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Potential coalbed methane resources in Atlantic Canada

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Abstract

Thirteen coal areas of the Maritime Provinces in Atlantic Canada are estimated to contain some 2.23 trillion m^3 (78.8 TCF) [TCF, BCF, MCF: trillion, billion, million cubic feet]) of coalbed methane resources. This compares with 510 billion m^3 (18 TCF) of natural gas calculated for the Sable offshore resources in eastern Canada. In the United States, where coalbed methane resource evaluations and production have increased substantially over the past 20 years, 7% (1.34 TCF) of total domestic gas production is derived from coalbed methane. In this period, the cumulative US production of coalbed methane has exceeded 198 billion m^3 (7 TCF) and more than 8000 coalbed methane wells have been drilled. In Maritime Canada, the largest coalbed methane resources occur in the offshore areas of the Gulf of St. Lawrence and Sydney Basins where 196 and 26 billion m^3 (69 and 9.3 TCF) of gas, respectively, have been projected. In the old mines, the greatest resources are present in the Prince and Phalen mines of the Sydney coalfield, which together contain 1.70 billion m^3 (60 BCF) of gas, and in the Westville mine of the Pictou coalfield with 198 million m^3 (70 BCF). Vitrinite is the dominant constituent in 27 of the 42 coals examined. Vitrinite/inertinite ratios for these 27 coals range from 4.0 to 8.4. These high values may indicate the presence of highly fractured coals with corresponding high permeability and flow efficiency, favourable for the storage and flow of methane gas. Coal rank has a pronounced effect on coalbed methane generation, and the prime gas zone often lies between 1.2% and 1.6% Ro max. (medium to low volatile bituminous). The prime zone in the Maritimes Basin underlies much of the central and eastern Gulf of St. Lawrence, and extends for significant distances seaward into the offshore Sydney Basin. Coalbed methane production from the very large resources available in Atlantic Canada may provide a valuable and long-lasting energy resource, largely free of polluting components.
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Keywords: Coalbed methane; Coal rank; % Ro (max); Coal porosity; Coal macerals

1. Introduction

With the closure of the Phalen Colliery in December 1999, the coal mining operations in the Sydney coalfield, which had lasted some 280 years, nearly ceased (Calder et al., 1993). Only one mine, the Prince Mine in the Point Aconi area, remains in operation (Calder, 1985). Local coal, which at one time provided about 70% of the electricity generation in Nova Scotia, has been largely replaced by oil, and soon the energy of natural gas from the offshore fields will become available. Coal was produced from some 22 collieries during the peak period in the early 1940s (MacKay, 1947), and the total amount extracted from the Sydney field has been calculated at 400 million short tonnes (since 1785). The remaining measured resources, which nearly all occur in the submarine area (Hacquebard, 1979, Fig. 1) are estimated at 175 million tonnes.

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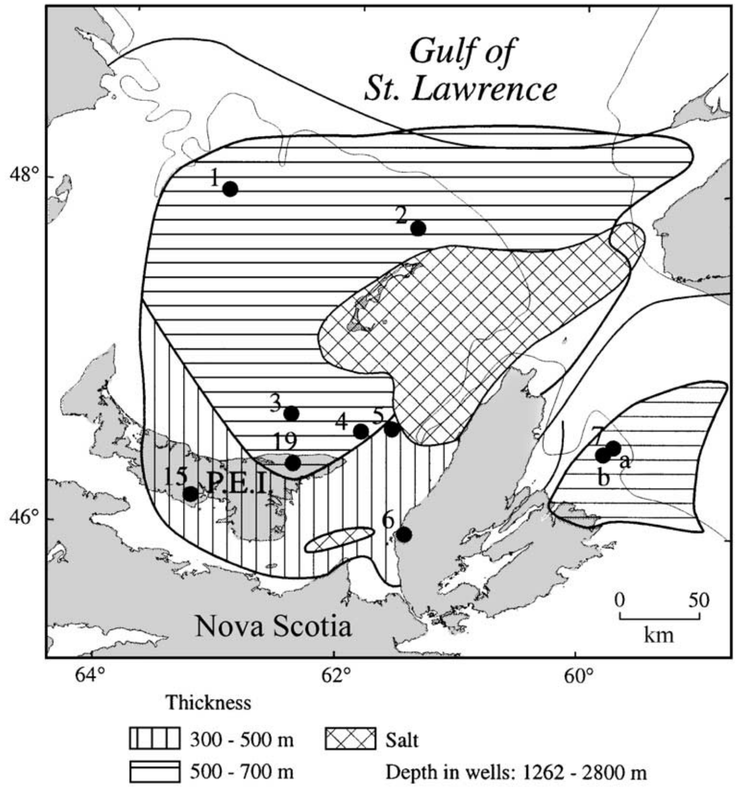

Fig. 1. Thickness variations of main gas generation zone between 1.2% and 1.6% Ro (max) rank in Gulf of St. Lawrence and Sydney basins (for well identification see Table 3).

Although the mining of coal has practically ended in Atlantic Canada, the energy present in the form of coalbed methane, i.e., methane trapped within the porous system of coal, is still available, and represents a most valuable energy resource (Calder and MacDonald, 1994). This report evaluates the methane potential of abandoned mines and coal resource areas in the Maritime Provinces that are still accessible by modern techniques. This largely untapped resource could make a substantial contribution to Canada's energy requirement through the 21st century and beyond.

2. Coalbed methane characteristics, coal rank, coal maceral composition and coal porosity

Methane is a nonpoisonous, tasteless, odorless and colorless gas. It is also known as marsh gas (CH_4) and, when mixed with air, it forms fire-damp. It is violently explosive at a mixture of 9% air, having at least 12% oxygen. The amount of methane in underground workings of coal can be determined by the Davy safety lamp. The height of the flame shows the presence of 1–4% methane. Fire-damp is much lighter than air and becomes concentrated in the roof strata of the coal seams (Moore, 1947). It has been the cause of major mine accidents in different parts of the world. In Nova Scotia, the most recent disaster occurred at the Westray Mine of the Pictou coalfield, where in 1992 an explosion killed 26 miners. The presence of methane and coal dust was considered the cause. A similar explosion occurred in 1979 in No. 26 Colliery at Glace Bay, claiming the lives of 12 men.

Methane is the result of the alteration of vegetal matter (present in peat) into coal. The latter is both the adsorption and the gas release, or desorption medium. The coal porosity is a major factor. It is related to the rank of the coal and increases from high volatile to medium and low volatile bituminous coal and anthracite.

Coal rank has a significant effect on the methane production of coal. It increases with rank from 4.5 m^3/tonne in high volatile B bituminous coal (at St. Rose) to 15 m^3/tonne in low volatile bituminous coal (at Westville) (Grant and Moir, 1992; Creedy, 1988; Ryan, 1992; Rightmire and Coate, 1986). Actual methane measurements were not available, and the amount of methane was entirely calculated from the corresponding rank of the coal.

Studies by Lamberson and Bustin (1993) on the methane adsorption of coal have shown that the maceral composition is at least as important as coal rank. They found an increase with the amount of vitrinite and a decrease with the content of inertinite.

Studies by Harvey and Dillon (1985) greatly simplified the correlation of maceral composition and methane production by introducing the vitrinite/inertinite ratio. This ratio is an inverse index of the degree of oxidation that occurred during the peat stage. High inertinite indicates a high oxidation due to greater exposure of the peat bogs to air because of lower water tables. High vitrinite reflects higher water coverage with less oxidation, and better preservation of the plant tissues. High vitrinite/inertinite (V/I) ratios occur adjacent to fossil river channels.

The maceral composition and V/I ratios of 42 coals present in the 12 coal areas examined are shown in Table 1. They are also plotted in the bar diagrams of Fig. 2.

Within the coals examined, the V/I ratios vary between 2.3 and 13.2. The average value is 5.6. Vitrinite averages 72% and inertinite 16%. This shows that in the coals of Atlantic Canada, the peat deposition took place under high water table conditions preventing strong oxidation. As these conditions promoted the formation of vitrinite and reduced the content of inertinite, it favourably affected the capacity of coal to adsorb methane. As a result, high adsorption ratios are present.

This relationship is related to the development of porosity in coal and the cleat distribution. The porosity is initially high in low-rank coals (maximum 23%), decreases to 4% in high volatile bituminous coals, stays constant until low volatile bituminous rank and increases sharply (up to 10%) in anthracite. Three pore size classes are recognized: (1) macropores with a diameter larger than 30 mm; (2) mesopores between 1.2 and 30 mm; and (3) micropores with diameter less than 1.2 mm. These pore sizes vary with rank. Lignite is in the macropore range; high volatile bituminous B and C have macro- and mesopore sizes and higher-rank coals are microporous. With the micropores, a large internal surface is present and can provide substantial storage for coalbed methane in bituminous coals (Gan et al., 1972; Lamberson and Bustin, 1993).

For the determination of existing coal resources, only those projected from old mine workings have been used. Entire coal basins have not been considered.

3. US coalbed methane production in 1999

US coalbed methane resource evaluations and production have increased substantially during the past 20 years (Levine, 1993). At present, 7% (1.34 TCF[1]) of total domestic gas production is derived from coalbed methane. In 1999, there were more than 8000 coalbed methane wells drilled and the total cumulative production over 20 years exceeded 198 billion m^3 (7 TCF) (Nelson, 1999).

In 1999, the total coalbed methane resources of the US was estimated at 4 trillion m^3 (141.4 TCF)or 11.7% of the total natural gas resources. The coalbed methane resources occur in 16 basins with deposits of Pennsylvanian to Tertiary geological ages (Nelson, 1999). Several are present in the Permian–Pennsylvanian coals of the eastern US, which extend into the Canadian Maritime Provinces. The most productive areas are in the high volatile bituminous coals of the San Juan Basin of Colorado and New Mexico, and medium volatile bituminous coals of the Black Warrior Basin of Alabama. In both basins, high permeability coals are present.

[1] TCF, BCF, MCF: trillion, billion, million cubic feet.

Table 1
Whole seam maceral and vitrinite reflectance data of main coal seams in Atlantic Canada

Location	Section or Well	No. in Figs. 1 and 4	Depth (m) in well or section	Seam name or thickness (incl. ptgs) (m)	Vitrinite (%)	Inertinite (%)	Exinite (%)	Mineral matter (%)	Vitrinite/inertinite ratio mineral matter-free	Ro (max) data (%)
					Mineral matter-free in: M-1 only					
Mabou Mines	M-1 Mabou Mines	6	1067	7 Ft	78	14	8	9	5.6	0.6
			1082	8 Ft	82	10	8	3	8.2	
			1143	15 Ft	79	14	7	8	5.6	0.7
			1189	5 Ft	82	11	7	8	7.5	
			1265	3 Ft	80	14	6	11	5.7	
Inverness			549	7 Ft	82	14	5	6	5.9	0.6
Gulf of St. Lawrence Basin	East Point E-49	5	2652	1.8	80	10	5	5	7.6	1.21
	Naufrage No. 1	19	2560	1.8	65	12	8	15	5.4	1.47
	Cable Head E-95	3	2210	2.1	70	24	2	4	2.9	1.20
			2225	2.1	85	6	–	9	13.2	1.30
	Tyrone No. 1	15	2637	1.8	78	12	–	10	6.7	1.46
	Bradelle L-49	1	1295	1.5	75	11	8	6	6.7	0.80
			1737	2.1	65	16	10	9	4.0	1.14
	Brion Island No. 1	2	975	4.7	72	14	5	9	5.3	0.73
			1402	1.4	64	14	5	17	4.5	0.81
Sydney Basin	Stratigraphic section, Sydney coalfield	7	0	Point Aconi	69	22	5	4	3.1	
			107	Lloyd Cove	67	22	6	5	3.1	0.92
			152	Hub	77	13	5	5	5.8	0.8–1.0

