CARDIUM FORMATION

Current Situation

The Cardium Formation is not an exploration target in B.C. Where it has been tested, it is as a secondary target, and often with a straddle drillstem test run on the basis of a prospective well log signature. The formation has thus been open to drilling fluids for an extended period of time, and wellbore damage is likely to be severe. This situation is exacerbated by lack of reservoir "sweet spots", shallow drilling depths and subnormal formation pressures.

Velvet Exploration undertook an exploration program in 2000/2001 for fractured Cardium shoreface sandstones in the Copton-Narraway area of Alberta, in the southeastern corner of Map 2. There do not appear to be a substantial number of new Cardium wells on production in this area, and Velvet's successor, El Paso, is not drilling new wells on the play.

Tight Gas Potential

The Cardium presents an attractive in-place gas resource, with massive sandstones of substantial thickness distributed continuously over a large area (Map 2) (Table 1). Because of its shallow burial depth, there has been less reservoir degradation by compaction than for deeper tight gas reservoirs. However, low reservoir pressures reduce in-place gas volumes, particularly within the subnormally-pressured Deep Basin. By qualitative comparison with the Cadotte and Spirit River, we speculate an in-place gas resource of 1-3 BCF/section.

Cardium tight gas will likely be a secondary, uphole target to be exploited in conjunction with deeper tight gas plays. Locally, Cardium gas production may occur where:

- operators stumble upon conglomeratic sweet spots, or
- fracture-enhanced reservoir sections are defined in the Foothills, where the Cardium section is thickest.

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Table 1
GAS RESOURCE POTENTIAL, TIGHT GAS RESERVOIRS, NORTHEASTERN B.C.

FORMATION	RESOURCE RANGE (BCF/DSU)	PROSPECTIVE AREA (km2)	RESERVOIR CONTINUITY	TOTAL GAS RESOURCE RANGE (TCF)	COMMENTS
Cardium	1 - 3	4 000	High - shoreface	4 - 10	Deep Basin, shallow; little production
Dunvegan	1 - 3	7 000	Low - channels	7 - 15	Deep Basin, shallow; little production
Sikanni / Goodrich	<1 - 3+ (?)		High - shoreface; vertical barriers?	??	Foothills; little information
Scatter	??	11 000	High - shoreface; vertical barriers?	??	Liard Basin; no production
Cadotte	3 - 6	5 500	High - shoreface	16 - 25	Deep Basin; established strat. sweet spot production
Spirit River	3 - 12+	7 500	High - shoreface	20 - 50	Deep Basin; established strat. sweet spot production; multiple units
Bluesky (south)	1 - 4	5 000	Moderate - deltaic	5 - 10	Deep Basin; production from discontinuous basal Bluesky
Bluesky (north)	2 - 5	2 500	Moderate (?) - valley fill	5 - 10	Some production; fracture enhancement possible
Cadomin / Gething (south)	2 - 7	10 000	Moderate - alluvial fan / plain	20 - 50	Deep Basin; production to east; no strat. sweet spots in B.C.
Cadomin / Gething (north)	2 - 7	5 000	Moderate (?) - valley fill	10 - 20	Some production; fracture enhancement possible
Nikanassin (south)	??	10 000	Mixed - variety of environments	Large ??	Isolated production; Deep Basin and Foothills (fractured); very tight; very large gas in place
Buick Creek (north)	2 - 6	6 000	Moderate - deltaic	12 - 25	Fracture enhancement required - local fold trends
Pardonet / Baldonnel	3 - 20 (?)	12 000	Dependent on fracturing	35 - 100	Production from natural fractures assoc. with structure; water risk
Halfway / Doig	1 - 7	27 000	High - shoreface	25 - 100	Deep Basin and fracture-enhanced production; what is potential of thick tight sections?
Belloy / Stoddart	??	??	Dependent on fracturing	??	Production from natural fractures assoc. with structure; water risk
Mattson	<1 - 5 (?)	3000	High - shoreface / delta	1 - 10	Production from sweet spots along Bovie Fault and Foothills fractures; water risk
Jean Marie	1 - 10	28 000	Moderate - shelfal carbonates	25 - 100	Widespread production - moderate fracturing; no water
Middle Devonian / older	??	??	??	??	Unknown - thick regional subcrop; fracturing?

