

Determination of Reservoir Properties from XRF Elemental Data in the Duvernay Formation*

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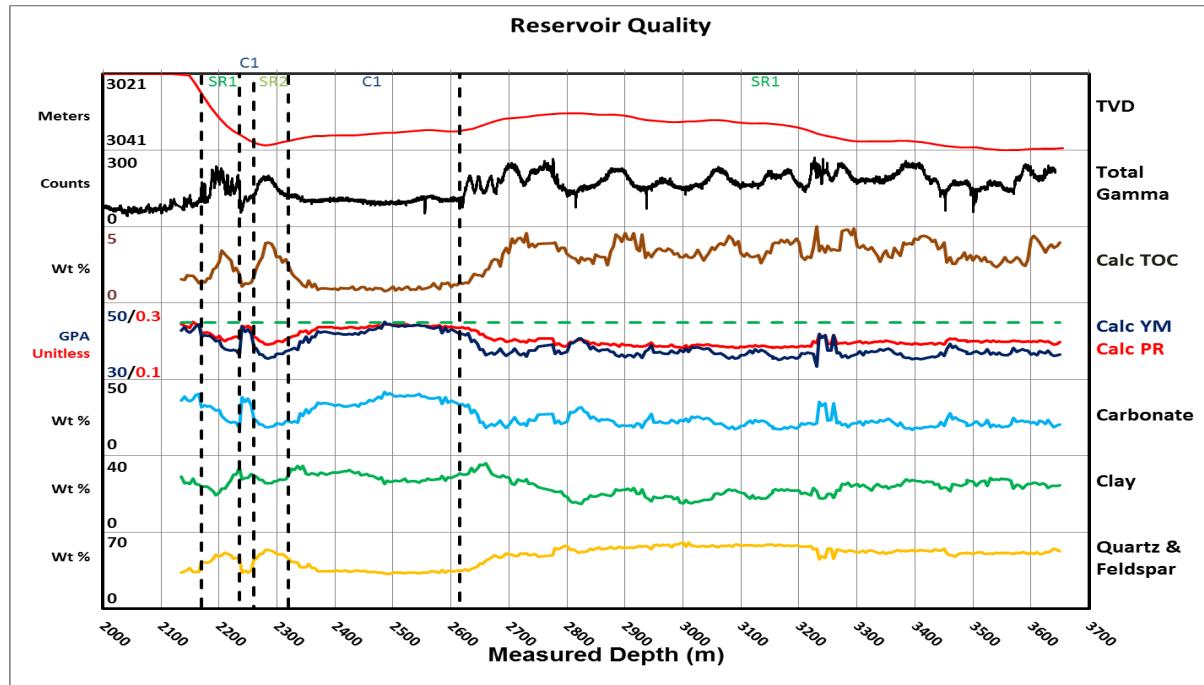
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Abstract

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



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)



chemical solutions to geologic problems

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



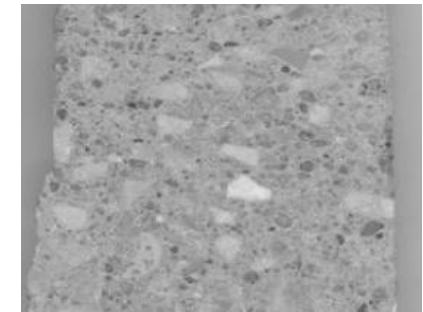
Sample Cups



Innov-X Canada Delta Premium
XRF Analyzer



Core Slab



Geochem Mode (120 Sec)

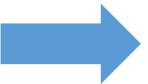
- Calibrated Major Elements
- Ca, Si, Al, K, Fe, Mg, S
- Calibrated Trace Elements
- U, Th, Rb, Sr, Zr, V, Mn, Mo,
- Ti, Cr, Co, Cu, Zn, P, Y, Pb
- plus Ni, Cl
- Excel Spreadsheet (CSV)



XRF Modelling Process: Step 1



XRF



CORE (VERTICAL WELL)



