Evolution of Tight Gas Sandstone Plays and Production, Western Canada Sedimentary Basin*

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Abstract

Tight gas sandstone plays in the Western Canada Sedimentary Basin (WCSB) (Figure 1) have been pursued and produced actively for several years. Exploration companies initially tried to adopt successful strategies from basins of the western United States but found that many of these were not viable in the stratigraphic and structural regime of the WCSB. A broad spectrum of tight gas plays has now evolved in western Canada, as operators have developed new mapping, drilling, and completion techniques to suit the geology of the basin.

WCSB tight gas sandstone reservoirs range from Triassic to Late Cretaceous age and span depositional environments from distal turbidites to alluvial fan conglomerates. Three examples characterize the range of play types and strategies that have evolved since 2001:

1. Nikanassin structural play -- thick (up to >1000 m) fluvial to shallow marine sandstone-dominated section, with permeability enhanced by natural fractures associated with faulting in the Foothills. Multiple zones are fracture-stimulated and commingled.
2. Cretaceous multi-formation commingled play -- reservoirs are evaluated in up to 10 separate formations, with production commingled from the 4-5 best zones in each wellbore. Regional mapping by formation is important in high-grading development areas.
3. Triassic siltstone plays -- porosity associated with particular facies and diagenetic trends within the overpressured Deep Basin is exploited, using horizontal and downspaced vertical wells and advanced completion techniques.

Although the WCSB tight gas play spectrum is much different than that in the U.S. Rockies, huge gains in reserves and productivity have been attained with improved understanding of the reservoirs.

Nikanassin Structural Play

Nikanassin strata (Figure 2) comprise a thick (in places >1000 meters), easterly-thinning wedge of clastics, deposited as the Jurassic Fernie Sea retreated northward from the WCSB, in response to eustatic sea level fall and immense volumes of sediment being shed from the rising Columbian Orogen to the west. Blocky to fining-upward sandstone bodies are interbedded with siltstones, shales, and minor coal. Net sandstone / gross thickness ratios may exceed 50%, so that more than 500 meters of clean sandstone are found in some areas. Deposition took place in marginal marine to continental settings, resulting in an absence of regional stratigraphic markers and mappable depositional trends. Burial depths range from 1000 meters in the Peace River Plains, up to 3500-4000 meters in the deep Foothills.

The Nikanassin has been tested throughout the basin, but is productive only where it is extensively fractured by deformation associated with thrust faulting in the outer Foothills.

Reservoir Characteristics

Reservoir sandstones consist primarily of fine- to medium-grained siliceous litharenites, deposited as channelized bodies on the order of 5 to 15 meters thick, although individual channels may stack into thicker bodies. Regional shoreline or valley-fill trends, where reservoir sandstones would preferentially occur, have not been mapped. Reservoir quality is very poor. In hand section, sandstones are glassy and brittle, and break across sand grains, indicating strong and pervasive cementation. Petrographically, they are poorly sorted, highly compacted litharenites, composed primarily of quartz, chert, and sedimentary rock fragments, cemented tightly with silica. Pores are generally small and isolated -- most primary porosity has been destroyed, and little solution porosity has developed. Conventional core analysis porosity values are generally up to 6%, while permeabilities are 0.1 md or less. Where the Nikanassin is productive, however, core and thin-sections show extensive fracturing (Figures 3 and 4).

Tight Gas Production

Several companies are developing Nikanassin tight gas pools along structural trends in the outer Foothills of northeastern British Columbia and adjacent Alberta. Wells are drilled along northwest-southeast fairways, parallel to the leading edges of thrust faults. Thrust repeats of Cretaceous and Upper Jurassic strata have been identified in several wellbores, but high-quality seismic is required to optimize locations where thrust-associated deformation has fractured the Nikanassin sufficiently to impart economic permeability. Wells drilled off thrust fronts are generally non-productive.

Up to five zones within the Nikanassin are typically completed, and each is fracture-stimulated separately. Many wells have only recently been put on stream, so it is still early to assess long-term productive potential. Several of Shell's wells at Chinook Ridge have produced up to 90 $10^6 m^3$ (3.2 BCF) in less than two years, although some of these include contributions from commingled uphole zones. Many wells to the northwest at Hiding Creek show lower initial productivities, although production from uphole zones in this area is more often segregated in separate wellbores. The ultimate prize in this play is represented by one of the original wells at North Grizzly, which has produced 577 $10^6 m^3$ (20.4 BCF) since 1979.

Nikanassin reservoirs and thrust deformation can be mapped northwest and southeast of the current production area, giving this play considerable upside as seismic control and facilities expand.

