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# Characterization of natural fractures of the Upper Devonian Duvernay Formation in the Kaybob Area, Alberta

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## Summary

Natural fractures (NFs) in a shale reservoir tend to interact with hydraulic fractures (HFs) resulting in the development of complex fracture network that allows enhanced fluid conductivity and controls the efficiency of well treatment. The analysis of NFs may help to predict vertical and lateral propagation of HFs and optimize HF.

The main objective of this research project is to study natural fractures in the Upper Devonian Duvernay Formation and integrate these data with lithofacies and mechanical properties of the mudrocks. A detailed description on distribution, composition, type, geometry, and orientation of natural fractures in the Duvernay Formation is conducted in core for selected wells in the Kaybob area. Natural fractures are distinguished from drilling induced fractures (DIF).

The obtained data on natural fractures in the Duvernay Formation are correlated with rock type, previous analysis of sequence stratigraphy of the formation, bed thickness, porosity and permeability data, and mechanical rock properties. Well logs are also used to correlate lithofacies and NFs described in cores. Location of the analyzed wells with respect of the Duvernay paleofacies distribution and structural position in the WCSB is taken into account.

## Geologic Background

The Upper Devonian Duvernay Formation is an organic-rich shale formation that is being developed as an unconventional shale resource in the Western Canada Sedimentary Basin (WCSB) since 2011 with technology of horizontal wells and multistage hydraulic fracturing (HF) (Preston et al., 2016). The Duvernay Formation occurs in the West and East Shale Basins separated by the Leduc Rimbey Meadowbrook Reef Trend. It is composed of organic-rich mudstones with variable content of organic matter and carbonates. In the Kaybob area of the West Shale Basin, it is divided into three members: The Lower Duvernay member, composed by organic-rich siliceous mudstones; the Middle Duvernay member, including carbonate-rich mudstones; and the Upper Duvernay member, mainly made of siliceous mudstones with lower organic content than the Lower member (Andrichuk, 1961; Stoakes, 1980; Stoakes and Creaneu, 1985; Dunn and Humenjuk, 2014). Depositional facies of the Duvernay mudstones generally vary from bioturbated carbonate-rich siltstones to siliceous mudstones (Harris et al., 2018). Five lithofacies were previously identified in the Duvernay cores from the Kaybob area characterized by composition, grain size, sedimentary structures, bioturbation, and cement (Shaw, 2020).

Natural fractures were previously described in the Duvernay mudstones from core data and image logs (Davies et al., 2014; Fothergill et al., 2014; Soltanzadeh et al., 2015; Currie, 2021).

Slickensides, non-mineralized, mineralized, vertical, sub-vertical, inclined, irregular/complex, and horizontal natural fractures have been identified in the Duvernay from core data. The height of the fractures is highly variable, ranging from less than 10 centimeters to higher than 100 centimeters (Currie, 2021). The measurement of the orientation of natural fractures is relevant as their response to the stress field can be different, depending on their orientations relative the present-day stress orientation (MacKay et al., 2018).

In the Western Canadian Sedimentary Basin, the maximum horizontal stress ($S_{Hmax}$) is generally oriented NE-SW with a mean value 45º±5º (Fig. 1) and characterized by a strike-slip tectonic regime in the Kaybob area (Bell, et al., 2004; Bell and Grasby, 2011; Reiter et al., 2014; Shen et al., 2019).