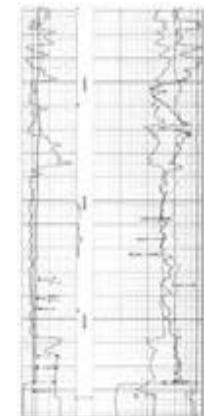
BULK ELEMENTAL COMPOSITION

Mag/CD	C03			S02			A03			F03			F03			P04			C04				
	W	%	W	%	W	%	W	%	W	%	W	%	W	%	W	%	W	%	W	%	W	%	
0.00	27	99	55.95	7.12	25	5.9	3.49	2.51	6.60	89.74	1.62	10.37	4.52	1.62	3.39	8.00	0.00	0.00	0.00	0.00	0.00	0.00	
4.72	48	99	42.26	8.61	1.83	2.92	1.65	4.66	61.80	1.27	8.30	0.69	1.27	2.38	4.06	1.00	0.00	0.00	0.00	0.00	0.00		
0.00	49	98	38.96	5.58	1.68	2.87	1.47	4.44	50.19	1.06	5.19	3.39	1.06	1.92	3.39	0.87	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	48	11	44.15	8.61	2.21	4.08	2.38	4.07	46.30	1.37	11.41	5.27	1.37	2.38	4.07	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	49	24	56.45	8.61	2.47	4.08	2.38	4.07	46.30	1.37	11.41	5.27	1.37	2.38	4.07	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	29	94	56.21	8.12	3.64	3.99	2.79	4.44	118.54	1.92	14.52	5.57	1.92	3.64	3.99	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	34	53.24	8.16	3.04	3.96	2.87	4.03	110.85	1.79	13.48	5.00	1.79	3.04	3.96	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	29	94	56.21	8.12	3.64	3.99	2.79	4.44	118.54	1.92	14.52	5.57	1.92	3.64	3.99	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	29	94	54.69	8.69	3.13	4.34	2.66	5.55	136.64	1.86	17.73	6.13	4.90	8.69	13.64	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	27	86	53.86	8.43	3.62	3.94	2.43	4.05	126.62	1.84	14.52	5.00	1.84	3.62	3.94	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	27	86	53.86	8.43	3.62	3.94	2.43	4.05	126.62	1.84	14.52	5.00	1.84	3.62	3.94	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
4.81	45	20	37.89	5.54	1.70	3.15	1.36	3.66	43.38	1.14	7.26	3.39	1.14	2.27	3.66	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
4.81	29	86	54.48	8.44	2.74	3.24	1.61	5.04	83.44	1.78	8.30	6.40	1.78	3.24	5.04	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	20	58.08	5.45	8.48	2.71	3.47	1.73	0.51	78.77	1.75	7.26	7.16	1.75	2.71	3.47	1.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	28	39	53.49	8.48	2.71	3.17	1.40	5.77	82.03	1.72	7.30	6.03	1.72	2.71	3.17	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	27	79	54.80	8.43	2.46	3.48	1.68	6.66	77.41	1.79	7.26	6.40	1.79	2.46	3.48	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	86	56.20	8.03	2.95	3.65	1.60	6.84	67.68	1.87	4.17	5.65	1.87	2.95	3.65	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	86	56.20	8.03	2.95	3.65	1.60	6.84	67.68	1.87	4.17	5.65	1.87	2.95	3.65	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	31	93	51.38	8.15	2.63	3.27	1.83	6.81	32.29	1.63	6.00	4.40	1.63	2.63	3.27	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	31	87	51.87	8.30	2.64	3.37	1.28	6.86	81.50	1.67	5.19	5.65	1.67	2.64	3.37	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	27	57	55.87	8.84	2.68	3.21	1.27	1.17	27.96	0.00	0.00	4.91	0.00	2.68	3.21	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	43	54.73	8.12	2.47	3.48	1.42	6.66	66.32	1.92	5.17	5.60	1.92	2.47	3.48	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	28	20	55.85	9.31	2.98	3.21	1.42	1.13	66.32	1.92	5.17	5.60	1.92	2.98	3.21	1.00	0.00	0.00	0.00	0.00	0.00	0.00	



XRF DATA

MINERAL COMPOSITON (Phase Theory) (Normative Mineralogy)



ALGORITHMS FOR MODELLING RESERVOIR PROPERTIES

AVAILABLE REFERENCE DATA FOR RP

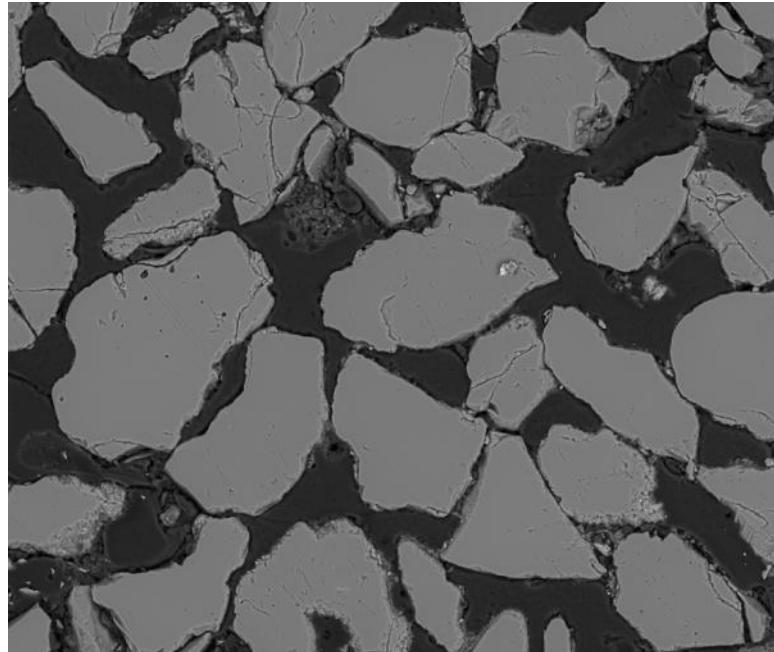
Geologic Controls on Reservoir Properties

Geology

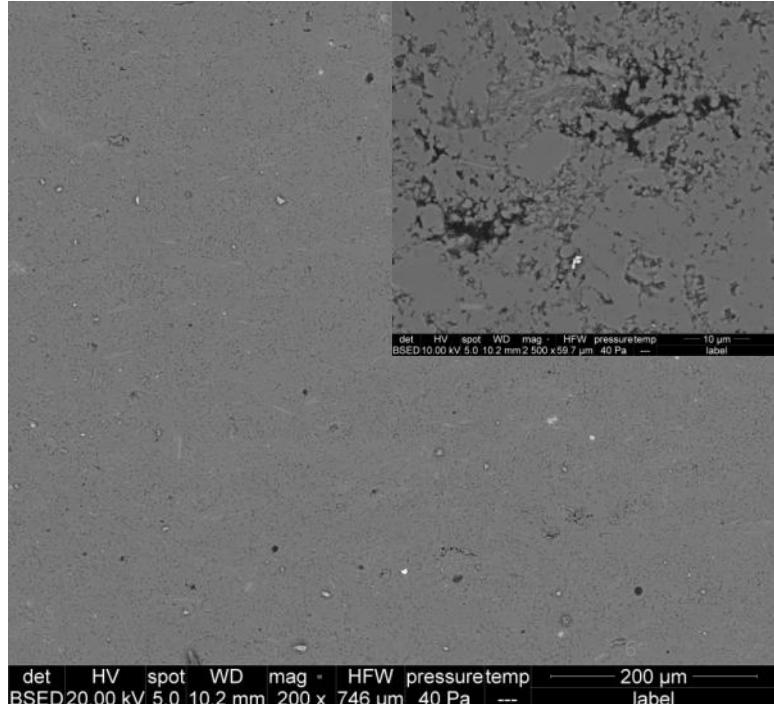
- **Composition (quartz)**
- **Fabric (top open detrital)
(bottom welded)**

