Even though the coal had the capacity to hold significant quantities of methane gas, it had not generated sufficient gas to be adsorbed. Data indicate no significant differentiation between the major coal zones (Table 90). Volatile matter ranges from 19.06 to 35.28% (as-received) and, when recalculated to a dry-ash-free basis, ranges from 34 to 44%, with most samples indicating rank in the high volatile bituminous A to C range.

**Table 89**
**Desorption data, BHP Pine Creek**

| Seam name | Sample number | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Val D'Or/Arbour | 3 | 725.70 | 1.78 | 2.49 |
| Val D'Or/Arbour | 4 | 724.27 | 2.43 | 2.73 |
| Val D'Or/Arbour | 5 | 725.01 | 1.73 | 2.36 |
| Val D'Or/Arbour | 6 | 726.95 | 2.20 | 2.73 |
| Val D'Or/Arbour | 7 | 727.63 | 0.78 | 0.92 |
| Val D'Or/Arbour | 8 | 728.43 | 2.49 | 2.83 |
| Val D'Or/Arbour | 9 | 730.62 | 2.09 | 2.63 |
| Val D'Or/Arbour | 10 | 731.04 | 1.22 | 2.37 |
| Val D'Or/Arbour | 11 | 732.95 | 2.39 | 2.74 |
| Val D'Or/Arbour | 12 | 734.79 | 2.67 | 3.06 |
| Val D'Or/Arbour | 13 | 736.81 | 1.30 | 2.58 |
| Val D'Or/Arbour | 14 | 737.60 | 0.84 | 0.94 |
| Val D'Or/Arbour | 15 | 739.42 | 0.56 | 0.68 |
| U Silkstone | 16 | 748.05 | 1.46 | 1.88 |
| U Silkstone | 17 | 749.25 | 1.70 | 2.43 |
| U Silkstone | 18 | 754.60 | 2.54 | 3.07 |
| L Silkstone | 19 | 770.41 | 2.74 | 3.00 |
| Mynheer | 20 | 785.85 | 1.51 | 2.72 |
| Mynheer | 21 | 787.47 | 1.97 | 2.43 |

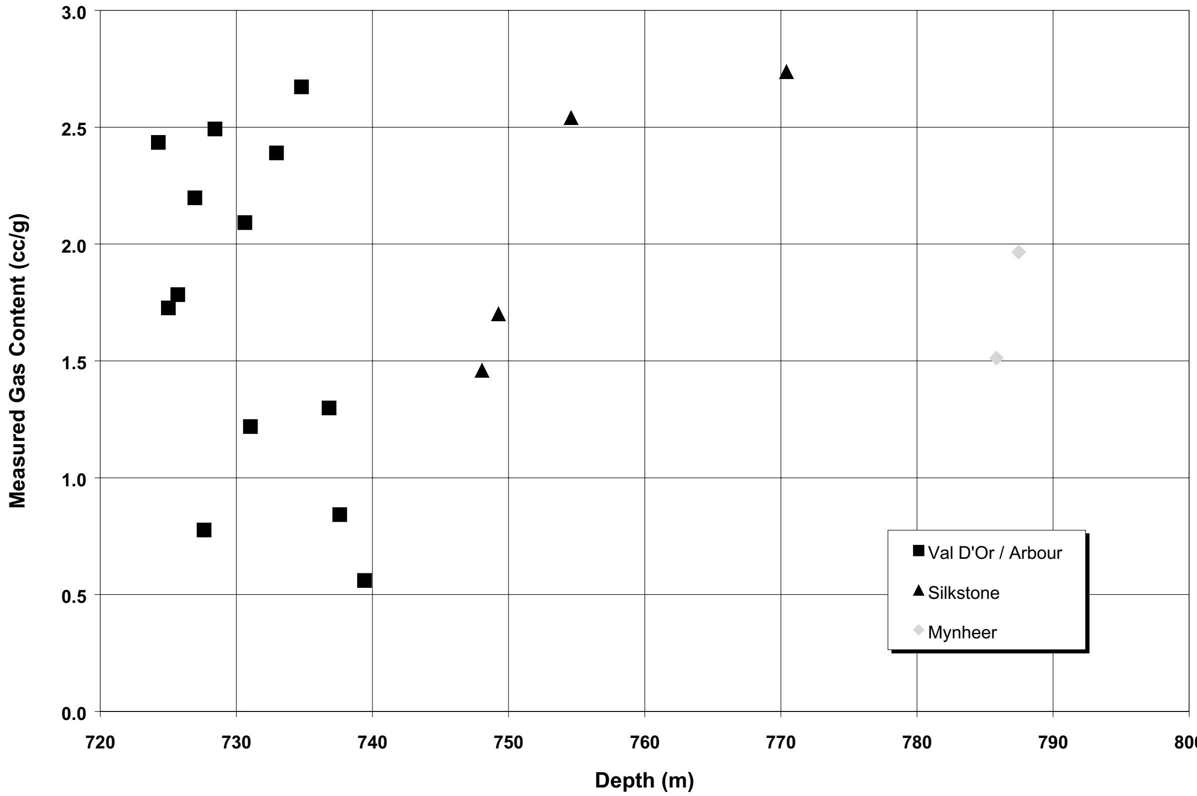


***Figure 139.*** *Measured gas content versus depth of intersection, BHP Pine Creek samples.*

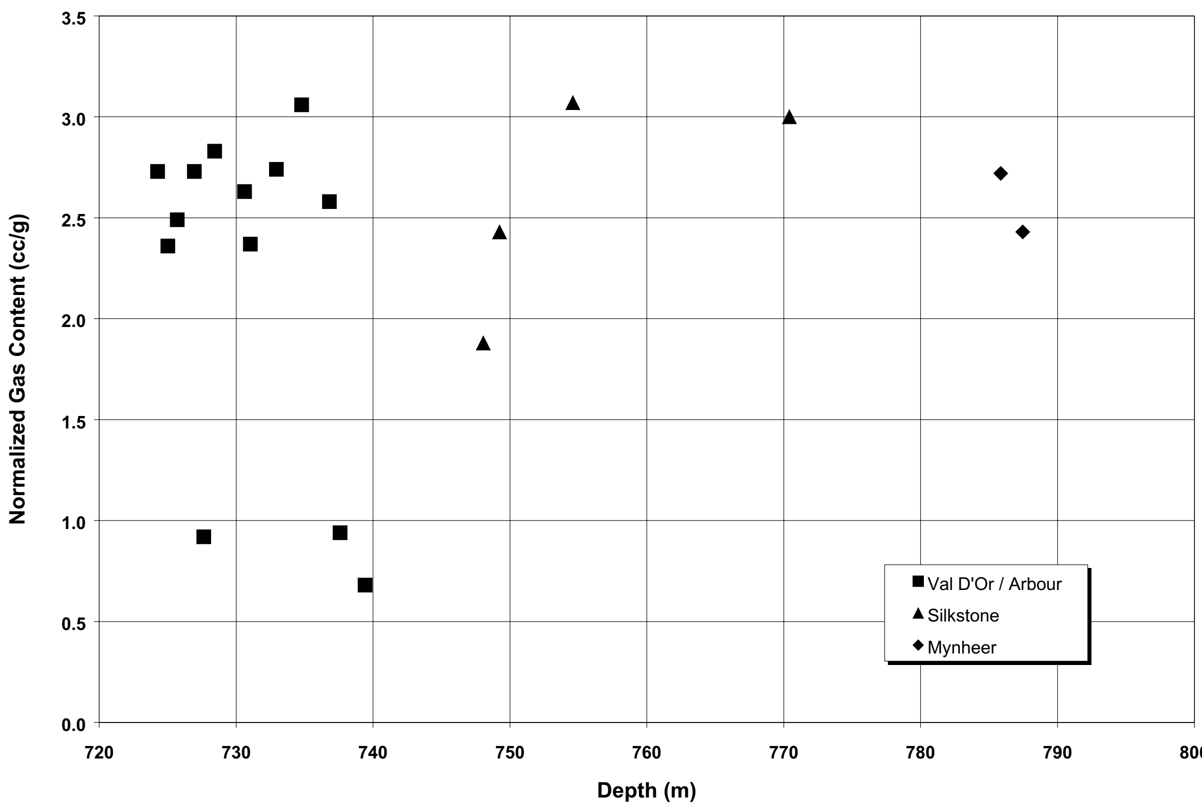


***Figure 140.*** *Normalized gas content versus depth of intersection, BHP Pine Creek samples.*

**Table 90**
**Proximate analyses, BHP Pine Creek**

| Seam name | Sample no. | Depth of intersection (m) | Moisture content (%) (a.d.b.) | Ash content (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Volatile matter (%) (a.d.b.) |
|---|---|---|---|---|---|---|
| Val D'Or/Arbour | 3 | 725.70 | 5.73 | 28.57 | 36.93 | 28.77 |
| Val D'Or/Arbour | 4 | 724.27 | 6.68 | 10.93 | 47.11 | 35.28 |
| Val D'Or/Arbour | 5 | 725.01 | 6.13 | 26.56 | 38.39 | 28.92 |
| Val D'Or/Arbour | 6 | 726.95 | 5.82 | 19.56 | 44.81 | 29.81 |
| Val D'Or/Arbour | 7 | 727.63 | 5.68 | 15.13 | 47.09 | 32.10 |
| Val D'Or/Arbour | 8 | 728.43 | 5.75 | 12.09 | 48.73 | 33.43 |
| Val D'Or/Arbour | 9 | 730.62 | 5.49 | 20.42 | 43.63 | 30.46 |
| Val D'Or/Arbour | 10 | 731.04 | 4.54 | 48.51 | 26.31 | 20.64 |
| Val D'Or/Arbour | 11 | 732.95 | 5.49 | 12.89 | 49.78 | 31.84 |
| Val D'Or/Arbour | 12 | 734.79 | 5.03 | 12.64 | 52.04 | 30.29 |
| Val D'Or/Arbour | 13 | 736.81 | 3.87 | 49.56 | 27.51 | 19.06 |
| Val D'Or/Arbour | 14 | 737.60 | 5.29 | 10.55 | 52.31 | 31.85 |
| Val D'Or/Arbour | 15 | 739.42 | 4.68 | 17.63 | 48.85 | 28.84 |
| U Silkstone | 16 | 748.05 | 5.62 | 22.33 | 47.51 | 24.54 |
| U Silkstone | 17 | 749.25 | 5.06 | 30.12 | 40.32 | 24.50 |
| U Silkstone | 18 | 754.60 | 5.08 | 17.38 | 48.26 | 29.28 |
| L Silkstone | 19 | 770.41 | 4.61 | 8.55 | 53.66 | 33.18 |
| Mynheer | 20 | 785.85 | 3.75 | 44.40 | 31.44 | 20.41 |
| Mynheer | 21 | 787.47 | 5.23 | 18.88 | 43.70 | 32.19 |

The as-received ash range is 8.55 to 49.56%, with an average value of 22.6%. The high values indicate that in many cases, thin inorganic partings have been included in the samples placed in desorption canisters. This is inevitable when lengths of continuous core are the preferred samples for desorption testing. Moisture content is primarily between 4 and 7%. Hardgrove grindability indices are similar for most samples and generally range from 46 to 57. Sample 16 is higher at 66. Sulphur content (air dried basis) is generally low, ranging from 0.09 to 0.31%, except for Sample 2, which is much higher at 0.81%.

Gas composition appears to be predominantly methane (>74%) and there is some indication that the samples were contaminated with air. Gas analyses from similar coal at Pembina contained as much as 99% methane.

*Formation testing.* Pine Creek was the first well drilled by BHP in their appraisal program. Following completion of the drilling, several wellbore tests were completed. A conventional drillstem test was run over the main Val D'Or/ Arbour coal zone. Results from the test indicated that the coal zone was relatively tight and had permeability values of less than 10 mD. Subsequently, an injection test was completed on the borehole. Permeability results from this test indicated that the coal had a reservoir permeability of 15 to 20 mD. Further analysis of data suggested that the reservoir had actually been fractured during the injection test, and that true reservoir permeabilities were less, probably between 5 and 10 mD.

*Technical assessment.* Lower than expected gas content values coupled with high ash content of the coal tends to downgrade the exploration viability of the BHP Pine Creek methane exploration target. The Coalspur Formation has the potential for significant coal reserves ($80x10^6$ tonnes per sq mile) but the low gas content results in the in-situ gas resources being low, averaging less than 4.9 Bcf/section. The coal was highly cleated, with calcite deposited in the fracture faces. Even though the results of the injection test were invalidated by the fracturing of the coal, permeability appeared to be good at between 5 and 10 mD. If areas of gas storage enhancement could be found, the reservoir producibility might be high enough to obtain reasonable gas production.

