Abstract

The Triassic section of the Western Canada Sedimentary Basin is the richest interval within the basin in terms of volume of oil per volume of rock. The Lower and Middle Triassic Doig Formation has been historically known for the limited production from its conventional reservoirs in British Columbia (BC) and Alberta (AB). More recently, the Doig has received attention for its unconventional potential as a gas and natural gas liquids play, with estimates of total gas in-place ranging from 40 to 200 Tcf. The Doig has been informally subdivided into a lower Phosphate Zone (DPZ), and an upper siltstone interval. While the source-rock reservoir potential of the Doig is undoubtedly large, so are the uncertainties related to the spatial and stratigraphic distribution of its reservoir facies and properties. This study is an investigation of the reservoir facies of the Doig Formation in BC and characterizes its variability in porosity, pore throat size distribution, mineralogy and organic content. A grid of 15 cored wells covering its entire extent in BC, was selected. Eight reservoir facies are recognized, based on lithofacies, mineralogy by X ray diffraction (XRD), total organic carbon by Rock-Eval pyrolysis, porosity and pore size distribution by helium pycnometry and mercury intrusion, and permeability by pressure pulse-decay. In contrast to many shale reservoirs, the Doig is characterized mineralogically by a low clay content, and higher quartz and carbonate, especially dolomite. The DPZ is more clay and organic rich than the upper Doig, showing overall lower porosity and smaller average pore throat radii. In spite of these generalizations, facies stacking patterns confer a high degree of internal heterogeneity within these two major zones. Coarser and clay poor facies are characterized by median pore throat sizes three to four times larger than the finer clay rich facies. Pore throat size has a high degree of correlation with matrix permeability, which spans four orders of magnitude, from 10E-7 and 10E-4 md. Additional heterogeneity is caused by superimposing diagenetic features, such as authigenic pyrite, apatite, calcite veins and clay-smeared fractures, and may not be defined at the core or well log scales.
Mineralogical and Petrophysical Characterization of the Reservoir Facies of the Doig Formation in British Columbia, Triassic of Western Canada Sedimentary Basin

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Mineralogy

The Doig is primarily composed of silicates and carbonate, with minor amounts of quartz, feldspars, and calcite. Pyrite commonly occurs, correlating with high TOC values. The clay content of the Doig is highly variable, with samples ranging from 5% to 40% clay. Other significant silicate minerals are orthoclase and albite with average values of 8% and 40% respectively. The sandstones of the upper Doig C have no clay, and are predominantly composed of quartz, feldspars, and calcite.

Porosity and Permeability

Matrix permeability spans four orders of magnitude, ranging from $7 \times 10^{-2}$ mD to $7 \times 10^{-10}$ mD. Mercury injection porosimetry measurements provided insights into the pore structure of the Doig rocks, showing a high fraction of small pores with diameters less than 3 nm. The stress sensitivity of permeability obtained from measuring permeability at different effective stress ranges.

Pore Size Distribution and Pore Structure

The pore throat size distribution of the different reservoir facies of the Doig is highly variable, spanning three orders of magnitude (P10-P90 range). Pore throat distribution is used in the identification of mineral phases, as well as sample photograph, XRD mineralogy and SEM images.
The Triassic Doig Formation of the Western Canada Sedimentary Basin is continuous across northeastern British Columbia and western Alberta. It historically had limited production from conventional reservoirs and was viewed as a source-rock for other conventional reservoirs in the basin. In the last five years, the Doig Formation has been recognised as an important unconventional reservoir for gas and natural gas liquids. Estimates of total gas in-place range.

The Doig was deposited in the Middle Triassic, between the Anisian and Rhaetian stages, and is part of the Daler Group with the underlying Montney Formation.

The Doig Formation is informally subdivided into three units. The basal unit, Doig A, is also known as the Doig Phosphate is an organic-rich radioactive mudstone with common phosphate granules and nodules. The intermediate Doig B is primarily composed of intercalated mudstones and siltstone. The upper Doig C is composed of relatively organic-lean siltstones and fine sandstones.

Methods

This study is based on core and sampling from 25 wells from British Columbia and adjacent area in Alberta, distributed along the entire spatial extent of the Doig Formation. Samples were analyzed to determine mineralogy, porosity, pore-size distribution (PSD), permeability, total organic carbon (TOC), temperature of maximum hydrocarbon generation (Tmax), and kerogen type.

Porosity was determined on all core samples by a combination of helium pycnometry skeletal density and mercury buoyancy bulk volume measurements. Another source of porosity data, as well as pore throat size distribution is mercury injection porosimetry. Mineralogy was determined by X ray diffraction (XRD). Permeability was determined by pulse-decay gas permeameter, and Tmax and kerogen type were determined through Rock-Eval type pyrolysis on cutting samples in order to achieve a higher data density and continuous profiles. The pore structure was investigated with the use of scanning electron microscope (SEM) images.

