Assessment of Continuous Gas Resources in the Horn River Basin, Cordova Embayment, and Liard Basin, Canada, 2019

Using a geology-based assessment methodology, the U.S. Geological Survey estimated undiscovered, technically recoverable mean resources of 135.4 trillion cubic feet of continuous gas in Devonian–Mississippian shales in the Horn River Basin, Cordova Embayment, and Liard Basin of Canada.

Introduction

The U.S. Geological Survey (USGS) quantitatively assessed the potential for undiscovered, technically recoverable continuous, or unconventional, gas resources in Devonian–Mississippian organic-rich shales in the Horn River Basin, Cordova Embayment, and Liard Basin of the Alberta Basin Province in Canada (fig. 1). From the Middle Devonian to Early Mississippian, carbonate platforms and adjacent deepwater basins were located along the western passive margin of North America, with open-marine conditions to the west and northwest. Carboniferous through Triassic subduction and collision of several terranes along the western margin of North America resulted in a long period of uplift, erosion, or nondeposition. The Late Jurassic development of an east-verging, fold/thrust belt and foreland basin (Price, 1994), and its continued subsidence into the Late Cretaceous through Paleogene, provided the necessary burial for adequate thermal maturity for oil and gas generation (Creaney and Allan, 1990; Fowler and others, 2001).

This study focuses on the assessment of organic-rich shales that were deposited in the deep, oxygen-deficient basins adjacent to the carbonate platforms (Ross and Bustin, 2008; Chen and Hannigan, 2016; Ayranci and others, 2018). These shales include the Evie Member and Otter Park Member of the Horn River Formation, the Muskwa Formation, and the Exshaw Formation in the Horn River Basin (British Columbia Oil and Gas Commission, 2014); Evie Member, Otter Park Member, Muskwa Formation, and Exshaw Formation in the Cordova Embayment; and the Besa River Formation in the Liard Basin (fig. 2). The Besa River Formation is equivalent to the stratigraphic interval from the Evie Member through the Exshaw Formation. Several hundred meters of Middle Devonian to Mississippian shales were deposited within these basins, but organic-rich shales only constitute part of the total shale thickness. Placing the shales in a sequence-stratigraphic context defines the intervals of organic-rich shales for the assessment (Jonk and others, 2013; Kam and others, 2015; Ayranci and others, 2018). The Evie Member represents a transgressive shale deposited across the underlying Keg River carbonate platform and is a distal, condensed, low-clay percentage siliceous shale that is a primary target for shale-gas development. The overlying Otter Park Member is a complex stratigraphic unit. The lower and upper parts of the Otter Park Member are lowstand wedges that are organically lean and are not petroleum source rocks. The middle part of the Otter Park Member is a transgressive, organic-rich shale that drapes the lowstand wedge and is a source rock. The Muskwa Formation, like the Evie Member, is an organic-rich transgressive shale that thins landward. The Exshaw Formation, an equivalent to the Bakken Formation, is a transgressive organic-rich shale (Smith and Bustin, 2000). The clinooinform of the Fort Simpson Formation (and equivalent strata of the Besa River Formation) is an organic-lean interval that is generally not a source rock, but opinions vary as to source rock potential (Ross and Bustin, 2008; National Energy Board, 2016).

The Evie Member is a specific target shale reservoir for horizontal drilling. However, because fractures within the Otter Park Member propagate up into the Muskwa Formation (Kam and others, 2015), the Otter Park Member and Muskwa Formation shales together form a horizontal drilling target (Virués and others, 2013; Mack and others, 2016; Teklu and others, 2018; Urban-Rascon and others, 2018; Agar and others, 2019). The overlying Exshaw Formation, like the Evie Member, is a single horizontal drilling target. The importance of natural and induced fractures to the production of shale gas in these...
units has been the subject of intensive study (Reynolds and Munn, 2010; Rogers and others, 2010; Novlesky and others, 2011; Ehlig-Economides and others, 2012; Khan and others, 2012; Dong and others, 2017; Yang and others, 2018; Agar and others, 2019). These studies have shown that the organic-rich shales are lithologically and structurally heterogeneous, which can affect spacing, length, orientation, and conductivity of natural and induced fractures and can also affect shale-gas production.