## BHP Petroleum Embarras project

BHP Petroleum (Canada) Inc. drilled a coalbed methane exploration borehole (BHP Embarras) southeast of the village of Weald in west-central Alberta in February 1995 as part of a four-well appraisal program (Fig. 141). The borehole targeted thick coal of the Tertiary Coalspur Formation. Three coal zones, Val D'Or B-D, Arbour, and Mynheer were cored and sampled for gas content, gas composition, and coal quality. Total cumulative zone thickness of the cored coal was 13.1 m, of which net coal thickness was 10.5 m. An upper split of the Val D'Or coal zone and two splits of the Silkstone zone were intersected in the non-cored portions of the well. Geophysical logs

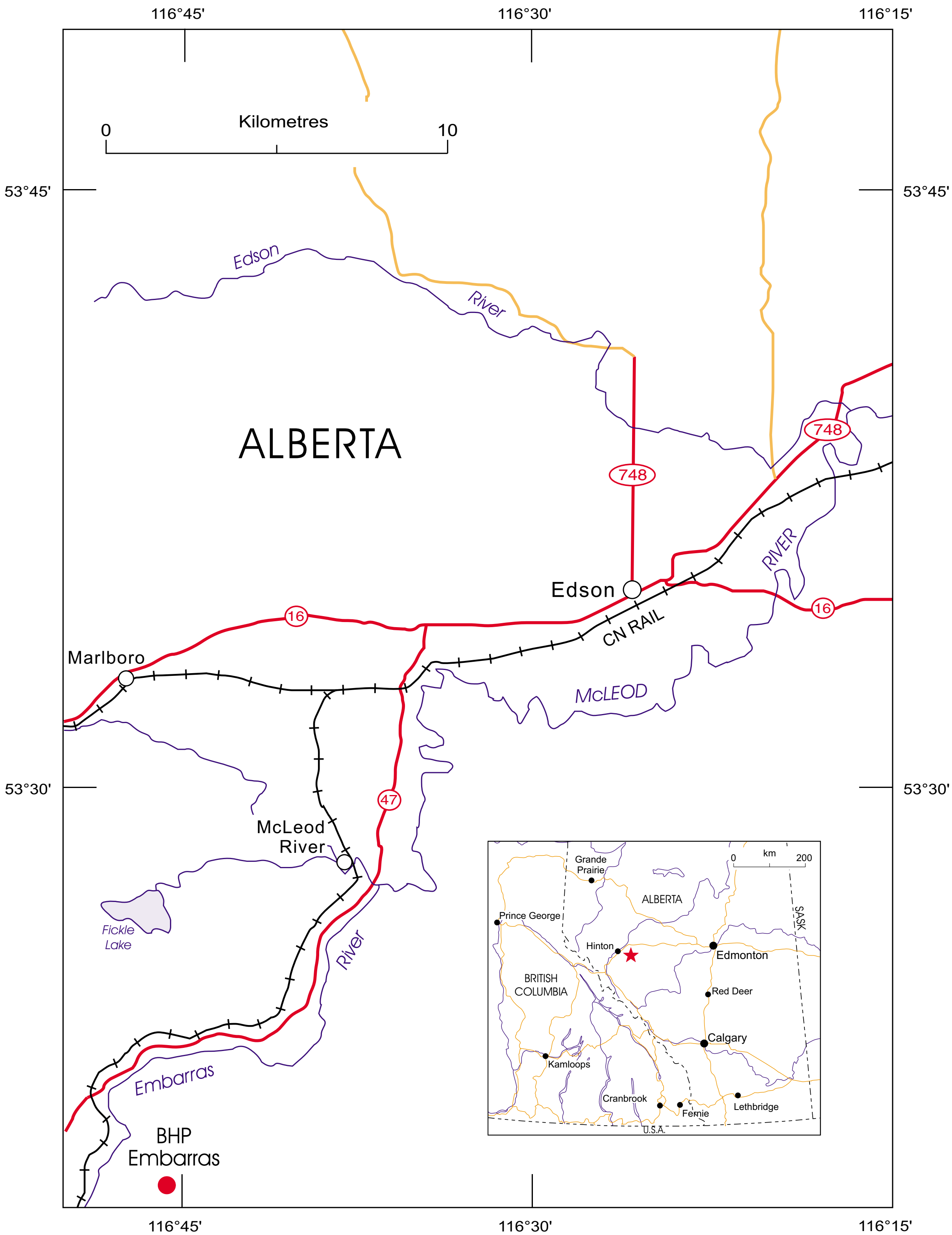


***Figure 141.*** *General location map of the BHP Embarras (10-19-50-19W5M) borehole.*

indicated a total coal zone thickness of 12.3 m, of which 6.8 m was coal. For the lower Coalspur Formation, total coal thickness was 17.3 m in the Embarras well.

*Data acquisition.* The BHP Embarras borehole was drilled using a conventional oil and gas exploration drilling rig. Borehole diameter was 200 mm and drilling fluid was a polymer based mud system. The borehole was drilled open hole to 546 m, and then a continuous core was taken of part of the upper Coalspur Formation, including the Val D'Or and Arbour coal zones, to a depth of 609 m. A second cored interval (679–704 m) recovered the Mynheer coal zone at the base of the upper Coalspur Formation.

Upon reaching core point, the drill string was tripped out of the hole and replaced with a wireline string. A 3 m core barrel with a split inner tube was used for coring. The use of a wireline string and several inner tubes minimized trip times and consequently reduced the time between coring of coal and sealing samples in desorption canisters. Typical trip times were 10 to 15 minutes, and a further 30 to 40 minutes were required for core description and sampling.

The coal core was photographed and described in detail, and selected samples were placed in desorption canisters to determine gas content. Thirteen coal samples were sealed in canisters and desorbed for 100 days.

*Geology.* The BHP Embarras well intersected the Coalspur coal measures at a depth of between 506 and 702 m, a thickness of 196 m. Seven coal seams in four zones were intersected and three zones were cored (Fig. 142; Table 91). Net coal thickness in each cored zone included coal interpreted from geophysical logs in intervals where core was lost, with the exception of the Mynheer zone. Despite repeated attempts, it was not possible to run the logging tools below the uppermost part of the Mynheer seam and consequently, an interval of 0.83 m near the top of the seam (Fig. 142) could not be interpreted. The net coal thickness in this zone should be considered a minimum value. Table 91 also lists coal thicknesses interpreted from logs in coal seams penetrated in the non-cored sections of the well.

The coal cored in the Embarras well is of high volatile bituminous B–C rank. In general, the seams are relatively dull, and bright, and banded, bright lithotypes are rare. The seams contain numerous thin clastic partings, which is reflected by the relatively high ash values determined on most of the canister samples.

Many of the clastic interbeds in the Mynheer coal zone are bentonitic. Swelling of these units might be responsible for failure to lower logging tools below the top of this seam. The lithology in the 0.83 m core loss near the top of the seam cannot be interpreted, as logs are not available.

In general, the brighter coal lithotypes are well cleated with distinct face cleat at a spacing of 5 to 10 mm and less common and less distinct butt cleat with a spacing of 10 to 15 mm. Cleat is not usually apparent in duller lithotypes and where present, is more widely spaced. Large fractures commonly developed in the cores along the face cleat direction. This was probably because of shearing caused by rotational effects within the barrel during drilling.

*Gas content.* Desorption samples were collected for three coal intervals: Val D'Or, Arbour, and Mynheer. The total number of canisters was 13, with seven from the Val D'Or and four and two taken from the other two seams, respectively. Three of the samples were taken from bagged chips, or from the shale shaker, several hours after the seams had been drilled.

Desorption data for these three samples are considered unreliable and not tabulated in this report. The trip time for sample 25 was long (almost five hours) and because of very low desorbed gas volume, the temperature of desorption was not increased, resulting in data considered to be unreliable. Table 92 summarizes the desorption data for the nine valid samples. The desorption results indicate that "as-received"

**Table 91**
**Coal intersections, BHP Embarras**

| Seam name | Top depth (m) | Base depth (m) | Total zone (m) | Net coal thickness (m) |
|---|---|---|---|---|
| Val D'Or A* | 516.1 | 524.2 | 8.1 | 4.4 |
| Val D'Or B–D | 558.7 | 560.9 | 2.2 | 1.8 |
| Arbour | 599.7 | 604.3 | 4.6 | 3.4 |
| Upper Silkstone* | 632.1 | 632.8 | 0.7 | 0.7 |
| Lower Silkstone* | 658.8 | 662.3 | 3.5 | 1.7 |
| Mynheer | 693.3 | 699.6 | 6.3 | 5.3 |

*Coal intersections not cored.

**Table 92**
**Desorption data, BHP Embarras**

| Seam name | Sample no. | Depth of intersection (m) | Measured gas content (cc/g) | Normalized gas content (cc/g) |
|---|---|---|---|---|
| Val D'Or B–D | 26 | 552.53 | 0.75 | 1.29 |
| Val D'Or B–D | 27 | 558.73 | 1.26 | 1.96 |
| Val D'Or B–D | a | 559.30 | 0.90 | 1.28 |
| Arbour | 37 | 600.57 | 1.94 | 2.43 |
| Arbour | 38 | 602.49 | 1.90 | 2.15 |
| **Arbour** | 39 | 602.70 | 1.75 | 2.31 |
| **Arbour** | 40 | 604.00 | 1.40 | 1.91 |
| **Mynheer** | 41 | 698.20 | 1.70 | 2.07 |
| **Mynheer** | b | 694.93 | 0.58 | 1.02 |

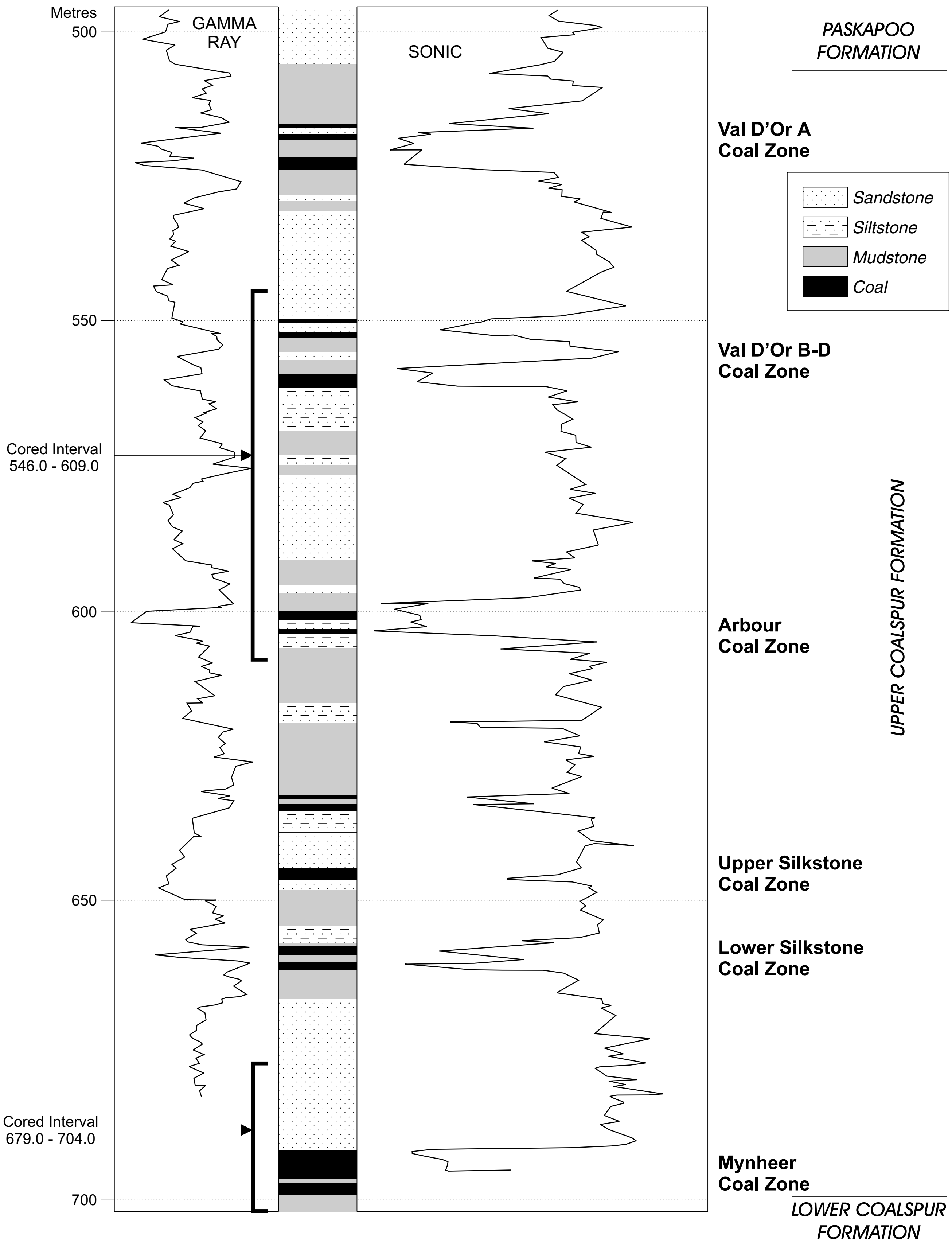


***Figure 142.*** *Detailed stratigraphic section illustrating the four major coal zones intersected in the BHP Embarras borehole.*

gas content was relatively low, ranging from 0.58 to 1.94 cc/g. The lost gas component generally varied between 1 and 6% and averaged 3% of the total gas content. Consequently, any potential errors in the lost gas component probably would not contribute significantly to errors in estimation of total gas. Canister 25 has a lost gas component of 28%, reflecting the long time (almost five hours) between coring and sealing the sample.

A comparison of as-received gas content data for all samples revealed that the average for the Arbour zone was somewhat higher than that for the Val D'Or and Mynheer zones and there was no apparent relationship between gas content and depth (Fig. 143). Average gas content for the Arbour zone was 1.75 cc/g, whereas the Val D'Or and Mynheer were 0.97 and 1.14 cc/g, respectively. When the desorption data were normalized to a dry ash free basis (d.a.f., Fig. 144), the Arbour seam still showed a higher average gas content (2.32 cc/g) than the Val D'Or and Mynheer (1.61 and 1.63 cc/g, respectively) and there was no relationship with depth. The depth interval was relatively small (145 m) and it is unlikely that there would be any rank change through the cored interval. The Arbour values were higher than for the shallower Val D'Or seam, as might be expected. However, values in the deeper Mynheer were lower than in the Arbour. This suggests that factors other than rank and dilution by ash, such as those related to coal composition or permeability, influenced the gas content. Low gas content in the Mynheer zone has been reported from other appraisal wells in the Alberta Plains.

Measured gas content was relatively low, ranging from an average of 0.97 cc/g in the Val D'Or coal zone to 1.14 cc/g for the Mynheer zone and 1.75 cc/g for the Arbour zone (all on an as-received basis). The gas content appeared to be lower than expected and, as has been reported elsewhere, the Mynheer coal zone at the base of the section appeared to have a gas content even lower than expected relative to the other coal zones. Only nine desorption samples were considered valid from this well, so these conclusions are based on a small data set. As expected, there is a strong inverse relationship between as-received gas content and ash (Fig. 145).

*Coal quality.* Following completion of desorption measurements, all coal samples were sent to Loring Laboratories for proximate analyses. The analytical results are presented in Table 93. Volatile matter (d.a.f.) ranged between 23.26 and 43.10%, indicating coal rank of high volatile bituminous B to C. Most samples had relatively high ash contents, most likely because of the presence of thin, inorganic interbeds within the sampled cores. The Val D'Or samples had higher ash contents (30 to 40% a.d.b.) and the Arbour coal had lower ash contents, ranging from 11 to 27%. The two Mynheer samples had different ash contents (17.98 and 43.10%). Moisture content ranged between 3.33 and 4.24% and averaged 3.92%. Hardgrove grindability indices were similar for all samples, ranging between 49 and 53, and sulphur content was generally low (0.16 to 0.40% a.d.b.), except for Canister 26, which had a higher sulphur content of 0.66%.