			274	Harbour	73	12	5	10	6.2 (12 samples)	0.9–1.1
			366	Backpit	69	17	10	4	4.0	
			396	Phalen	81	12	4	3	7.0 (10 samples)	0.9–1.1
			426	Emery	81	10	6	3	8.1	
			594	Gardiner	79	12	7	2	6.8	
			762	Mullins	82	10	6	2	8.1	0.80
			945	Tracey	76	18	4	2	4.2	
	P.05 Murphy Well	7a	610	A	28	46	6	20	0.6	0.74
			732	Point Aconi	69	22	7	2	3.2	0.91
			823	Lloyd Cove	77	15	6	2	5.3	0.89
			884	Hub	80	11	7	2	7.5	1.01
			976	Harbour	68	18	10	4	3.7	1.01
			1067	F	70	22	6	2	3.3	1.02
	G-24 Shell Well	7b	649	A	62	27	4	7	2.3	0.83
			756	Point Aconi	67	22	4	7	3.0	0.94
			805	Lloyd Cove	68	23	4	5	3.0	0.94
			846		80	12	4	4	6.4	1.00
			921	Hub	82	12	3	3	7.1	1.10
			968		80	12	2	6	6.5	1.04
			1015	Harbour	80	16	2	2	5.1	1.16
			1277	Gardiner	79	12	1	8	6.6	1.22
			1317		83	12	2	3	7.2	1.22
			1317	Mullins	68	20	7	5	3.4	1.55
New Brunswick	Minto Field	2	7 ± 67	Minto	59	23	9	9	2.6	0.7

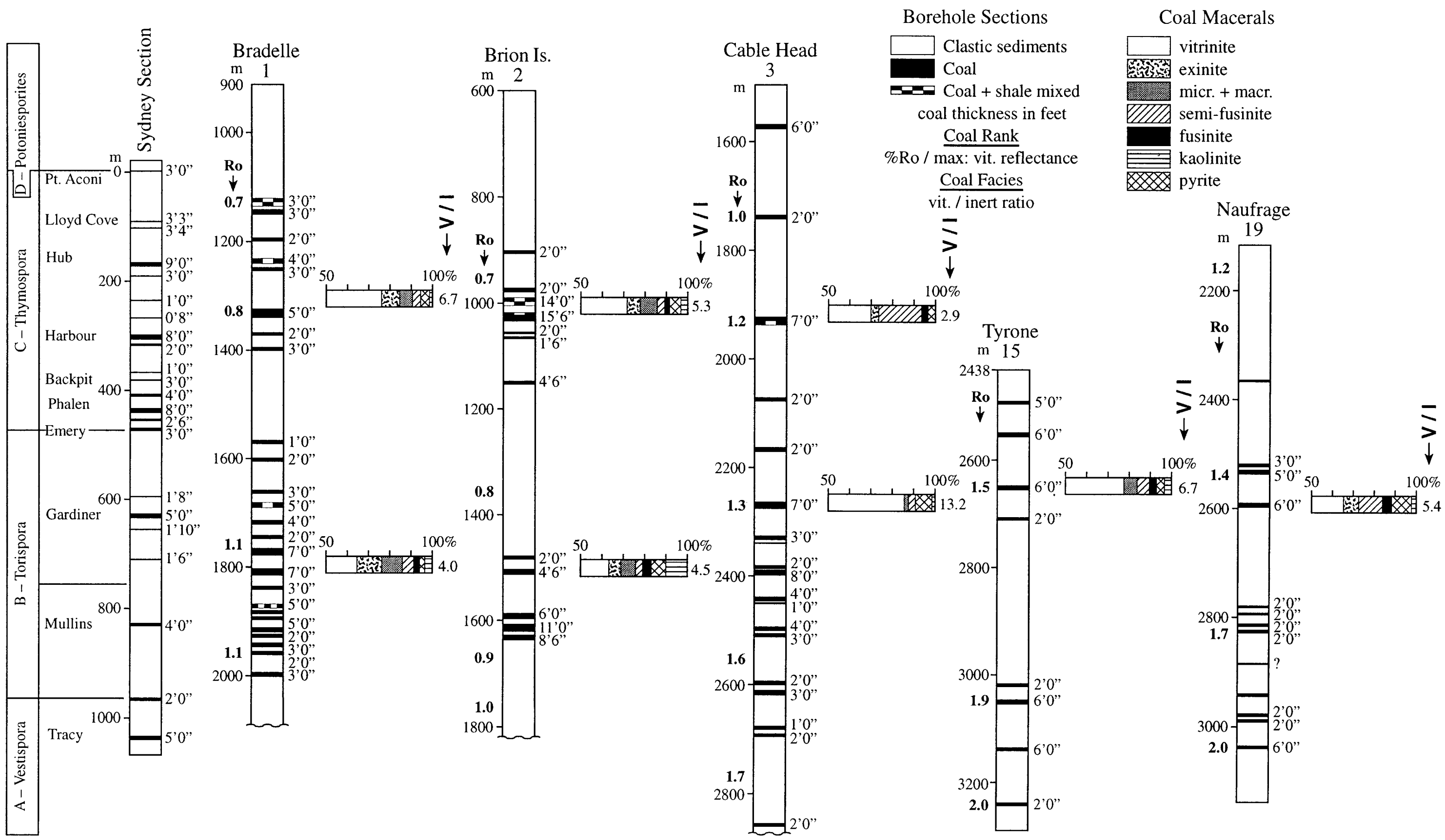

Fig. 2. Maceral composition, V/I ratio and coal rank (% Ro) data of five borehole sections of Prince Edward Island and the Gulf of St. Lawrence Basin (for borehole lithology and locations, see Figs. 1 and 4).

The fastest growing coalbed methane play is in the subbituminous coals of the Powder River Basin of Wyoming and Montana. This basin encompasses 58,275 km^2 and contains a coal in-place resource of 1.18 trillion metric tonnes; the largest coal deposit of the US (Nelson, 1999, p. 8).

Several improved methods of coalbed gas recovery have been introduced in recent years. These include: (1) Horizontal drilling (Morgan Hydrocarbons, 1992); (2) Enhanced recovery by nitrogen injection (Murray, 1996); (3) Dynamic open hole cavitation techniques on vertical wells, in which the casing is not run past the coal intersections (Murray, 1996); (4) Advanced hydraulic fracture treatments (Murray, 1996). These different gas recovery systems have greatly increased the overall daily US methane production from coal during the past 10 years (from 28.3 to 85 billion m^3 (1.0–3.0 BCF) (Murray, 1996).

4. Coalbed methane resource calculations of 12 coal areas in the maritime provinces (Fig. 3)

For each coal area, 11 essential data are presented in Table 2. With few exceptions, these areas represent abandoned underground workings, or remaining resources. In the abandoned mines, the coal resources are calculated in two categories, i.e., "in situ coal" and "mined coal". The latter relates to the coal still present in the mine after room-and-pillar and longwall extraction. For this, a figure of 50% of the original in-place resources has been used (Fig. 3) (Table 2A).

For the amount of methane generation, the essential data are: (a) thickness of the coal seams and calculation of the total coal resources present; the distribution and thickness of the coal deposits in the virgin coal areas are shown in the borehole and stratigraphic sections of Fig. 4 (Fig. 4A); (b) the methane generation is a function of the coal rank and composition, as has been previously discussed. This has been incorporated in the methane resource calculations.

Calculation of the amount of coalbed methane is as follows: (1) tonnage of coal: area (km^2) × seam thickness (m) × spec. gr. (1.3); (2) methane per tonne: 4.5–15 m^3 in high volatile bituminous to low volatile bituminous coal (0.65–2.0% Ro (max); (3) conversion to cubic feet, use factor 35.3 for 1 m^3 (Table 2A).

The effect of coal rank on the occurrence and distribution of potential coalbed methane gas zones is shown in Fig. 1 and Table 3. Two zones, ranging in thickness from 300 to 700 m, are recognized. The thickest zone of 600–700 m is projected in the Gulf of St. Lawrence, northwest of the Magdalen Islands. The zone here lies at a depth of about 2000 m. Over Prince Edward Island (PEI), the zone is 450–600 m thick and also occurs at about 2000 m. Most of the previously drilled wells actually intersected both zones.

5. Detailed descriptions of coalbed methane resource areas in the maritime provinces

Resource areas, which are named in Table 2, are shown in Fig. 3 by the numbers 1 to 12. They are mostly abandoned mines and exploration wells.

5.1. Offshore area in Gulf of St. Lawrence northeast of Prince Edward Island (Fig. 5) (fig. 5a in Grant and Moir, 1992; Barss et al., 1979)

The area measures 8750 km^2 and includes five wells marked 3, 4, 5, 6 and 19 (Fig. 5). These wells intersected both the *Thymospora* and the *Torispora* zones (Table 4, zones C and B; Hacquebard et al., 1989). Coals occur in both zones, but considerably more in the latter zone. Between 12 and 13 seams were intersected in each well, which together amount to 63 m of coal. This averages to a coal thickness of 13 m per well (Fig. 4).

The coal rank is between 1.2% and 1.47% Ro (max), except in well 6 (Mabou Mines) where it is only 0.65% Ro (max). With the exception of the latter reflectance, this translates to medium volatile bituminous coal, which has a methane generation capacity of 13 m^3 per tonne of coal (Nikols and Rottenfusser, 1991; Ryan, 1992). The total in situ coal of 150 billion tonnes could contain 1.95 trillion m^3 (69 TCF) of methane.

Access to this large resource may be possible through some of the previously drilled wells, if they can be relocated, or by drilling new wells.

Table 2
Detailed data on coalbed methane of 15 coal areas in Atlantic Canada

Figure no.	Region	Area shown in Figs. 1–12		Surface area (km^2)		Depth of coal zone below sea level	Stratigraphic interval of coal zone, no. of seams + wells (Fig. 3—spore zones)
Fig. 5A	Gulf of St. Lawrence	A	Gulf of St. Lawrence	8750		2100–2940 m	*Torispora*, zone B, 70 seams, 5 wells
Fig. 5B	Sydney coalfield	B	Offshore	2600		0–1200 m	*Thymospora*, zone C, 26 seams, 3 wells
Fig. 7		A′	Prince Mine	38	58	0–450 m	*Thymospora*, zone C, 1 seam, 7 wells
		B′		20			
Fig. 8		C′	Phalen Mine	25.5	32.5	0–1200 m	*Thymospora*, zone C, 1 seam, 6 wells
		D′		7			
Fig. 9A		C (Donkin)	Lloyd Cove area	40		150–600 m	*Thymospora*, zone C, 1 seam, 6 wells
Fig. 9B			Hub area	72		150–750 m	*Thymospora*, zone C, 1 seam, 8 wells
Fig. 9C			Harbour area	77		200–800 m	*Thymospora*, zone C, 1 seam, 12 wells
Fig. 10	Inverness County	D	St. Rose	2.3		+ 50–200 m	Westphalian A, 1 seam, 10 wells
Fig. 11		E	Inverness	29		13 ft: 0–1078 m 7 ft: 0–1200 m	*Thymospora*, zone C, 2 seams, no wells
Fig. 12		F	Mabou Mines	20		13 ft: 78–1078 m 7 ft: 300–1200 m	*Torispora*, zone B, 2 seams, 2 wells
Fig. 13		G	Port Hood	6.2		0–600 m	Westphalian A, 1 seam, 4 wells
Fig. 14	Pictou County	H	Westville Mine	6.3		+ 50–610 m	Westphalian C
		I		5.1		− 600–1400 m	
Fig. 15		J	Allan Mine	5.2		− 50–450 m	Westphalian C
		K		0.6		− 50–350 m	Westphalian C
		L		0.25		0–300 m	Westphalian C
		M		2.8		− 200–700 m	Westphalian C
Fig. 16	Cumberland County	N	Syndicate Slope	0.25		− 90– + 150 m	Westphalian B
		O	Springhill No.2 Mine	0.44		− 1200–1800 m	Westphalian B
		P		1.95		− 1200– + 150 m	Westphalian B
Fig. 17	New Brunswick		Minto Field	410		7– + 67 m	*Vestipora*, zone D, 1 seam Grand Total

5.2. Onshore and offshore Sydney coalfield (Fig. 5) (figs. 5 and 6 in Grant and Moir, 1992; Hacquebard, 1998; Barss et al., 1979; Hacquebard, 1976a)

The area measures 2600 km^2 and includes wells 7a, 7b and 7s (Figs. 5B, and 6). These wells and the onshore seams of 7s occur in the *Thymospora* zone (Table 4, zone C). Between 7 and 15 coal seams were intersected in each well. This gives an aggregate coal thickness of 35 m or an average coal thickness of 11 m per well (Fig. 4).

