Abstract

The Alberta Geological Survey estimates the Duvernay Formation to contain more than 400 TCF of natural gas as well as significant NGLs and oil. In order to exploit this resource to its full potential, cost effective means for acquiring reservoir properties, especially in horizontal production wells, are required. Portable X-Ray Fluorescence (XRF) instruments allow a large amount of data to be obtained rapidly, with minimal sample preparation or drilling impact, and at low cost. Rock powders, cuttings, slabs, or core faces can be analyzed directly using this non-destructive technique. XRF analyses provide highly precise, and if calibrated properly, accurate data on the bulk chemistry. Proprietary normative mineral algorithms are applied in order to convert the elemental chemical data to mineralogy. Mineral abundances determined from the XRF analyses correlate well with those obtained by X-Ray Diffraction, thin section point counting, and SEM analyses. The vast majority of the data fall within the 5% envelope expected from the precision of the XRD analyses when compared with XRF determined mineralogy. Mineralogy in the Duvernay is variable and the most abundant minerals are quartz, calcite, K-spar, illite, kaolinite, and pyrite. Mineralogy and trace element data are used to determine reservoir properties through a set of semi-empirical equations. Porosity and mechanical properties, including Poisson's ratio and Young's modulus, determined by XRF algorithms correlate well with values obtained from wireline logs and lab analyses in vertical wells. Formation specific algorithms developed from vertical wells can be applied to cuttings analyzed from horizontal production wells, where conventional log analyses are impractical or too expensive. The information obtained is particularly valuable for geosteering purposes if conducted on site in real time or for post well completion planning. Data obtained using portable X-Ray Fluorescence instruments provide a cost-effective means for optimization of both completions and production from horizontal wells.
Determination of Reservoir Properties from XRF Elemental Data in the Duvernay Formation

Tom Weedmark, P. Geol

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Outline

- Introduction
- XRF Process
  - Data Collection
  - XRF Modelling Process
- Unconventional XRF Applications
  - Duvernay Vertical Core (XRF Modelling)
  - Duvernay Horizontal Well (XRF Logging)
  - Advantages of XRF (Unconventional)
Tom Weedmark, P. Geo (President)

- B.Sc. Geology, University of Calgary (2007)
- M.Sc. Geology, University of Calgary (2014)

- President, XRF Solutions (2012-2016)
- P. Geo (2016)

- Developing XRF applications in sedimentary rocks since 2010 (Horn River)
  - Duvernay, Montney, Horn River, Exshaw/Banff, Nordegg, 2nd White Specks, Chinook, Dunvegan, Falher, Rock Creek, Ellerslie, Cardium, Clearwater and McMurray.
Data Collection: Portable XRF

**Bulk Cuttings**

**Sample Cups**

**Innov-X Canada Delta Premium XRF Analyzer**

**Core Slab**

**Geochem Mode (120 Sec)**
- Calibrated Major Elements
  - Ca, Si, Al, K, Fe, Mg, S
- Calibrated Trace Elements
  - U, Th, Rb, Sr, Zr, V, Mn, Mo,
  - Ti, Cr, Co, Cu, Zn, P, Y, Pb
- plus Ni, Cl
- Excel Spreadsheet (CSV)
XRF Modelling Process: Step 1

XRF DATA → CORE (VERTICAL WELL) → BULK ELEMENTAL COMPOSITION

XRF DATA → MINERAL COMPOSITION (Phase Theory) (Normative Mineralogy) → ALGORITHMS FOR MODELLING RESERVOIR PROPERTIES → AVAILABLE REFERENCE DATA FOR RP
Geologic Controls on Reservoir Properties

Geology
• Composition (quartz)
• Fabric (top open detrital) (bottom welded)

Reservoir Properties
• Porosity
• Permeability
• Mechanical Properties
Characterization of Reservoir Properties

Specific Mineral Interaction Model:

\[ \text{RP} = \alpha_{(\text{RP})} + \sum_i \beta_i^0 \text{DV}_i + \sum_i \sum_j \beta_{i,j}^1 \text{DV}_i \text{DV}_j + \sum_i \gamma_i \text{CV}_i + \sum_i \theta_i \text{RV}_i \]

RP is a reservoir property:
(porosity, permeability, Poisson’s ratio, Young’s modulus)

\( \text{DV}_i \) is the *detrital volume* fraction of solid phase \( i \), \( \text{CV}_i \) is the *cement volume* fraction of solid phase \( i \) and \( \text{RV}_i \) is the *recrystallized volume* fraction of solid phase \( i \).