*Formation testing.* The low gas content obtained from the canister tests indicated to the operators that no formation tests need be conducted on the coal zones in this borehole. The borehole was subsequently plugged and abandoned.

*Technical assessment.* The BHP Embarras well was drilled to assess the coalbed methane potential of the Coalspur Formation in west-central Alberta within a relatively small acreage held by BHP Canada Ltd. The borehole intersected the upper Coalspur Formation coal measures at a depth ranging from 506 to 702 m. Four coal zones were penetrated, three of which, the Val D’Or, Arbour, and Mynheer, were cored and sampled. Cored coal zone thicknesses ranged from 2.2 m to greater than 6.3 m. Total net coal thickness for the cored portion of the Coalspur Formation was 10.5 m. In the non-cored sections, geophysical logs indicated another three coal seams (portions of the Val D'Or and Silkstone coal zones), which contained a net coal thickness of 6.8 m.

**Table 93**
**Proximate analyses, BHP Embarras**

| Seam name | Sample no. | Depth of intersection (m) | Moisture content (%) (a.d.b.) | Ash content (%) (a.d.b.) | Fixed carbon (%) (a.d.b.) | Volatile matter (%) (a.d.b.) |
|---|---|---|---|---|---|---|
| Val D'Or B–D | 26 | 552.53 | 3.01 | 41.75 | 30.42 | 24.82 |
| Val D'Or B–D | 27 | 558.73 | 3.77 | 35.63 | 34.95 | 25.65 |
| Val D'Or B–D | a | 559.30 | 4.83 | 29.72 | 39.35 | 26.10 |
| Arbour | 37 | 600.57 | 4.00 | 20.16 | 46.16 | 29.68 |
| Arbour | 38 | 602.49 | 3.89 | 11.54 | 52.55 | 32.02 |
| Arbour | 39 | 602.70 | 4.42 | 24.23 | 42.56 | 28.79 |
| Arbour | 40 | 604.00 | 3.80 | 26.86 | 40.78 | 28.56 |
| Mynheer | 41 | 698.20 | 3.33 | 17.98 | 45.04 | 33.65 |
| Mynheer | b | 694.93 | 4.24 | 43.10 | 29.40 | 23.26 |

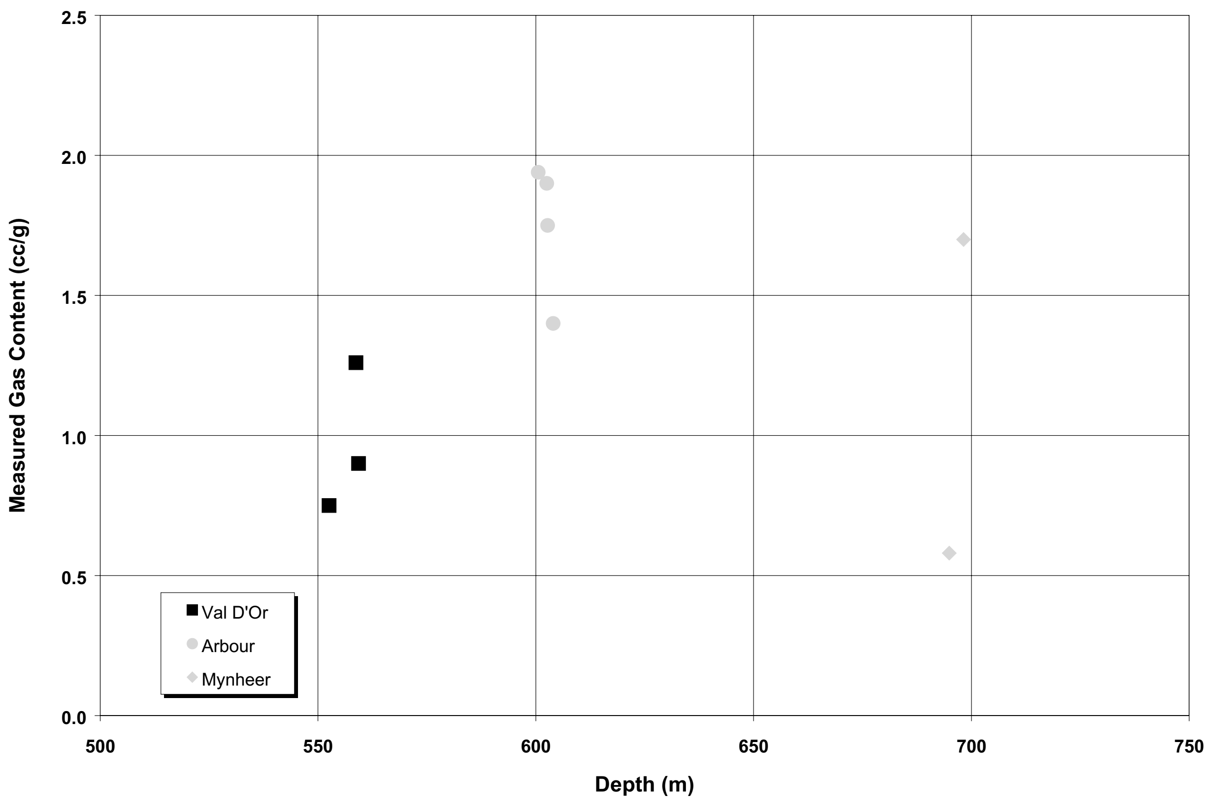


***Figure 143.*** *Measured gas content versus depth of intersection, BHP Embarras samples.*

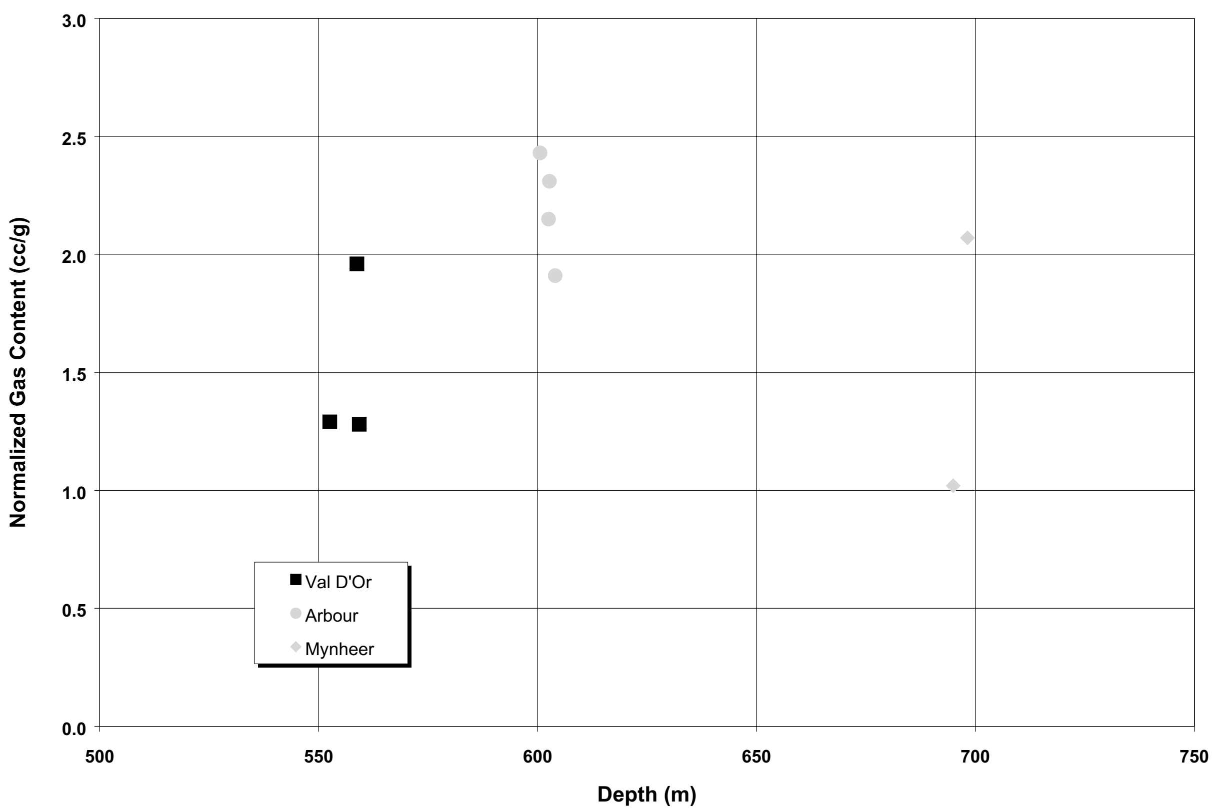


***Figure 144.*** *Normalized gas content versus depth of intersection, BHP Embarras samples.*

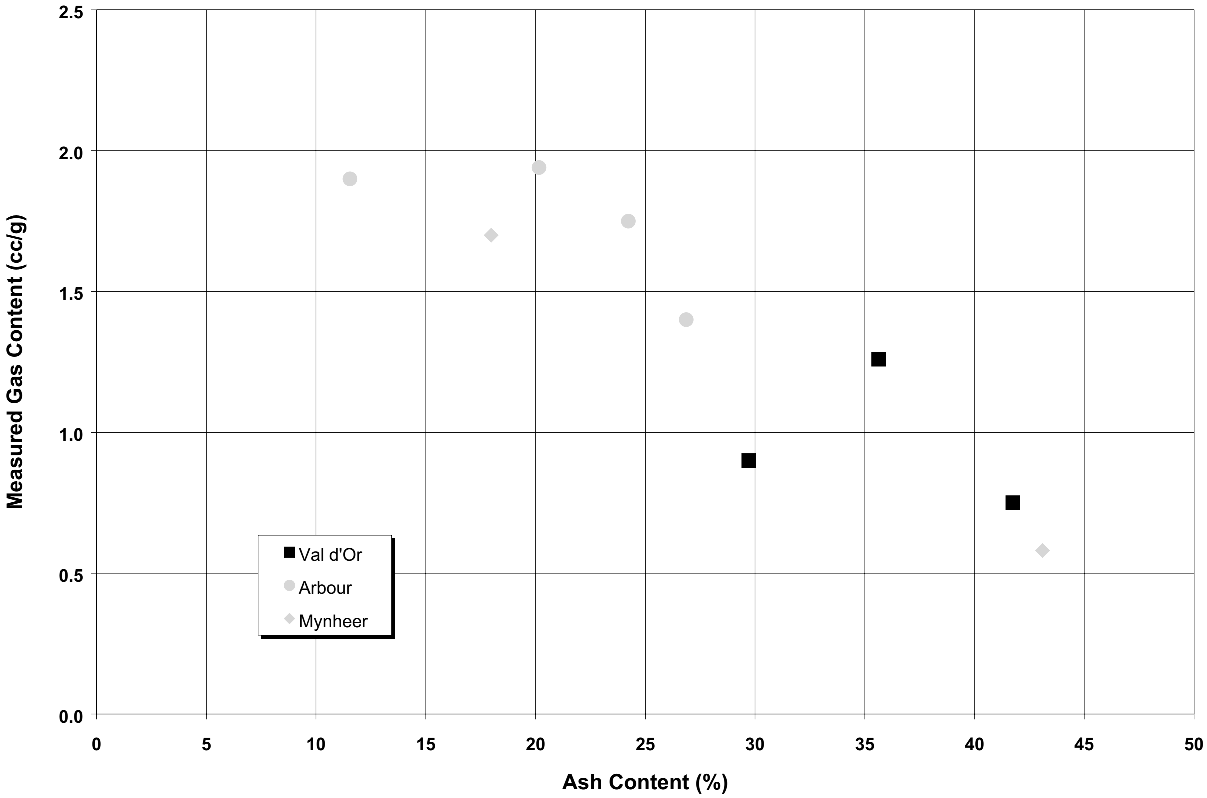


***Figure 145.*** *Measured gas content versus ash content (a.d.b.), BHP Embarras samples.*

In-situ gas desorption results were disappointing, with highest values recorded from the Arbour coal zone (average 1.75 cc/g; a.d.b.). Val D'Or samples averaged 0.97 cc/g and the Mynheer zone, 1.14 cc/g. Ash content values for the samples were generally high and variable, ranging from 11.54 to 43.10% and averaging 27.9%. Overall results indicated that the Mynheer coal zone, although somewhat deeper at the base of the section, had lower gas content than coal of the Arbour zone. Ash contents in the Arbour zone samples were low compared to the other zones, and this might account for higher gas values, even after correcting for ash content. Relatively low gas content has been reported for the Mynheer seam in other locations, so the controlling factors might also be related to coal composition or permeability.

The low gas content values, coupled with the relatively high ash content of the coal suggest that the coalbed methane potential for the BHP Embarras well is low, even though significant coal resources are present within the upper Coalspur Formation.

## Alberta Energy Company Columbia project

Alberta Energy Company drilled two wells in the Brazeau River area, northwest of Nordegg, in 1991 (Fig. 146). Columbia 1 (1-34-45-15W5) was specifically targeted for coalbed methane assessment, with plans to core four coal zones in the Tertiary upper Coalspur Formation and conduct formation testing on each zone. The second well (Columbia 2; 8-28-45-15W5) was drilled for conventional hydrocarbon purposes and coal cuttings were collected from the upper Coalspur Formation to provide basic coalbed methane-related data.

Three fully desorbed coal core samples from Columbia 1 yielded total gas content values ranging from 4.1 to 5.0 cc/g (as received), which are in accordance with the low rank of the coal (high volatile bituminous C; Ro 0.52%). In Columbia 2, cuttings samples yielded gas contents of 0.22 to 2.4 cc/g.


***Figure 146.*** *General location map of Alberta Energy Company's exploration boreholes: AEC Columbia No. 1, 01-34-45-15W5M; AEC Columbia No. 2, 08-28-45-15W5M.*

*Data acquisition.* Both wells were drilled with petroleum rigs. Columbia 1 was fitted with wireline coring equipment to facilitate recovery of four targeted coal zones. Coring commenced below the first target coal and only three zones were recovered (Fig. 147). Representative samples of the three cored coal zones were desorbed in 12 canisters at 25$^{o}$C. Lost gas times were relatively short. Residual gas content and proximate analysis were determined on only three samples. Two closed chamber drillstem tests were performed on the No. 2 and No. 3 coal zones.

