[PS]Mapping Duvernay Mineralogy: From Core to Log to Field*

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Abstract

Chevron Canada, in partnership with KUFPEC, has acquired rights to the Devonian Duvernay Formation across 325,000 acres of land in West-Central Alberta. The Duvernay Formation in this region is dark organic-rich calcitic/siliceous marine shale interbedded with argillaceous limestone with an average thickness of 50 m at depths of 3000 - 4000 m. Organic content ranges between 2% - 6%, porosity between 3% - 8%, pore pressure gradient between 18-20 kPa/m, and fluid varies from black oil to dry gas. Like other shale plays, the Duvernay Formation requires hydraulic fracture stimulation to maximize extraction of hydrocarbons. Economic production will not merely come from intervals of favorable properties but will also depend on the completion design. The rock elasticity property has significant controls on hydraulic fracture effectiveness and is directly related to the mineralogy of the formation. Understanding and being able to map the mineralogy of the Duvernay Formation will assist us in prioritizing development areas and fracturing strategies. Mineral modeling with Multimin in Geolog®* Formation Evaluation software requires some advance logging suites but most of the wells in this field do not have suitable log data to be properly modelled. Whole cores from six Chevron wells (350 m) from the Duvernay Formation across the Chevron land base were tested with QXRD and Best rock from 180 samples. A process called NIMBLE in Geolog® allows calibration from these core data sets to wells with only quad combo logs. This allows for maximum use of legacy data to understand mineralogy and rock property variation vertically and laterally. One of the challenges involved during multimin modeling of a field is in understanding when normalization of the logs is needed. Utilization of multi-vendor historic logs introduces additional uncertainty in the multimin model, however additional constraints, such as quartz and calcite volume relationship, reduce the model uncertainty. Utilization of distinct stratigraphic packages in the Duvernay and applying different models to each zone has also reduced the uncertainty. Geologically distinct areas in the Duvernay are more carbonate rich than others and this impacts log reading throughout the area. Integration of geology, petrophysics, and rock mechanics will ultimately allow for more effective hydraulic fracture design in appraisal and development. *Trademark of Paradigm Geophysical Ltd.

References Cited

Alberta Geological Survey, 2015, Alberta Table of Formations; Alberta Energy Regulator.

Ewy, R., 2013, Summary of Rock Mechanics Results – Werner Brelsford 9H, January 2013.

McCarty, D.K., P.N. Theologou, T.B. Fischer, A. Derkowski, M.R. Stokes, and A. Ollila, 2015, Mineral-Chemistry quantification and Petrophysical Calibration for Multimineral Evaluations: A Nonlinear Approach: AAPG Bulletin, v. 99/7, p. 1371-1397.

Theologou, P., 2012, NIMBLE Workflow in Geolog, FE Interpretation Product, September 2012.

Mapping Duvernay Mineralogy: From Core to Log to Field

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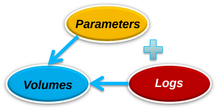
1. Introduction

The Duvernay Formation is dark organic-rich calcitic/siliceous marine shale interbedded with argillaceous limestone with an average thickness of 50 m in the Kaybob area. The elastic property has significant controls on hydraulic fracture effectiveness and is directly related to the mineralogy of the formation. Understanding and being able to map the mineralogy of the Duvernay Formation will assist us in prioritizing development areas and fracturing strategies.

This poster presents a workflow for generating a regional mineral model for the Kaybob Duvernay play using logs and core data. Whole cores from six Chevron wells (total of 350 m) from the Duvernay Formation were tested with Quantitative X-Ray Diffraction (QXRD) and BestRock™ (McCarty et al, 2015) from 180 samples. A process called NIMBLE (Figure 1b) in Geolog® uses this mineral data to calibrate the Petrophysical model on wells with only quad combo log suites. This enables for maximum use of legacy data to understand mineralogy and rock property variation vertically and laterally. Some public wells with X-ray Diffraction (XRD) data were consulted in this modeling process.



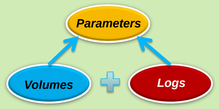
Standard Multimin Interpretation

Solves for optimized volumes over a single depth frame. From measured **logs** and **response parameters** – solve for the best *volumes*

(1a)

(Modified from Theologou, 2012)

Method Used in this Study:

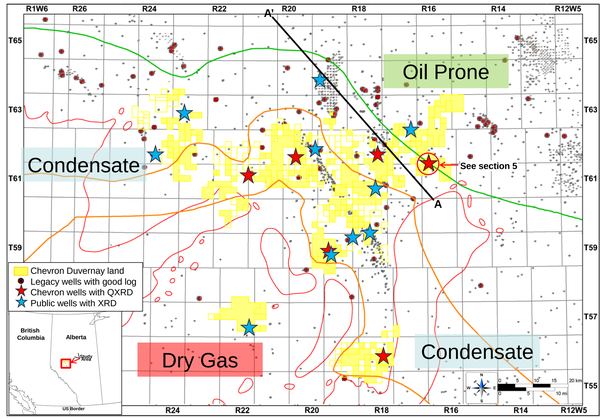


Numeric **I**nversion **M**odeling **B**y **L**inear **E**quations (**NIMBLE**)

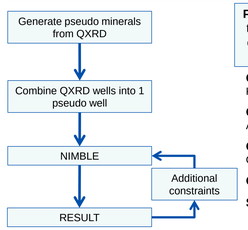
Solves the inverse problem using a Multimin model over multiple depths. From measured **logs** and **volumes** – it solves for the best log *response parameters*

(1b)

2. Study Area



3. Work Flow



Pseudo minerals from QXRD: the number of minerals solved depends on the number of log data available

Quartz = Quartz + Plagioclase + K-feldspar

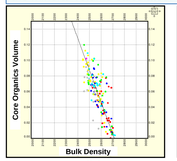
Carbonate = Calcite + Dolomite+ Ankerite + Fe-Dolomite

Clays = Illite-smectite + Kaolinite + Chlorite

Organics = Organics

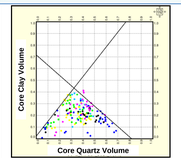
Sulfides = Pyrite + Marcasite

Additional constraints: separate equations for organics volume (Figure 3a), quartz-clay relationship boundary (Figure 3b) and model separation based on vertical zones (Figure 3c) were added to the workflow to support the algorithm and to increase the accuracy of the mineral volume calculated.



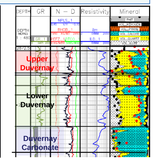
(3a)

Additional volume of organics curve calculated from density log



(3b)

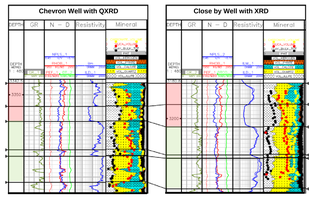
Additional user constraints for quartz and clay relationship



(3c)

Separate model for Upper and Lower Duvernay, and Duvernay Carbonate

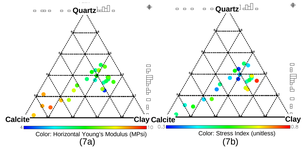
4. XRD Pitfalls



(4a) (4b)

There are inconsistencies of XRD measurements and reporting from different companies. Use public data with caution when calibrating mineral model. Only QXRD data is used in this study, Figure 4a.

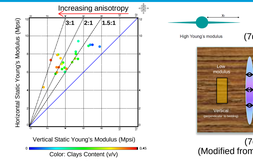
7. Mineralogy Vs Elastic Property Vs Fracture Geometry



(7a) (7b)

$$Young's\ Modulus\ (E): \quad E = \frac{Stress}{Strain}$$

$$Stress\ Index: \quad K_0 = \frac{E_{horz}}{E_{vert}} \frac{\nu_{vert}}{(1 - \nu_{horz})}$$



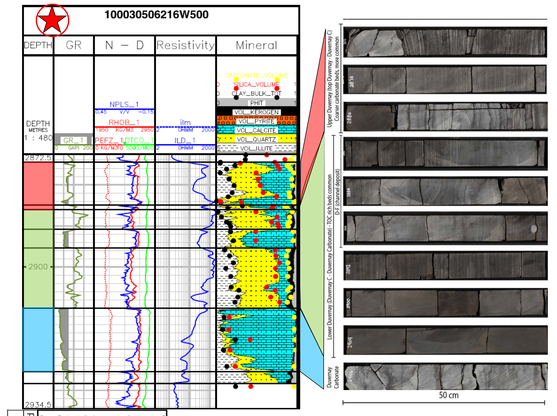
(7c)

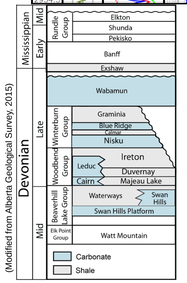
(7d)

(7e)
(Modified from Ewy, 2013)

- Comprehensive QXRD and triaxial tests from full diameter core have shown strong relationships between mineralogy and rock elastic properties.
- Carbonate content tends to be a good predictor of Young's modulus (Figure 7a). while clay content is a good stress index indicator (Figure 7b).
- Shaly formations can have high modulus anisotropy. In the Duvernay, the horizontal and vertical modulus ratio ranges from 1.5:1 up to 3:1. Young's modulus parallel to bedding is much higher (stiffer) than perpendicular to bedding, see Figure 7c above.
- If Young's Modulus is high, hydraulic fracture width will be small (Figure 7d).
- A vertical hydraulic fracture has to work against the horizontal (the highest) Young's modulus, Figure 7e above.