The coal rank is between 0.8% and 1.1% Ro (max), which compares to high volatile A bituminous coal, which has a methane generation capacity of 8 m^3 per tonne of coal (Creedy, 1988). The total in situ coal of 28.5 billion tonnes can contain 226.5 billion m^3 (8 TCF) of methane.

Total coal resources present (in situ + coal left after mining) (tonnes)	Total coal per interval or name of seam (tonnes)	Average seam thickness (m) (incl. ptgs)	Coal rank		Methane capacity factor (per m^3)	Total methane (m^3)	Conversion to TCF (at 1 m^3 = 35.3 cu. ft)	
			ASTM	% Ro (max)				
150 billion	63 million	13	M.V.	1.2–1.5	13	1.95×10^{12}	69	
33 billion	35 million	11	H.V.A	0.8–1.1	8	2.63×10^{9}	9.3	
145 million	Hub seam	2.3	H.V.A	0.75	5	0.73×10^{9}	0.025	
97 million	Phalen seam	2.3	H.V.A, M.V.	0.94–1.13	12	0.98×10^{9}	0.033	
125 million	Lloyd Cove	2.4	H.V.A	0.9–1.0	8	0.10×10^{9}	0.035	
206 million	Hub seam	2.2	H.V.A	0.8–1.0	8	1.65×10^{9}	0.058	
300 million	Harbour seam	3	H.V.A, M.V.	0.9–1.1	8	2.4×10^{9}	0.084	
6.3 million	No.5 Seam	2, 2.2	H.V.B	0.65	4.5	0.021×10^{9}	0.026	
147 million	13 Ft seam, 7 Ft seam	1.4 and 2.1	H.V.B	0.7	5	0.125×10^{9}	0.025	
116 million	13 Ft seam, 7 Ft seam	1.7 and 2.6	H.V.B	0.6–0.7	5	0.067×10^{9}	0.024	
18.5 million	6 Ft seam	1.8	H.V.B	0.7	5	0.08×10^{9}	0.003	
42 million	Acadia seam	3	M.V.	1.1–1.3	13	0.03×10^{9}	0.075	0.055
		3.2	L.V.	1.5–2.0	15	0.06×10^{9}		0.02
34.2 million	Foord seam	10	H.V.A	1.0	10	0.35×10^{9}	0.022	0.012
5.8 million	Foord seam	9.5	H.V.A	1.0	10	0.058×10^{9}		0.002
2.3 million	Foord seam	7.1	H.V.A	1.0	10	0.023×10^{9}		0.0008
20.7 million	Foord seam	5.6	H.V.A	1.0	10	0.21×10^{9}		0.007
0.87 million	No.3 Seam	2.7	H.V.A	1.0	8	0.007×10^{9}	0.0025	
15.4 million	No.2 Seam	2.7	M.V.	1.25	13	0.020×10^{9}	0.085	0.007
68 million	No.2 Seam	2.7	M.V.	1.15	13	0.031×10^{9}		0.018
9 million	Minto seam	0.45	H.V.A	0.7	8	0.072×10^{9}	0.025	
184.359 million					Grand Total	2.233×10^{9}	78.82 TCF	

The "mined" coal amounts to 9.5 billion tonnes, of which 50% remained after extraction, or 4.75 billion tonnes. This could generate 36.8 billion m^3 (1.3 TCF) of methane. The total methane would then amount to 263 billion m^3 (9.3 TCF).

Loss of methane in mined coal from remaining pillars is difficult to evaluate and has not been considered.

5.3. Prince Mine area of the Hub seam (Fig. 7) (Hacquebard, 1974; Hacquebard and Avery, 1992)

The total resource area measures 58 km^2, of which area A′ occupies 38 km^2 and area B′ covers 20 km^2. The Hub seam was intersected in seven boreholes at a depth of between 25 and 450 m below sea level. The seam varies in thickness between 2.2 and 2.4 m (Fig. 7).

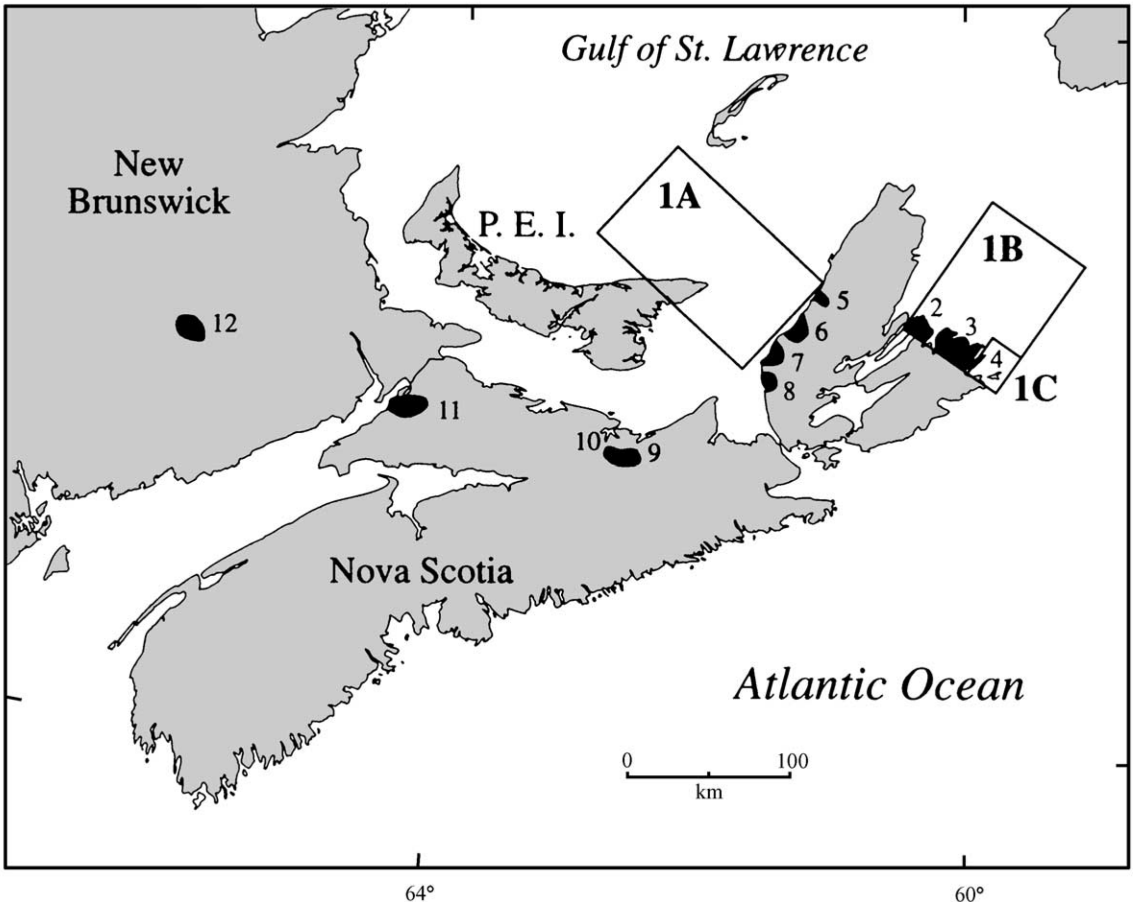

Fig. 3. Coal deposits of the Maritime Provinces with coalbed methane potential (1A: Gulf of St. Lawrence; 1B: Sydney coalfield; 1C: Donkin Reserve; 2. Prince Mine; 3. Phalen mine; 4. Donkin seams; 5. St. Rose; 6. Inverness; 7. Mabou Mines; 8. Port Hood; 9. Westville; 10. Allan Mine; 11. Springhill; 12. Minto).

The coal rank averages 0.75% Ro (max), which compares with high volatile A bituminous coal. At this rank level the methane generation from coal is equal to 5 m^3 per tonne (Creedy, 1988). For area A′, with an average thickness of 2.3 m and total in situ coal of 115 million tonnes, the methane resource calculates to 570 million m^3 (20 BCF). For area B′, with a thickness of 2.3 m and total "mined" coal of 61 million tonnes, of which 50% remained after room-and-pillar and long-wall extraction, the methane resource calculates to 1.42 billion m^3 (50 BCF).

The aggregate methane generation potential of the Prince Mine (areas A′ and B′) totals 710 million m^3 (25 BCF). Access to the Prince Mine methane resource could be obtained through the existing Main Deep with boreholes at both areas A′ and B′.

5.4. Phalen Colliery area of the Phalen seam (Fig. 8) (Hacquebard, 1976b; Hacquebard and Avery, 1989)

The total resource area measures 32.5 km^2, of which area C′ occupies 25.5 km^2 and area D′ covers 7 km^2. The Phalen seam was intersected in six boreholes at a depth of between 12 and 1077 m below sea level. The seam averages 2.3 m in thickness (Fig. 8).

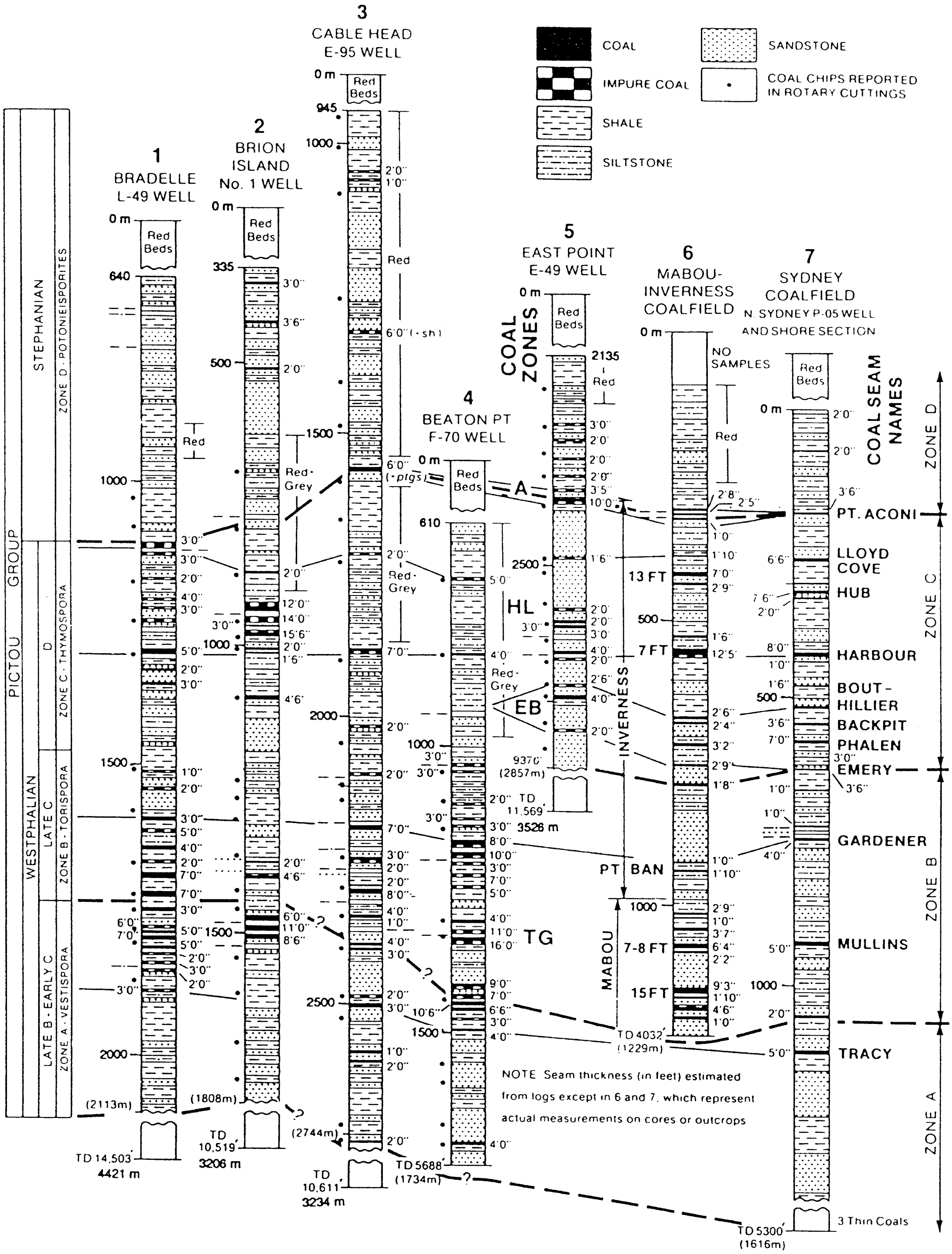

Fig. 4. Coal seam intersections of wells drilled in the Gulf of St. Lawrence and Sydney Basins (after Hacquebard, 1986).