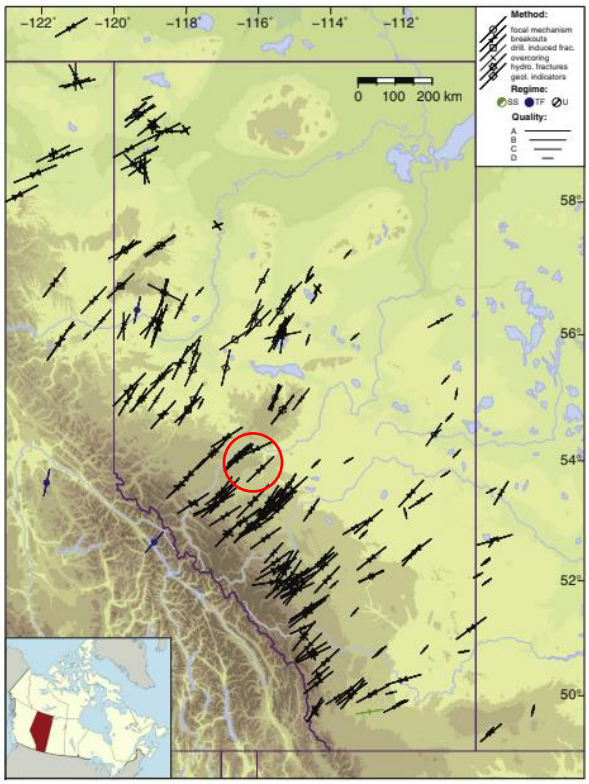


Fig. 1. Orientation of maximum horizontal stress ($S_{Hmax}$) in Western Canada Sedimentary Basin, Alberta, after (Reiter et al., 2014). Location of study area is highlighted by the red circle.

## Methods

Lithofacies and natural and induced fractures were described in the core at the base of the Ireton and the Duvernay Formations in several wells of the Kaybob area. Fracture type (open or healed), fracture filling, height, aperture and orientation to core axis and bedding, fracture spacing, in the core were recorded and analyzed. The parameters of fractures are correlated with rock composition, bed thickness, porosity and permeability from core testing results.

The continuous profiles of the dynamic and static elastic parameters (Young Modulus and Poisson Ratio) and unconfined compressional strength (UCS) were estimated from well logs and calibrated by the results of core testing data available in the CRC AER reports. Correlation equations for estimation of static elastic parameters from dynamic ones and UCS from static Young Modulus are taken from previous studies in the Duvernay Formation (Konstantinovskaya et al., 2021). The UCS profile is calibrated by hardness measurements in the core conducted in this study or published previously (Dong et al., 2018).

## Results

In this study, we present the initial observations that were obtained in one of three wells that were analyzed in the Kaybob area at the beginning of this project.

Several lithofacies were preliminary determined in the Duvernay core (Fig. 2).