In Columbia 2, cuttings were collected from the interval 529.5 to 602 m, which includes three significant coal zones, and were desorbed in five canisters.

*Geology.* The target coal occurs in the upper Coalspur Formation, a Tertiary sequence of interbedded siliclastics and regionally correlatable coal, which forms a clastic wedge thinning from west to east on the western margin of the Western Canada Basin. The upper Coalspur is up to 275 m thick and contains up to six major coal zones with cumulative coal thicknesses of up to 40 m (Fig. 147).

In Columbia 1, coal was intersected in the interval from 325.10 to 433.65 m and was correlated with Coalspur stratigraphy established in subsurface studies in the BHP Brazeau River project (Table 94). Net coal thickness in the sequence is 13.51 m and the most attractive intervals were the Val D'Or C–D, Arbour, and Silkstone. It is possible that the Val D'Or C and D and Arbour zones could be commingled into a single gas production zone to yield 6.91 m of net coal in a stratigraphic interval of 21.78 m.

In Columbia 2, the coal-bearing strata occurs at depths ranging from 530.2 to 652.5 m, and correlation with the coal zones in Columbia 1 is problematic. The depth of intersection is anomalous, given that the difference in kelly bushing of the two wells is only 20 m. The wells are in close proximity to each other. In Columbia 1, thinner coal seams, which may be Maastrichtian coal seams of the lower Coalspur Formation, lie below what has been called the Mynheer zone. Net coal thickness is about 11.5 m. The most prospective coal zones are Val D'Or C–D, Arbour, and Silkstone with net coal thicknesses of 4.2, 2.5, and 2.5 m within intervals of 6.4, 4.5, and 3.1 m, respectively.

*Gas content.* In Columbia 1, 12 samples from four major coal zones were desorbed (Table 95). Measured gas content ranged from 1.2 to 5.0 cc/g. Ash content was determined on only three samples and normalized gas content ranged from 4.3 to 6.0 cc/g. Residual gas content was determined on only three samples (6, 7, and 11, Table 95). The residual gas component was high (60 to 80% of desorbed gas) and consequently had a significant impact on total gas content. It could be expected that the gas content of the other seven samples in this well would be increased by at least 60% if the residual gas content had been measured. The mean gas content of the three fully desorbed samples was 4.5 cc/g, whereas for the remaining samples it was 2.1cc/g. The total gas content was revealed in only three samples, and ranged from 4.1 to 5.0 cc/g (4.3 to 6.0 cc/g ash free). Three gas analyses from Canisters 6, 7 and 11 yielded methane contents from 91 to 98%.

In Columbia 2, all samples were derived from cuttings, which are known to have a high diffusion rate that most likely leads to significant underestimation of lost gas and consequently of total gas content. It is not clear if residual gas was determined but it appears unlikely. All but one of the samples was "cleaned" and if this were done with a heavy liquid to remove inorganic material it is likely that micropores were choked and desorption suppressed. All these factors lead to a severe underestimation of total gas content; tabulated data represent minimum gas content only.

*Coal quality.* Vitrinite reflectance analyses indicated rank of high volatile bituminous C (sub-bituminous A) in both wells, with rank lower in Columbia 2, despite the deeper intersection of the coal. Volatile matter content also indicated the same rank. Coal at this level of maturity is in the earliest stages of thermogenic gas generation, so gas content is expected to be low. As expected with random samples, ash content was variable, ranging from 5.2 to 48.7%.

**Table 94**
**Coal zones, AEC Columbia wells**

| Coal zone | Columbia 1 (1-34-45-15W5) | | | Columbia 2 (8-28-45-15W5) | | |
|---|---|---|---|---|---|---|
| | Interval (m) | Thickness (m) | Net coal (m) | Interval (m) | Thickness (m) | Net coal thickness (m) |
| Val D'Or A | 325.10-325.82 | 0.72 | 0.57 | 530.20-530.80 | 0.60 | 0.60 |
| Val D'Or B | 333.55-334.06 | 0.51 | 0.46 | 536.70-537.20 | 0.50 | 0.50 |
| Val D'Or C | 350.22-352.22 | 2.00 | 1.89 | 554.40-556.30 | 1.90 | 1.60 |
| Val D'Or D | 352.82-357.12 | 4.30 | 2.52 | 557.20-560.60 | 3.40 | 1.50 |
| Arbour | 368.12-372.00 | 3.88 | 2.50 | 577.80-582.30 | 4.50 | 2.50 |
| Silkstone | 390.75-393.42 | 2.67 | 2.47 | 602.70-605.80 | 3.10 | 2.50 |
| Mynheer | 424.15-433.65 | 9.50 | 3.10 | 639.70-652.50 | 12.80 | 2.30 |
| Total | | | 13.51 | | | 11.50 |

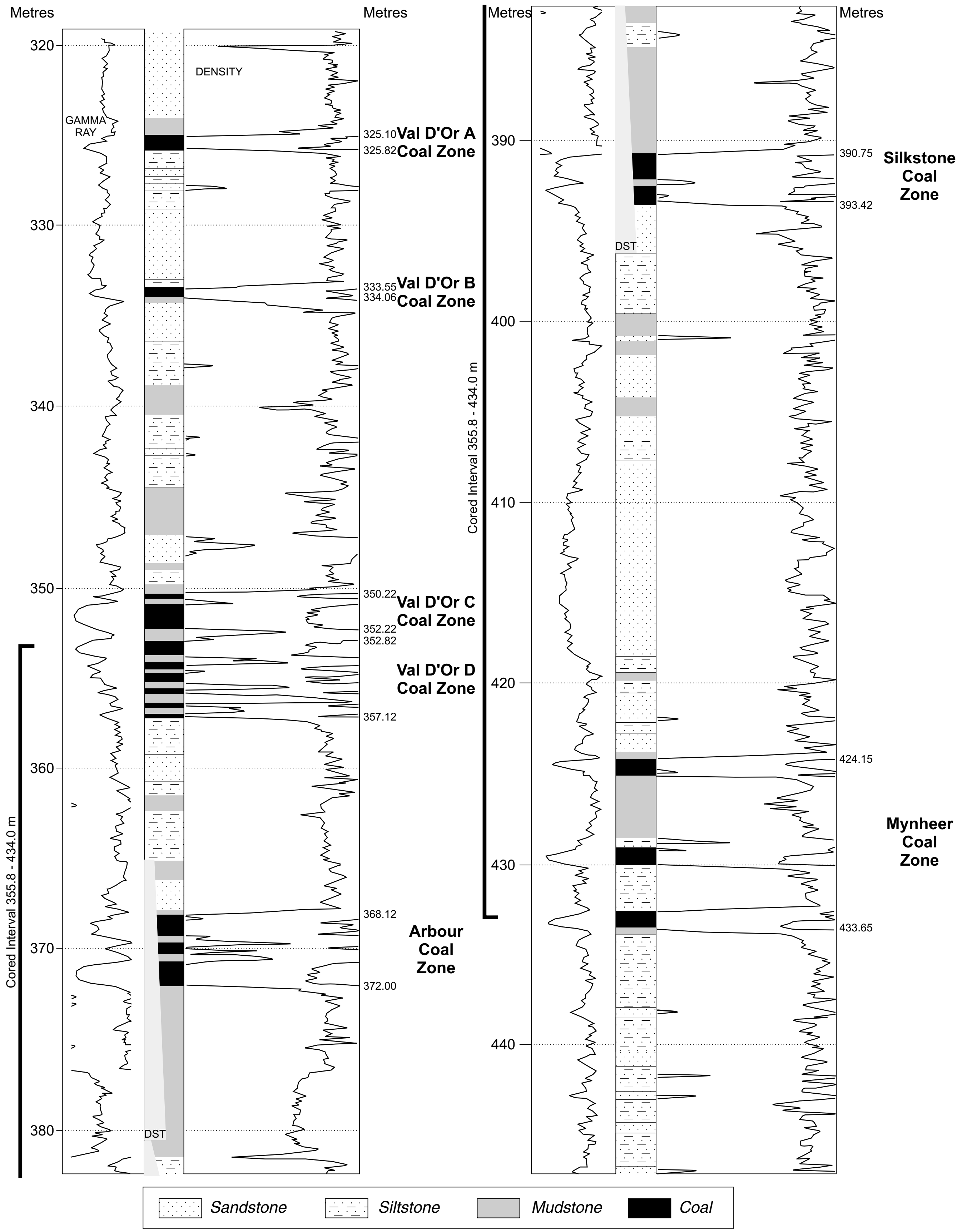


***Figure 147.*** *Detailed stratigraphic section of the AEC Columbia No. 1 borehole.*

**Table 95**
**Desorption data, AEC Columbia wells**

| Coal zone | Canister | Top (m) | Thickness (m) | Sample type | Measured gas (a.r.) (cc/g) | Ash (%) (a.r.) | Normalized gas (a.f.) (cc/g) |
|---|---|---|---|---|---|---|---|
| **1-34-45-15W5** | | | | | | | |
| Val D'Or D | 1 | 355.8 | 0.2 | Core | 1.9 | | |
| Val D'Or D | 2 | 358 | 0.4 | Core | 1.9 | | |
| Arbour | 3 | 368.4 | 0.3 | Core | 1.2 | | |
| Arbour | 4 | 369.3 | 0.3 | Core | 2.1 | | |
| Arbour | 5 | 371.1 | 0.3 | Core | 2.5 | | |
| Arbour | 6 | 372.3 | 0.3 | Core | 4.5* | 5.2 | 4.7* |
| Silkstone | 7 | 391.7 | 0.3 | Core | 5.0* | 17 | 6.0* |
| Silkstone | 8 | 392.1 | 0.3 | Core | 2.3 | | |
| Silkstone | 9 | 393.1 | 0.3 | Core | 2.3 | | |
| Mynheer | 10 | 424.9 | 0.3 | Core | 2.5 | | |
| Mynheer | 11 | 430.1 | 0.3 | Core | 4.1* | 5.3 | 4.3* |
| Mynheer | 12 | 433.7 | 0.3 | Core | 2.2 | | |
| **8-28-45-15W5** | | | | | | | |
| Val D'Or A | 1 | 529.5 | | Cuttings | 1.6 | 32 | 2.4 |
| Val D'Or B | 2 | 542 | | Cuttings | 0.2** | | |
| Val D'Or C | 3 | 554 | | Cuttings | 2.4** | 23.3 | 3.1** |
| Val D'Or D | 4 | 577 | | Cuttings | 1.9** | 23.3 | 2.5** |
| Arbour | 5 | 602 | | Cuttings | 1.0** | 48.7 | 1.9** |

* Residual gas determined; ** samples "cleaned".

*Adsorption isotherms.* No isotherm tests were performed in either well.

*Formation testing.* In Columbia 1 (1-34-45-15W5) two closed-chamber tests were run over the Arbour and Silkstone coal zones (Table 96). The tests were run separately with 15.89 m perforated pipe set across the entire coal zone. In the Arbour zone, mechanical problems required that the test be run with three flow and two shut-in periods. In the Silkstone zone, the planned test program was run with two flow and two shut-in intervals. Pressure data indicated that the Silkstone is underpressured; data were inconclusive for the Arbour. Total testing time was four and seven hours, respectively.

For both intervals there was little inflow, and pressure buildup was slow. This indicated that permeability was low, estimated at < 0.1mD in both zones. Low gas flow rates were determined during the preflow period in both tests.

No formation tests were conducted in Columbia 2.

*Technical assessment.* The Columbia 1 borehole appears to have been well planned and supervised by experienced staff. Twelve cored samples were obtained for gas testing. However, it is unfortunate that residual gas and proximate analyses were determined on only three samples. The gas content values determined for these three samples are the only true in-situ gas values, as all other samples provide only minimum values. The low gas content determined is, as might be expected, derived from coal of low rank (high volatile bituminous C) that is well below the maturation levels at which peak gas generation occurs.

The gas content values from cuttings (Columbia 2) are significantly lower than those derived from core in Columbia 1. As the cuttings were derived from greater depths than the cores, and the coal is of similar rank, theoretically the gas content should be higher in Columbia 2 than in Columbia 1. The high rate of diffusion from cuttings and "cleaning" of the samples (presumably in heavy liquid) both led to the underestimation of gas content. Consequently, the gas content determined in this well

**Table 96**
**Formation tests, AEC Columbia 1**

| Coal zone | DST number | Depth (m) | Permeability (mD) | Initial pressure (kPa) | Final pressure (kPa) | Flow rate ($m^3$/d) | Recovery |
|---|---|---|---|---|---|---|---|
| 2 | 1 | 365.1-381.0 | < 0.1 | 266 | 828 | 7 | 14 m water |
| 3 | 2 | 380.6-396.5 | < 0.1 | 302 | 732 | 8 | 16 m water |

represents minimum values only. Rank can be accurately assessed with vitrinite reflectance analysis on cuttings.

The formation testing was performed with only minor technical problems, which have probably not affected results significantly. Although formation test times were relatively short for adequately evaluating coal reservoirs, the low permeability determined would probably not be significantly increased by extended testing.

The low rank of the coal and the low gas content determined in the three Columbia 1 samples indicates little economic coalbed methane potential in the immediate area.

## Canadian Hunter Red Rock project

The Red Rock (Fig. 148) well, which was drilled in 1984, was not intended for coalbed methane assessment. Flow testing was performed through perforations within a major coal zone and gas was collected for analysis from coal cuttings. The coal seam was also cavitated. However, problems within the well prevented flow testing following the cavitation. No desorption tests were performed.

*Data acquisition.* This well was intended for conventional hydrocarbon assessment. It was drilled with gel chem from surface to 456 m where the circulating fluid was changed to invert mud. Cores were cut in the Chinook and Cadotte formations and drillstem tests were performed in the Cadotte, Fahler, Gething and Cadomin formations.

A major coal seam at 3066 to 3074 m was stimulated and tested for gas flow rates and was later cavitated.

