The Foothills of Western Canada, a Fold and Thrust Belt Natural Gas Play*
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Gas Supply and Demand

The Foothills of the Western Canadian Sedimentary Basin (WCSB) has a long history of natural gas production for the Canadian and American markets. As a supplier to the North American gas market, the Foothills will continue to play an important role over the next 10 years due to the steady upward pressure on natural gas prices resulting from increased demand and decreased supply. This firming in price, coupled with the existence of an established infrastructure in the Foothills, will allow the economical development of many of the remaining natural gas prospects.

The current reserves of natural gas for all of North America that are tied into the natural gas market are 250 TCF. Based on the 2000 figures from the National Petroleum Council, the consumption of this product is currently 25 TCF per year for Canada and the United States. This figure is expected to increase to 30 TCF per year by the year 2010. However, the discovery rate for new gas to replace the continual consumption is decreasing each year. Using numbers published annually by the Alberta Energy and Utilities Board (AEUB), the British Columbia Ministry of Economic Development (BCMED), and the Federal National Energy Board (NEB), it appears that there is annual shortfall in Canada of 7% between produced marketable reserves and booked marketable reserves of natural gas. Taking the North American market as a whole, this figure could be as high as 10%. The steady increase in natural gas prices is providing an incentive to explore for new natural gas reserves and efficiently deplete already proven reserves in the Foothills of the WCSB.

Foothills

The Foothills is part of the WCSB that lies within the fold and thrust belt of the Canadian Rocky Mountains (Figure 1). The area is situated on the eastern side and directly adjacent to the Canadian Rocky Mountains. It covers 40,000 square miles of land that runs from the northwest to southeast through four of Canada’s territories and provinces. The northwesternmost point lies just north of the Northwest Territories border at the town of Fort Liard. The Foothills is also in part of the adjacent Yukon Territory and then runs southeast through the provinces of British Columbia and Alberta. It terminates at the
American/Canadian border at the town of Waterton. The Foothills has already provided 40 TCF of in-place natural gas reserves and has the potential to provide more. It is tied-in via pipeline to the North American gas gathering system that feeds natural gas to eastern Canada, the eastern seaboard, midwest and northwest parts of the United States, and California.

Figure 1. Location map of the Canadian Rocky Mountain fold and thrust belt and Foothills in Western Canadian Sedimentary Basin.

The northwestern and southeastern limits of the Canadian Foothills are controlled by political boundaries and the extent of the natural gas gathering system. The width of the belt is defined more on geological grounds (Figure 2). An area called the Triangle Zone defines the eastern side of the Foothills. This is a descriptive term for the subsurface cross-sectional structural style that forms the effective edge of the fold and thrust belt. Beyond this lie the conventional exploration and development plays of the WCSB. The western edge of the Foothills belt is defined generally by the topographic high that is formed by the Front Ranges of the Rocky Mountains. This topographic high provides limitations of access due to its extreme relief. It is also frequently the eastern edge of national or provincial parks, which provide another restriction to access.
Framework

One of the reasons for the unique nature of the Foothills belt is the type of geological structures found at the surface and in the subsurface. The Foothills is part of the larger fold and thrust belt of the Rocky Mountains, a geological structural domain where the sedimentary rock sequence of the WCSB has been deformed by horizontal compression. The rocks have been effectively shortened by one of two mechanisms. In some cases, the structural complexes have reservoir rocks faulted and stacked on top of each other to form structures in which the reservoir rock may be fault-repeated two or three times. In other cases, the rocks have been folded by horizontal compression into tight folds where the reservoir rock may be broken or fractured. In areas where the reservoir rock has been fault-repeated, the fields in the Foothills may have multiple individual pools of hydrocarbons stacked on top of each other. Where the reservoir rock has been tightly folded, the resultant fractures can greatly enhance the productive capacity of a reservoir that would not produce had it not been folded.

Many of the Foothills fields have reservoir rock that has been fractured naturally. This fracturing leaves a degree of uncertainty in the calculation of marketable gas reserves. This is reflected by the unusually large difference between the marketable and gas-in-place reserve figures seen in certain Foothills pools. A good example of the under evaluation of a fractured Foothills reservoir is seen in the production profile for the Moose Mountain Field, a Foothills natural gas field that has a naturally fractured reservoir. Between 1985 and 2000 the field produced steadily from two pools. No additional wells were tied-in, nor was there any work on the existing wells to access more reserves. The original marketable reserves were given as 130 BCF with the gas-in-place reserves of 250 BCF (AEUB). Over the subsequent years, as the cumulative production increased, the gas-in-place reserves have correspondingly been revised upwards. In 1999 the total production exceeded the original marketable reserves, and the field is still producing 40 MMCF per day.
One of the major additions to marketable reserves in the Foothills may well come from an increase in the understanding of naturally fractured reservoirs. If this is true, it may not be unreasonable to add an extra 10 TCF of gas to the marketable reserves of the Foothills belt purely through the more effective development of current in-place reservoirs.