(a)

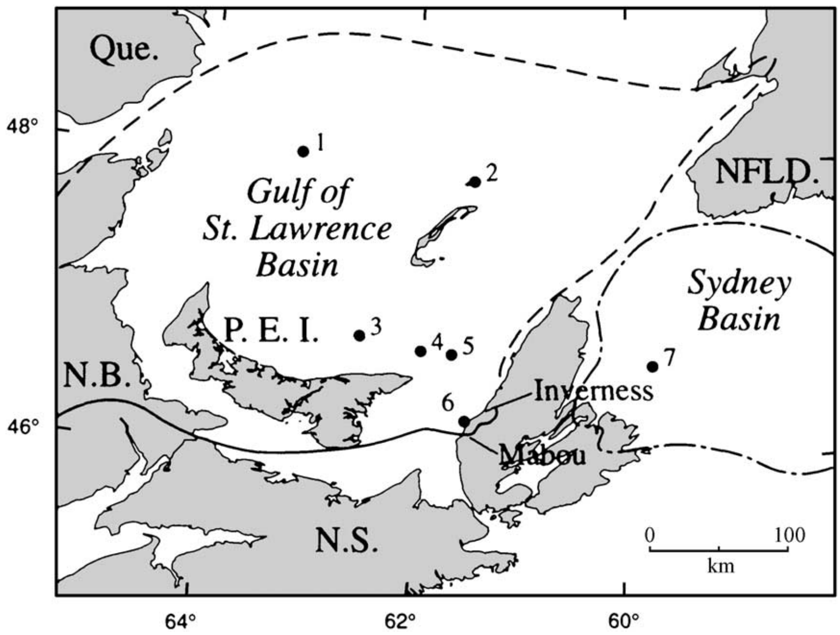

Fig. 4a. Locations of sections shown in Fig. 4.

The coal rank increases with the depth below sea level from 0.94% to 1.13% Ro (max), which compares with high volatile A bituminous to medium volatile bituminous coal. At this rank level the methane generation from coal varies from 8 to 12 m^3 per tonne (Creedy, 1988). For area C′, with an average thickness of 2.3 m and total in situ coal of 77.4 million tonnes, the methane resource (at 12 m^3 per tonne) calculates to 850 million m^3 (30 BCF). For area D′, with a thickness of 2.3 m and total "mined" coal of 20 million tonnes, of which 50% remained, or 10 million tonnes at 8 m^3 methane per tonne. The methane resource is estimated at 80 million m^3 (3 BCF).

The total methane generation potential of the Phalen Colliery (areas C′ and D′) comes to 930 million m^3 (33 BCF).

Access to the Phalen Mine methane resource can be obtained through the existing Main Deep with underground boreholes at both areas C′ and D′.

The Phalen Colliery was opened in 1987 and was closed December 20, 1999. The closure was due to roof cavings and hazardous conditions (not because of fire-damp). A methane ventilation project was carried out in 1985 in the adjoining Dominion No. 26 Colliery. It contained 45 million tonnes of coal and

Table 3
Thickness and depth of prime gas generation zone between 1.2% and 1.6% Ro (max) of coal rank

No. in Fig. 1	Name of well	Depth in wells (m)		Interval thickness (m)
		at 1.2% Ro (max)	at 1.6% Ro (max)	
1	Bradelle L-49	1973	2600	627
2	Brian Island No. 1	2096	2800	704
3	Cable Head E-95	1900	2440	540
4	Beaton Point E-70	2600	3200	500
5	East Point E-49	2585	2930	345
6	Mabou M1	2252	2580	328
7a	Murphy PO-5	1332	2000	668
7b	Shell G24	1262	1862	600
15	Tyrone No. 1	2195	2680	485
19	Naufrage No. 1	2112	2750	638

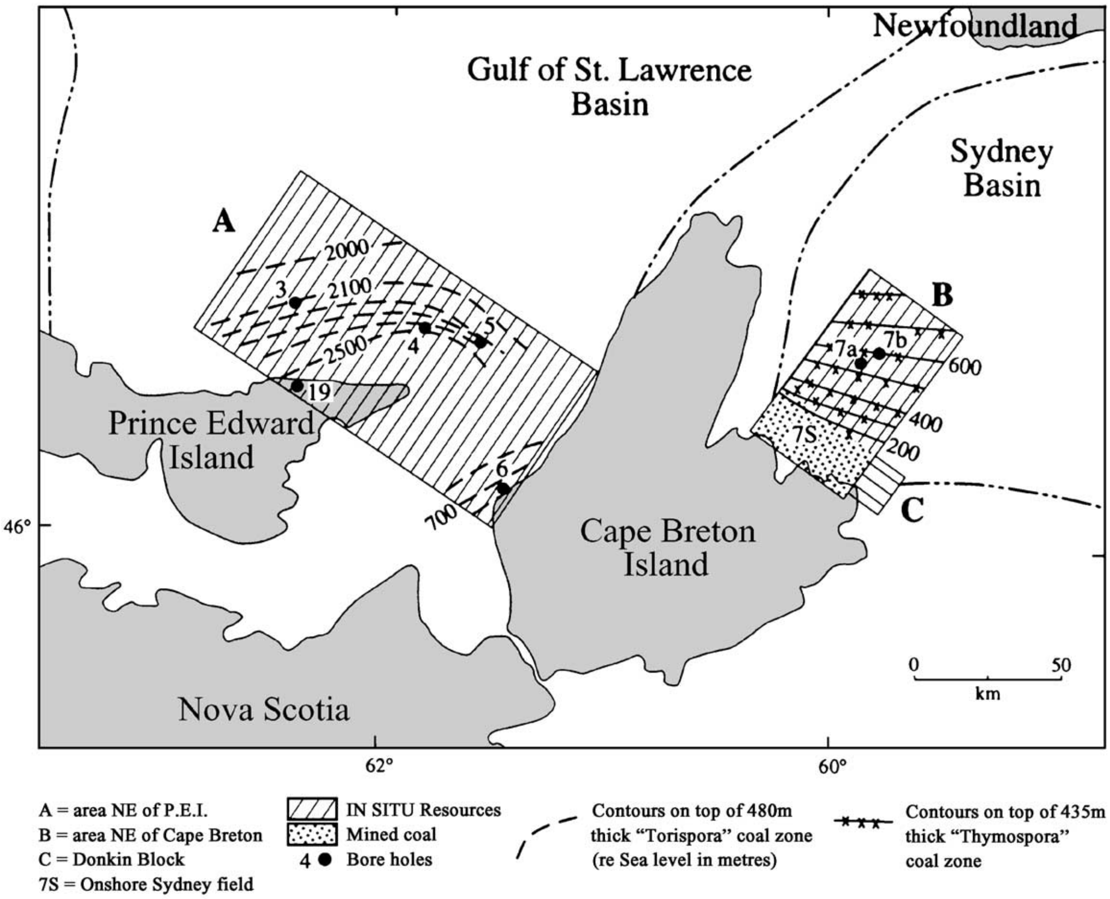

Fig. 5. Coalbed methane resource areas (A, B and C) of the Gulf of St. Lawrence and Sydney basins.

produced 70,800 m^3 (2.5 MCF) of gas per day (Lyndon and Blais, 1990).

5.5. Donkin area of Sydney coalfield (Figs. 5 and 6) (Hacquebard, 1978, 1993a; Hacquebard and Avery, 1988)

The Donkin area occupies the extreme eastern part of the Sydney coalfield. It is entirely submarine and measures 189 km^2 in area, lying adjacent to old submarine workings on the Harbour and Phalen seams.

In this block, 26 boreholes were drilled from a drill ship in 1978 and 1979. These holes ranged in depth from 262 to 843 m and totaled 5811 m. They intersected three separate seams of mineable thickness that vary between 2.2 and 3 m. The total in situ tonnage is calculated at 631 million tonnes, of which 300 million tonnes are present in the Harbour seam.

Access to the Donkin block of the Harbour seam was obtained by a rock tunnel rather than by a slope, because the seam dips seaward and outcrops at the sea floor (Fig. 9). The tunnel, which started at the shore, is 3.5 km long and was completed in 1984. At the intersection with the Harbour seam, a 125-m-long cross-cut was driven (Fig. 1 in Hacquebard and Avery, 1988).

The four seams intersecting in the Donkin block are: (1) Point Aconi seam; (2) Lloyd Cove seam;

Table 4
Stratigraphic diagram for Upper Paleozoic rocks in eastern Canada (after Hacquebard et al., 1989)

Age			Barss & Hacquebard: Group	Barss & Hacquebard: Spore Zones
Permian - Lower			Pictou	E
Carboniferous	Stephanian		Pictou	D
Carboniferous	Westphalian	D	Pictou	C
Carboniferous	Westphalian	C	Pictou	B
Carboniferous	Westphalian	C	Pictou	A
Carboniferous	Westphalian	B	Cumberland	F
Carboniferous	Westphalian	A	Cumberland / Riversdale	E
Carboniferous	Namurian		Riversdale	D
Carboniferous	Namurian		Canso	B / C
Carboniferous	Visean		Windsor	A ↓ ?
Carboniferous	Visean		Horton (Windsor/Horton boundary ?)	G
Carboniferous	Tournaisian		Horton	F
Carboniferous	Tournaisian		Horton	E
Carboniferous	Tournaisian		Horton	D
Devonian	Upper		Horton	C
Devonian	Upper		Horton	B
Devonian	Middle		Horton	A

(3) Hub seam; and (4) Harbour seam. They are listed in descending stratigraphic order and encompass a thickness of 250 m. In thickness they vary from 1.5 m (Point Aconi) to 2.4 m (Lloyd Cove) to 2.3 m (Hub) to 3.3 m (Harbour). The seam developments of three of the seams are shown in Fig. 9A, B and C. (No plan has been prepared of the Point Aconi seam, it was intersected in two boreholes only.)

5.6. Lloyd Cove seam (Fig. 9A) (Hacquebard, 1978, 1998)

The resource area A, B, C, D, E, F, G measures 40 km^2. The Lloyd Cove seam was intersected in six boreholes at a depth of between 150 and 600 m below sea level. The average seam thickness is 2.4 m.

The coal rank increases with the depth below sea level from 0.90% to 1.00% Ro (max), which is equivalent to high volatile A bituminous coal. At this rank level the methane generation from coal is equal to 8 m^3 per tonne. For the entire area, with total in situ coal of 125 million tonnes, the methane resource calculates to 999 million m^3 (35 BCF).

Access to the Lloyd Cove methane resource can be obtained through the underlying Harbour seam, which lies 150 m below it.

5.7. Hub seam (Fig. 9B) (Hacquebard, 1978, 1998)

The resource area A, B, C, D, E measures 72 km^2. The Hub seam was intersected in 10 boreholes at a depth of between 150 and 750 m below sea level. The average seam thickness is 2.2 m.

The coal rank increases with the depth below sea level from 0.80% to 1.0% Ro (max), which is equivalent to high volatile A bituminous coal. At this rank level the methane generation from coal is equal to 8 m^3 per tonne. For the entire area, with total in situ coal of 206 million tonnes, the methane resource calculates to 1.64 billion m^3 (58 BCF).

Access to the Hub methane resource can be done through the underlying Harbour seam which lies 100 m below it.