Reservoir Properties

- **Porosity**
- **Permeability**
- **Mechanical Properties**



det HV spot WD mag . HFW pressure temp
BSED 20.00 kV 5.0 10.0 mm 200 x 746 µm 40 Pa ---
200 µm label



det HV spot WD mag . HFW pressure temp
BSED 20.00 kV 5.0 10.2 mm 2500 x 59.7 µm 40 Pa ---
200 µm label

Characterization of Reservoir Properties

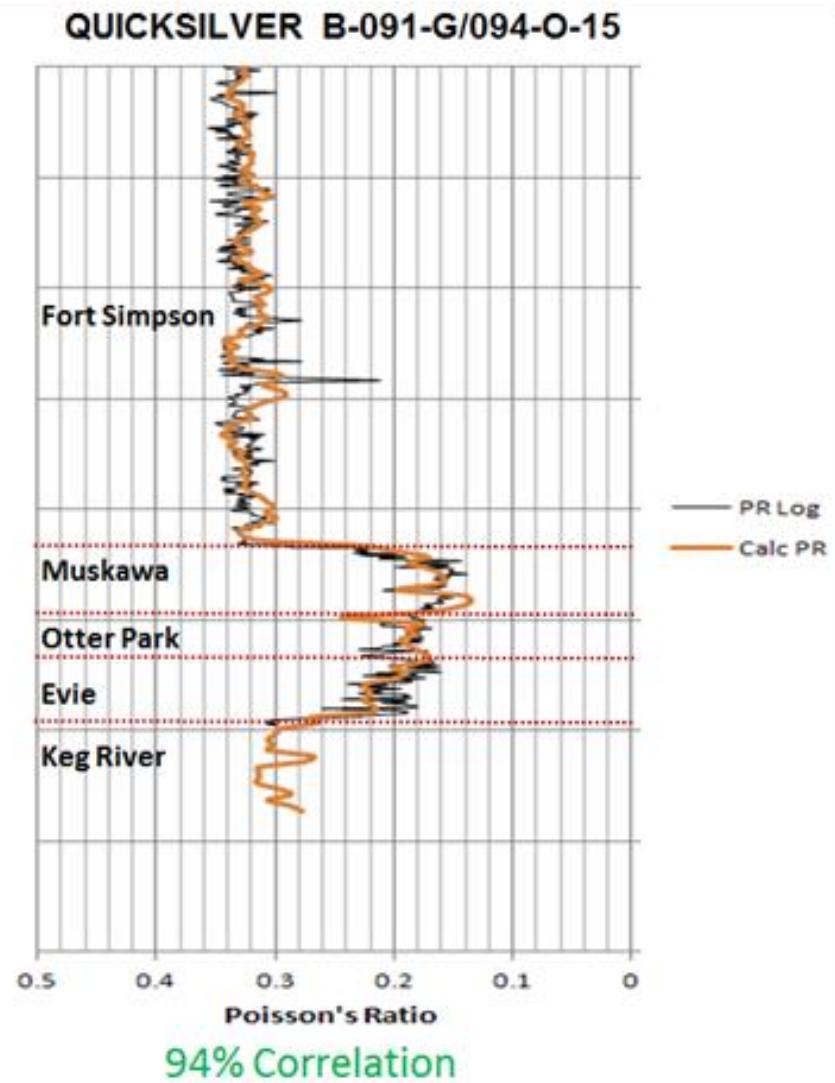
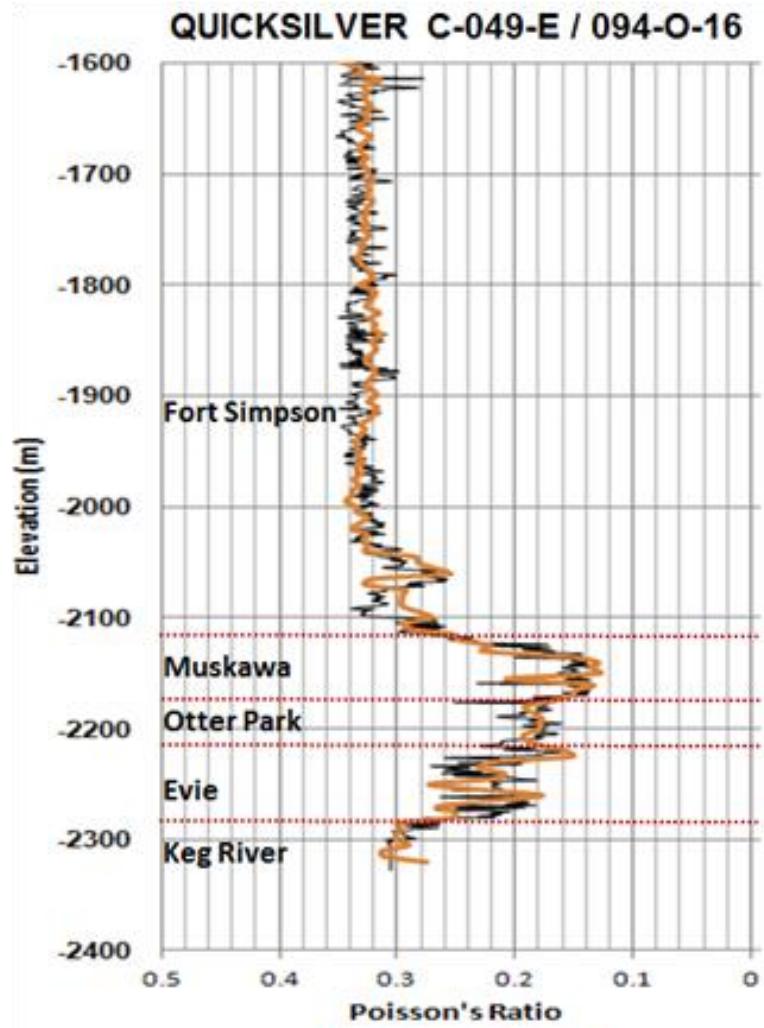
Specific Mineral Interaction Model:

