The future of natural gas exploration in the Foothills of the Western Canadian Rocky Mountains

Andrew C. Newsom, Moose Oils Ltd., Calgary, Alberta, Canada

The Foothills of the Western Canadian Sedimentary Basin (WCSB) cover 40,000 miles² in the fold and thrust belt of the Canadian Rocky Mountains. The topmost northwestern point lies just north of the Northwest Territories border at the town of Fort Liard. The Foothills also occupy part of the adjacent Yukon Territory, run southeast through British Columbia and Alberta, and terminate near the U.S./Canadian border (Figure 1).

The northwestern and southeastern limits are controlled by political boundaries and the extent of the natural gas gathering system. The width is defined on more geologic grounds. The Triangle Zone (Figure 2) defines the eastern side. This is a descriptive term for the subsurface shape of the rocks (in cross-section) that form the effective edge of the fold and thrust belt beyond which lie WCSB’s conventional exploration and development plays. The western edge is defined generally by the topographic high formed by the front ranges of the Rocky Mountains. The extreme relief of this topographic high limits access. It is also frequently the eastern edge of national or provincial parks, another restriction to access.

The Foothills are part of the larger fold and thrust belt of the Rocky Mountains, where the sedimentary rock has been deformed by horizontal compression. The rocks have been effectively shortened by one of two mechanisms. In some cases, 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, horizontal compression created tight folds in which the reservoir rock may be broken or fractured. In areas where the reservoir rock has been fault repeated, fields may have multiple individual pools of hydrocarbon 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 Foothills fields have reservoir rock that has been fractured naturally. This fracturing causes 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 figures in certain Foothills pools. A good example of undervaluing a reservoir is Moose Mountain, a 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 billion ft³ with the in-place reserves of 250 billion ft³ (AEUB 1985). In 1999, total production exceeded the original marketable reserves and the field is still producing at 40 million ft³ per day.

Opportunities. Exploration and development of hydrocarbon reserves in this area are significantly assisted by several factors, including:

- A large public domain data set that is available for this area because of technical mistakes made developing the Turner Valley Field. When exploitation of this field was just beginning in the 1920s, the gas cap of the yet undiscovered oil leg was depleted for about five years—leaving a billion barrels of oil in the field that are beyond recovery. As a result, a joint government and industry regulatory agency, the Energy Resources Conservation Board (a precursor to AEUB), was formed. Among the legacies of this agency is the data set it compiled and made public on all of Alberta’s wells, pools, and fields. Similar action in British Columbia, the Yukon, and the Northwest Territories has also made these data publicly available.
- The Geological Survey of Canada began mapping the Rocky Mountains in 1886 and has produced high-quality surface geologic maps for much of the Foothills.
- Each year about 15,000 wells are
added to the 333,000 wells already drilled in the WCSB. At present, 300 wells are drilled in the Foothills per year. As a result, a wide range of equipment is readily available for drilling, seismic acquisition, gas processing, or laying pipelines.

- The Foothills have inspired much advanced research over the years. Articles in technical bulletins have made a significant contribution to the effectiveness of the exploration and development in the area, and many technical papers on the Foothills have become landmark papers for overthrust belts around the world. Thus, technical sophistication about this area is high.

- Lastly, the Foothills belt is already connected to the North American gas gathering system. With natural-gas pipelines and plants in existence from Fort Liard in the north to Waterton in the south, the area is well served by infrastructure and has good access to the natural-gas markets of North America.

**Foothills models.** Foothills play types have been broken up into five categories based on three components: structural style, stratigraphic framework, and history of discovery.

Structures in the Foothills may be considered in the light of two end members of structural style: fault bend folds and detachment folds. The fault bend fold (Figure 4) is a structure in which the fold shapes and size are controlled by the relative position of the fault ramp in the hanging-wall and the fault ramp in the footwall. It has nearly equal amounts of displacement on both sides of the structure. The detachment fold (Figure 5) is a structure in which the fold shape and size is controlled by the amount of displacement and the position of a flat fault in the core of the structure. It has very marked difference in displacement on both sides of the structure.

Five components are used to define these two structural styles. In a fault bend fold, (1) displacement on the fault on both sides of the structure will be nearly equal; (2) beds will be flat, unless a later-stage movement deforms them; (3) bed thickness will remain constant throughout the bulk of the structures; (4) the angle between the limbs of the structure will be small (40-90°); and (5) the structure will exhibit high bedding dips on the fold limbs, and it will be a high-amplitude structure.

In a detachment fold, (1) displacement on both sides of the structure will be very unequal; (2) beds will have a syncline; (3) bed thickness will vary greatly throughout the structure due to disharmonic folding and small-scale back thrusts and fore-thrusts; (4) the angle between the limbs of the structure will be small (40-90°); and (5) the structure will exhibit high bedding dips on the fold limbs, and it will be a high-amplitude structure.