5. Result: Comparing mineral model and QXRD to core

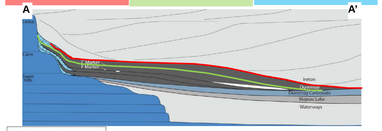




Upper Duvernay
- Lower Total Organic Carbon (TOC) (enriched in thorium)
- More clay and calcite, less siliceous
- Higher water saturation (Sw); higher clay

Lower Duvernay
- TOC-rich (enriched in uranium)
- Lowest clay and carbonate, most siliceous
- Highest phit (4-8%)
- Lowest Sw
- Main landing zone for horizontal wells
- Local variability

Duvernay Carbonate
- Dense nodular limestone; mostly non-reservoir
- Non reservoir
- Frac barrier in most area

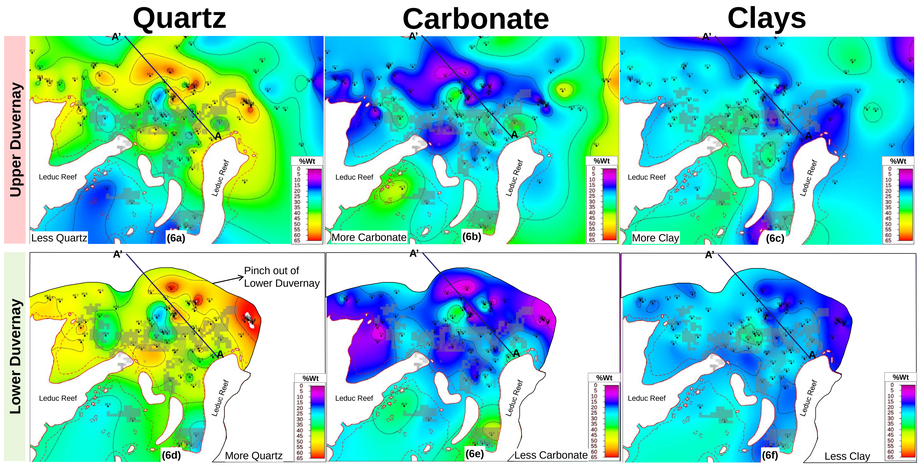


Upper Duvernay
Lower Duvernay

Schematic geologic cross section (A – A' from Section 6) highlighting stratigraphic complexity observed in the Duvernay

6. Result: Regional mineralogy map calculated from legacy wells

- The resulting pseudo mineral model was applied to 112 legacy wells with quad combo log data (gamma ray, neutron, bulk density, photoelectric factor, sonic, resistivity).
- Regional mineral mapping shows increasing silica content towards the basinal area, Figure (6a) and (6d) and higher calcite content closer to Leduc reefs, Figure (6b).
- Quartz: Lower Duvernay has proportionally higher quartz content (up to 60%) than the upper Duvernay, Figure (6a) and (6d).
- Carbonate: Lower Duvernay has slightly less carbonate content overall but has more interbedded limestone in east part of Kaybob, Figure (6e).
- Clays: Upper Duvernay has slightly more clay content than the lower Duvernay, Figure (6c).



8. Challenges

- Difficulties in assigning parameters for similar pseudo minerals for different areas within the same field.
- Organic matter grain density is difficult to measure and has a large impact on the Petrophysical model.
- Normalization of old log data is challenging and should be done on a well by well basis to ensure a consistent dataset.

9. Lesson Learned

- When constructing mineral models with limited log suites, it is necessary to combine similar minerals into pseudo minerals.
- Additional stratigraphic constraints improve the model uncertainty by correcting for geologic variability.
- XRD from different companies proved to be inconsistent.

10. Best Practices

- The NIMBLE workflow in Geolog ® is a powerful tool to assist in calculating the end point parameters of lumped pseudo-minerals
- Continual model refinement as additional wells are acquired is needed to maintain a useful model.

References:

1. Alberta Geological Survey (2015): Alberta Table of Formations; Alberta Energy Regulator.
2. Ewy, R. "Summary of Rock Mechanics Results – Werner Brelsford 9H." January 2013.
3. Theologou, P. "NIMBLE Workflow in Geolog", FE Interpretation Product, Sept 2012.
4. McCarty, D. K., P. N. Theologou, T. B. Fischer, A. Derkowski, M. R. Stokes, A. Ollila (2015) Mineral-chemistry quantification and petrophysical calibration for multimineral evaluations: a nonlinear approach, *AAPG Bulletin*, 99:7, 1371-1397,