*Geology.* A coal bearing interval was intersected between 2971 and 3127.7 m (Fig. 149), most probably within the Falher Member of the Lower Cretaceous Gates Formation. Net coal thickness was about 11 m, with abundant carbonaceous beds.

*Gas content.* No desorption tests were conducted in this well. Gas was collected from coal cuttings for compositional analyses, which yielded methane content of 51 and 50%, suggesting high levels of air contamination.

*Formation testing.* A 3 m perforated zone was established between 3069 and 3072 m within a major coal seam. The test zone was apparently stimulated with acid and surfactant followed by ball sealers and a radioactive tracer sand. Flow capacity was estimated to be extremely low at 0.00085mD with a skin factor of 1.5 m. The initial flow rate was about 80 mcf/d dry gas, then decreased to about 23 mcf/d. Production following stimulation was estimated at 193 Mcf/d in the first year.

A jetting tool was used to create a cavity within this coal zone and coal recovery was monitored. The intention was to conduct flow tests following cavitation. However, problems with equipment jamming in the hole precluded further testing.

*Adsorption isotherms.* No isotherm testing was conducted.

*Technical assessment.* This well was not intended for coalbed methane purposes and little information relevant to coalbed methane was generated.

Low permeability is to be expected at the depth tested (3070 m) and economic coalbed methane extraction is unlikely. The use of invert mud for circulation might have contributed to the low permeability.

## Alberta Energy Company Karr project

Alberta Energy Company drilled the Karr well for conventional hydrocarbon assessment in the Alberta Deep Basin (Fig. 150). Cuttings were collected from coal in the Lower Cretaceous Spirit River Formation, and two samples were desorbed.

*Data acquisition.* Coal cuttings were collected and used for two gas desorption tests. Ash content and vitrinite reflectance were also determined.

*Geology.* The coal-bearing interval was intersected between 1987 and 2154 m (Fig. 151). Six coal zones include about 10.2 m of cumulative net coal. Cuttings were collected from 2109 m from a thick coal zone (5.5 m), which includes about 3.5 m net coal. This zone is probably equivalent to the Medicine River coal zone of the Mannville Group farther south.

*Gas content.* Two desorption samples of coal cuttings from 2109 m gave a measured gas content of 2 cc/g, which represents a normalized gas content of 3.7 cc/g. These values are low for coal of this rank, and represent minimum values because the rapid diffusion from cuttings, together with the relatively long lag time from >2000 m, results in significant underestimation of the lost gas component.

*Coal quality.* Vitrinite reflectance of 0.71% indicates rank of high volatile bituminous A/B, a level where reasonable gas generation would be expected. Ash content in the desorption samples is high, reflecting the significant clastic component in the cuttings.

*Adsorption isotherms.* No isotherm testing was conducted on coal from this borehole.

*Formation testing.* No formation tests were performed within the coal-bearing interval.


***Figure 148.*** *General location map of the CanHunter Red Rock (03-16-63-08W6M) borehole.*

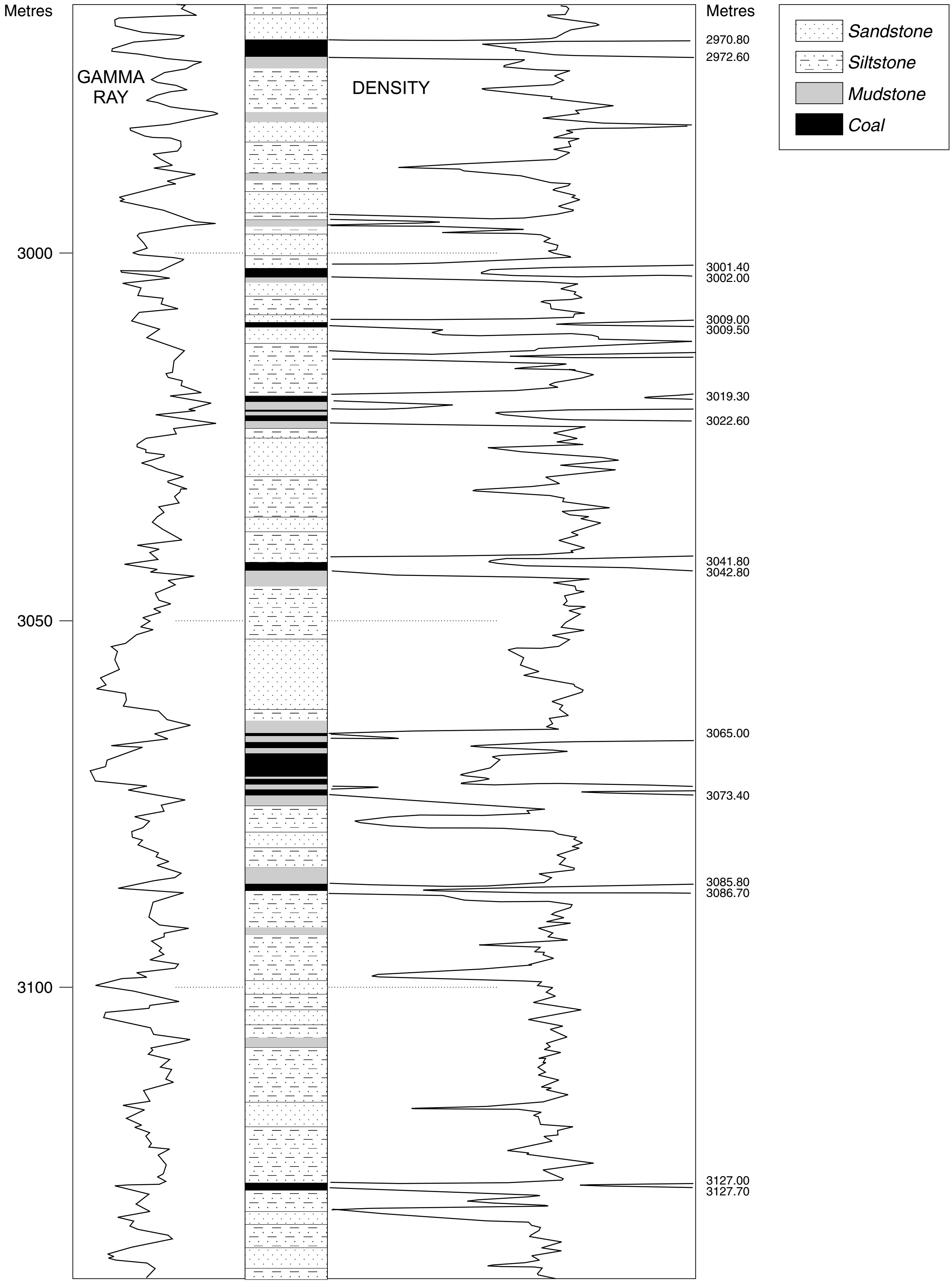


***Figure 149.*** *Detailed stratigraphic section of the CanHunter Red Rock borehole.*


***Figure 150.*** *General location map of the AEC Karr (06-06-66-03W6M) borehole.*

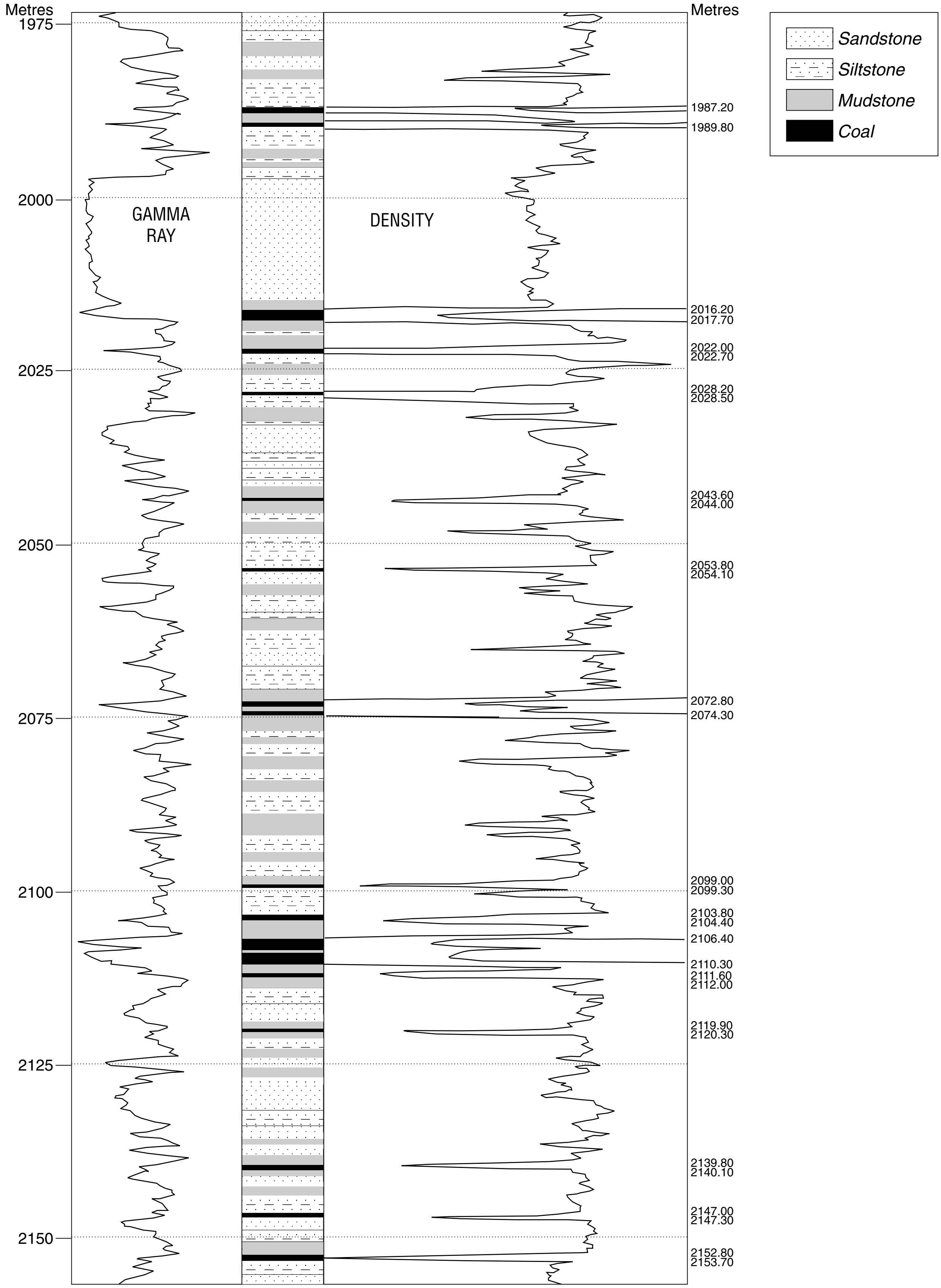


***Figure 151.*** *Detailed stratigraphic section of the AEC Karr borehole.*

*Technical assessment.* The limited amount of data available from the well tests precludes any technical assessment. Coal depths greater than 2000 m indicate that there might be permeability barriers.

## NOVA SCOTIA

There is a long history of coal mining in Nova Scotia, and coal deposits are relatively common throughout the province. Limited coalbed methane exploration has taken place and there have been attempts to commercialize degasification of subsurface mines. Available gas content data indicate relatively low values (2 to 9 cc/g), lower than expected from coal of high volatile A and B rank.

*Data acquisition.* Limited data are available from the few coalbed methane evaluation projects undertaken in Nova Scotia. Algas Resources Ltd./Noval Technologies undertook two projects in 1979–80: a three-well degasification program in the Foord Seam and a nine-well coalbed methane assessment program in the Pictou Coalfield. The latter program generated 183 coal samples, some of which were subject to desorption testing.

In 1980–81, the same companies undertook a program to evaluate coalbed methane potential in several Nova Scotia coalfields, including Port Hood, Inverness, Glengarry Valley, Springhill, Joggins and Chignecto. The exploration program eventually consisted of 22 boreholes in which gas desorption and coal quality testing were performed.

Resource Enterprises Inc. and their partner Nova Scotia Power currently hold exploration permits in the Cumberland and Stellarton basins. Limited gas content data from the nine wells drilled or current have been made available by Nova Scotia Department of Natural Resources. However, detailed information is to be kept confidential for a period of five years.

*Geology.* Coal deposits of Carboniferous age occur in several basins in the Atlantic Provinces of Nova Scotia, New Brunswick, and Newfoundland. Only in Nova Scotia has there been any attempt to evaluate the commercial viability of coalbed methane. The principal coalfields of Nova Scotia are shown in Figure 152.

Carboniferous strata in the region were deposited in the large-scale, transcurrent fault setting of the Appalachian Geosyncline. Deposition of coal bearing sequences began in Westphalian A and continued to Westphalian D. Widespread syndepositional block faulting and basinal subsidence resulted in the deposition of several discrete coal deposits. Except for the major Sydney Basin, which is of paralic origins and mainly lies offshore between Nova Scotia and Newfoundland, most of the sub-basins are small and were deposited in intermontane settings.

The Sydney Basin is the main economic coalfield in Nova Scotia. The coal-bearing Morien Group has up to 13 seams, and resources of immediate interest are reported as 345 megatonnes (measured). In the Pictou Coalfield (Stellarton Basin), where there is recent coalbed methane activity, the coal-bearing sequence includes 15 major coal seams ranging from 1 to 14 m in thickness. About 20 megatonnes of measured, immediate interest resources have been reported.

The Cumberland Basin is also of current coalbed methane interest. In the Joggins/Chignecto coalfield the coal-bearing sequence is about 1500 m thick and thins rapidly to the east. Seams are generally less than 1 m thick, and extensive mining has depleted much of the readily available resources. In the Springhill coalfield, the coal measures are more than 1000 m thick and have been severely deformed by underlying diapiric structures. Measured resources of immediate interest are estimated at 5 megatonnes.

*Gas content.* Little data are available on gas content from early evaluation projects. It is believed that gas content was generally low, in the order of 3 to 7 cc/g. At the typical rank levels for Nova Scotia coal (high volatile bituminous A to B), higher gas content would be expected. Associated coal analyses generally indicate high to very high ash content, which might account for the low gas values.

As at October 1966, Resource Enterprises Inc (REI) had drilled six wells in the Cumberland Basin and planned production tests in two of them before the end of that year. In addition, REI and their partner Nova Scotia Power had drilled three wells in the Stellarton Basin, although one did not reach the target depth.