The application of the stratigraphic model in classifying structural styles can be illustrated by the Mississippian-aged Turner Valley Formation of the south-central Alberta Foothills, an area that contains 70% of Foothills reserves. This part of the Foothills has several major far-traveled thrusts that run northwest and southeast, parallel with the edge of the Foothills belt. These thrusts are the Livingstone, Moose, and Brazeau thrust faults. The facies of the Turner Valley Formation varies considerably across these thrusts. To the northeast side of the fault, this formation is dominantly a grainstone; on the southwest side the facies is dominated by packstone and wackstone. This transition in facies of the reservoir rock can occur in just 6-8 miles, as between the Jumping Pound West and Morley gas fields. If the reservoir rock were returned to its prethrusting position, this distance would be more than 66 miles. This has a considerable impact on the interpretation of the stratigraphic model for these two fields. In other Foothills formations, the relationship is more complicated, especially if the direction of movement on the fault or fold is oblique to the facies belt.

The earliest significant Foothills discovery was in 1913, the Cretaceous and Mississippian gas condensate and oil play at Turner Valley. This
started 25 years of active development of this field. In 1957 came the discovery of Waterton, the Foothills’ largest gas condensate field. This Mississippian and Devonian play has in-place reserves of 4 trillion ft³. Then in 1968 came the discovery of the Ricinus Cretaceous gas condensate play. All three fields are dominated by a fault bend fold structural style. It was not until 1977, with the Sukunka discovery in the Triassic-aged rocks, that the industry began to appreciate the importance of the detachment fold. The last important date is 1979, the first well in Blackstone Field. This proved the potential of the Devonian Beaver Hill Lake group reefs.

**Foothills play types.** The Foothills have been divided into five categories based on structural style, stratigraphic framework, and history of exploration (Figure 6).

First-Generation plays of the Mississippian aged reservoir formation dominated Foothills exploration from 1914 to 1960. These plays have contributed 37% of in-place gas reserves. They are 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 is reflected in the grainstones that form most of the Turner Valley Formation. The outer Foothills area has less rugged topography with softer Cretaceous surface rocks that allow better seismic imagery of the structures. Turner Valley (Figure 7) is an example of this type of play.

Second-Generation plays dominated exploration from 1945 to 1980. These plays represent 27% of in-place reserves. 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 style. Second-Generation plays lie in the inner Foothills belt in the part of the Turner Valley Formation formed in a lower energy environment of deposition that resulted in the rock matrix being dominated by packstones and wackstones. These rocks are generally inferior to the grainstones of the outer Foothills and need fractures to enhance productivity. The inner Foothills area has ruggered topography, often with high-velocity Paleozoic Carbonates at the surface. These factors contribute to the poor quality seismic data recorded. However, because some parts of the structure may be exposed at surface, geologic surface mapping becomes an effective tool. Moose Mountain (Figure 8) is a good example of this play type.

Third-Generation play types have become increasingly important in Foothills exploration since 1970. To date, these plays have contributed about 20% to the in-place reserve base. Third-Generation plays form structures that are dominated by the detachment fold structural style. This style has the ability to fracture the reservoir rock due to the way this fold style develops. As a result, rocks with moderate to poor matrix reservoir can become good producers. However, the disadvantage is that fields that are made up of good matrix reservoir rock may have their cumulative production negatively affected by fractures. The structures in this play type have steep dips and disharmonic folding. This leads to problems with seismic imaging, although they can often be effectively mapped using surface mapping techniques because of the amplitude of the folds. Findley (Figure 9) is a good example.

Reef/stratigraphic plays have had a relatively minor role in Foothills exploration strategy from 1970 to 2000 and contributed only 5% of in-place reserves. This is dominantly a stratigraphic play that extends from the conventional part of the WCSB and can occur in either the regional or on thrust sheets in the Foothills. In both cases, seismic imag-
ing 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 Swan Hills group and moderately good from the Devonian Palliser, Nisku, and Leduc. It is a play that relies heavily on advances in seismic technology for the imaging necessary to provide successful drilling locations.

The Triangle Zone is actually a complex interaction of the two structural styles; i.e., 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 in-place reserves. 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. Cabin Creek is a good example (Figure 10).

Geographically, the Foothills can be divided into two areas by using the Alberta/British Columbia border. The play types in the southern part are dominated by the fault bend fold structural style. The northern half (British Columbia, Yukon, and Northwest Territories) is dominated by the detachment fold style, although examples of both types of structural style occur in either area.