\( \alpha_{(\text{RP})} \) is a function of the reservoir property, \( \beta^0, \beta^1, \gamma \) and \( \theta \) are *fabric dependent coefficients* that vary as a function of \( T, P \) (depth) and rock composition.
Porosity, matrix permeability and the mechanical properties of rock strength (Young’s Modulus) and brittleness (Poisson’s Ratio) are directly related to composition and fabrics.
XRF Modelling Process: Step 2

1. XRF DATA
2. BULK CUTTINGS (HORIZONTAL WELL)
3. BULK ELEMENTAL COMPOSITION
4. XRF Modelling Process: Step 2
5. BULK ELEMENTAL COMPOSITION
6. HORIZONTAL CHEMICAL LOGS
7. ALGORITHMS FOR MODELLING RESERVOIR PROPERTIES
8. HORIZONTAL CHEMICAL LOGS
Duvernay Vertical Core
Applying an XRF Model (Duvernay)
Applying an XRF Model (Duvernay)

Molecular Percentages

<table>
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<th>Component</th>
<th>Upper SR</th>
<th>Middle Carbonate</th>
<th>Lower SR</th>
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<tr>
<td>MgCO₃</td>
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<td></td>
</tr>
<tr>
<td>CaCO₃</td>
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</tr>
<tr>
<td>SiO₂</td>
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<tr>
<td>CaSO₄</td>
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<tr>
<td>Al₂O₃</td>
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<td>K₂O</td>
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<td>PO₄</td>
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<tr>
<td>FeS₂</td>
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</tr>
</tbody>
</table>

Measured Depth (m)

60m

Wt %
Applying an XRF Model (Duvernay)

Redox & TOC

Calc TOC  WL Gamma  Mn  V  U  Mo

Measured Depth (m)

60m

Upper SR  Middle Carbonate  Lower SR
Applying an XRF Model (Duvernay)

Mechanical Properties

- Youngs Modulus (GPa)
- Poisson's Ratio

Measured Depth (m)

- 60m

Layers:
- Upper SR
- Middle Carbonate
- Lower SR
Applying an XRF Model (Duvernay)
Duvernay Horizontal Well
XRF Horizontal Logging (Duvernay)

XRF Spectral Gamma

Calculated TOC (Wt %)
MWD GR (API)
XRF GR (API)
XRF Th (PPM)
XRF U (PPM)
XRF K (Wt %)

Measured Depth (m)
XRF Horizontal Logging (Duvernay)

Major Oxides

Measured Depth (m)
XRF Horizontal Logging (Duvernay)

Mineralogy

- Pyrite
- Anhydrite
- Illite/Mica
- Chlorite
- K-Spar
- Plag
- Quartz
- Calcite
- Dolomite

Measured Depth

Amount (Wt%)
XRF Horizontal Logging (Duvernay)

TOC Potential

Measured Depth (m)

0 5 10

2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700

Mo (ppm)
U (ppm)
Py (Wt %)
Mn (ppm)
Gamma (API)
Calc TOC (Wt %)
XRF Horizontal Logging (Duvernay)

Mechanical Properties

- Geopicks
- YM XRF
- PR XRF

Poisson’s Ratio

Young’s Modulus (GPa)

Measured Depth (m)
XRF Horizontal Logging (Duvernay)
XRF Horizontal Logging (Duvernay)
Advantages of XRF (Unconventional)

• Additional tool for evaluating reservoir quality in vertical wells:
  - Large amount of data provided at low cost
  - Locate zones with best mineralogy, (low cement, low clay)
  - Locate zones with best TOC (if applicable)
  - High resolution XRF analysis of can locate best interval for well placement
  - Modelling of XRF data to lab data can locate controls on reservoir properties

• Primary tool for evaluating reservoir rock in horizontal production wells:
  - Anything modelled in vertical wells can be logged in horizontal well
  - Mineralogy and TOC around wellbore, much more info than just MWD data
  - Calculated values for mechanical properties and/or porosity
  - XRF chemical logs can help to plan hydraulic fracture treatments
  - XRF chemical logs can be compared with production to optimize future wells
  - Low cost for horizontal well logging without risk of tools in well
  - No effect on drilling operations
  - Geo-steering Applications
Questions?

XRF Solutions
chemical solutions to geologic problems

Tom Weedmark MSc., P.Geo
President
209, 255 17th Avenue SW
Calgary, Alberta T2S 2T8

Cell 403.710.8422
Work 403.903.4269
Fax 403.287.9572
tweedmark@xrfolutions.ca