Gas content, as reported by the Nova Scotia Department of Natural Resources, ranged from 2 to > 9 cc/g (Table 97). Most of the data from these wells are to be held confidential for five years. Only limited information is currently available.

**Table 97**
**Gas content in the Stellarton and Cumberland basins**

| Basin | Well number | Gas content (cc/g) |
|---|---|---|
| Stellarton | 1 | 2 – 5 |
| | 2 | 3 – 7 |
| | 3 | N/A |
| Cumberland | 1 | Incomplete |
| | 2 | > 7 |
| | 3 | 5 – 9 |
| | 4 | Incomplete |
| | 5 and 6 | N/A |

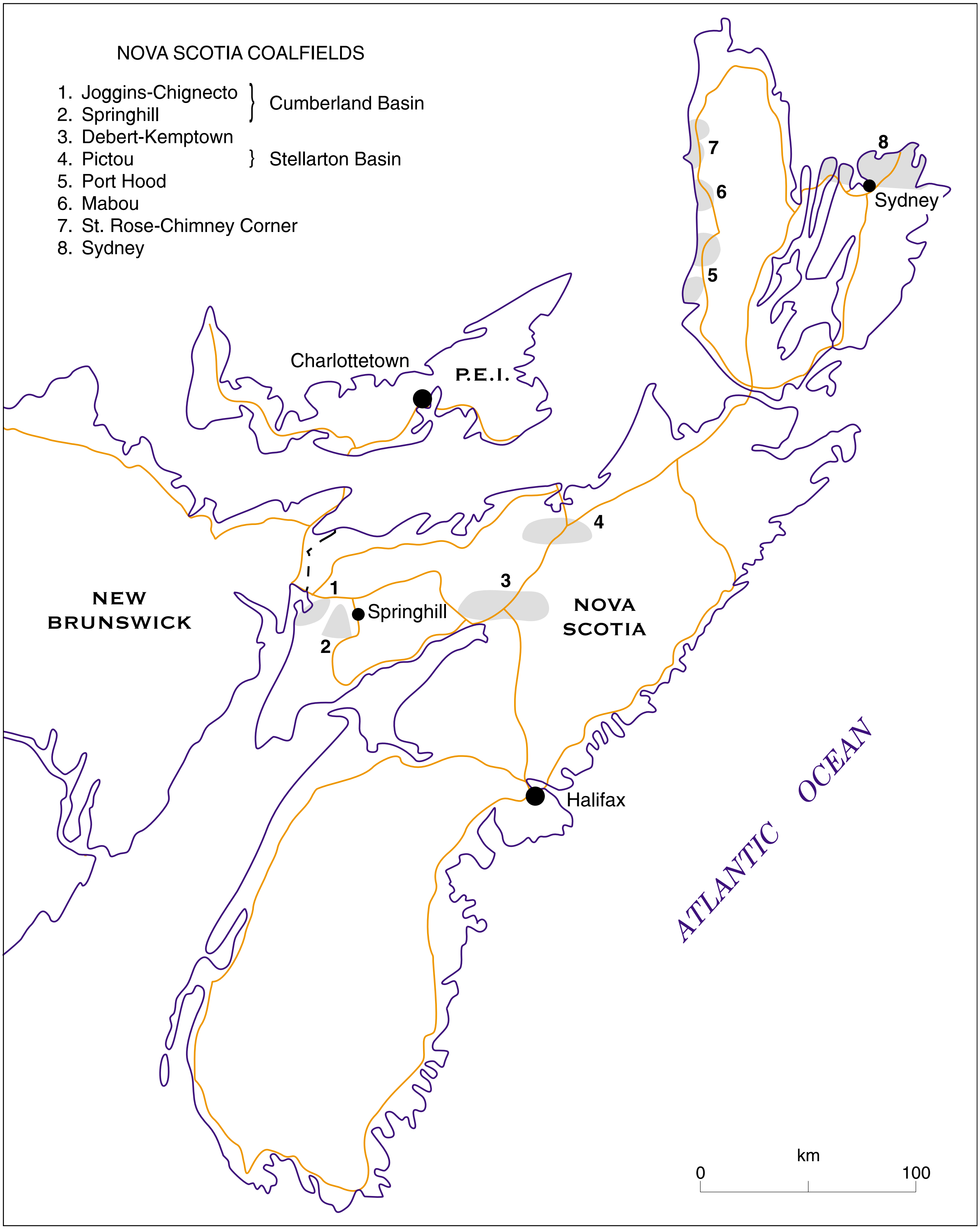


*__Figure 152.__ General location map of major Nova Scotia coalfields.*

*Coal quality.* The rank of most of the coals in Nova Scotia is high volatile bituminous A to B (vitrinite reflectance 0.7 to 1.1%, $Ro_{max}$), which is a favourable level for generation of coalbed methane. Some deeper seams attain medium volatile rank. Typically, raw coal ash content is relatively high, which might account for the low measured gas content.

*Adsorption isotherms.* No information on isotherm testing was available.

*Formation testing.* No formation testing data are available from the new exploratory wells in Nova Scotia. Noval Technologies Ltd. completed three production wells in Pictou County during 1981. Two of the wells were hydraulically stimulated and production in one well exceeded 566 $m^3$/d (20 Mcf/d). Production and monitoring continued into 1989, when the wells were abandoned.

*Technical assessment.* It is not possible to evaluate the technical aspects of coalbed methane exploration projects in Nova Scotia from the limited information available. The abundant coal in the region is of sufficiently high rank that gas content of potentially economic levels might be expected.

Gas content values significantly higher than those reported could be expected on the basis of regional rank levels. It is possible that the reservoirs tested to date have been underpressured or coals have been depleted in gas by regional aquifers or proximity to surface. Low gas content in some of the Pictou County wells has been ascribed to proximity to subsurface mine workings.

The ash content of coal in Nova Scotia Basins is variable, but commonly high, and it is possible that areas of low ash content could yield higher gas content.

## EXPLORATION ASSESSMENT

### Exploration effectiveness

Although the coalbed methane potential of Canada is considered vast, no commercial production has been achieved to date, despite apparently significant exploration by the oil and gas industry. Over 140 boreholes have been drilled to date, and samples collected to test at least one element of the coal for methane potential. This effort has either specifically targeted coalbed methane or has been part of a conventional hydrocarbon drilling program, where coalbed methane was the secondary target. However, exploration success has commonly been hindered or compromised by factors external to the coal reservoir.

Target locations have often been chosen based on land tenure or the opportunity to “piggyback” on other drilling prospects, rather than coalbed methane prospectivity. The drilling techniques employed have commonly reflected the general lack of understanding of the nature of the coal reservoir and the sensitivity of the reservoir to formation damage. In addition, application of conventional wellbore testing techniques to coal reservoirs has often led to misleading results and interpretations of the reservoir characteristics of the coal seams.

When the number of coalbed methane test wells is quantified by degree of exploration, a more realistic picture of the true exploration effort in Canada becomes apparent. Table 98 gives a summary of the number of exploration boreholes by type of exploration effort.

By comparison, the San Juan and Black Warrior basins have more than 2000 and 2600 producing wells, respectively. This is partly because of the exploration stimulation that resulted from the Section 29 Tax credits. The Western Canada Sedimentary Basin alone is larger than the San Juan, Piceance, Raton, Uinta and Green River basins combined.

### *Restricted basins*

The limited exploration for coalbed methane in the restricted basins in western and eastern Canada has generally been conducted with few problems. In the Comox/Tsable River region, Quinsam Coal measured the gas content of the coal purely as a safety precaution for their underground mine operations. The boreholes drilled were relatively shallow (< 350 m) and have not been optimized for in situ coalbed methane assessment. Although this does not allow a full evaluation of the coalbed methane potential of the downdip extension of the coal, there is no indication that the gas content will not increase with depth.

In the Cumberland and Stellarton basins of Nova Scotia, REI conducted a nine-borehole exploration program, followed by drilling limited production wells in areas of greatest prospectivity. The original drilling plan defined borehole locations without the aid of all the geological data available, but the actual drilling and testing of the wells was

**Table 98**
**Number of boreholes and exploration effort**

| Borehole | Number |
|---|---|
| Drilled specifically for coalbed methane | 67 |
| Undergone reservoir testing | 25 |
| Undergone reservoir stimulation | 6 |
| Undergone limited production tests | 10 |
| Undergone extended production tests | 3 |
| Currently in production | 1 |
| Total | 140 |

completed with few problems. Site location was at times difficult because of the well developed infrastructure.

### *Shallow Alberta foreland basin*

The shallow coals of the foreland basin in Alberta have been tested for coalbed methane by BHP, Amoco, Gulf, AEC, PetroCanada, Conoco and Norcen. Other than the four-borehole program conducted by BHP, all other tests were primarily designed to test the gas content of the Scollard/Coalspur Formation coal where the companies had an existing land position. In some cases, such as Conoco Hanlan and AEC Columbia, the wells were drilled to protect a land position, and not for a specific coalbed methane target. Results from all of the desorption tests indicate that the gas content was low, as expected for coal of low rank that has not reached the thermogenic window of gas generation.

In the BHP exploration program, after the coal samples were collected, various borehole tests were conducted to determine reservoir properties. Injection tests and conventional drillstem tests were performed, but in most cases, the tests were not long enough to measure beyond the immediate wellbore radius. In the Pembina area, two production wells were drilled and stimulated: one by hydraulic fracture and the other by cavitation. The cavitation well outperformed the fractured well initially, but borehole additives used by BHP wellsite personnel to assist in the removal of cuttings, effectively terminated gas production. Subsequently, gas production averaged less than 20 Mcf/d.

From the limited production test conducted by BHP on the Pembina wells, one could expect sustained gas production of between 40 and 50 Mcf/d. It is possible that cavity stimulation could lead to gas production of 75 to 100 Mcf/d.

### *Deep Alberta foreland basin*

The coal of the Mannville Group in the Alberta plains region has been targeted by a number of companies. In all cases, the companies drilled where an existing land position dictated the exact location of the borehole(s). Most of the boreholes were drilled as part of a "piggyback" project. Wellbore testing mostly consisted of conventional drillstem tests. In most cases, the validity of the tests were compromised because of inadequate test times. Depth of coal intersections ranged from less than 900 m to greater than 2000 m. Gas contents were variable, ranging from less than 5 to greater than 15 cc/g, and reflect the increase in rank with increasing depth to the west.

The major difficulty encountered in Mannville Group coalbed methane exploration is the limited target window. At depths attractive for reservoir permeability, the coal is of low rank, with limited cleat development and lower gas content. Where rank is sufficiently high to place the coal in the thermogenic gas generation window, the coal is commonly deeper than 1500 m and the reduction of permeability due to overburden pressure can be a problem.

Some companies have initiated subsurface studies of the Mannville Group coal to determine areas of optimum coal development and possible structural draping that would lead to permeability enhancement. Both Gulf and PanCanadian drilled their coalbed methane wells near Stettler on the flanks of a Paleozoic high. However, the results indicated that permeability enhancement was either not present, or the stimulation undertaken was not effective in linking the wellbore to the natural fracture system of the coal seam. For its Battle Lake play, PetroCanada used geophysical log responses of the SP tool to determine regions of maximum permeability in the coal seam, but no boreholes have been drilled to prove or disprove this approach.

The large number of tests on Mannville Group coal, along with poor production results from the Fenn/Big Valley field of Gulf and the Chigwell field of Lionheart indicate that this coal will not be economically productive without some form of permeability enhancement. However, the only production attained from the Mannville coal is from recompletion wells, where the degree of formation damage from drilling fluid or cement is unknown. All production wells were stimulated by hydraulic fracturing and no cavitation completions were attempted. Similarly, no horizontal boreholes were attempted.

### *Foothills and mountain regions*

The foothills and mountain regions of Alberta and British Columbia have been attractive areas of exploration for coalbed methane, primarily because of the number and rank of the coal seams. Southeast British Columbia has been the focus of most of the activity, in part because of land posting and also the proximity of the major gas pipeline into the United States. The exploration efforts to determine the coalbed methane potential of the foothills and mountain regions have been fraught with difficulty and not restricted to any one company. Borehole locations have been compromised because of accessibility limitations. Depths of boreholes have been inadequate because of drilling rig limitations; core recovery has been hampered by poor drilling techniques or the wrong type of equipment; geological prognoses of target zones have been wrong because of a lack of understanding of the geological variability in this structurally complex terrain.

Testing of the wells has also been problematic. The greatest problem encountered in testing and producing from the coal zones in the foothills and mountainous terrain was borehole stability. The coal was commonly friable or sheared, and sloughing of fines into the borehole led to numerous problems. Borehole tests, such as drillstem or injection/fall-off tests, could only be conducted for short intervals because of the increased risk of borehole caving and subsequent loss of testing equipment. Results from the tests have been mostly inconclusive, as they did not reflect the formation reservoir properties but only the near wellbore region, which is commonly subject to fluid damage.

Stimulation of the boreholes for short-term production testing has led in a number of cases to "self cavitation" of the borehole, where a large volume of coal flows into the borehole. The removal of this material is time consuming and costly, and without any firm idea about the amount of coal that eventually will flow into the borehole, companies have been reluctant to continue with this type of stimulation.

Hydraulic fracturing of the reservoir commonly encounters fracture problems because of the friable nature of coal. Even though the actual fracture stimulation might be successful, maintaining communication between the propped fracture and the wellbore has proven to be difficult.

### *Southeast British Columbia and southwest Alberta*

In southeast British Columbia, exploration drilling conducted by Mobil, Saskoil, and Gulf in the Fernie Basin was designed to assess the gas content of the coal in proximity to the Alberta Gas Transmission pipeline that cuts through the basin south of Fernie. These boreholes were drilled in the early 1990s, when the understanding of coalbed methane in Canada was limited. The expectation of most operators at that time was that to simply drill a borehole, intersect coal seams, and pump water would yield large volumes of gas. Little thought was given to location of borehole with respect to the regional groundwater table and topography. At the same time, regulations imposed by the B.C. government restricted the type of drilling rigs and equipment that could be employed.