Values are estimated for order of magnitude comparison only. Gas resource refers to gas in place; no recovery factors assumed.

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DUNVEGAN FORMATION

Current Situation

The Dunvegan has been explored only slightly more than the Cardium in B.C. Thin Doe Creek sandstones are conventional gas and oil producers at Kelly, and several wells have been drilled for them (Map 3). There has been virtually no exploration for the rest of the Dunvegan, however, as it shares several problems with the Cardium – shallow depths, lack of "sweet spots", low formation pressures, and drilling damage.

Dunvegan sandstones produce from thick, tight, fractured reservoirs at Lynx in the Alberta Foothills, but there have been no further discoveries (and only limited development) on this play in the past 10 years.

Tight Gas Potential

Dunvegan tight gas potential is less attractive than other Cretaceous targets, as reservoir distribution is much less continuous, prospective channelized trends have not been mapped regionally, and much of existing production is oil. Similar to the Cardium, the Dunvegan represents uphole secondary target potential, not a primary exploration target (Table 1).

Dunvegan tight gas may have economic potential locally where thick channel sandstones can be mapped, particularly if they occur where fracturing can enhance reservoir quality.

SIKANNI / GOODRICH SANDSTONES

Current Situation

Sikanni and Goodrich sandstones are not exploration targets at present. Penetrations are limited, as the sands are best developed close to the front of Foothills, where drilling is expensive because of deep targets, environmental sensitivities, and high access costs. The single gas completion at Bougie (Map 4) is intriguing, but has not yet driven further exploitation.

Tight Gas Potential

There are thick potential reservoirs in the Sikanni and Goodrich, distributed over large areas of northeastern B.C. (Map 4) (Table 1). Interbedded shales substantially impair reservoir continuity and gas volumes at Bougie, although cleaner sandstones may occur in sections closer to the Foothills. As for the Cardium and Dunvegan, shallow burial depths and lack of "sweet spots" also

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detract from their economic potential. There is no established Deep Basin regime, and faulting may breach potential Deep Basin pressure seals in the Foothills.

Sikanni/Goodrich tight gas potential may be realized in the future, in areas where other exploration activities have provided ready access to optimal reservoirs in the deep Plains and outer Foothills.

SCATTER FORMATION

Current Situation

Scatter reservoirs have not been evaluated systematically to date. Drilling in the Liard Basin has been very limited, except in the Maxhamish Field (Map 5). Even here, there have been very few Scatter tests, as wells have been targeted to develop the deeper Chinkeh reservoir. Scatter reservoirs are difficult to evaluate on well logs because of their heterolithic bedding.

Tight Gas Potential

Scatter potential is an unknown, even more than the Sikanni and Goodrich (Table 1). Presence of hydrocarbons, either in conventional or Deep Basin accumulations, has not been demonstrated. There are no known “sweet spots”, and widespread fracture enhancement of reservoir quality appears unlikely. Nevertheless, widespread, lithologically similar Upper Cretaceous sandstones produce gas over large areas of southeastern Alberta and adjacent Saskatchewan.

A systematic uphole evaluation of the Scatter over the Maxhamish Field would help to quantify its productive potential. Elsewhere, lack of facilities and pipelines make Scatter plays uneconomic.

CADOTTE MEMBER

Current Situation

The Cadotte contains true regional tight gas potential. There is abundant production from conglomeratic sweet spots, and numerous moderate- to low-rate gas tests from coarse-grained strata with poor to moderate reservoir quality. Conventional fracture stimulations can produce low-rate gas flows from sub-millidarcy rock anywhere within the Deep Basin regime (Map 6). Natural fractures have likely enhanced reservoir quality at certain locations (e.g. c-63-G/93-I-15).

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Current exploration programs target sweet spot plays with conventional reservoir quality. There has been no systematic effort to produce from Cadotte tight sands.