The rock formations that produce hydrocarbons in the Foothills are spread throughout the stratigraphic column (Figure 3). The youngest producing formation is the sandstone of the Cardium Formation. The oldest producing formation is the carbonates of the Beaverhill Lake Group. The bulk of the gas produced to date is from the Mississippian-aged rocks, which have produced 26 TCF of the total reserves. The next most prolific producers are the Triassic- and Devonian-aged rocks which have produced 6 TCF each. The Cretaceous has added 2 TCF to the reserves.

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<tr>
<td></td>
<td>800</td>
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Figure 3. Stratigraphic column of Foothills, with identification of productive reservoirs.

Play Types

The Foothills has been divided into five categories based on structural style, stratigraphic framework, and history of exploration: First Generation, Second Generation, Third Generation, Reef/Stratigraphic, and Triangle Zone play types (Figure 4).
The First Generation plays of the Mississippian-aged reservoir formation dominated the early Foothills exploration effort from 1914 to 1960. These plays have contributed 37% of the in-place gas reserves to the Foothills. They are found in structures formed by single thrust sheets and generally follow a fault-bend-fold structural style. Formed along the outer edge of the Foothills belt, these plays lie in the part of the Turner Valley Formation where the environment of deposition was dominantly high-energy, as reflected in the grainstones that form most of that formation. The outer Foothills area has less rugged topography, with softer Cretaceous rocks at the surface, allowing for better seismic imagery of the structures.

The Second Generation play type dominated exploration efforts from 1960 to 1980. These plays have contributed 27% to the gas-in-place reserves of the Foothills. They contain both Mississippian- and Devonian-aged reservoir rocks and are formed in structures composed of multiple thrust sheets with a dominant fault-bend-fold structural
Second Generation plays lie in the inner Foothills belt in the part of the Turner Valley Formation that was formed in a lower energy environment of deposition. The resulting rock types were dominated by wackestones and packstones. These reservoir rocks are generally inferior to the grainstones of the outer Foothills, and they need fractures to enhance the productivity. The inner Foothills area has rugged topography, often with high-velocity Paleozoic carbonates at the surface. These factors contribute to the poor quality of the seismic data recorded. However, because some parts of the structure may be exposed at the surface, geological surface mapping becomes an effective exploration tool.

Third Generation play types have become increasingly important in Foothills exploration since 1970. To date, these plays have contributed about 20% to the gas-in-place reserve base. Third Generation plays form structures that are dominated by the detachment fold structural style. This deformation has the ability to fracture the reservoir rock intensively. As a result, rocks with moderate to poor matrix reservoir can become good producers. However, this fracturing may negatively affect fields that have good matrix reservoir rock if they have a very active water drive. The structures in this play type have steep dips and disharmonic folding. This leads to problems with seismic imaging, although these plays can often be effectively mapped using surface mapping techniques because of the amplitude of the folds.

Another play type is the Reef/Stratigraphic type. It played a relatively minor role in Foothills exploration strategy from 1970 to 2000 and has contributed only 5% of the gas-in-place reserves in the Foothills to date. This play type is dominantly a stratigraphic play that extends from the conventional part of the WCSB and can occur either in the regional autochthone or in thrust sheets in the Foothills. In both cases the seismic imaging of the play is hampered by the complex geology of the shallower strata, large variations in topography, and steep dips of the reservoir rock itself or in the overlying strata. On the positive side, the reef plays to date have been prolific producers from good matrix reservoirs in the Devonian. It is a play that relies heavily on advances in seismic technology to provide the direct imaging necessary to provide successful drilling locations.

The Triangle Zone is a complex interaction of the two structural styles--it has multiple thrust sheets as well as a detachment folding component to enhance tight reservoir rock. There has been a resurgence in exploration of this play type since 1995. It has contributed 10% of the gas-in-place reserves in the Foothills. This play type involves primarily Cretaceous-aged sandstone reservoir rocks. Because of its position in the outer Foothills and the velocity contrast between the rocks, it is well imaged on seismic data.

Production from the various play types has changed over time (Figure 5). Early production was dominated by the Reef/Stratigraphic, First and Second generation plays. Since the mid 1980’s the Third generation and Triangle zone plays have contributed an increasing amount to the annual production.
The Foothills has a long history and has proved itself capable of producing large amounts of gas at high rates. Current published data gives the gas-in-place reserves for the Foothills as 40 TCF, of which 19 TCF are considered marketable gas and 13 TCF have already been produced. It currently produces nearly a TCF of raw gas a year. Based on the latest work by the Canadian Gas Potential Committee, using a discovery history process model, it has 27 TCF yet to be discovered in existing plays. The three largest fields left to be discovered in the WCSB will be in the Foothills and each will be greater than 1 TCF in size.

All gas reserve figures are in-place numbers, unless otherwise stated.