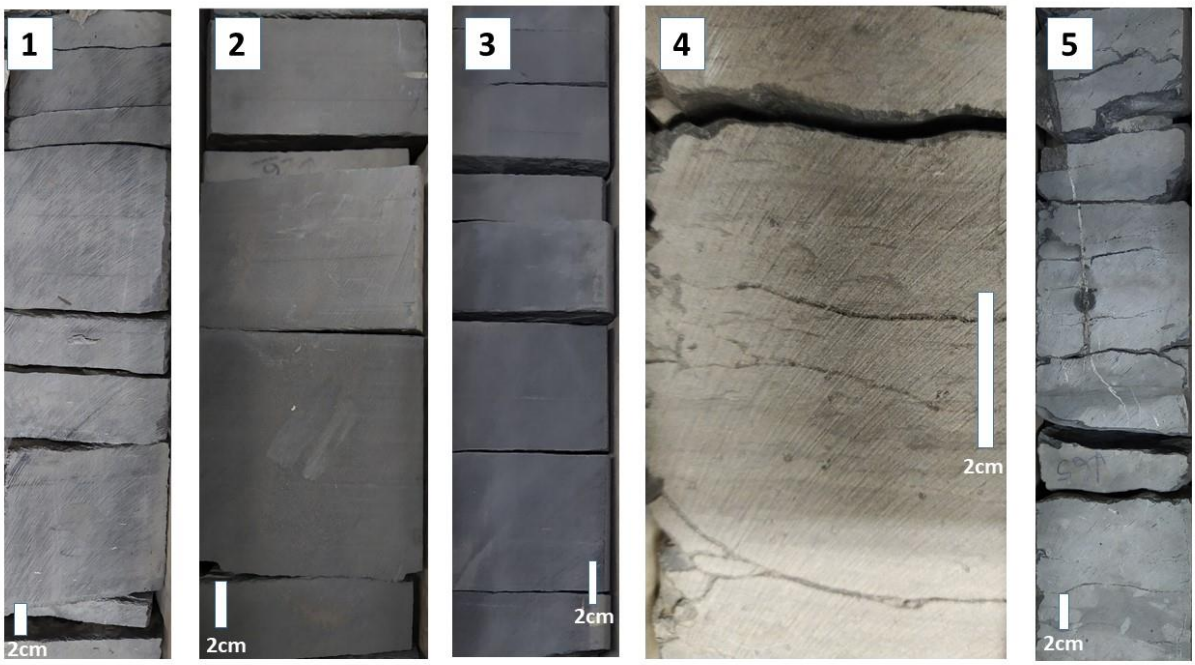


Fig. 2. Main lithofacies preliminary identified in the Ireton (1) and the Duvernay (2-5) core, well 102/11-26-062-20W5/00. Kaybob area: (1), light-grey relatively coarse-grained carbonate-rich organic-poor silty mudstones, 3260.18 m MD; (2), brown hemipelagic fine-grained planar-laminated organic-rich biosiliceous mudstones, 3279.12 m MD; (3), dark-grey fine-grained faintly laminated clay-rich mudstones, locally with thinly layered carbonate-rich interbeds, 3270.08 m MD; (4), light-brown bioturbated wackestones, 3287.60 m MD; (5), light-grey carbonate-rich nodular mudstones, 3304.82 m MD.

The relatively coarse-grained carbonate-rich organic-poor silty mudstones are typical for the base of the Ireton Formation (Fig. 2 (1)). The brown hemipelagic fine-grained organic-rich biosiliceous mudstones form the intervals of the Upper and Lower Duvernay (Fig. 2 (2)). The dark-grey fine-grained clay-rich mudstones with thinly laminated carbonate- or silt-rich interbeds are generally observed in the Upper Duvernay (Fig. 2 (3)). The light-brown bioturbated wackestones are present as localized beds in the Upper Duvernay (Fig. 2 (4)). The light-grey carbonate-rich nodular mudstones are typical for the Middle Duvernay (Fig. 2 (5)).