5.8. Harbour seam (Fig. 9C) (Hacquebard, 1978, 1998; Hacquebard and Avery, 1982)

The resource area A, B, C, D, E, F measures 77 km^2. The Harbour seam was intersected in 11 boreholes at a depth of between 200 and 800 m below sea level. The average seam thickness is 3 m.

The coal rank increases with the depth below sea level from 0.9% to 1.1% Ro (max), which is equivalent to high volatile A to medium volatile bituminous coal. At this rank level the methane generation from coal is equal to 8 m^3 per tonne (Creedy, 1988). For the entire area, with total in situ coal of 300 million tonnes, the methane resource calculates to 2.38 billion m^3 (84 BCF).

Access to the Harbour methane resource can be obtained through the existing 3400-m-long tunnel (now flooded).

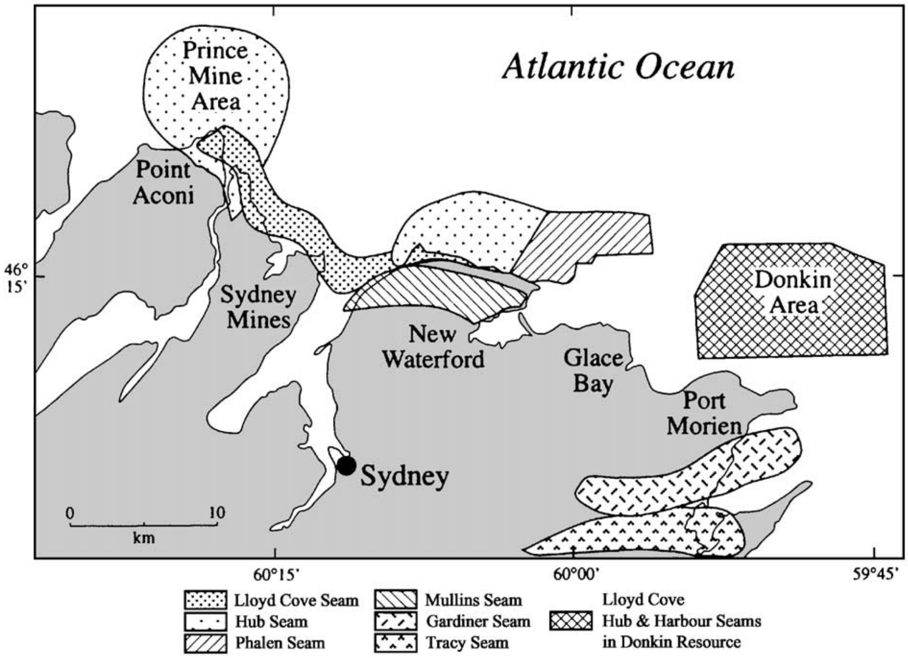

Fig. 6. Sydney coalfield showing onshore and nearshore resource areas of major coal seams (after Hacquebard, 1998, Fig. 8).

5.9. St. Rose coalfield—Inverness County (Fig. 10) (Hacquebard et al., 1989; Hacquebard, 1951)

The total area measures 2.3 km^2 and consists of area D′ with 1.3 km^2 and area D″ with 1 km^2 areas. It includes 11 boreholes, marked SR1 to SR12 in Fig. 10. There are five seams present which range in thickness from 0.1 to 2.5 m. Of these seams, only the No. 5 seam, which is 2–2.2 m thick, has been mined. It lies between + 50 and − 200 m below sea level. The coal rank is between 0.65% and 0.7% Ro (max), which compares with high volatile B bituminous coal. At this rank level the methane generation level is equal to 4.5 m^3 per tonne (Creedy, 1988).

For area D′, with an average thickness of 2 m and total in situ coal of 3.4 million tonnes, the methane resource calculates to 14 million m^3 (5 BCF). For area D″, with a thickness of 2.2 m and total "mined" coal of 2.9 million tonnes, of which 50% remained after room-and-pillar extraction, the methane resource calculates to 590 million m^3 (21 BCF). The total available methane resource comes to 740 million m^3 (26 BCF).

Access to this gas can be obtained through the existing Main Deep on the No. 5 Seam.

5.10. Inverness coalfield—Inverness County (Fig. 11) (Hacquebard et al., 1989; Hacquebard, 1993b)

The in situ resource area E′ (I, J, K, L in Fig. 11) measures 29 km^2 and has not been intersected by boreholes. It contains two coal seams, as projected from the mined area. These seams are the 13- and 7-Ft seams, which are 1.4 and 2.1-m thick, respectively. The tonnages are as follows: 54 million tonnes in the 13-Ft seam, and 81 million tonnes in the 7-Ft seam.

The coal rank is 0.7% Ro (max), or high volatile B bituminous coal, which produces 5 m^3 methane per tonne. The 7-Ft seam in area E′ lies between 500 and 1200 m below sea level. The methane contents calculate as follows. For the 13-Ft seam: 250 million m^3 (9 BCF) and for the 7-Ft seam: 400 million m^3 (14 BCF).

In addition, there is a resource of "mined" coal in area E″. It contains 11.6 million tonnes in the 7-Ft seam, of which 50% remained after room-and-pillar extraction or 5.8 million tonnes. This coal can produce 28 million m^3 (1 BCF) of methane. A same amount is present in the "mined" coal of the 13-Ft seam, also 28 million m^3 (1 BCF). The total available

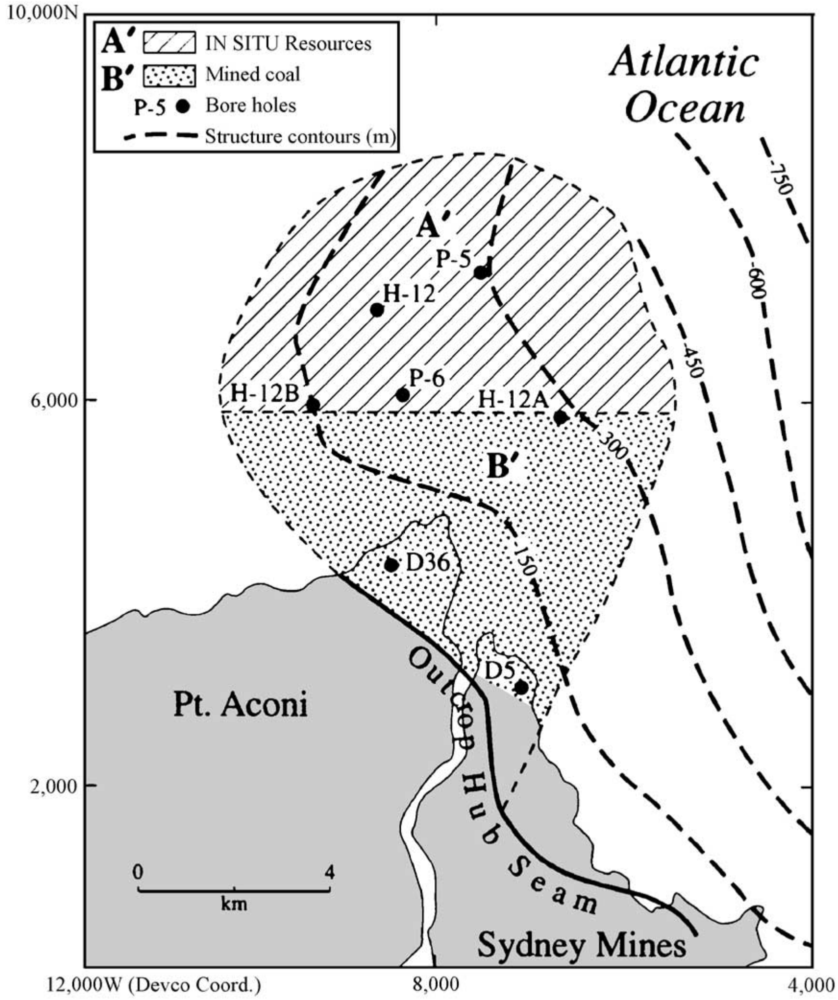

Fig. 7. Sydney coalfield. Prince Mine area of the Hub seam, coalbed methane resources.

methane of the Inverness coalfield comes to 710 million m^3 (25 BCF).

Access to the methane resource of area E′ could be obtained from the face of the old Main Deep of No. 1 Mine. A 700-m-long horizontal borehole would be required or a 2000-m-long borehole from the entry of the Main Deep.

5.11. Mabou Mines area—Inverness County (Fig. 12) (Hacquebard et al., 1989; Hacquebard, 1993b)

The in situ resource area F′ (C, D, E, F in Fig. 12) measures 20 km^2 and has been intersected by one offshore borehole, M-2A. It contains two coal seams as interpreted from nearshore geology, including borehole M-1A. These seams have been correlated with the 13- and 7-Ft seams of the Inverness coalfield.

The former is 1.7 m thick and contains 45 million tonnes, and the latter seam has a thickness of 2.6 m and contains 69 million tonnes. The 7-Ft seam in area F′ lies between 300 and 1200 m below sea level.

The coal rank is between 0.6% and 0.7% Ro (max), or high volatile B to high volatile C bituminous coal. A methane generation level of 5 m^3 has been used. The methane resources of the 13-Ft seam calculates to 230 million m^3 (8 BCF). The

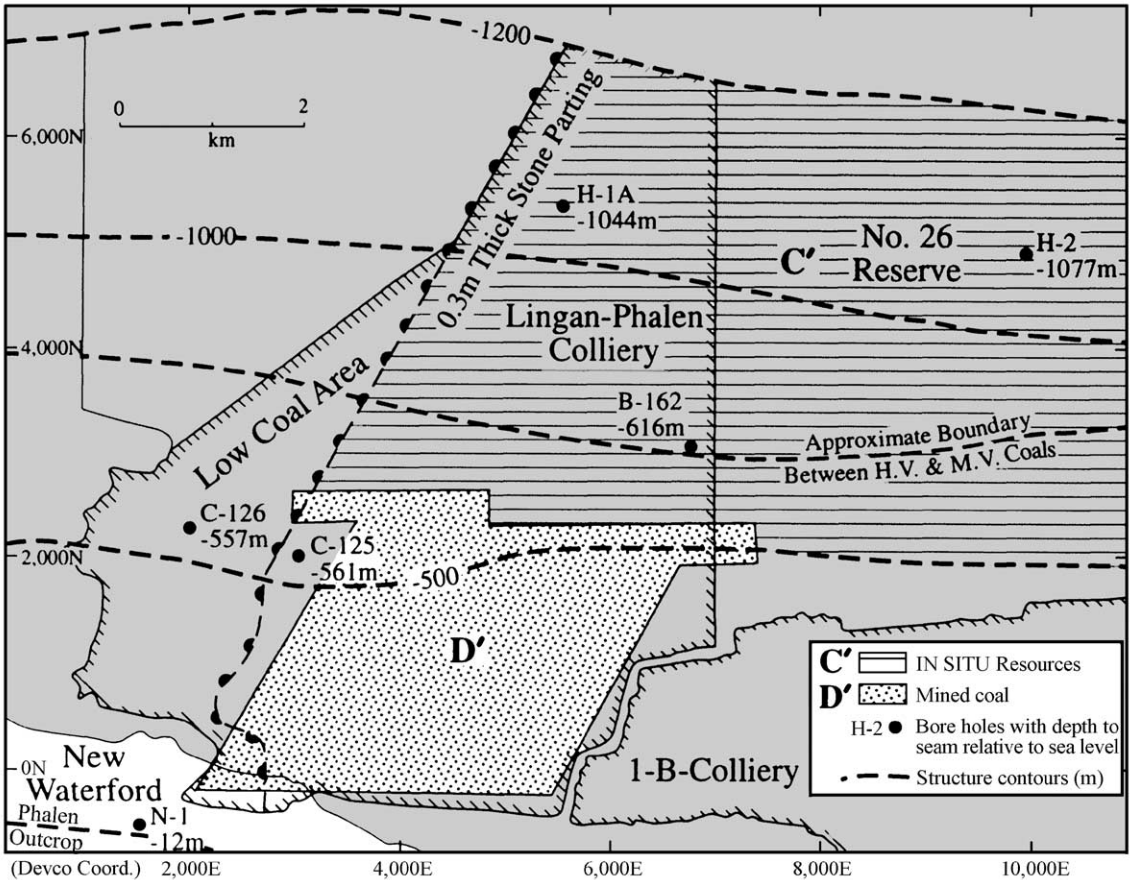

Fig. 8. Sydney coalfield. Phalen Coliery area, coalbed methane resources.

methane content of the 7-Ft seam is 340 million m^3 (12 BCF).