Tight Gas Potential

Throughout the Deep Basin, tight Cadotte sandstones contain in-place gas resources comparable to sweet-spot reservoirs, as porosity of fine-grained tight sands is very similar to that of conglomerates (generally 6-10%), even though permeabilities are orders of magnitude lower. Gas-in-place is commonly calculated in the range of 3-6 BCF per drilling spacing unit, varying with reservoir pressure and thickness (Table 1). Considering conventional Cadotte gas alone (Alberta and B.C.), Stockmal et al. (2001) tabulated discovered gas-in-place at 24,872 e^6m^3 (878 BCF) and gas to be discovered at 43,265 e^6m^3 (1528 BCF). The tight gas resource base must be several times larger.

Because of its regional distribution, mappability, and huge in-place gas resource, the Cadotte is an ideal target for tight gas production using advanced drilling and completion techniques. Coarse-grained facies with poor to moderate reservoir quality are widespread, and offer more attractive potential than fine-grained, uniformly tight middle shoreface sandstones (Core log 4).

Well-developed production infrastructure in the prospective area is an additional positive economic factor.

SPIRIT RIVER FORMATION

Current Situation

Like the Cadotte, Spirit River shorefaces produce from conglomeratic sweet spots, and feature numerous low- to moderate-rate gas completions throughout the Deep Basin. Although a huge tight gas resource is recognized, exploration and production is focused entirely on conventional reservoirs.

Tight Gas Potential

In-place gas resources for each shoreface unit of the Spirit River Formation compare closely to those of the Cadotte. Map 6 shows that total reservoir sandstones in the Spirit River are up to five times thicker than the Cadotte, however, as there are up to six stacked reservoir intervals (Table 1). Stockmal et al. (2001) tabulated discovered in-place gas at 102,582 e^6m^3 (3623 BCF) for conventional Spirit River reservoirs, with 28,888 e^6m^3 (1020 BCF) remaining to be discovered. The Canadian Gas Potential Committee figures are 155,356 e^6m^3 (5514 BCF) and 140,200 e^6m^3 (4976 BCF), respectively. The tight gas resource base will be several times larger than these figures.

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Spirit River sandstones are thus also ideal targets for tight gas production using advanced drilling and completion techniques. As for the Cadotte, numerous Spirit River sections offer relatively attractive tight gas potential in coarse-grained, but conventionally subeconomic reservoirs (e.g. Core log 6). Interbedded coals provide local gas sources, and may even contribute to deliverability where appropriately fractured.

Burlington Resources announced upon taking over Canadian Hunter Exploration that they would exploit Deep Basin tight gas resources using techniques learned in the San Juan Basin (Daily Oil Bulletin, 02/06/18). Many observers thought these efforts would be directed toward Falher tight sandstones, but no such program has been unveiled to date.

BLUESKY FORMATION

Current Situation

Bluesky production in the southern Deep Basin is from isolated, discontinuous basal Bluesky sweet spots. Some basal Bluesky sections with marginal reservoir quality have yielded low-rate gas, but there is no production from widespread deltaic sandstones of the Chamberlain Member. A small number of exploration wells have targeted stratigraphic plays for basal Bluesky conglomerates.

In the Buick-Laprise Valley, scattered gaswells produce from sweet spots with conventional reservoir quality arising from one or more of: i) intergranular porosity in conglomerates; ii) secondary solution porosity in medium- to coarse-grained sandstones; or iii) fracture enhancement through structural deformation. The valley trend is lightly drilled, and discoveries have not been extensively developed, as operators are not confident that they understand the play. There have been no efforts to exploit the thick valley-fill sandstones with advanced drilling or completion technologies.

Tight Gas Potential

Tight gas potential in the southern Deep Basin is limited by the argillaceous, heterolithic nature of the Chamberlain Delta sandstones, and discontinuous distribution of basal Bluesky facies (Table 1). Bluesky tight gas potential here is a secondary target to be evaluated between the more attractive Spirit River and Cadomin plays.

Bluesky valley-fill sandstones in the Buick-Laprise valley are more mappable, and offer in-place gas potential of several BCF per DSU, given greater reservoir thicknesses and porosities comparable to the Cadotte, but shallower burial depths. Locally, a Bluesky tight gas play might be economically attractive,

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particularly where facilities are available and access costs are reasonable. Laramide fold crests would offer particularly attractive targets, so that risk of water is minimized, and potential for fracture enhancement maximized.