In this poster we present preliminary results on the petrophysical and organic geochemical properties of the Doig Formation, which are part of an ongoing petroleum system analysis of the Doig. The project objectives are:

• Understand the spatial and stratigraphic variability in the petrophysical properties of the Doig Formation;
• Determine how lithofacies and mineralogy affect the pore size distribution and permeability;
• Assess the potential for gas and natural gas liquids over the entire extent of the Doig by determining the organic richness, maturity range and timing of hydrocarbon generation and migration.

Figure 1 - Stratigraphic chart of the Western Canada Sedimentary Basin and expanded view of the Triassic (after Mossop and Shetsen, 1994; Golding et al., 2016).

Figure 3 - Wells included in this study, overlain on isopach map of the Doig-Halfway interval (after Dixon, 1999).

The timing of hydrocarbon generation and migration is poorly constrained, but hydrocarbon generation is thought to have started in Late Jurassic, reaching maximum transformation rate during Early Cretaceous, before the last major erosion. Hydrocarbon migration from the Doig is thought to have occurred as late as Early Cretaceous. Studies on petrophysics and organic geochemistry of the Doig are sparse and limited in scope. The geological control on the petrophysical and organic geochemical properties of the Doig and their spatial and stratigraphic distribution is also currently poorly understood.
The Doig samples analyzed show a wide range of TOC and degree of thermal maturity. The average TOC is 1.9% and the maximum is 6.4%, with the 80% confidence interval distributed between 0.8% and 3.3%. The highest TOC values are observed in the upper Doig A member. Most samples are mature and within the oil window. Less than 5% of the samples were overmature, with Tmax values as high as 490 °C. A few samples were immature, albeit most of which are unreliable due to poor quality Tmax peak. There is a wide range of Tmax values for any given present-day depth across the basin, suggesting the paleo-depth of burial had a strong influence on the present-day maturity. Although, shallower wells in the eastern portion of the basin tend to show lower maturities, second and third order controls impose a more complex picture. Especially in the thicker successions of the westernmost wells, a wide range of maturity is observed on a single well.

Combined use of pseudo van Krevelen and Tmax vs. HI plots suggests that the organic matter is primarily of kerogen type III, with minor contribution from type II-III.

Conclusions

Mineralogy

- The Doig siltstones and mudstones are primarily composed of silicates and carbonate, with only minor amounts of clay; the main clay mineral is illite, with subordinate amounts of chlorite.
- The Doig C is the most homogenous member being composed primarily of clay-free quartz-rich massive siltstones and cross-bedded fine sandstones.
- Doig B is the most variable member in terms of facies and mineralogy, ranging from carbonate-rich massive, bioturbated or bioclastic mudstones to silica-rich wavy laminated siltstones with sparse carbonate laminae.
- The Doig A mudstones have the highest amount of clay, and common occurrence of pyrite, but show a highly variable proportion between silica and carbonate.

Porosity, Pore Size and Permeability

- Porosity is highly variable, ranging from 0.6% to 16.4%.
- Porosity is partly controlled by clay and calcite, probably in the form of carbonate mud; the higher porosity samples are poor in clay and calcite and rich in silicates.
- Mercury injection porosities are consistently lower than the helium pycnometry ones, due to pore size accessibility limitations, but are demonstrated to be reliable if properly corrected.
- Matrix permeability spans four orders of magnitude, from 7E-02 mD to 3.5E-05 mD at effective stresses of 2,500 psi and show a good correlation with porosity; the mineralogy plays a key control in determining pore volume compressibility; the quartz-rich siltstones do not have stress dependent permeability.
- The pore size is also a key controlling factor in determining the permeability, with the mostly meso and microporous relatively clay-rich mudstones showing the lowest permeability values; the silicate-rich siltstones, which have median pore throat size two orders of magnitude larger, well in the macroporosity region, exhibit the highest permeabilities.

Organic Geochemistry

- The average TOC is 1.9%, with a minimum of 0.3% and maximum of 6.4%.
- The primary kerogen is of type III, with secondary contribution from type II-III.

Future and Ongoing Work

- Low-pressure gas adsorption to characterize the distribution, and FIB-SEM to image the structure of the microporosity.
- Additional mercury injection and pulse-decay permeability measurements for refining the correlation between pore throat size and permeability.
- Additional X-ray diffraction and triaxial tests in order to derive correlation between mineralogy, ultrasonic velocity and geomechanical properties.
- Petroleum system analysis of the Doig with a basin model calibrated to source-rock and reservoir properties, as well as present-day thermal maturity indices.

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References


Figure 15 - Pseudo van Krevelen plot showing the thermal evolution path of the two types of kerogen/parent.

Figure 16 - Tmax vs. HI plot showing the kerogen type and thermal degradation path of kerogen from the immature to overmature windows.