The "mined" coal of area F″ relates to mining activities carried out during the turn of the century. It terminated in 1909 when the mine became flooded with seawater. Extensive development work was carried out, but only 54,000 tonnes of coal were extracted. The total coal present in this mine is estimated at 2 million tonnes, and the amount remaining after mining would then be 1,946,000 tonnes. This coal could produce 110 million m^3 (4 BCF) of methane. The total at Mabou Mines is 680 million m^3 (24 BCF).

Access to the methane resource in block F′ would require a 1500-m-long tunnel from the Finlay Point area, as shown in Fig. 12.

5.12. Port Hood coalfield—Inverness County (Fig. 13) (Hacquebard et al., 1989)

The area measures 6.2 km^2 and includes borehole PH-3. There are two seams present of which only the 6-Ft seam has been mined. This seam is 1.8 m thick and lies between 0 and 600 m below sea level (Fig. 13).

The coal rank is 0.7% Ro (max), or high volatile B bituminous coal. The in situ resource of area G′ has 14.7 million tonnes and there are 3.8 million tonnes of the "mined" coal in area G″. The methane generation factor used is 5 m^3 per tonne. The methane content of the in situ coal in area G′ is 74 million m^3 (2.6 BCF). For the "mined" coal of area G″ it is 20 million m^3 (0.7 BCF). Of this amount

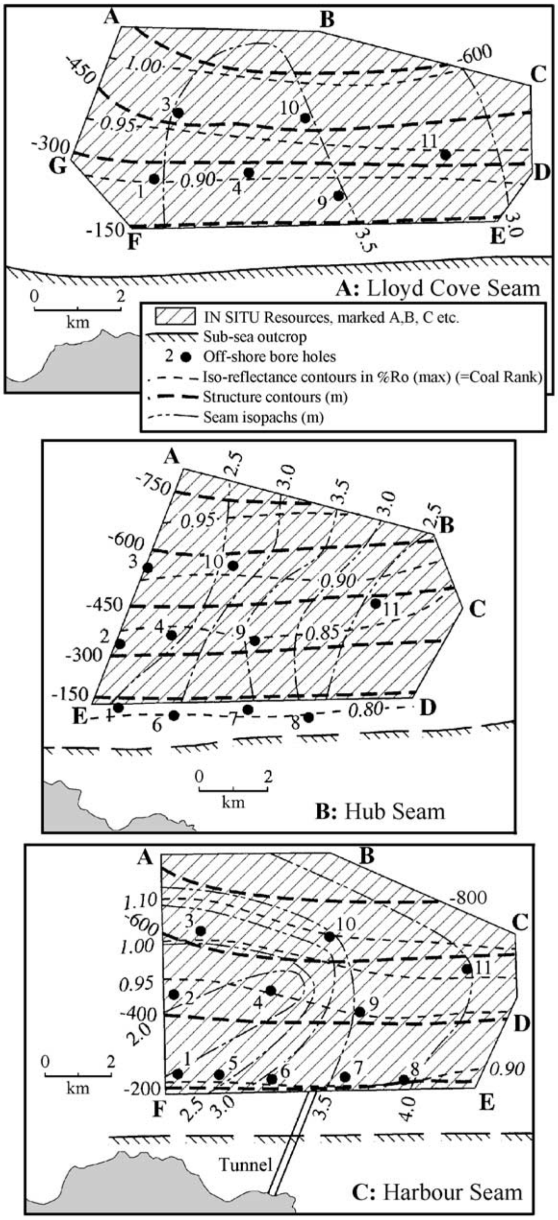

Fig. 9. Sydney coalfield. Donkin offshore area, coalbed methane resources of the Lloyd Cove, Hub and Harbour seams.

about one-half, 9.9 million m^3 (0.35 BCF), remained after extraction. The total available methane of the Port Hood coalfield then amounts to 80 million (3 BCF).

5.13. Westville Mine of Acadia seam—Pictou coalfield (Fig. 14) (Hacquebard and Avery, 1976; Smith, 1979; Pl.2, p. 157 in Hacquebard and Donaldson, 1969)

The total area measures 11.4 km^2 and includes five boreholes, marked P-104, P-18, P-23, P-25, P-46 and ML-9, which represent a column sample. Only one seam, the Acadia seam, has been mined. It is 3–3.2 m thick and lies between +50 and −1400 m relative to sea level (Fig. 14).

The coal rank varies from 1.1% to 2.0% Ro (max), or from medium volatile to low volatile bituminous coal. The in situ resource of area I has 36.8 million tonnes and there are 25 million tonnes of the "mined" coal in area H. The methane generation factor used for area I is 15 m^3 per tonne, and 13 m^3 per tonne for area H (Creedy, 1988). The methane content of the in situ coal in area I is 570 million m^3 (20 BCF). For the "mined" coal of area H it is 310 million m^3 (11 BCF). Of the "mined" coal, 50% remained after room-and-pillar extraction. This can still produce 1.56 billion m^3 (55 BCF) methane. The total available methane of the Westville Mine therefore amounts to 2.12 billion m^3 (75 BCF).

Access to the methane resources could be done through the existing mine slopes (for area H) and through boreholes for area I.

5.14. Allan Mine of Foord seam—Pictou coalfield (Fig. 15) (Calder, 1979; fig. 11 in Hacquebard, 1971)

The total area comprising areas J, K, L, M measures 8.85 km^2 and includes nine boreholes marked 6, 9, 15, 22, 27, 28, 45, 46, 47, and the two Allan Mine shafts. Only the Foord seam has been mined. It varies in thickness between 5.6 and 10 m (which is the greatest coal thickness encountered in Nova Scotia). The Foord seam lies between 0 and 700 m below sea level (Fig. 15).

The coal rank is equal to 1.0% Ro (max) or high volatile A bituminous coal. The methane generation factor used is 10 m^3 per tonne (Creedy, 1988). The in situ coal resources amount to 28.8 million tonnes. In area K: 5.8 million tonnes; in area L: 2.3 million tonnes; and in area M: 20.7 million tonnes. The thicknesses used are 9.5, 7.1 and 5.6 m, respectively. The methane contents of these areas are as follows: in K: 57 million m^3; in L: 230 million m^3; and in

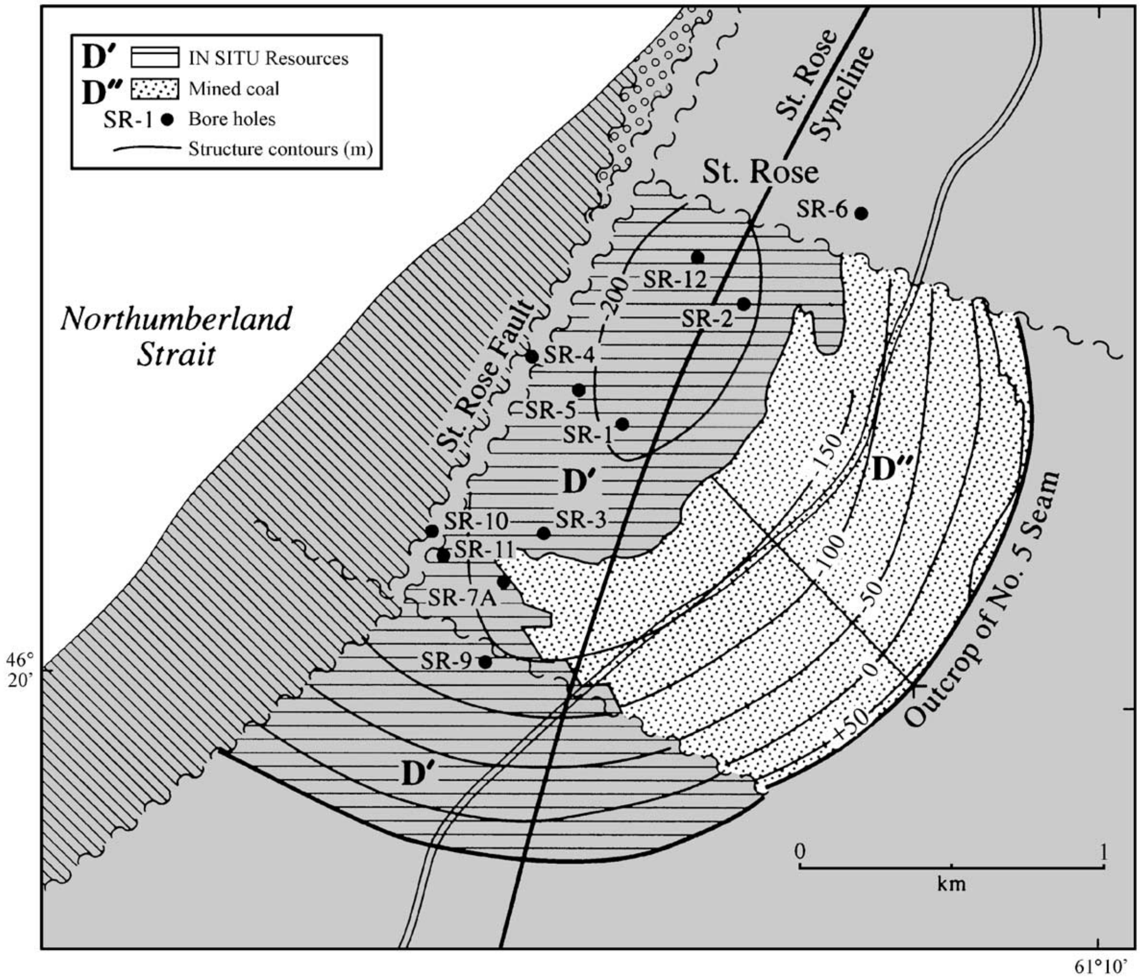

Fig. 10. Inverness County coalfields. St. Rose Field, coalbed methane resources.

M: 200 million m^3 (2 BCF, 8 BCF, 7 BCF). From the in situ coal deposits, therefore a total of 280 million m^3 (10 BCF) methane could be available.

The "mined" coal of area J measures 5.2 km^2 and contains 68.4 million tonnes, which at 10 m^3 per tonne could generate 680 million m^3 (24 BCF). After mining with room and pillar, about 50% of the coal remains. This could contribute 340 million m^3 (12 BCF) of methane. The grand total of the Foord seam workings therefore comes to 620 million m^3 (22 BCF). Exploitation of coalbed methane in the Stellarton area of the Allan Mine by Pan Canadian Petroleum has recently been agreed upon. The company plans to drill three wells in 2001, which will pump water and sand into the coal face to force out the gas. In 1991, the Westray Mine was opened in area M. It closed in 1992 due to a methane and coal dust explosion, which killed 26 miners (Looker, 2000; Comish, 1993).

5.15. Springhill coalfield—Cumberland County (Fig. 16) (Hacquebard and Donaldson, 1961)

The total area of the No. 2 seam, comprising areas O and P measures 2.4 km^2. The average seam thickness is 2.7 m and occurs between +150 and −1200 m relative to sea level. The in situ resources of area O are 15 million tonnes (Fig. 16).