CADOMIN / GETHING FORMATIONS

Current Situation

Despite numerous gas tests in the southern Deep Basin, the Cadomin produces primarily along the updip Deep Basin edge in Alberta (production in B.C. at Kelly Lake is primarily from isolated Gething channels) (Map 9). Efforts to downspace and to drill directionally and horizontally have succeeded only in particular areas. In the 1990's, Canadian Hunter was forced to write down hundreds of BCF of tight gas reserves assigned to the Cadomin in the Alberta Deep Basin, as they were judged not to be economically accessible.

There is no production from fractured Cadomin sections in the B.C. Foothills, although the Cadomin is reportedly a component of the fractured reservoirs play that has been pursued for the past several years to the southeast at Copton / Narraway.

To the north, Cadomin/Lower Gething strata produce only at Kobes, where fracturing associated with folding and thrusting has probably enhanced reservoir quality. There have been no efforts to explore for Gething gas in the valley trends outlined on Map 9, although several gas and oil discoveries have been developed in conventional reservoirs within large valleys to the east.

Tight Gas Potential

Much like the Cadotte and Spirit River, the Cadomin holds immense volumes of tight gas resources in the southern Deep Basin (Table 1). Porosities are generally lower, but the Cadomin section is continuous, and thickens substantially to the northwest (Map 9). Unfortunately, the Cadomin lacks reservoir sweet spots, and lies below most conventional Deep Basin targets. Thus, relatively few wells penetrate it. Horizontal wells are expensive and difficult to drill in the highly siliceous, poorly-sorted chert pebble conglomerates.

Thick, brittle Cadomin sections should be highly prone to fracturing in the Foothills, but lack of production to date makes future potential difficult to quantify. If the Cadomin is indeed a contributor to production at Copton / Narraway, the play should soon move northwestward into the Foothills of northeastern B.C.

To the north, thick lower Gething sands offer good reservoir potential, by tight gas standards. It would appear that the Gething has not been properly evaluated, particularly along the linear fold play that enhances reservoir quality in

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several other reservoir units. Scattered water recoveries pose the risk of encountering water, but aquifers are likely to be structurally and stratigraphically discontinuous.

MINNES GROUP (NIKANASSIN / BUICK CREEK)

Current Situation

Nikanassin tight gas potential has not been explored in the southern Deep Basin. Like the Cadomin, it lacks mappable sweet spots, and it lies below many of the primary drilling targets. In the adjacent Foothills, production at Wolverine, Grizzly North and Grizzly South has been attained in wells drilled for the Pardonet/Baldonnel (Map 10). Nikanassin fractured tight gas reservoirs have been a primary target in recent drilling at Copton / Narraway, immediately east of the Alberta border, and that play is now beginning to move into 93-I-9.

To the north, tight Buick Creek sandstones are one of the targets in the outer Foothills linear fold belt trend. Although it has been exploited extensively near Blueberry, the Buick Creek has been eroded through the Beg/Jedney/Bubbles area, where Baldonnel and Halfway reservoirs are the prime targets.

Tight Gas Potential

Nikanassin sandstones in the southern Deep Basin host tremendous tight gas potential. The Deep Basin fairway is very large, net clean sand thicknesses exceed 100 metres in many places, and deep burial leads to relatively high reservoir pressures. However, realization of this potential is not going to occur until operators identify drilling and completion technologies that can stimulate economic gas production from the very low quality rock.

In the southern Foothills, thick, brittle, fractured Nikanassin sections may host reserves comparable to the Pardonet/Baldonnel, if operators are able to map comparable appropriate structural configurations. Experience with completing the Nikanassin at Copton/Narraway should open up the entire southern B.C. Foothills trend to Nikanassin fractured gas production, although the pace of exploitation may be controlled at times by facilities constraints more than the productivity of the reservoirs.

Similarly, to the north, there are many linear fold structures which have been delineated, but which have not been adequately tested in the thick Buick Creek section. A major uncertainty is the ability of very tight quartzarenites in the Buick Creek west of Blueberry to produce nearly entirely from fractures. By comparison, the Baldonnel along this play trend has substantial matrix porosity to provide reservoir capacity.