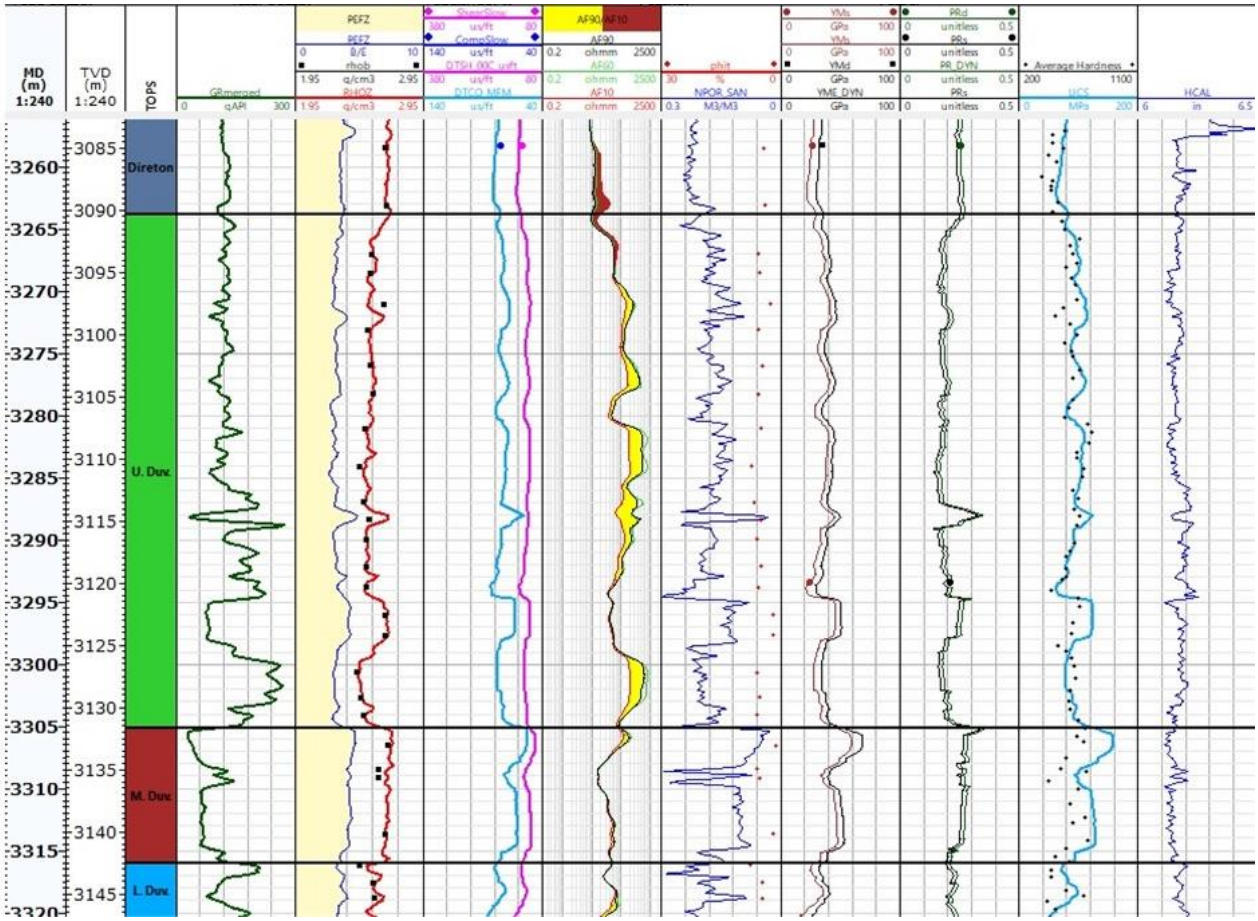


Fig. 3. Well logs and estimated profiles of dynamic and static elastic (Young Modulus, Poisson Ratio) and strength (UCS) parameters in the Duvernay Formation, well 102/11-26-062-20W5/00. Kaybob area. Calibrating core testing results are available from the CRC AER well reports. Hardness measurements (track 11) were conducted in this study.

The carbonate-rich lithofacies of the Middle Duvernay and in the lower portion of the Upper Duvernay are characterized by higher density and velocity values (Fig. 3), if compared to the overlying clay- and silt-rich or organic-rich biosiliceus lithofacies of the Upper and Lower

Duvernay. The static Young Modulus and UCS are greater in carbonate-rich mudstone intervals compared to other facies.

Natural fractures were observed at different depth intervals of the Duvernay Formation (Fig. 4). The most abundant natural fractures were observed in the Upper Duvernay. These fractures are most frequently filled with calcite. The vertical fractures are about 7-10 cm to 20-25 cm height and 0.2-0.3 mm aperture. These fractures are either limited by bedding surfaces (Fig. 4, (3)) or end by fracture tips fainting into the mudstone beds (Fig. 4, (4)).

Another set of fractures involve fracture splays of about 20-30 cm height inclined at about 10-30º to the core axis (Fig. 1, (1-2)). These fractures start with a single short subvertical tensile fracture that splits in two, which also split upward into several ones, thus forming a splay of fractures. Most of them have repeating intervals of tension openings, either filled or open, and shear segments, with no filling, depending on composition of thin mudtone beds.

A few sub-horizontal fractures were observed in the Duvernay core, usually filled with calcite.