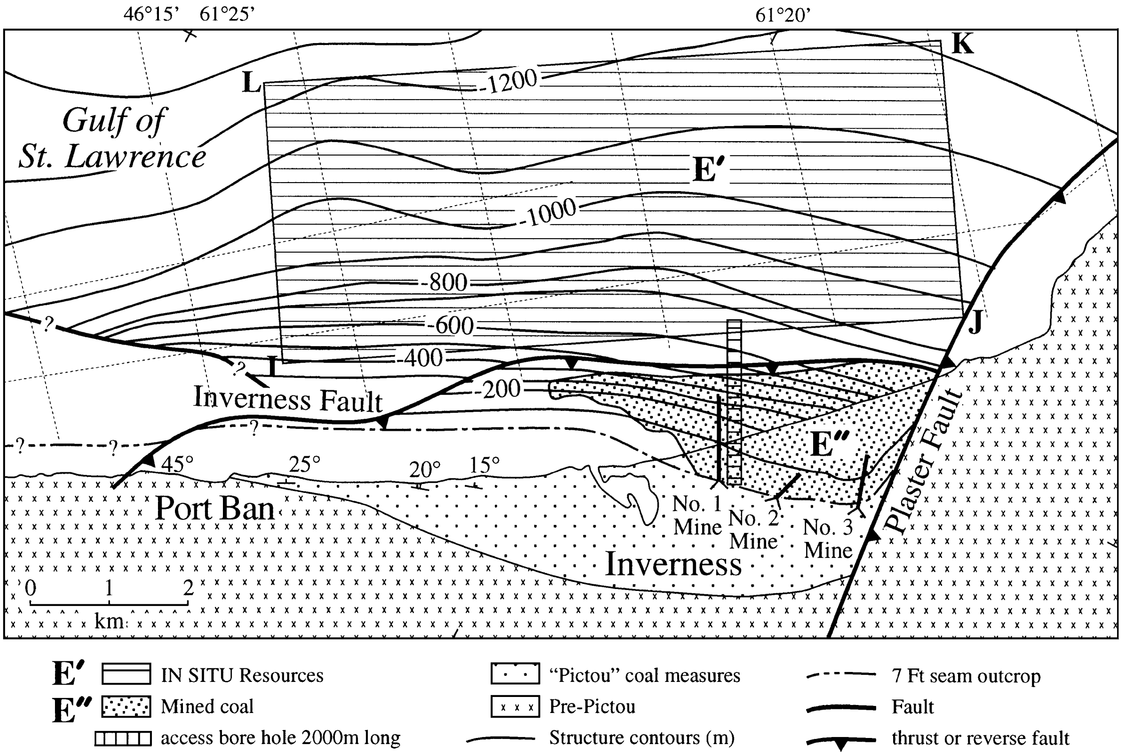

Fig. 11. Inverness coalfield, Inverness County, coalbed methane resources of the 7-Ft seam.

The coal rank is 1.25% Ro (max) or medium volatile bituminous coal. At this rank the coal could produce 13 m^3 methane per tonne. The methane contents of area O come to 200 million m^3 (7 BCF). The "mined" coal of area P measures 19.5 km^2 and contains 68 million tonnes, which at 13 m^3 methane per tonnes could generate 880 million m^3 (31 BCF).

Of the "mined" coal, 60% remained after room-and-pillar extraction (with strong roof conditions). This coal can still produce 60% of 510 million m^3 (18 BCF) of methane. Total for No. 2 seam therefore comes to 2.41 billion m^3 (85 BCF).

The area of the No. 3 seam measures 0.25 km^2 (area N). The seam thickness averages 2.7 m and occurs between − 90 and + 150 m relative to sea level. The in situ resource is 0.87 million tonnes (area extends to boundary with old workings of No. 3 Mine); the rank is 1.0% Ro (max) or high volatile A bituminous coal, with a methane generation factor of 8 m^3 per tonne. The methane resource calculates to 71 million m^3 (2.5 BCF).

The worst mine disaster in Nova Scotia occurred in 1891 in the No. 2 Mine at Springhill, where 125 men died in a methane gas explosion (Looker, 2000).

5.16. Minto coalfield—New Brunswick (Fig. 17) (Hacquebard and Barss, 1970; Muller, 1951)

The area measures 410 km^2 and includes 10 column sections with detailed seam records, marked 1 to 10. There is only one seam present, the Minto Main seam, which varies in mineable thickness between 40 and 75 cm. The average thickness is 45 cm. The seam lies between 7 and 67 m above sea level. Mining is by open-cut strip mining and originally by shallow shaft and slope mines (Fig. 17).

The coal rank is equal to 0.7% Ro (max) or high volatile A bituminous coal, which has a methane generation level of 8 m^3 per tonne (Creedy, 1988). Stratigraphically the seam occurs in the Westphalian C subdivision and has been dated by fossil spores in the *Vestispora* zone. The Minto coal is highly fractured

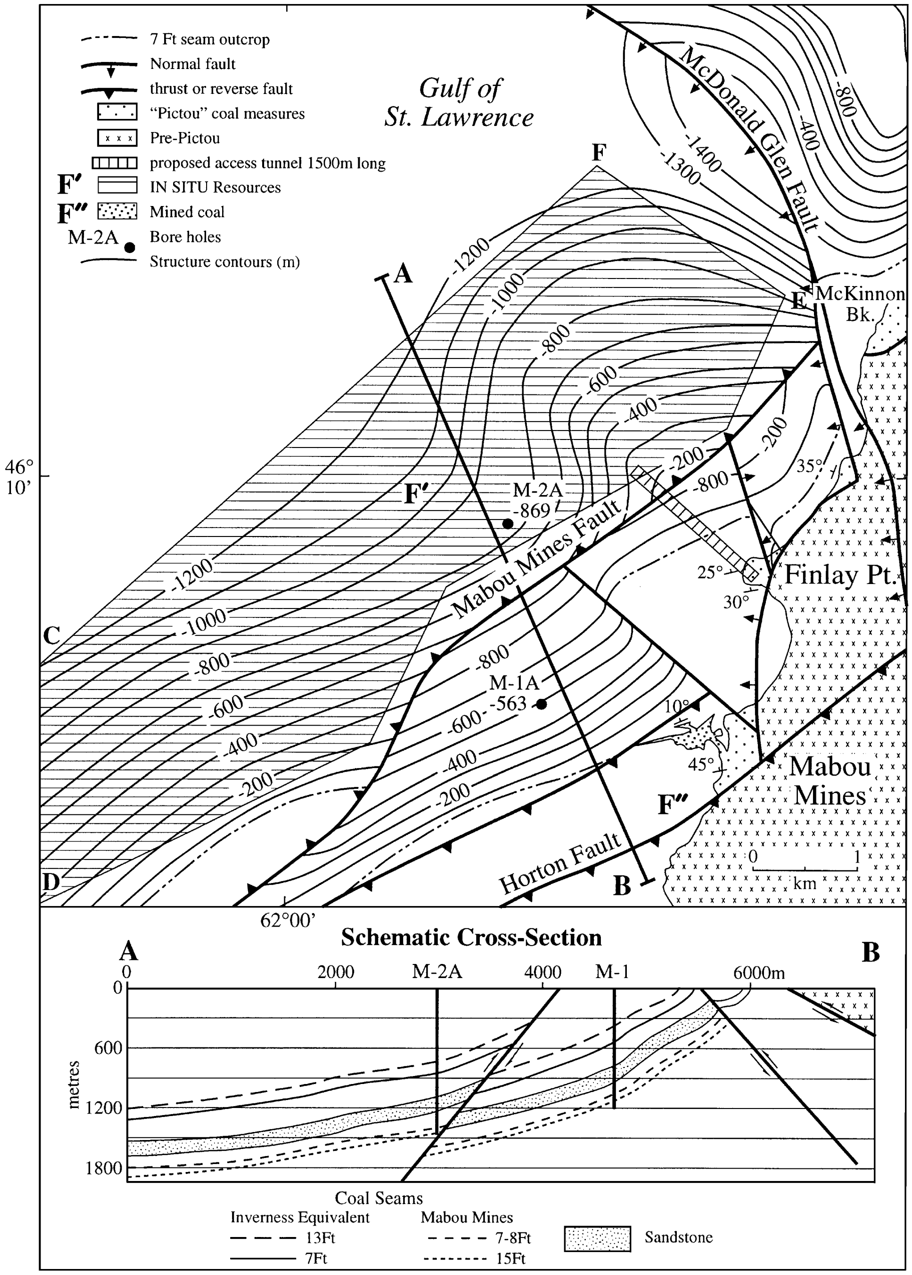

Fig. 12. Inverness County coalfields, Mabou Mines area, coalbed methane resources of the 7-Ft seam.

and produces much fine coal when mined. The vitrinite content of column MN-3 is 65% and inertinite is equal to 25%. The V/I ratio is 2.6 (all on mineral matter-free basis). No methane calculations of the mined coal have been made. The remaining portions after strip-mining and the friable nature of the coal likely resulted in considerable leakage of the methane that was present.

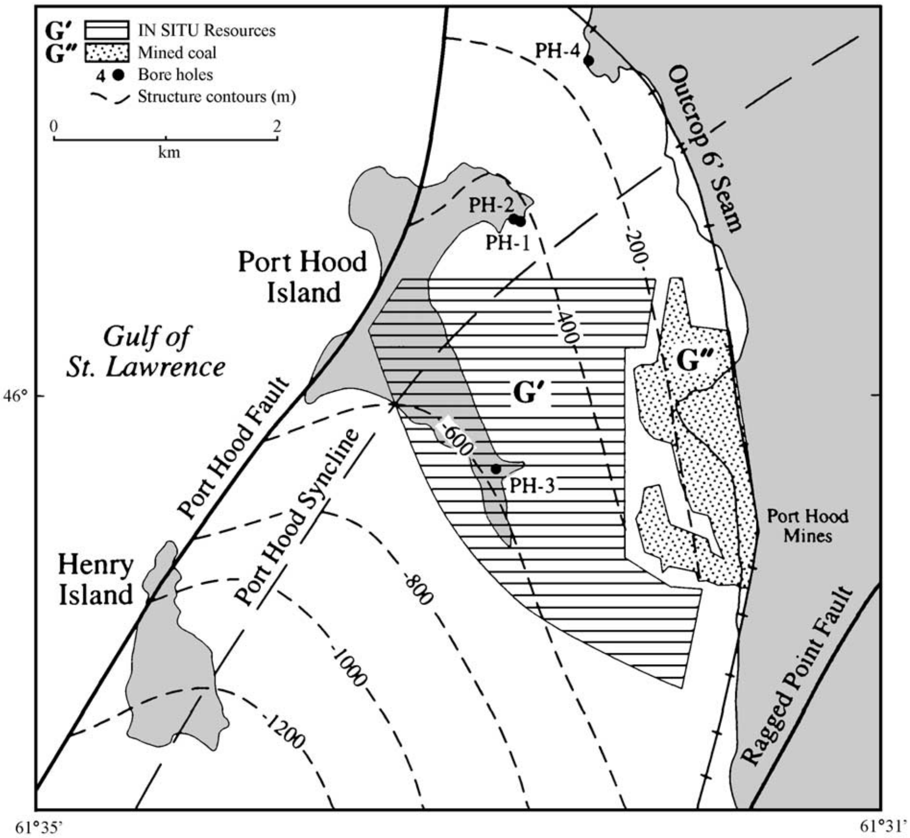

Fig. 13. Port Hood coalfield, Inverness County, coalbed methane resources of the 6-Ft seam.

The total in situ coal resources have been calculated at 9 million tonnes (from 1975 Revision of Coal Reserves by P.A. Hacquebard); at 8 m^3/tonne methane generation this calculates to 710 million m^3 (25 BCF). For the total available methane resource, only the in situ coal has been considered.

6. Conclusions

From extensive data on the coal deposits of Atlantic Canada, it is evident that very large coalbed methane resources are available. Their production could be integrated with the natural gas extraction of the Sable project. Coal no longer needs to be mined in the old manner by actual extraction, but it can be exploited by the drainage of methane gas. This gas, also known as fire-damp, once was one of the greatest hazards of underground mining. It may now provide a most valuable and long-lasting energy resource, largely free of polluting components.