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PARDONET / BALDONNEL

Current Situation

Although the Bullmoose/Sukunka fracture-dominant play trend was discovered over 30 years ago, stepout and exploration drilling is still taking place. Improved seismic imaging, better structural models, and growth of infrastructure have driven expansion of the play fairway. During the past decade, significant reserve additions have been booked, particularly at Murray and Highhat Mountain (Map 11). Although not as prominent, the Cypress play area has also experienced steady activity, and reserves have grown markedly at Graham.

The Baldonnel linear fold play trend has been one of the consistently busiest areas in northeastern B.C. during the past decade. New structures have been defined, while all of the older fields have been extended. Multiple tight gas reservoir potential has been exploited with infill and twinned wells.

Despite this history, Baldonnel tight gas reserves and production growth has been slowed by seasonal access, environmental issues, aboriginal land title questions, and pipeline/facilities limitations.

Tight Gas Potential

The Baldonnel is one of only two tight gas plays in northeastern B.C. (along with the Jean Marie) in which tight gas potential has been recognized and systematically exploited. There is abundant room in all three Baldonnel tight gas play fairways for additional discoveries and further exploitation, as summarized in NEB, GSC, and Canadian Gas Potential Committee projections:

National Energy Board, 1997:

- Baldonnel Grizzly: Discovered - 53.5 e^9m^3; Potential - 145 e^9m^3
- Baldonnel NW Foothills: Discovered - 46.2 e^9m^3; Potential - 27.2 e^9m^3

Stockmal et al. (2001) (GSC):

- Sukunka Triassic: Discovered - 84.1 e^9m^3; Potential - 184 e^9m^3
- Jedney Baldonnel: Discovered - 34.3 e^9m^3; Potential - 162 e^9m^3
  - includes Graham play area; all figures raw gas in place

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Canadian Gas Potential Committee (2001):

- Sukunka: Discovered - 100.5 e^9m^3 ; Potential - 76.9 e^9m^3
  - includes other reservoirs – Halfway, Charlie Lake, Belloy
- Graham: Discovered - 36.4 e^9m^3; Potential - 27.5 e^9m^3
  - includes other reservoirs – Debolt, Halfway
- Linear fold belt play trend – not specifically recognized

HALFWAY / DOIG FORMATIONS

Current Situation

Halfway sandstones are targeted in conjunction with other tight to moderate-quality reservoirs (Bluesky, Gething, Cadomin, Buick Creek, Baldonnel, Mississippian) along linear fold trends in the Kobes/Beg/Bubbles fairway in the northern Foothills (Map 13). This play has been drilled actively during the past several years, and numerous trends remain to be fully exploited.

Officially tabulated gas in place at Tommy Lakes has decreased dramatically during the past decade (1993 – 19,247 e^6m^3; 2001 – 12,518 e^6m^3), as marginal reservoirs on the fringes of the pool are no longer recognized as productive. At Monias, the assigned recovery factor was decreased from 90% to 60%, as the result of poor pool performance (National Energy Board, 2000). In both cases, low-permeability Halfway sandstones are not delivering gas at economic rates from conventional wellbores. There is no documentation of systematic efforts to exploit marginal Halfway reservoirs with advanced drilling or completion technologies.

Halfway exploration in the southern Deep Basin has occurred at low levels during the past decade. Although there are several interesting shows, commercial production has not been attained.

Doig reservoirs are conventional producers in isolated pools on the Peace River Plains, but show no tight gas prospectivity in the deeper Plains and Foothills areas.

Tight Gas Potential

Halfway tight sands contain immense gas resources in the deep Plains and outer Foothills (Table 1).

In the short to medium term, established reserves will continue to increase in the linear fold belt play trend as more structures are exploited, and as targeting of

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optimal fracture configurations improves. Rising gas prices and availability of infrastructure should support reserves additions through horizontal drilling and advanced completions in marginal reservoirs within and surrounding large pools such as Tommy Lakes and Monias.

In the long term, high-impact gas potential exists in two areas:

- advances in drilling and completion technology sufficient to make deep tight sands in the southern Deep Basin economically accessible.
- successful application of the Pardonet/Baldonnel fractured Foothills play model to the Halfway, thus opening up the entire thrusted outer Foothills trend
  - the NEB (1997) tabulated 0.36 e^9m^3 established reserves in the Halfway Grizzly Foothills play, but projected that 33.9 e^9m^3 remained to be discovered

BELLOY FORMATION / STODDART GROUP

As noted previously, recent (2002) high-deliverability gas discoveries at Sukunka (93-P-4) by Talisman and partners have been reported as occurring within Belloy/Stoddart strata, with possible contribution from Mississippian rocks (Debolt Formation?). To the south, two BP Canada wells at Ojay (93-I-9) tested high-rate gas from the Taylor Flat Formation; b-57-G/93-I-9 flowed 585 e^3m^3/d over a period of 24 days. Several outpost and exploration wells are active in both areas.