$$RP = \alpha_{(RP)} + \sum_i \beta_i^0 DV_i + \sum_i \sum_j \beta_{i,j}^1 DV_i DV_j + \sum_i \gamma_i CV_i + \sum_i \theta_i RV_i$$

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

DVi is the **detrital volume** fraction of solid phase i, CVi is the **cement volume** fraction of solid phase i and RVi is the **recrystallized volume** fraction of solid phase i.

$\alpha_{(RP)}$ is a function of the reservoir property, β^0 , β^1 , γ and θ are **fabric dependent coefficients** that vary as a function of T, P (depth) and rock composition.

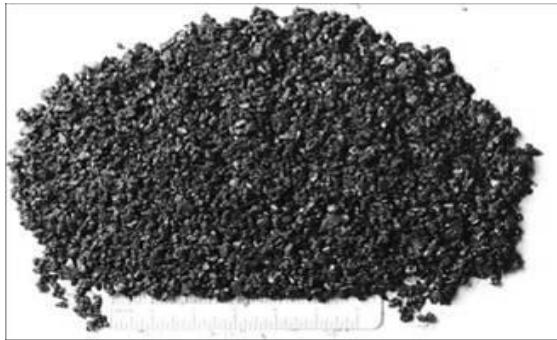


Porosity, matrix permeability and the mechanical properties of rock strength (Young's Modulus) and brittleness (Poisson's Ratio) are directly related to composition and fabrics.

XRF Modelling Process: Step 2



XRF

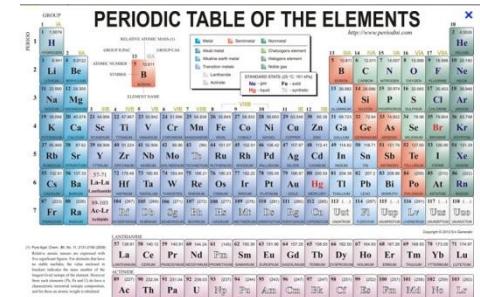


BULK CUTTINGS (HORIZONTAL WELL)