### Total Petroleum Systems and Assessment Units

The USGS defined a Middle–Upper Devonian Total Petroleum System (TPS) encompassing the (1) Horn River Basin Evie Shale Gas Assessment Unit (AU), (2) Horn River Basin Muskwa-Otter Park Shale Gas AU, (3) Cordova Embayment Evie Shale Gas AU, and the (4) Cordova Embayment Muskwa-Otter Park Shale Gas AU. Shales of the Evie Member, Otter Park Member, Muskwa Formation, and their equivalents are generally within the dry-gas generation window in these three basins (Ross and Bustin, 2008; Dong and Harris, 2013; Chen and Hannigan, 2016; Dong and others, 2017, 2018); so, standard geochemical parameters such as total organic carbon and hydrogen index are of limited use because of the high level of thermal alteration of organic matter. The geologic model for the Middle–Upper Devonian TPS is for oil and gas to have been generated from Middle to Late Devonian source rocks; oil was cracked to gas from Late Cretaceous–Paleogene foredeep burial, and gas was partially retained within the shales following expulsion and migration.

The USGS defined an Upper Devonian–Mississippian TPS to encompass the Horn River Basin Exshaw Shale Gas AU and the Cordova Embayment Exshaw Shale Gas AU. The Upper Devonian–Lower Mississippian Exshaw Formation in the Horn River Basin and Cordova Embayment is equivalent to the organic-rich shales in the upper part of the Besa River Formation in the Liard Basin (Ross and Bustin, 2008). The geologic model is for gas to have been retained within the shales following generation, migration, and structural deformation.

The Middle Devonian–Mississippian TPS was defined in the Liard Basin to include potential gas resources within organic-rich shales of the Besa River Formation (fig. 2). The Liard Basin Besa River Shale Gas AU was defined within this TPS. The Liard Basin is located on the western downdropped side of the regional Bovie Fault, and the Besa River Formation shales have been buried more than several hundred meters compared to the Horn River Basin (National Energy Board, 2016). Deeper burial and high thermal maturity in Besa River Formation shales in the Liard Basin may have adversely affected the quantities of recoverable gas.

Assessment input data are summarized in table 1. Input data for distributions of estimated ultimate recovery and drainage area were based on Chen and Hannigan (2016) and Yousefzadeh and others (2016).

### Undiscovered Resources Summary

The USGS quantitatively assessed continuous gas resources in seven AUs in the Horn River Basin, Cordova Embayment, and Liard Basin of the Alberta Basin Province in Canada (table 2). For undiscovered, technically recoverable continuous gas resources, the estimated mean cumulative resources are 135,350 billion cubic feet of gas (BCFG), or 135.4 trillion cubic feet of gas, with an F95–F5 fractile range from 38,096 to 254,252 BCFG and 335 million barrels of natural gas liquids (MMBNGL) with an F95–F5 fractile range from 83 to 710 MMBNGL. Of the potential continuous gas resources of 135,350 BCFG, about 107,036 BCFG—or 79 percent—is estimated to be in the Horn River Basin.
Table 1. Key input data for seven continuous assessment units in the Horn River Basin, Cordova Embayment, and Liard Basin of the Alberta Basin Province in Canada.

[Well drainage area, success ratio, and estimated ultimate recovery are defined partly using U.S. shale-gas analogs. The average estimated ultimate recovery input is the minimum, median, maximum, and calculated mean. Gray shading indicates not applicable. AU, assessment unit; %, percent; EUR, estimated ultimate recovery (per well); BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of natural gas liquids]

| Assessment input data—Continuous AUs | Horn River Basin Evie Shale Gas AU | Horn River Basin Muskwa-Otter Park Shale Gas AU |
|--------------------------------------|----------------------------------|-----------------------------------------------|
| Potential production area of AU (acres) | Minimum 1,000 | Mode 2,368,000 | Maximum 4,736,000 | Calculated mean 2,368,333 |
| Average drainage area of wells (acres) | Minimum 80 | Mode 120 | Maximum 160 | Calculated mean 120 |
| Area untested in AU (%) | Minimum 90 | Mode 94 | Maximum 98 | Calculated mean 94 |
| Success ratio (%) | Minimum 40 | Mode 60 | Maximum 80 | Calculated mean 60 |
| Average EUR (BCFG) | Minimum 2 | Mode 4 | Maximum 6 | Calculated mean 4.067 |
| AU probability | Minimum 1.0 | Mode 1.0 | Maximum 1.0 | Calculated mean 1.0 |

| Assessment input data—Continuous AUs | Cordova Embayment Evie Shale Gas AU | Cordova Embayment Muskwa-Otter Park Shale Gas AU |
|--------------------------------------|----------------------------------|-----------------------------------------------|
| Potential production area of AU (acres) | Minimum 1,000 | Mode 502,000 | Maximum 1,004,000 | Calculated mean 502,333 |
| Average drainage area of wells (acres) | Minimum 80 | Mode 120 | Maximum 160 | Calculated mean 120 |
| Area untested in AU (%) | Minimum 99 | Mode 100 | Maximum 100 | Calculated mean 99.7 |
| Success ratio (%) | Minimum 10 | Mode 50 | Maximum 90 | Calculated mean 50 |
| Average EUR (BCFG) | Minimum 2 | Mode 4 | Maximum 6 | Calculated mean 4.067 |
| AU probability | Minimum 1.0 | Mode 1.0 | Maximum 1.0 | Calculated mean 1.0 |