In the Elk Valley region, both Norcen and Fording Coal undertook coalbed methane exploration programs designed to prove and produce coal gas from shallow coal in the Alexander Creek syncline. Desorption testing was conducted without problems and the in situ resource proven. Reservoir testing was undertaken in each program and the results were to dictate the next stages for each company. Fording Coal's test results indicated the coal had low permeability, so the company abandoned the project. However, analysis of the data suggests that test results were compromised by faulty equipment and borehole location.

Norcen undertook similar tests, the results of which were misinterpreted. The company proceeded to drill a limited production well, which was subjected to formation damage from drilling fluid and cement invasion. The hydraulic fracture was completed over the wrong interval and resultant gas production was less than expected. This project was also subsequently terminated.

In both cases, the location of the borehole was not chosen to optimize the natural fracture system of the reservoir, as the understanding of the variability of the cleat development in the Mist Mountain Formation coal was limited.

### *Central and northern Alberta*

Farther north, Algas Resources attempted numerous wells to produce commercial volumes of coal gas at Canmore. Much of the program was plagued with operational and mechanical difficulties that resulted in intermittent gas and water production. At best, a maximum of 65 Mcf/d was achieved. Given the very high gas content at shallow depths, one would have expected high gas production. It appears the coal is generally highly sheared and, even though it contains large volumes of gas, the reservoir permeability is poor. This might be a result of the proximity of the high compressive stresses associated with the Rundle Thrust.

Mobil drilled exploratory wells to intersect Mist Mountain Formation coal at Turner Valley, and Gates Formation coal at Grande Cache. In both boreholes, the primary coal targets were missed, and coal sampling and reservoir testing were severely compromised. No truly representative tests were conducted on reservoir characteristics. Even though the Grande Cache well was stimulated and did produce a significant volume of coal gas during the limited production test, it was thought that formation damage had occurred and the true production potential of the well was not achieved.

### *Northeast British Columbia*

In northeast British Columbia, Phillips Petroleum drilled a number of boreholes to assess the in situ resource and producibility of Gates Formation coal. The geological testing of the gas content of the coal was successful, although drilling costs were inordinately high. Reservoir stimulation and production testing was restricted to the second choice borehole because of stability and casing problems in the optimal location. Cavitation of the seam(s) was attempted, the results of which are confidential. The coal of the Gates Formation was intersected at depths greater than 1200 m. The principal target of the Phillips drilling program was the coal measures in the axis of the Quintette anticline and syncline. In the anticlinal structure, the coal is believed to lie at depths of 500 m and seismic profiles indicate a possible natural gas cap in the crest of this structure. Borehole 64B was originally targeted for this structure, but the well was located too far to the east and the structure was completely missed.

### *Summary of geological parameters*

In the introduction, basic geological parameters were defined that are necessary for successful coal gas generation, storage and producibility. Exploration and evaluation of these parameters for the four major coalbed methane play types are summarized in Table 99.

Comparing the four play types is difficult because the weighting of each geological parameter is not equal. For example, although the gas content is low for the shallow foreland basin play type, the cost of drilling wells to a maximum depth of 500 m might offset lower production rates. Similarly, even though the foothills and mountain regions have attractive coal thicknesses and gas content, the limited infrastructure in many of the specific exploration targets hinders the development because of increased drilling and production costs. An attempt has been made to establish which geological parameters meet the minimum threshold levels defined in the introduction.

Figure 153 illustrates normalized gas content for all samples versus rank. Although most of the data are scattered, some data clusters reflect the four types of coalbed methane plays. A threshold line beyond which no data exists is plotted in Figure 153. Concerning shallow foreland coal (Coalspur), gas content values greater than 5 cc/g are probably not going to be found in the basin without some form of gas migration and trapping or biogenic supplementation. Similarly, gas content for the Mannville Group coal ranges from 3 to 10 cc/g and rarely achieves levels over 2 cc/g in the rank range encountered at the target interval (500 to 1500 m).

Mist Mountain Formation coal reflects a wide range of data, indicative of the geological setting in which the data were collected. Data points less than 5 cc/g are interpreted to have resulted from degassing of the coal because of hydrological flushing, and topographic elevation of coal intersection. Average gas content values, assuming no degassing, fall in the 10 to 20 cc/g range. The coals of the Mist Mountain Formation at a rank of 2.1% $Ro_{max}$ were collected from the Canmore region. Here gas content as high as 15 cc/g was recorded in coals that commonly occur at less than 200 m depth. However, this coal has low permeability, and gas production is low.

Coal of the Gates Formation tends to have a significantly higher gas content, in part reflecting the maturation level of the coal and also the type of drillhole program in which the samples were collected. Most of the samples represent data collected from the Phillips exploration program where the coal seams were intersected at depths greater than 1200 m.

In the next section, specific exploration opportunities are presented for each type of play.

## Exploration opportunities

Although the foreland basin setting of the Western Canada Basin might preclude the replication of the success of the San Juan “fairway zone”, the abundant coal resources within Canada indicate the possibility of successful commercial production of coalbed methane. However, to be successful, exploration companies must first understand the unique compositional, depositional, and structural characteristics of coal-bearing formations and regions to optimize exploration opportunities. To assist defining exploration opportunities, the major coal-bearing regions have been divided into four specific categories or play types:

**Table 99**
**Summary of geological parameters for coalbed methane play types**

| Geological parameter | Restricted basins | Shallow foreland basin | Deep foreland basin | Foothills and mountains |
|---|---|---|---|---|
| Coal thickness | 2-20 m | 5-15 m | 2-11m | 2-15 m |
| Coal quality | 10-20% ash | 15-20% ash | 5-15% ash | 5-25% ash |
| Coal rank | High volatile C* | Sub-bituminous C* | High volatile A, bituminous | High volatile A to semi-anthracite |
| Gas content | 7-12 cc/g | 2-4 cc/g* | 8-15 cc/g | 8-20 cc/g |
| Depth | 200-1500 m | 300-900 m | 900-3000 m* | 200-1600 m |
| Permeability | <1 to 3 mD | 1 to 10 mD | <0.1 to 2 mD* | <1 to 5 mD |
| Infrastructure | Poor* | Established | Established | Poor* |
| Water disposal | Saline to fresh* | Fresh water | Saline* | Fresh |

* Represents geological thresholds that are below the minimum desirable level for each geological parameter.

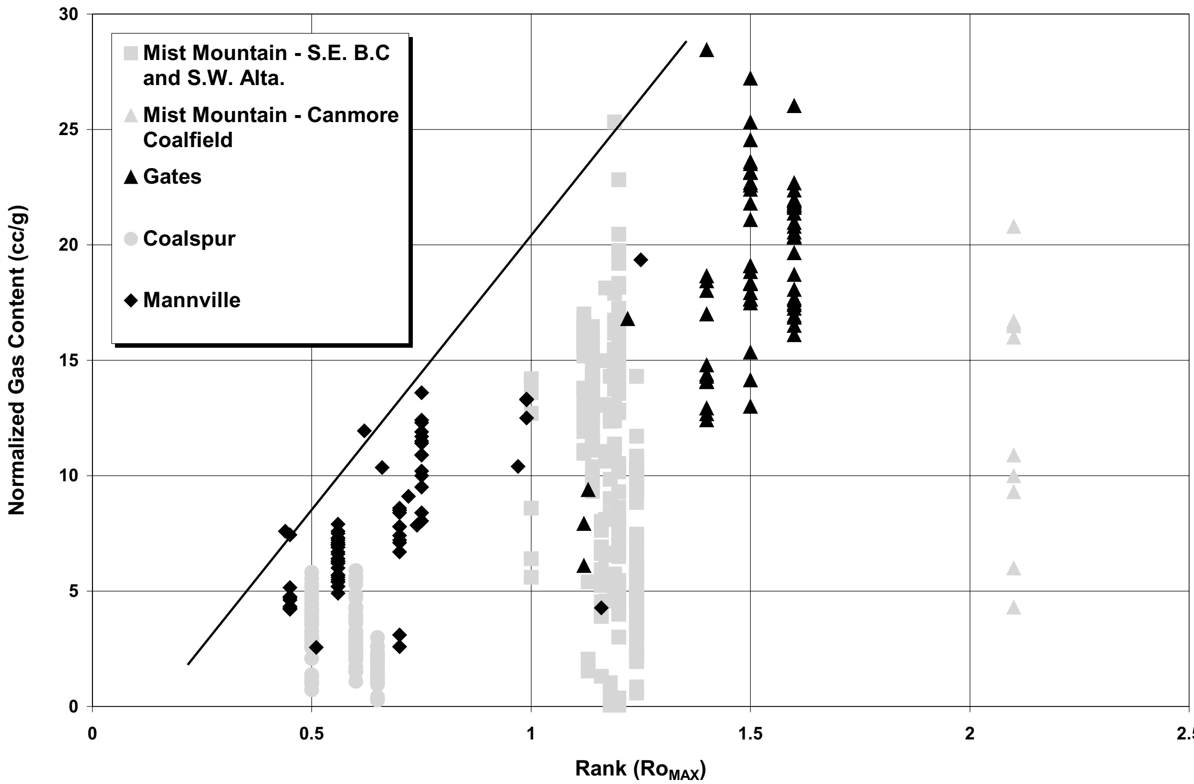


***Figure 153.*** *Comparison of normalized gas content versus $Ro_{MAX}$ for all coalbed methane data collected in Western Canada.*

- restricted basins
- shallow foreland basin deposits
- deep foreland basin deposits
- foothills and mountain structural deposits

Each of these categories has unique characteristics that exploration companies might find attractive for their specific corporate strategy. Targets within each category are ranked by prospectivity, and the positive and negative features of each area are highlighted. The ranking of one play over another is controlled to a large extent by the exploration philosophy a company might want to employ, and is not attempted in this study.

## *Restricted basins*

The restricted coal basins in Canada that have some coalbed methane potential are located on the Pacific and Atlantic margins of the country. On the west coast, exploration opportunities are present in the Comox Basin on Vancouver Island. The interior of British Columbia may present several small coalbed methane prospects. On the east coast, the Cumberland and Stellarton basins have some potential.

### *Comox Basin*

The Comox Basin is rated as a significant exploration target for coalbed methane. Ranking parameters are presented below. In situ resource volumes are estimated to be 0.59 to 0.66 Bcm/km$^2$.

<u>Positive factors</u>

The positive factors for the Comox Basin are:

- rank of coal in thermogenic window
- coal seams greater than 1.5 m thick
- reservoir depths of 300 to 600 m
- minor structure to enhance permeability

- possible hydrological recharge of reservoir
- close proximity to potential market
- history of coal gas production

Negative factors

The negative factors for the Comox Basin are:

- populated region/socio-economic issues
- lower gas content (7 to 8 cc/g)
- limited surface infrastructure

### *Stellarton and Cumberland basins*

These two basins in Nova Scotia have undergone some recent significant coalbed methane exploration and development through a licensing agreement with REI. Several wells are currently being production tested, but it is unknown whether they are economically viable.

Positive factors

The positive factors for the Stellarton and Cumberland basins are:

- rank of coal in thermogenic window
- coal seams greater than 1.5 m thick
- attractive government climate for development
- attractive depths for coal gas retention relative to drilling cost
- market opportunity

Negative factors

The negative factors for the Stellarton and Cumberland basins are:

- low gas content (3 to 7 cc/g)
- variability in coal seam thickness
- undefined permeability
- lack of surface infrastructure

### ***Shallow foreland basin deposits***

The shallow foreland basin deposits of the Western Canada Sedimentary Basin belong primarily to the Tertiary Scollard/ Upper Coalspur Formation. The coal-bearing sequence forms a thick clastic wedge that thins from west to east. In the region bordering the foothills, five main coal zones are developed: the Val D'Or, Arbour, Upper Silkstone, Lower Silkstone, and Mynheer. The cumulative thickness of coal from these seams is commonly more than 25 m. These seams are equivalent to the Ardley coal zone of the Scollard Formation that outcrops in central Alberta, which attains cumulative net coal thicknesses of up to 9 m. The Coalspur/ Ardley coal lies at depths of from less than 100 m to greater than 900 m. The rank of the coal is low by coalbed methane standards and resultant gas content is low. Coal is laterally continuous and appears to be well cleated with a high vitrinite content. Gas content ranges from less than 1 cc/g to greater than 4 cc/g, and average 3 cc/g. The reservoir tests performed indicate a permeability range from 1 to 10 mD.

In the Powder River Basin in Wyoming, coal of similar age and rank produce coal gas at economic rates in selected areas. Where the coal is thick and has been gently folded into broad structural traps, migration of coal gas has occurred. In these regions, gas production rates over 500 Mcf/d have been achieved. In the Western Canada Sedimentary Basin, no exploration activities have examined the relationship between gas migration and structural drape of the Tertiary coal. Most exploration wells that have been drilled for coalbed methane, and that have targeted the Tertiary coal, have defined and drilled exploration targets based upon coal thickness and land tenure. Gas production rates for wells from the Tertiary coal are equivalent to, or better than, the production attained from the deeper, higher rank coal of the Mannville Group.

Positive factors

The positive factors for shallow foreland basin deposits are:

- thick, laterally continuous coal-producing zones with greater than 19 m of cumulative net coal thickness
- shallow depth of intersection, allowing low cost drilling programs
- produced formation water generally fresh and requiring minimal remediation

- high vitrinite content leading to well developed cleat systems

- reservoir permeability measured between 1 and 10 mD

- opportunity for migration of gas into structural traps, allowing enhanced production

- large resource areas available for land acquisition

Negative factors

The negative factors for the shallow foreland basin deposits are:

- low gas content (averaging 3 cc/g)

- low reservoir pressures

- large number of wells required to attain economic volumes of gas production

Two other Upper Cretaceous formations contain coal of low rank that might have coalbed methane potential. The Horseshoe Canyon and Belly River formations have a number of coal zones with average cumulative net coal thicknesses of more than 5 m. The seams tend to be more laterally variable in thickness and quality. No desorption testing has been undertaken for these horizons, but coal rank is similar to that of the Tertiary coal, and gas content is probably similar. Some oil and gas companies are producing natural gas from sands stratigraphically adjacent to the basal coal of the Horseshoe Canyon Formation, but it is unknown whether the gas stored in the sand bodies was sourced from the coal seams. Gas production of more than 1 Mmcf/day has been achieved from these wells.