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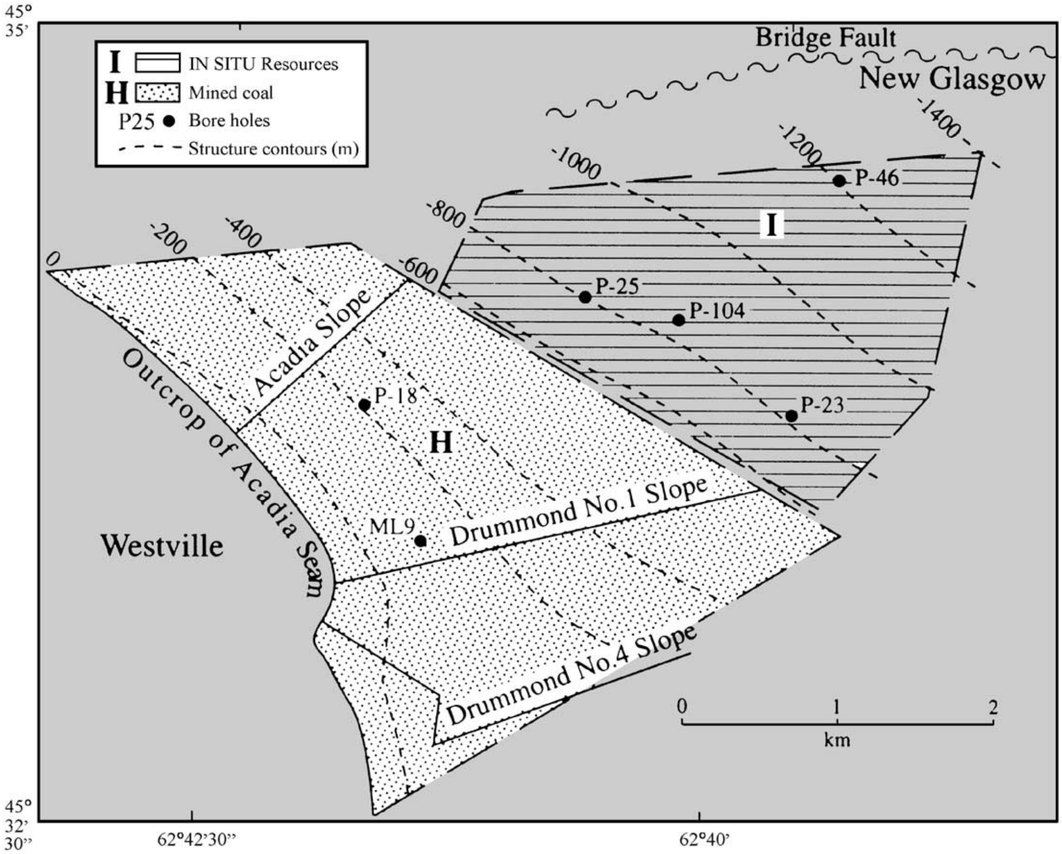

Fig. 14. Westville Mine of Acadia seam, Pictou coalfield, coalbed methane resources.

University in Hamilton, Ontario. Their efforts have been much appreciated.

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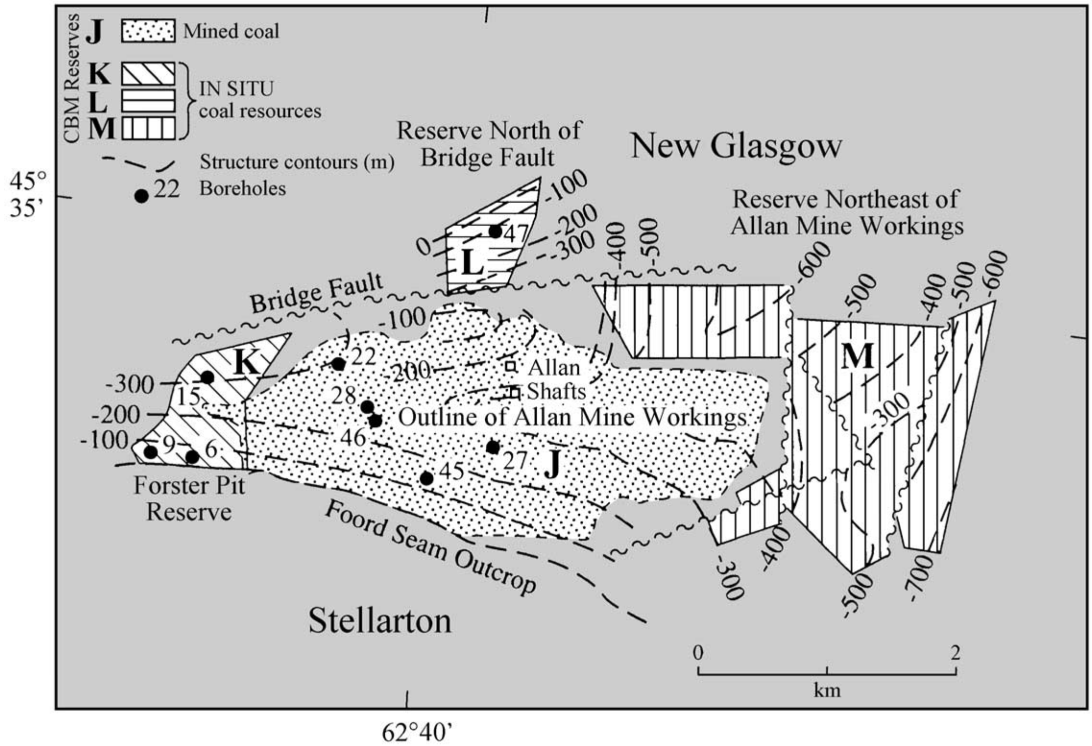

Fig. 15. Allan Mine of Pictou coalfield, coalbed methane resources of the Foord seam.

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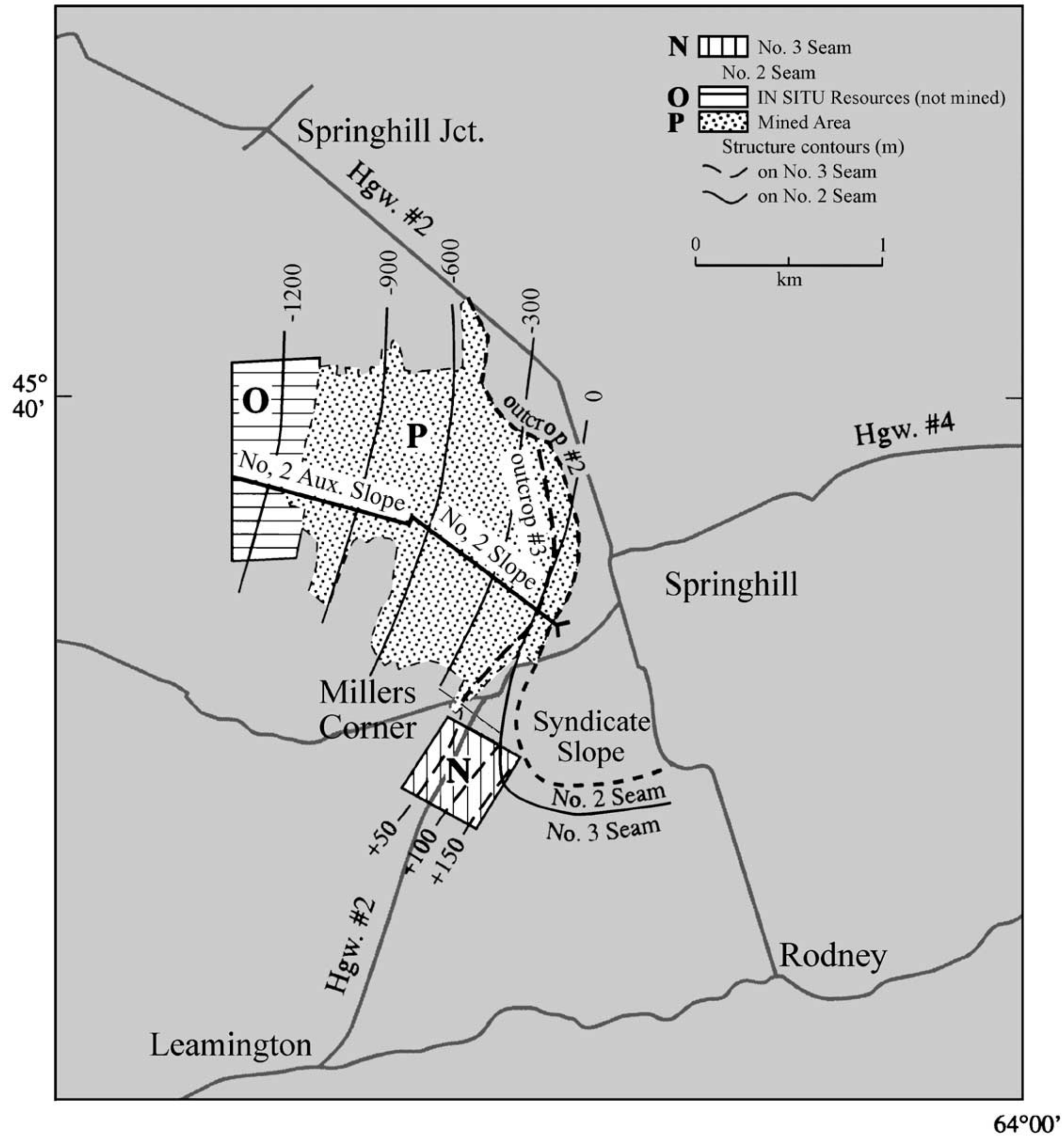

Fig. 16. Springhill coalfield, Cumberland County, coalbed methane resources of the No. 2 and No. 3 Seams.

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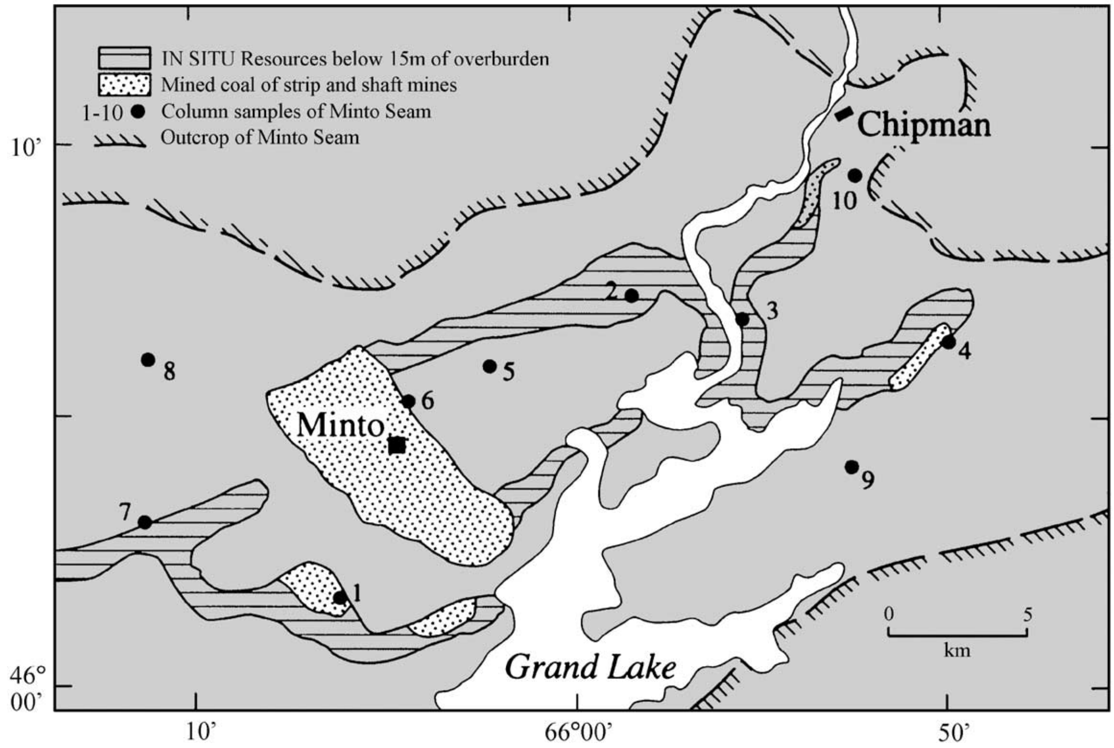

Fig. 17. Minto coalfield, New Brunswick, coalbed methane resources of the Minto Main Seam in in situ resource area.

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