Cretaceous Multi-Formation Commingled Play

Numerous Cretaceous reservoirs are productive in the Deep Basin (basin-centered gas area) of west-central Alberta and northeastern British Columbia. Until recently, exploration has been limited to the pursuit of prolific, high-permeability stratigraphic "sweet spots", many of them areally-limited conglomeratic shoreline facies. With advances in drilling and completion technology, operators are now developing strategies to access far larger gas volumes, by commingling production from stacked Cretaceous tight-gas sandstones.

The Cretaceous commingled play has been developed most intensively at Wild River, where almost every section in a four-township area has been downspaced to 2-4 (and in some cases 6) wells per section. The play area has expanded rapidly and will ultimately encompass 100 townships or more (based upon regional mapping of the main productive zones). By drilling to the Upper Jurassic Nikanassin Formation, up to ten reservoir intervals are evaluated, and the best four to five are generally completed. Major producers include:

- Nikanassin -- shallow marine sandstones subcropping beneath the pre-Cretaceous unconformity
- Cadomin -- fluvial sandstones and conglomerates, occurring as a channelized sheet across the area (Figure 5)
- Gething -- fluvial sandstones, mappable as discrete channel trends, stacked at several stratigraphic levels within a 100-metre thick continental succession (Figure 6)
- Bluesky -- marine shoreface sandstones, occurring in a relatively homogeneous sheet (Figure 7)
- Lower Spirit River -- nearshore facies capping progradational successions, locally exhibiting economic reservoir quality
- Upper Spirit River -- intricate valley fill network, incised during a mid-Cretaceous sea level fall and filled with massive, low-

quality lithic sandstones (Figure 8)

- Viking -- marine shoreface sandstones, in relatively distal and low-grade reservoir facies
- Dunvegan -- southern fringe of multicyclic fluvial / deltaic system; completed in only a few wells
- Cardium -- shoreface sandstone unit following a regional northwest-southeast trend. These sands are stand-alone producers to the southeast where fractured along thrust fault trends but are commingled at Wild River, where fracturing is less extensively developed.

Tight Gas Production

Only a few operators, such as Duvernay Oil, Canadian Natural, and Open Range Energy have established a significant presence in the Cretaceous commingled play at Wild River. While the activities of each of these operators is guided by strong geological mapping, careful attention to costs, and infrastructure access is required to achieve economic success.

Duvernay has drilled more than 220 wells on the Cretaceous commingled play to date, and has identified up to 1380 potential locations on their land base around Wild River (Duvernay corporate presentation, February 2008). They have established average reserves of 2.7 BCF / well, and first-year average production rates of 1.6 MMCF/D, although the best wells exhibit initial production rates of 5 to 10 MMCF/D. In 2006, Duvernay completed 5 zones per well, then increased to 7 zones per well in 2007. Open Range, operating in an area with somewhat less stacked potential, has still placed 57 pay zones on production in 19 wells (3 zones per well) (Open Range corporate presentation, November 2007).

Systematic cost improvements have been achieved in the past year with the construction of new infrastructure, and the implementation of regulatory changes, requiring less testing of individual zones. The impact of gas royalty changes proposed by the Alberta government, scheduled to take effect in 2009, has cast some uncertainty of the future viability of the Cretaceous commingled tight gas play (and other gas resource plays in Alberta).

Triassic Siltstone Play - Montney Formation

Montney strata accumulated on a broad continental ramp on the western flank of the North American craton during Early Triassic time. Aeolian processes supplied most Montney sediment, which is predominantly siltstone to very fine-grained sandstone, with little associated mud. Shoreface to subtidal facies in the east grade westward to basinal facies, cut by turbidite deposits associated with lowstand events. Good conventional reservoir quality is found in the shallower, updip portions of the basin, but westward, reservoir quality decreases in more distal facies that are buried to depths of up to 3500 meters.

Historically, deep Montney exploration has been focused on turbidite sandstone fairways in the lower Montney, which retain moderate reservoir quality into western Alberta and northeastern British Columbia. Since 2003, an exciting new tight gas play has emerged in areally-extensive upper Montney distal shoreface to shelfal siltstones. This play has attained great economic importance as companies have realized the immense gas resource available, which can be economically accessed by modern multi-frac completions in horizontal wells.

Reservoir Characteristics

The upper Montney comprises stacked sections of distal shoreface to shelf siltstones up to 150 meters thick. Cores show thick, homogeneous-appearing sections of laminated to massive siltstones. Although sometimes characterized as a shale gas play, the upper Montney is primarily siltstone -- the darker laminae in core commonly contain more organic material and pyrite than mud. Porosities range from less than 3% up to 10%, although pore throats are very small, and porosity networks appear poorly connected, resulting in sub-millidarcy permeability. Operators generally characterize reservoir in terms of 3% or 6% sandstone density porosity cutoffs and have reported net pay thicknesses in excess of 100 meters.