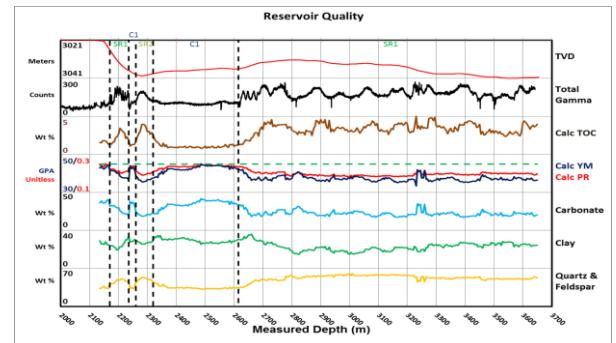
XRF DATA



ALGORITHMS FOR MODELLING RESERVOIR PROPERTIES



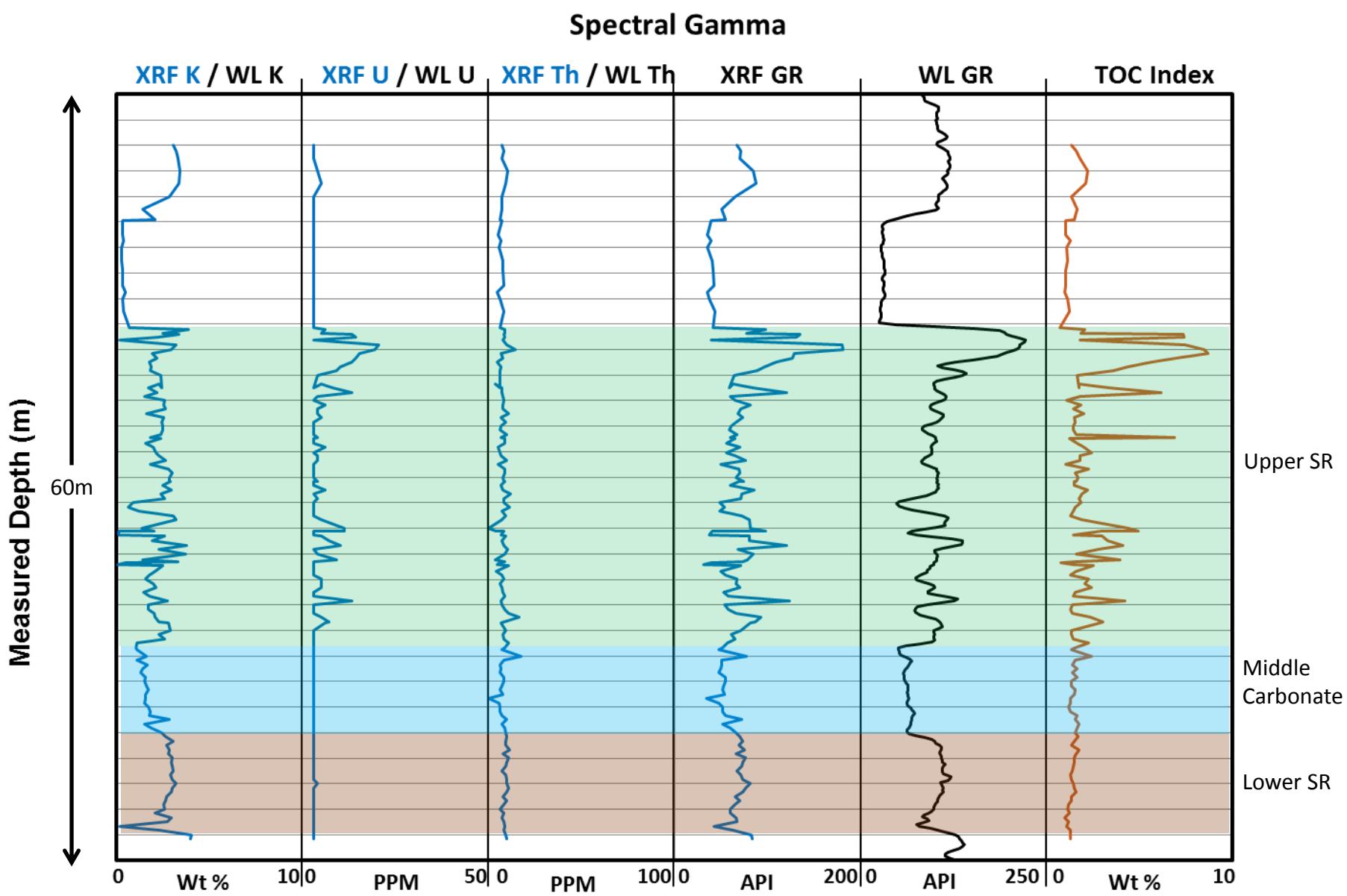
BULK ELEMENTAL COMPOSITION