Talisman has estimated reserves of 20-40 BCF/well, with 25 locations identified on the Sukunka play (Daily Oil Bulletin, 03/01/15). We speculate that this play is analogous to the Pardonet/Baldonnel Sukunka play, but taps into brittle, fractured reservoirs stratigraphically deeper. Further information will be required to verify this idea.

The NEB (1997) identified a Belloy – Grizzly Foothills play, to which they assigned only 0.27 e^9m^3 established reserves, but projected that 19.5 e^9m^3 remained to be discovered. This estimate appears conservative in light of recent discoveries.

The structurally-deformed, fractured tight reservoir play model that has been successfully exploited in the Pardonet/Baldonnel for more than 30 years is clearly applicable to other stratigraphic units with similar physical properties. Because of the need to target very specific structural configurations in order to ensure optimal fracturing, the geographic distribution of reserves at different stratigraphic levels will vary considerably.

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MATTSON FORMATION

Current Situation

Thick sandstones with conventional reservoir quality host most Mattson reserves and potential in structural traps along the Bovie Lake Fault Zone (Map 13; Barclay et al., 1997). However, production from upper Mattson tight sands and associated Fantasque chert at Tattoo (a-78-L/94-O-10) and at Beaver River (d-73-K/94-N-16) establish fractured reservoir potential in this unit.

There is no active exploration program for Mattson tight gas potential. Limited outpost and development drilling does occur along the Bovie Lake Fault, with conventional Mattson sands as one of the targets.

Tight Gas Potential

Tight Mattson sandstones occur as distal deltaic facies across northeastern 94N and adjacent 94O (Map 13), and productive potential should occur wherever fracturing has taken place in response to structural deformation. This appears most likely in outer Foothills structures such as Beaver River (K/94-N-16).

There are no data to support projections of Mattson tight gas resource potential.

JEAN MARIE MEMBER

Current Situation

The Jean Marie is an active and highly prospective gas play in northeastern B.C. To the north, pools discovered and initially developed during the late 80's and early 90's continue to expand, with current reserves several times higher than those tabulated ten years ago. To the southwest, EnCana Corporation describes the Greater Sierra gas field as a "world-class discovery", with more than 5 TCF of gas in place (Daily Oil Bulletin, 03/01/15). Since entering the play in 1998 (as Alberta Energy Company), EnCana has built a two million acre (net) land base, and claims an inventory of 600 drilling locations. Although attention has been focused on the Jean Marie shelf margin (at Gunnell Creek), stepout and development drilling is also taking place at Sierra and Ekwan to the east (Map 14).

Horizontal drilling has traditionally been seen as the best way to access fractured tight gas reservoirs of the Jean Marie, and was the key to the expansion at Helmet, Midwinter, and Peggo-Pesh in the 1990's. At Greater Sierra, EnCana's wells feature horizontal legs of up to 1000 metres, and are drilled underbalanced with nitrogen foam to avoid formation damage and water phase traps that would reduce productivity (Daily Oil Bulletin, 03/01/15).

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Tight Gas Potential

The Jean Marie contains by far the largest accessible tight gas resource in British Columbia. The entire Jean Marie shelf fairway is prospective, and current technology is sufficient to develop much of it.

Economics will determine the pace of discovery and exploitation. Now that EnCana has established the Greater Sierra play, the entire shelf margin play trend is available. Gas in place ranges from 5 to 10 BCF (140-280 e^6m^3) per square mile (drilling spacing unit). In winter 2002/2003, EnCana is running 30 rigs in the area, has deliverability exceeding 150 MMCF/D (4250 e^3m^3/d), and has booked reserves in excess of 600 BCF (17 e^9m^3). Total gas in place is predicted to exceed 5 TCF (142 e^9m^3). On the Jean Marie shelf to the east, gas in place figures are lower because of thinner pays and shallower burial, but the play continues to grow with advancing drilling and completion technology, and continued growth of pipeline and facilities infrastructure.