Upper Montney distal shoreface facies are mappable over a large area of west-central Alberta and adjacent British Columbia. Several internal log markers highlight major clinoform surfaces in the overall progradational succession. Variations in cementation, bioturbation, and organic content can be seen in core across these markers but have not been systematically mapped on a regional basis.

Tight Gas Production

Productive potential of the upper Montney was first realized in 2001, when it was completed uphole in a deep exploratory well at Dawson in northeastern B.C. ARC Resources developed the pool using conventional vertical wells, stimulated with large (up to 100-tonne) fracs. To the south at Swan Lake, EnCana began a Montney development program in 2005, first using vertical wells, then moving to horizontal wells, stimulated with several staged fracs. Initial rates of 4 MMCF/D or greater were reported in the horizontals, and EnCana moved to a development program focused entirely on horizontal wells in the upper Montney, targeting gas-in-place of 25-40 BCF/section. Lower Montney turbidites are seen as future upside, with gas-in-place of 30-50 BCF/section. ARC adopted the horizontal development strategy at Dawson, drilling 6 horizontals in 2007, and planning 6 more in 2008 (ARC corporate presentation, February 2008).

The upper Montney is now one of the hottest gas plays in Western Canada. It is credited with more than $200 million in Crown land sales in northeastern British Columbia since late 2007. A number of large development programs are underway around the Dawson / Swan Lake core area: to the south at Tupper (Murphy Oil), to the west at Groundbirch (Duvernay Oil), and to the east at Pouce Coupe (Birchcliff Energy). Each of the major players is forecasting multi-TCF in-place resource potential, and plans multi-year development programs to sustain production in the 50-100 MMCF/D range or more.

At this early stage of play evolution, regional geology suggests a huge potentially productive area. Development projects are radiating from areas of initial discoveries or strategic land positions and will likely merge into a massive resource play over the next several years.

Conclusions

Although the WCSB tight gas play spectrum is much different than that in the U.S. Rockies, huge gains in reserves and productivity have been attained with improved understanding of the reservoirs, application of new drilling and completion technologies, and infrastructure growth.

The three plays highlighted here - fractured Nikanassin sandstones in the outer Foothills, stacked commingled Cretaceous targets in the Alberta Deep Basin, and Montney shoreface siltstones completed with horizontal, multifrac wells - are only a few examples of our evolving ability to produce gas economically from tight reservoirs. In each case, exploitation strategies have been built upon detailed geological understanding of the reservoirs.