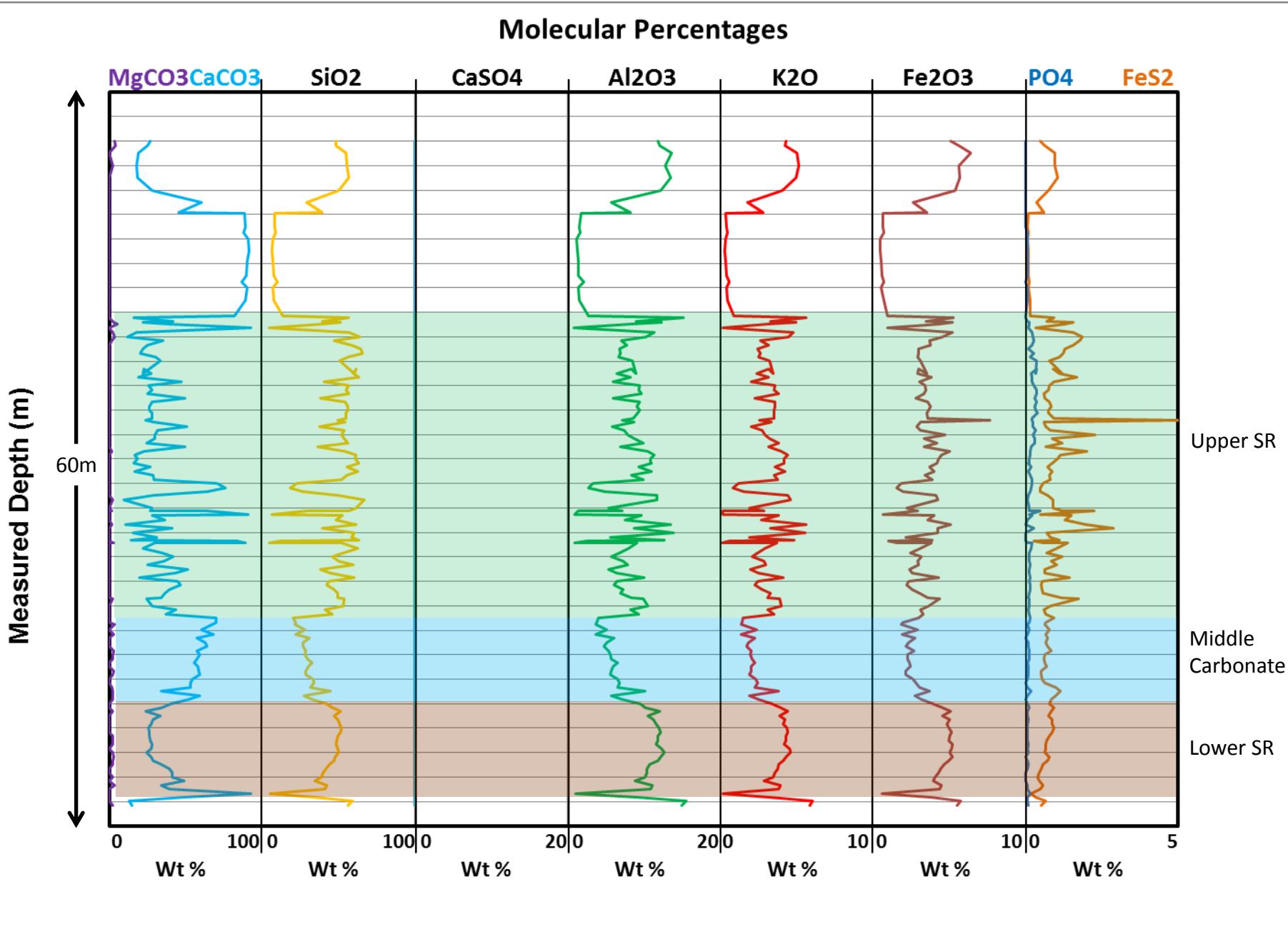
HORIZONTAL CHEMICAL LOGS

Duvernay Vertical Core

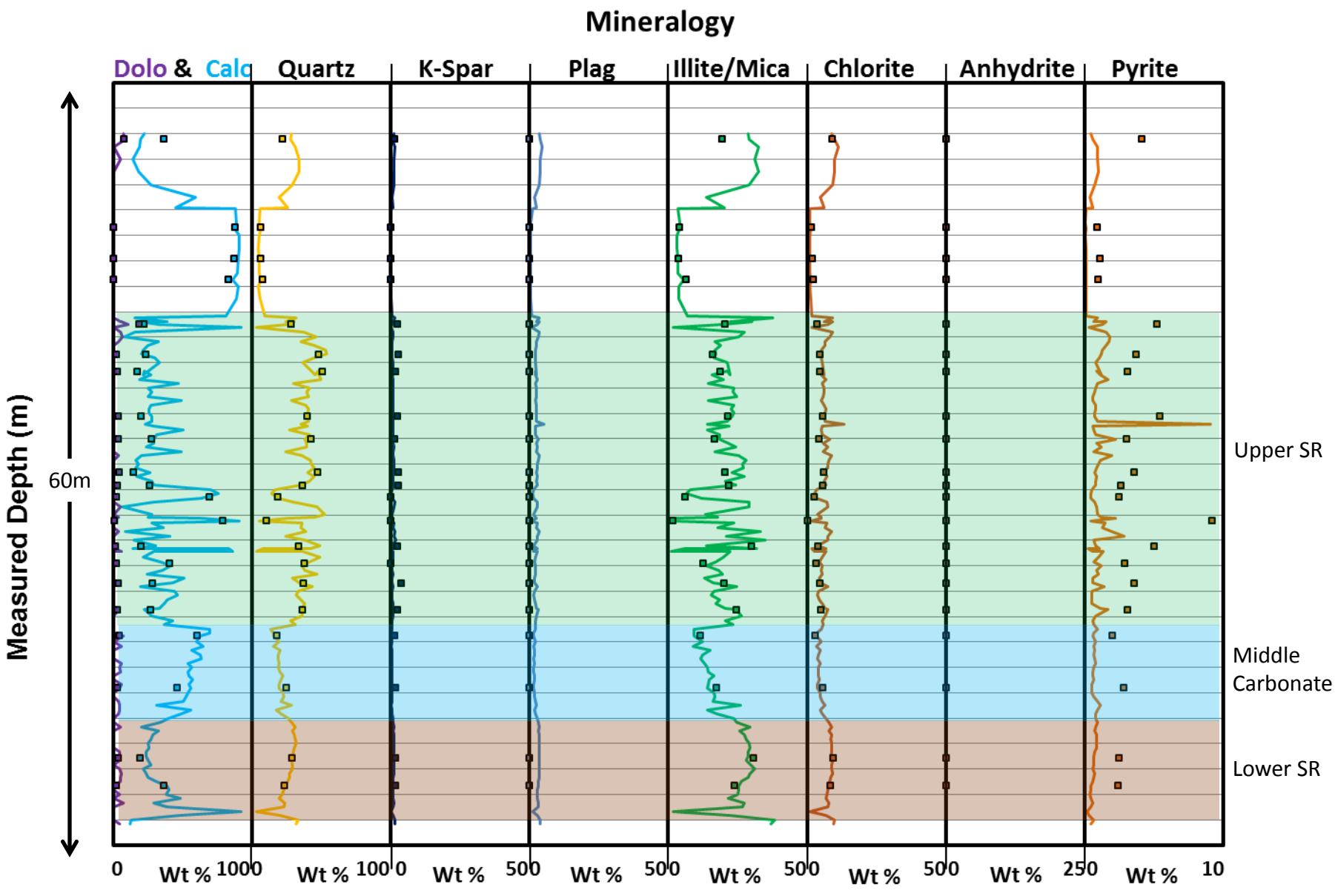
Applying an XRF Model (Duvernay)