Alberta’s First-Generation plays are generally in the outer part of the Foothills. Second-Generation plays are in the inner part close to the front ranges. Third-Generation plays are not numerous but are more common in the north near the Alberta/British Columbia border. Triangle Zone plays are concentrated on the outer edge of the Alberta Foothills. Reef/stratigraphic play types also are concentrated in the central part of the Foothills.

As of the end of 1998, Alberta’s Foothills fields were producing 500 billion ft³ of natural gas per year. They have 29 trillion ft³ in place, of which 16 trillion ft³ is marketable. Production to date has been 10 trillion ft³.

To the north, the distribution of plays is very different. The dominant play is the Third-Generation play type. First-Generation play types do not form a significant part of these fields, and there is no production
from Second-Generation, Triangle Zone, or reef/stratigraphic play types. As of the end of 1998, these northern fields were producing 100 billion ft$^3$ of natural gas per year. They have 9 trillion ft$^3$ in place, of which 5 trillion ft$^3$ is marketable. This area has produced 3 trillion ft$^3$.

The future. The real excitement in the Foothills is the opportunities for new play development—the ideas that add new reserves and value to some existing reserves. These ideas tend to fall into the following categories:

**New concepts**—ideas that have the ability to make significant changes to the exploration and development potential of the Foothills plays.

There is an uncertainty in the booked reserves of the Foothills because of the fractured nature of reservoir rocks. The published figures are 40 trillion ft$^3$ in place, with 21 trillion ft$^3$ being marketable. Even allowing for the sour nature of the gases, the difference between these numbers is too high. Some of this 19 trillion ft$^3$ represents an uncertainty of booked reserves. As seen at Moose Mountain, marketable reserves of some Foothills play types are under-evaluated. Better understanding the generation of fractures and their contribution to production may add substantial marketable reserves to the Foothills.

Also, as exploration groups deal with more plays formed by the smaller, poorly imaged detachment folds, linkages within structure and between structure become important. Much existing interpretation assumes constant displacement faults that are “hard” linked. However, in detachment folding domains, many structures are not linked in this manner and they are best described as “soft” linked.

Lastly, there are numerous examples of wells missing the leading edge of structure in the Foothills. Although this is often attributed to poor seismic imaging, enough evidence suggests that the kinematic model for fold and fault generation at the leading edge of thrust sheets is more variable than presently understood. This is well illustrated by the F-25 Northcore et al. Liard well on the Liard anticline (Figure 11). There is enough evidence on the dipmeter and sample description to interpret a detachment between the Nahanni Formation carbonates and the overlying Besa River shale. This detachment appears very localized to the leading edge of the structure.

**New structural opportunities that involve all play types.** First-Generation plays are still being successfully developed and are frequently close to established production. The northern extension to Wildcat Hills is a good example.

Second-Generation plays are still being sought as well. The 1998 well Northstar et al. Highrock c-67-B 82-G-15 west of the Crowsnest Pass in southeastern British Columbia is a good example. This well was designed to test a large structure found beneath the Lewis Thrust.

Third-Generation plays are being very actively pursued. The well Husky Benjamin 16-28-28-8 W5M drilled by Husky in 1991, is a good example of a very successful well drilled into a detachment fold.

Triangle Zone plays are being developed in several locations along the Alberta Foothills (e.g., in the eastern edge of the Foothills between townships 27 and 56). In addition, potential exists for older abandoned triangle zone faults to the west of the traditional location of these play types.

**New stratigraphic opportunities based on advanced technology.** The Devonian Reef play in the Central Alberta Foothills is exciting. The technical challenge of directly imaging it is one that has yet to be overcome.

Other opportunity exists in untested areas in the Foothills where reef development may exist on either...
the thrust sheets or in region.
Lastly there is the opportunity to develop stratigraphic plays on the large far-traveled thrust sheets. In this situation the formation may be gently dipping. This could allow direct detection of hydrocarbons by seismic attributes.

New formation opportunities. A large percentage of existing reserves that have been added are in the Mississippian-aged rocks. Other rocks in the stratigraphic column offer potential as well. Many of the criteria for a successful play are found deeper in the Cambrian Formation. Elsewhere, the Permo-Penn in the Foothills appears to be a worthwhile target. Shallow Cretaceous and Triassic rocks also offer potential in the correct structural position.

New area opportunities. Some areas of the Foothills have less than one well per township. With about 2000 key wells scattered throughout the Foothills, it is far from being “drilled up.” To the north, beyond the present end of Foothills development at Fort Liard, is another 40 000 miles² that terminates at the Arctic Ocean. It has many of the characteristics of the Foothills. It is underexplored, with only 200 wells drilled in to it. It is a relatively narrow band of complex geology in a remote area with difficult access. At the moment, it lacks infrastructure to get any discovered gas to market. However, for the explorationist willing to accept the challenge, it offers structural and stratigraphic plays in abundance.