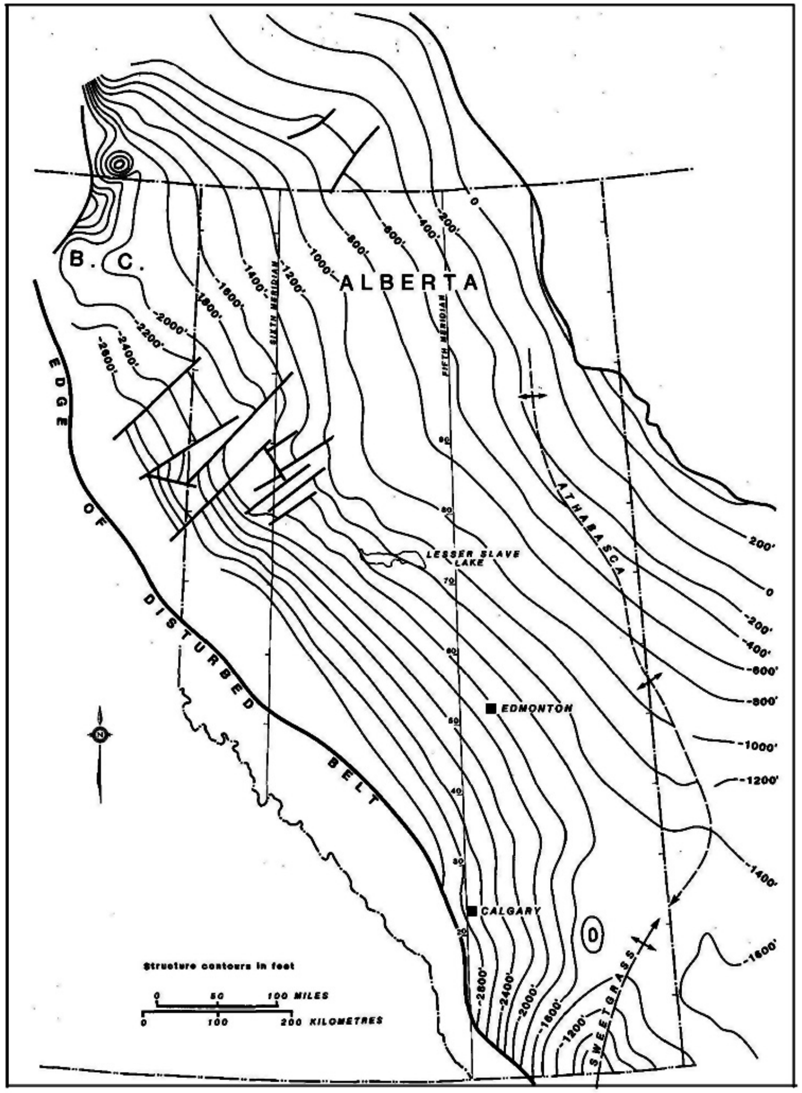

Figure 1. Precambrian structure map (data from Geological Society of Canada map 1251A) (from Masters, 1984).

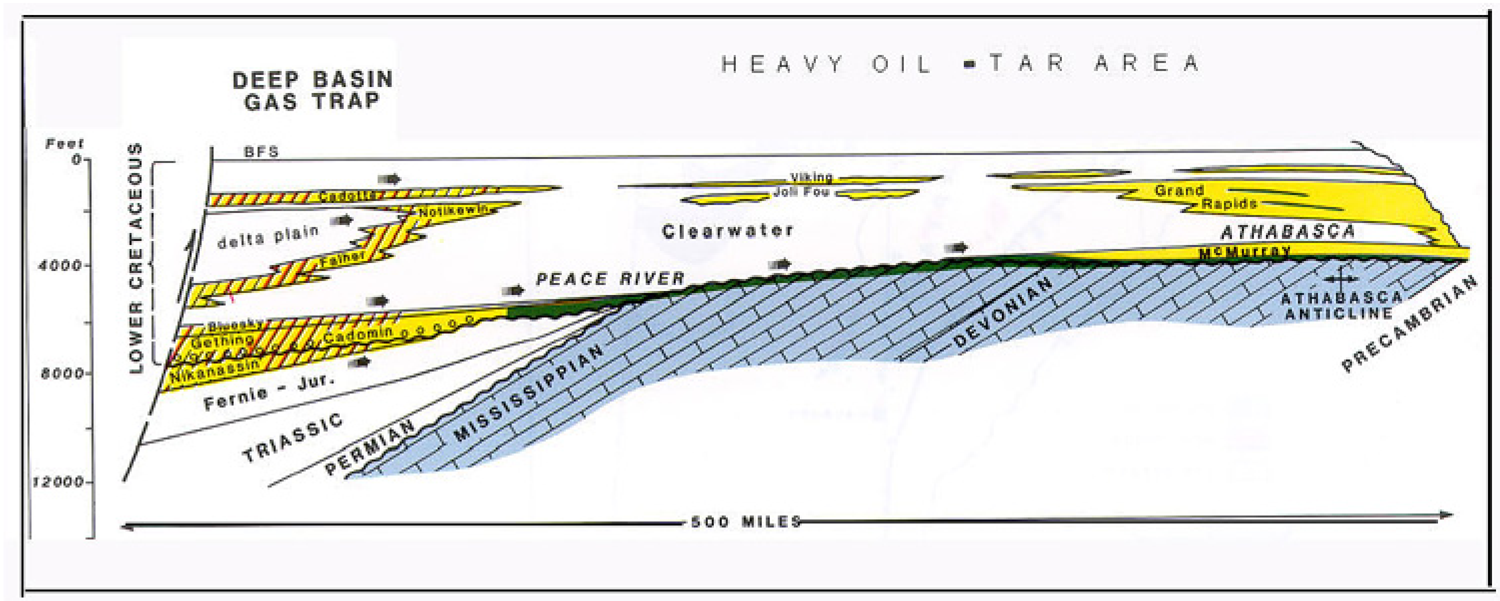

Figure 2. Diagrammatic cross section across Central Alberta (from Masters, 1984).

Figure 3. Extensively fractured fine-grained sandstone, Nikanassin Formation, North Grizzly field. Note partly rubbled core and isolated healed fractures.