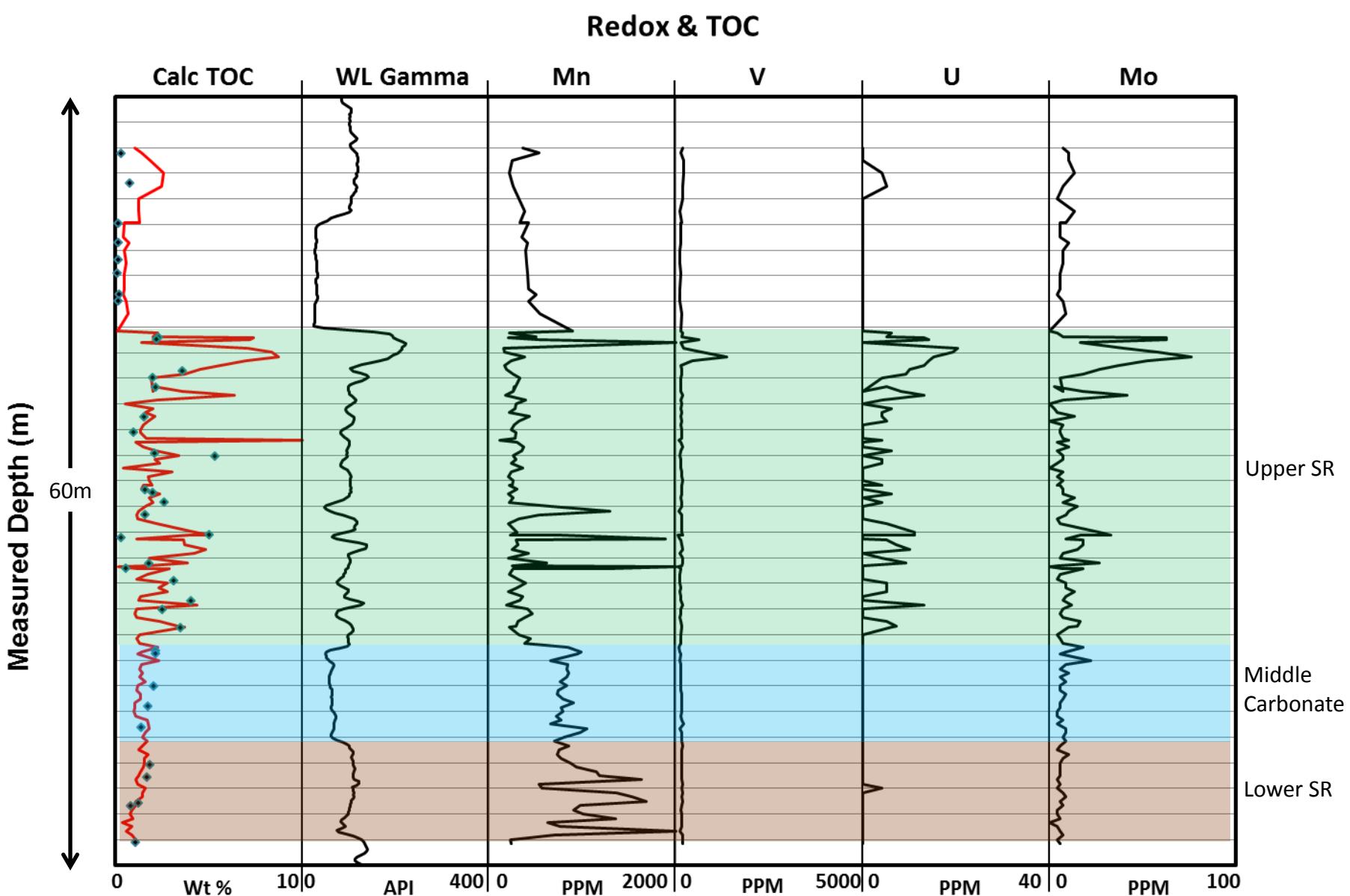
Applying an XRF Model (Duvernay)



Applying an XRF Model (Duvernay)