| Assessment input data—Continuous AUs | Horn River Basin Exshaw Shale Gas AU | Cordova Embayment Exshaw Shale Gas AU |
|--------------------------------------|----------------------------------|-----------------------------------------------|
| Potential production area of AU (acres) | Minimum 1,000 | Mode 2,368,000 | Maximum 4,736,000 | Calculated mean 2,368,333 |
| Average drainage area of wells (acres) | Minimum 80 | Mode 120 | Maximum 160 | Calculated mean 120 |
| Area untested in AU (%) | Minimum 100 | Mode 100 | Maximum 100 | Calculated mean 100 |
| Success ratio (%) | Minimum 10 | Mode 50 | Maximum 90 | Calculated mean 50 |
| Average EUR (BCFG) | Minimum 0.1 | Mode 1 | Maximum 2 | Calculated mean 1.036 |
| AU probability | Minimum 1.0 | Mode 0.9 | Maximum 1.0 | Calculated mean 1.0 |

| Assessment input data—Continuous AUs | Liard Basin Besa River Shale Gas AU |
|--------------------------------------|----------------------------------|
| Potential production area of AU (acres) | Minimum 1,000 | Mode 1,836,000 | Maximum 3,673,000 | Calculated mean 1,836,667 |
| Average drainage area of wells (acres) | Minimum 80 | Mode 120 | Maximum 160 | Calculated mean 120 |
| Area untested in AU (%) | Minimum 100 | Mode 100 | Maximum 100 | Calculated mean 100 |
| Success ratio (%) | Minimum 10 | Mode 50 | Maximum 90 | Calculated mean 50 |
| Average EUR (BCFG) | Minimum 0.1 | Mode 1 | Maximum 2 | Calculated mean 1.036 |
| AU probability | Minimum 1.0 | Mode 1.0 | Maximum 1.0 | Calculated mean 1.0 |

Table 2. Results for seven continuous assessment units in the Horn River Basin, Cordova Embayment, and Liard Basin of the Alberta Basin Province in Canada.

[Results shown are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Gray shading indicates not applicable. BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of natural gas liquids]

| Total petroleum systems and assessment units (AUs) | AU probability | Accumulation type | Total undiscovered resources | Gas (BCFG) | NGL (MMB NGL) |
|-----------------------------------------------|----------------|------------------|------------------------------|------------|---------------|
| Middle–Upper Devonian Total Petroleum System |
| Horn River Basin Evie Shale Gas AU | 1.0 | Gas | F95 13,680 | F50 44,144 | F5 82,957 | Mean 45,742 | 29 | 97 | 215 | 107 |
| Horn River Basin Muskwa-Otter Park Shale Gas AU | 1.0 | Gas | F95 15,286 | F50 49,592 | F5 92,273 | Mean 51,111 | 32 | 109 | 242 | 119 |
| Cordova Embayment Evie Shale Gas AU | 1.0 | Gas | F95 2,092 | F50 7,842 | F5 17,579 | Mean 8,565 | 4 | 17 | 45 | 20 |
| Cordova Embayment Muskwa-Otter Park Shale Gas AU | 1.0 | Gas | F95 2,906 | F50 9,519 | F5 17,855 | Mean 9,861 | 6 | 21 | 47 | 23 |
| Upper Devonian–Mississippian Total Petroleum System |
| Horn River Basin Exshaw Shale Gas AU | 1.0 | Gas | F95 2,302 | F50 9,042 | F5 21,991 | Mean 10,183 | 7 | 28 | 81 | 34 |
| Cordova Embayment Exshaw Shale Gas AU | 0.9 | Gas | F95 0 | F50 1,747 | F5 4,546 | Mean 1,941 | 0 | 5 | 17 | 6 |
| Middle Devonian–Mississippian Total Petroleum System |
| Liard Basin Besa River Shale Gas AU | 1.0 | Gas | F95 1,830 | F50 7,084 | F5 17,051 | Mean 7,947 | 5 | 22 | 63 | 26 |
| Total undiscovered continuous resources | | | | | | | | 38,096 | 128,970 | 254,252 | 135,350 | 83 | 299 | 710 | 335 |