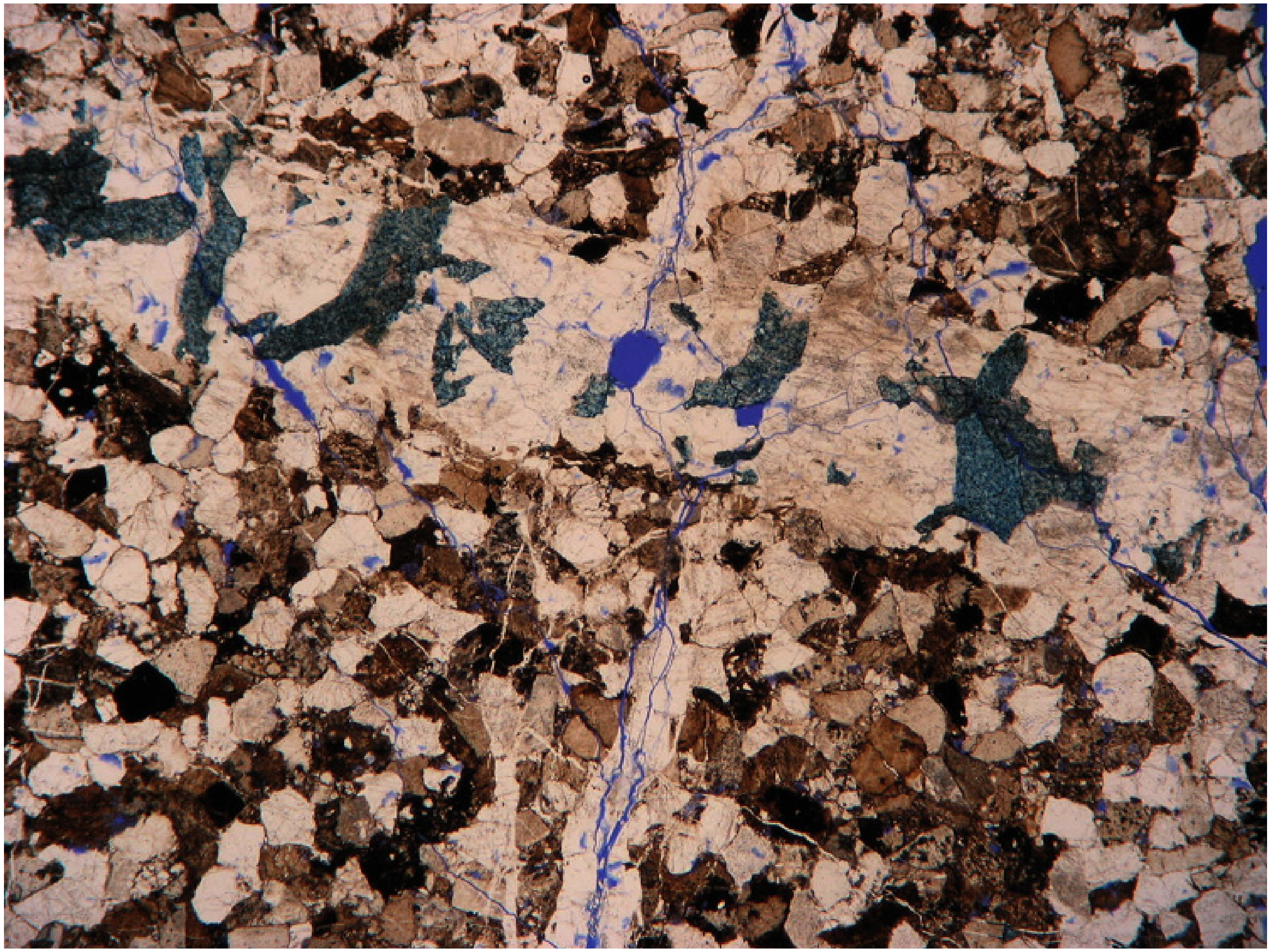

Figure 4. Fractured medium-grained sandstone, Nikanassin Formation, North Grizzly field.
Two generations of fractures are present, each largely healed by silica and ferroan dolomite cements.

Figure 5. Poorly-sorted fluvial conglomerate, Cadomin Formation,
Wild River field. Clay and carbonate cements partly fill interpebble porosity.

Figure 6. Large-scale, low-angle cross-bedded fluvial sandstone, lower Gething Formation, Wild River area.

Figure 7. Burrowed shoreface sandstone,
Bluesky Formation, Wild River area.

Figure 8. Massive lithic fluvial sandstone,
upper Spirit River valley fill, Wild River area.

Reference

Masters, John A., 1984, Lower Cretaceous oil and gas in Western Canada, *in* Elmworth: Case Study of a Deep Basin Gas Field, John A. Masters, ed.: AAPG Memoir 38, p. 1-33.