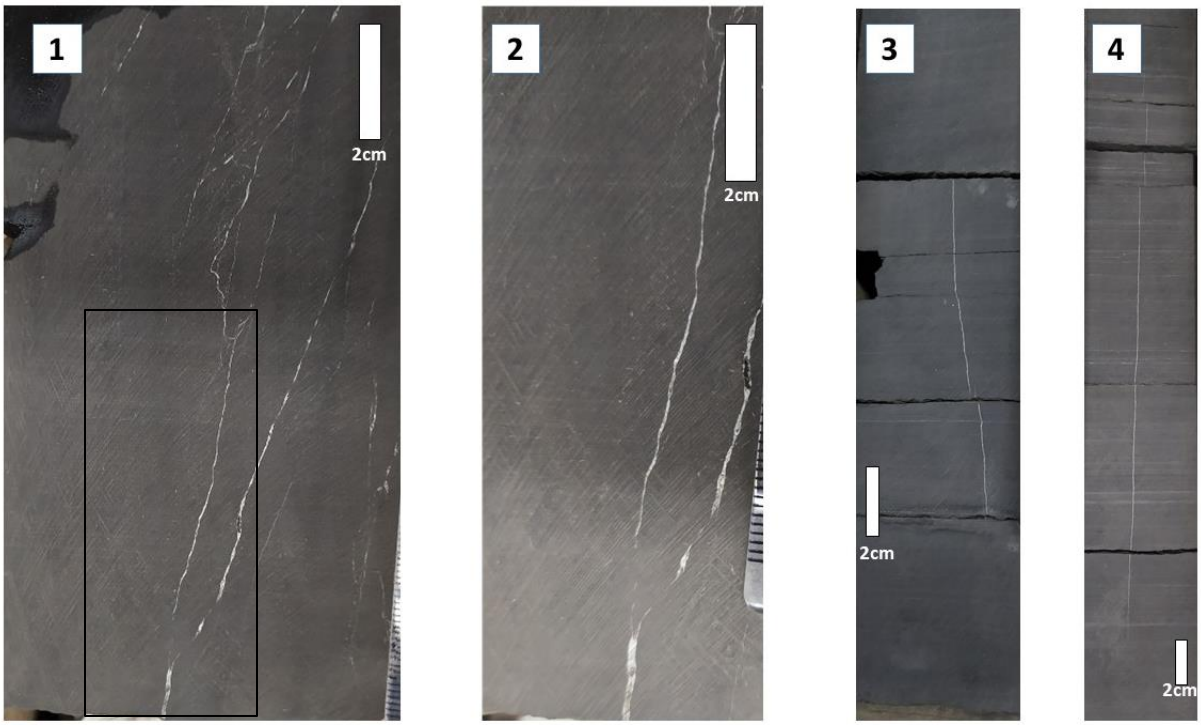


Fig. 4. Natural fractures identified in the Upper Duvernay Formation: (1) a splay of inclined open or calcite-filled complex fractures with repeating segments of shear and tensile deformation, 3285.19 m MD; (2) enlargement of (1) displaying shear and tensile segments of fractures; (3) vertical calcite-filled fracture limited by bed thickness, 3280.54 m MD; (4), vertical calcite-filled fracture fainting into the mudstones at the top and bottom tips of the fracture, 3282.14 m MD.

## Further steps

The further description of lithofacies and fractures in the Duvernay core and analysis of well log and core testing data in wells of the Kaybob area are planned. The study will help to try establishing a relationship between fracture intensity and mechanical stratigraphy of the Duvernay mudstones, considering lateral and vertical variations in lithofacies and the proximity of analyzed sections to the Leduc reefs in the basin. The study of outcrops of Upper Devonian shale formations as analogs of the subsurface Duvernay Formation is planned to analyze the correlation between fracture geometry and distribution vs carbonate content in the mudstones, bed thickness and tectonic deformation.

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