### *Deep foreland basin deposits*

The deep foreland basin coal deposits are mostly restricted to the Alberta plains region. The Mannville Group coal extends throughout much of the central and northern part of the province and ranges in depth from 900 to more than 3000 m near the foothills. Gas content is variable, but ranges from less than 3 cc/g to more than 12 cc/g. Gas content reflects the increase in rank from east to west, and generally increases to the west with increasing depth.

Coal is commonly dull and bright banded but cleating is poorly developed, particularly in the regions where the coal is less than 0.7% $Ro_{max}$ (high volatile bituminous B). The lack of cleat development, particularly in the butt cleat direction, can probably be attributed not only to the coal's maturity but also to the maceral composition. While the coal tends to have a high vitrinite content, much of it is unstructured vitrinite B. This type of maceral, even though it might have macro cleats, does not have micro-cleating and resembles a groundmass matrix. The lack of cleat development appears to be typical of the Mannville coal. Core descriptions of most of the coalbed methane boreholes that have drilled the Medicine River coal zone indicate that cleat development, while present, is widely spaced in the face cleat direction and poorly developed, if present at all, in the butt cleat direction. Reservoir properties generally reflect this poorly developed natural fracture system and permeability is commonly less than 1 mD.

An exception to this trend might be the Battle Lake play, currently held by PetroCanada. In the Baytex Energy well, the Medicine River coal seam is well cleated with closely spaced face and butt cleat fractures. PetroCanada has attributed this fracture enhancement to draping of the coal over the underlying Paleozoic reef structure. An alternative interpretation is the presence of basement faults that have reactivated over time to produce a vertical natural fracture system, which not only enhanced the gas content of the coal but also the reservoir permeability. The GSC is currently conducting a research project to examine the relationship between coal fracturing and the predominant basement faulting present throughout the Alberta foreland basin. Although there are some questions about how the coal in the Battle Lake region has undergone fracture enhancement, this type of secondary overprinting was probably necessary to achieve adequate reservoir permeability for sufficient production volumes. Determining “sweet spots” for the Mannville Group coal would be a logical exploration step before drilling costly test wells.

Positive factors

The positive factors for the deep foreland basin deposits are:

- laterally continuous coal seams with cumulative net coal up to 11 m thick

- gas content averaging 9 to 10 cc/g

- well developed surface infrastructure

- excellent geological database for subsurface mapping

- possibility of fracture enhancement due to draping or basement faulting

- numerous boreholes that may be used for re-completion technology

- widespread distribution of coal measures, thus allowing regional studies to determine sweet spots

Negative factors

The negative factors for the deep foreland basin deposits are:

- coal is at depths where permeability barriers from overburden pressure might occur
- coal is of rank that might not have adequate cleat development
- maceral composition might impinge on the development of the micro-cleat system
- extensive formation damage on re-completion wells might exist
- Mannville Group tends to be underpressured
- limited opportunity for meteoric recharge of reservoir and for gas migration
- produced waters are saline and would require costly disposal
- exploration costs might be high because of depth of target zone
- land acquisition opportunities limited because of conventional hydrocarbon targets

In the plains region, assuming that the pre-defined criteria are met for depth and rank of coal, a narrow target window exists for the Mannville Group. Depths greater than 1500 m (that region west of the $5^{th}$ meridian) probably will encounter permeability barriers because of depth of overburden. Conversely, although the coal is at an attractive exploration depth in the areas east of Range 20 west of the $4^{th}$ Meridian, the rank tends to be below the thermogenic window, and gas content is commonly less than 7 cc/g. There are bound to be exceptions outside of this target zone where fracture enhancement has offset the reduction in permeability from overburden pressure, or where biogenic methane might have enhanced the gas content at shallower depths. Finding these anomalies requires subsurface geological mapping and log interpretation. The obvious first step is to evaluate the validity of the PetroCanada model, then undertake a regional subsurface study to determine the presence of other possible anomalies in the basin.

To date, re-completions of the Mannville coal zones from existing wellbores have had limited success. Gas production rates are generally less than 50 Mcf/d, and it appears that the formation damage from drilling and cementing the wellbore has not been overcome, even with large hydraulic fracture stimulation. If the coal beds have permeability values of less than 1 mD, any kind of drilling additive can do irreparable damage to the zone. No testing has been undertaken on re-completions where natural fracture enhancement might have occurred, so it cannot be currently stated that re-completions do not work. No cavity stimulation has been attempted in the Mannville Group coal. This is probably due to the low initial permeability and the resultant probability of success.

The most prospective targets for Mannville Group coalbed methane opportunities are probably to be found in regions where anomalous high gas content values have been recorded. The premise of this argument is that if the gas content is higher than expected, one could assume that gas migration through a natural fracture system has occurred. This hypothesis satisfies the two governing criteria of the Mannville Group: gas content and reservoir permeability. Results from the borehole analysis of this study indicate that two regions appear to have anomalously high gas content: PetroCanada's Battle Lake and the Norcen Por Fir areas. In both cases, reported gas content was greater than 15 cc/g and ash content of the coal appears to be acceptable.

### *Foothills and mountain structural deposits*

The foothills and mountain regions of Alberta and British Columbia present significant opportunity for coalbed methane exploration and development. Although most previous coalbed methane exploration was carried out in southeast British Columbia, much of this work was completed in the early 1990s, when the understanding of the key geological elements that control the storage and producibility of coal gas was limited. Consequently, results from many of the boreholes drilled are not a true reflection of the potential of the area.

The coals of the foothills and mountain regions are generally of higher rank than equivalent age horizons in the plains region. Average rank ranges from 0.9 to 2.1% $Ro_{max}$ (high volatile bituminous A to semi-anthracite), well within the thermogenic gas generation window. Gas content is accordingly higher, ranging from 8 to over 20 cc/g. A number of boreholes have been drilled where measured gas content is significantly lower than the range reported above, but in these specific cases, unique geological conditions have led to degassing of the coal zone. Variation in gas content can mainly be attributed to geological setting of the coal deposit and differences in coal quality (predominantly ash content).

The foothills and mountain regions are structurally complex, with a high variability in topography. The relative elevation of the coal horizons with respect to the local and regional water tables determines the presence and retention of gas within the seams. In this region, where topography is highly bisected by river and stream valleys, it is common for coal to outcrop along valley sides. If the coal is elevated above the valley floor (immediate water table), reservoir pressures tend to be reduced and the coal is commonly degassed with methane migrating to the seam outcrop.

The coal of the foothills and mountain regions is widely variable in composition. In the Mist Mountain Formation of southeast British Columbia and southwest Alberta, the vitrinite content ranges from less than 50% to more than 80%. There is a trend of increasing vitrinite content with stratigraphic elevation above the base of the formation. Coal high in vitrinite tends to have a more prevalent cleat system. The high inertinite coal of the lower Mist Mountain Formation tend to be poorly cleated. Resultant permeability reflects this trend. In the lower part of the formation, permeability is commonly less than 1 mD. Tests on the upper seams indicate permeability values ranging from 1 to 5 mD. Much of the exploration efforts have concentrated on the thick basal seams; the upper, vitrinite-rich seams have not been tested.

In structurally complex areas, coal is commonly sheared or crushed, and a lot of fine material can enter the borehole. If the over hole interval is insufficient, fines production will clog or block the downhole pump, leading to extensive wear on the downhole equipment and expensive workovers.

The diffusion rate of the gas adsorbed in the Mist Mountain coal is very short (days compared to months). Much of the gas is held by adsorption at low pressures. Increasing the reservoir pressure does not significantly increase the gas adsorption capability of the coal. It has been observed that the higher the reservoir pressure with respect to the critical desorption pressure, the more likely the occurrence of borehole instability during depressurization. The overburden pressure becomes too great compared to the reduced reservoir pressure, thus causing borehole instability and collapse of the coal zones into the wellbore.

The Gates Formation coal is similarly affected by the structural overprinting that led to friability and self cavitation problems. The coal tends to have higher gas content, lower inherent ash and higher vitrinite content. Cumulative coal thickness of the formation is less than the Mist Mountain Formation, but still averages 25 m. Gas content ranges from 13 to 21 cc/g. Permeability tests, where completed, average 1 mD. The positive and negative factors of the two formations are given below.

### *Mist Mountain Formation*

<u>Positive factors</u>

The positive factors for the Mist Mountain Formation are:

- thick coal seams (cumulative up to 30 seams and 60 m net coal)
- coal of suitable rank for thermogenic methane generation
- shallow depths to intersect high gas content coal (300 to 700 m)
- reasonably close to pipeline facilities
- structural features that enhance reservoir permeability
- fresh water production from formation

<u>Negative factors</u>

The negative factors for the Mist Mountain Formation are:

- high inertinite content of the lower coal impinges the degree of cleat development
- coal is highly friable and subject to self-cavitation, commonly leading to borehole instability
- short diffusion rate limits gas release at higher pressures
- $CO_2$ concentration of gas content can be as high as 20%
- rocks are highly indurated and drilling costs are high
- limited surface facilities requiring extensive capital costs

### *Gates Formation*

<u>Positive factors</u>

The positive factors for the Gates Formation are:

- thick coal seams (cumulative up to 10 seams and 25 m net coal)
- coal of suitable rank for thermogenic methane generation
- vitrinite-rich coal leading to higher gas content with good cleat development
- some structures having coal at shallow depths and with high gas content (300 to 700 m)
- reasonably close to pipeline facilities

- structural features that might enhance reservoir permeability

- fresh water production from formation

Negative factors

The negative factors for the Gates Formation are:

- coal is highly friable and subject to self-cavitation, commonly leading to borehole instability

- limited structural opportunities for coalbed methane targets. Many of the structural targets are at depths greater than 1000 m

- rocks highly indurated and drilling costs are high

- limited surface facilities requiring extensive capital costs

## CONCLUSIONS

A technical analysis of all historical coalbed methane exploration activities completed in Canada reveals that, although about 140 boreholes have been drilled to test various components of coal gas reservoirs, few have actually been subject to a comprehensive evaluation. When details of the work completed on these wellbores is examined, it is apparent that few wells were drilled without encountering geological, technical or mechanical problems that compromised the subsequent data interpretation and conclusions. Many of the wells were drilled as part of a “piggyback” exploration project, so the types of samples collected and wellbore tests completed were inappropriate. Where specific coalbed methane wells were drilled, the subsequent borehole tests were too short to adequately evaluate the coal’s reservoir properties. In the foothills region, exploration targets were commonly missed as a result of mis-interpretation of geological information.

Some of the many errors and problems that have plagued the history of coalbed methane exploration in Canada can be attributed to specific geological settings. However, many of the mistakes were the result of exploration companies undertaking coalbed methane exploration as an afterthought, without a true corporate commitment to the success of the project. This environment provides an opportunity for companies to not only learn from errors made by their predecessors, but also to recognize exploration opportunities that might have been missed or misinterpreted in previous exploration programs.

Four distinct exploration play types were defined in this study: restricted basin, shallow foreland basin, deep foreland basin, and foothills and mountain regions. In each of these play types, previous coalbed methane exploration activities delineated potential coalbed methane reservoirs at varying depths from surface. In most cases, the companies have retrenched their exploration activities and specific opportunities are now available. For each play type, a number of targets have been delineated and ranked from high to low prospectivity.

### Restricted basins

In the restricted basin areas, the Tsable River area on Vancouver Island represents the greatest opportunity for coalbed methane exploration and development. Coal there is:

- of sufficient maturity to have generated thermogenic coal gas

- of adequate thickness to provide a significant in situ resource base

- of sufficient depth to retain coal gas in an adsorbed state but not too deep to encounter permeability barriers

- in a structural environment that could lead to enhanced permeability and producibility

- in a region that is currently undergoing rapid socio-economic growth with no other indigenous gas supplies

### Shallow foreland basins

The shallow foreland basin exploration play type represents an exploration opportunity through economy of scale. Although the coal has low gas content, it is thick and laterally continuous. Reservoir permeability is generally favourable (5 to 10 mD), and the coal lies at depths from 400 to 900 m. Gas production from individual wells might be in the 100 Mcf/d range, and on a single well basis, not economically viable. However, the availability of wide tracts of land could allow large cumulative volumes of gas to be produced through a number of low cost production wells. If the per well-cost savings can be maximized, coal gas could be produced economically.

## Deep foreland basins

The deep foreland basin play type is characterized by coal of the Mannville Group at depths ranging from 900 to more than 2000 m. Coal of the Medicine River zone is laterally continuous and gas content ranges from 8 to 15 cc/g. Wellbore tests completed on the Medicine River zone indicate low reservoir permeability (less than 2mD). In some wells, Baytex Westerose and Norcen Por Fir, anomalously high gas content and the development of a pervasive cleat system might be indicative of local regions where permeability enhancement resulting from underlying pre-Cretaceous structural features has occurred.

Production tests from the Mannville to date have been disappointing. The low production volumes achieved might reflect the types of completion attempted or the lack of a natural fracture system within the coal bed. Future exploration efforts for coalbed methane in the deep foreland basin must address the low permeability reservoirs and develop techniques to adequately link the natural fracture system to the wellbore. If recompletion techniques can be developed to overcome these technical problems, the abundance of conventional petroleum wells that have penetrated the Mannville Group could provide the surface infrastructure necessary to produce economical volumes of coal gas without the cost of drilling new wells.

## Foothills and mountain regions

The foothills and mountain regions of Alberta and eastern British Columbia provide the greatest opportunity for coalbed methane exploration and development. Numerous thick coal seams of suitable rank for thermogenic gas generation are present within the Mist Mountain Formation in the south and the Gates Formation in the north. The regions are structurally complex, and the unique feature of this play type is that each reservoir is defined by structural boundaries. Optimum exploration targets are believed to be the axes of anticlines or synclines, where tensional stress regimes allow the natural fracture system of the coal to be open. A number of prospective exploration targets exist that have demonstrated coalbed methane potential.

Although the foothills and mountain coalbed methane target regions meet or exceed the geological thresholds required for coal gas generation and storage, other technical issues impact the economical viability of the projects. The rocks are highly indurated and drilling costs by conventional means is both expensive and technologically challenging. Reservoir permeabilities can be severely influenced by coal seam friability and overburden pressures. Surface facilities are not as well developed as in the plains region, and coalbed methane development would probably incur higher capital costs.

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