It is interesting to note that Reinson et al. (1993) tabulated discovered in-place gas volumes of 11.6 e^9m^3 (410 BCF) for the Jean Marie, and ultimate potential of 24.0 e^9m^3 (849 BCF), numbers which are dwarfed by the potential of the Greater Sierra play. Similarly, established reserves in the Jean Marie Helmet play in 1997 (14.9 e^9m^3) exceeded the ultimate resource potential estimated in 1992 (14.3 e^9m^3), because of the success of horizontal drilling technology (National Energy Board, 1997). New play concepts and advancing technology have clearly revised our analysis of Jean Marie prospectivity.

MIDDLE DEVONIAN AND OLDER STRATA

There are no data to support tight gas exploration potential in pre-Middle Devonian strata. However, thick Proterozoic carbonate and clastic units subcropping beneath the Plains offer intriguing conceptual targets. Two primary mechanisms may exist to produce tight gas potential:

1. Reservoir fracturing, relating to Antler orogenic movements. Petrel Robertson (1995) noted Antler-generated fracturing in outcrop, and speculated that this might extend to the subsurface.

2. Limited carbonate reservoir enhancement through karst formation or hydrothermal dolomitization.

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ANALOGUE BASINS AND PLAYS

DEEP BASIN

Law (2002) classified the WCSB Deep Basin as a "direct-type" basin-centered gas accumulation, characterized by gas-prone source rocks and low-permeability sandstone reservoirs. In comparing analogous basins around the world, Law identified four reservoir pressures cycles during the development of basin-centred gas systems. The Canadian Deep Basin lies between Phase II, where gas generation has produced overpressured, gas-saturated reservoirs with little free water, and Phase III, where uplift, erosion, and cooling has produced underpressured accumulations. Although some Deep Basin reservoirs, such as the Viking and Belly River, exhibit well-defined downdip overpressured regions and updip underpressured regions, many others (e.g., Cadotte, Spirit River) are completely underpressured, and thus match the Phase III definition most closely.

The best analogues for the WCSB Deep Basin are the Cretaceous basin-centered gas accumulations of the western United States. Source and reservoir rocks were deposited in similar settings, and experienced a similar chronology of burial, maturation, and fluid migration. Law (2002) noted that the San Juan, Raton, and Denver Basins are underpressured, Phase III direct systems, and Popov et al. (2001) provided systematic descriptions of these basins. Individual reservoirs, such as the Muddy Sandstone of the Denver Basin (Higley et al., 2003) compare closely with units such as the Cadotte and Spirit River.

The reader is referred to the extensive reference lists compiled by Law (2002) and Popov et al. (2001) for more detailed information.

FOOTHILLS

Fractured Pardonet/Baldonnel reservoirs of the B.C. Foothills are extensively documented in terms of reservoir quality, fracture development, and exploitation. Most other highly-fractured, low-porosity, high-productivity reservoirs described in the literature, such as the Austin Chalk of the southeastern U.S., occur in much different tectonic settings. However, two examples stand out as good analogues for the Pardonet/Baldonnel and related reservoirs:

- Jurassic Twin Creek Limestone of the Foothills (overthrust belt) of Wyoming and Utah. Bruce (1988) described these widespread, low-porosity shelfal carbonates, deformed by six major tectonic events, most notably thrust faulting. It appears unlikely that sophisticated structural

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- models have been developed, as Bruce noted that “predictability of Twin Creek reservoirs is low”.

- Cretaceous Viking conglomerates of the Ricinus Field in west-central Alberta. Halwas et al. (1999, 2001) documented structure, compartmentalization, and fracturing in these low-porosity, brittle chert conglomerates and sandstones, and identified optimal drilling strategies.

NORTHERN PLAINS

As an underpressured basin-centered gas accumulation, the Jean Marie shares many characteristics with Deep Basin reservoirs. Law (2002) noted only one example of a BCGA carbonate reservoir, in the Sichuan Basin of China. Law was likely unaware of the Jean Marie, as it has not been clearly documented in the literature in terms of basin-centered gas.