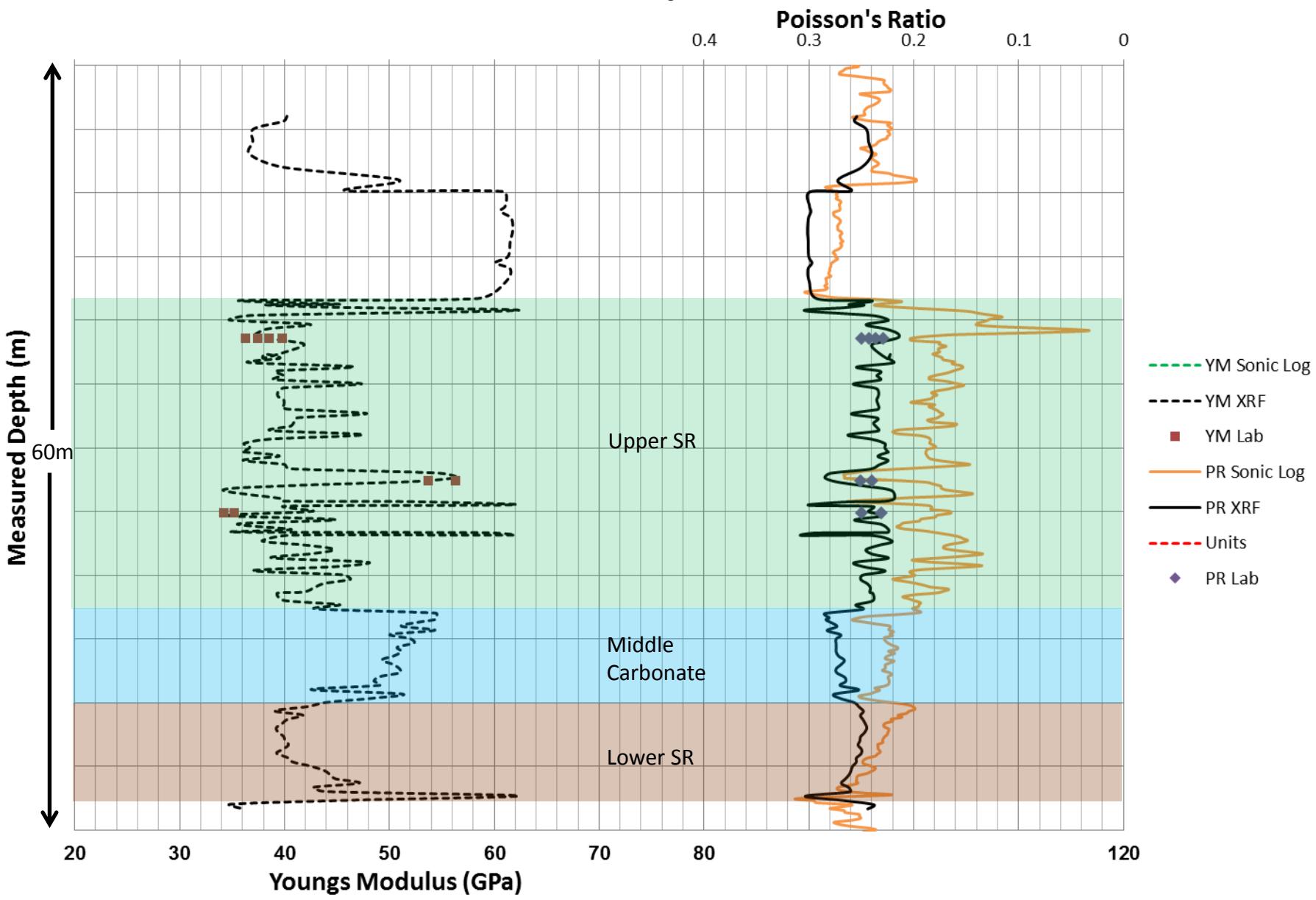


Applying an XRF Model (Duvernay)

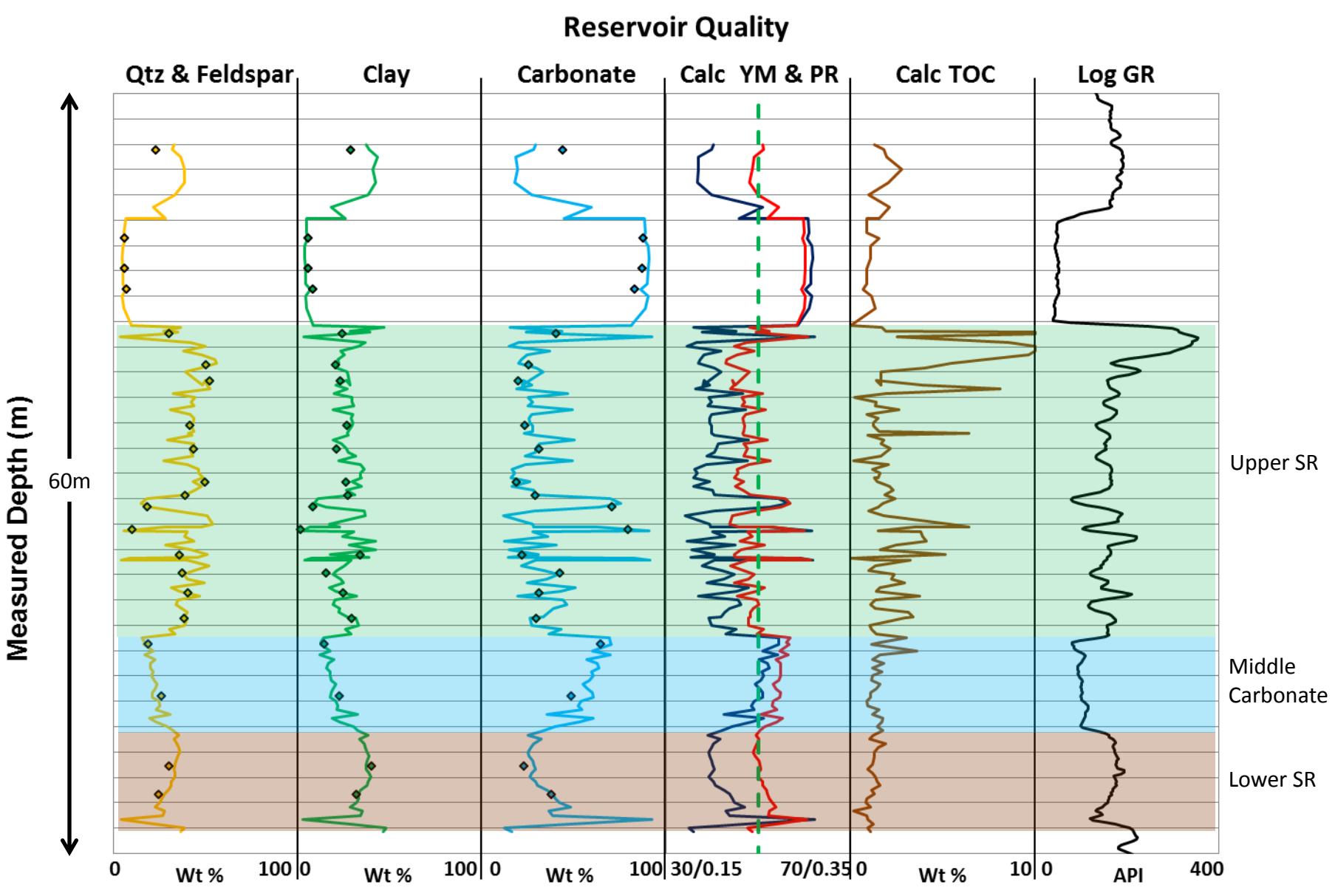


Applying an XRF Model (Duvernay)

Mechanical Properties

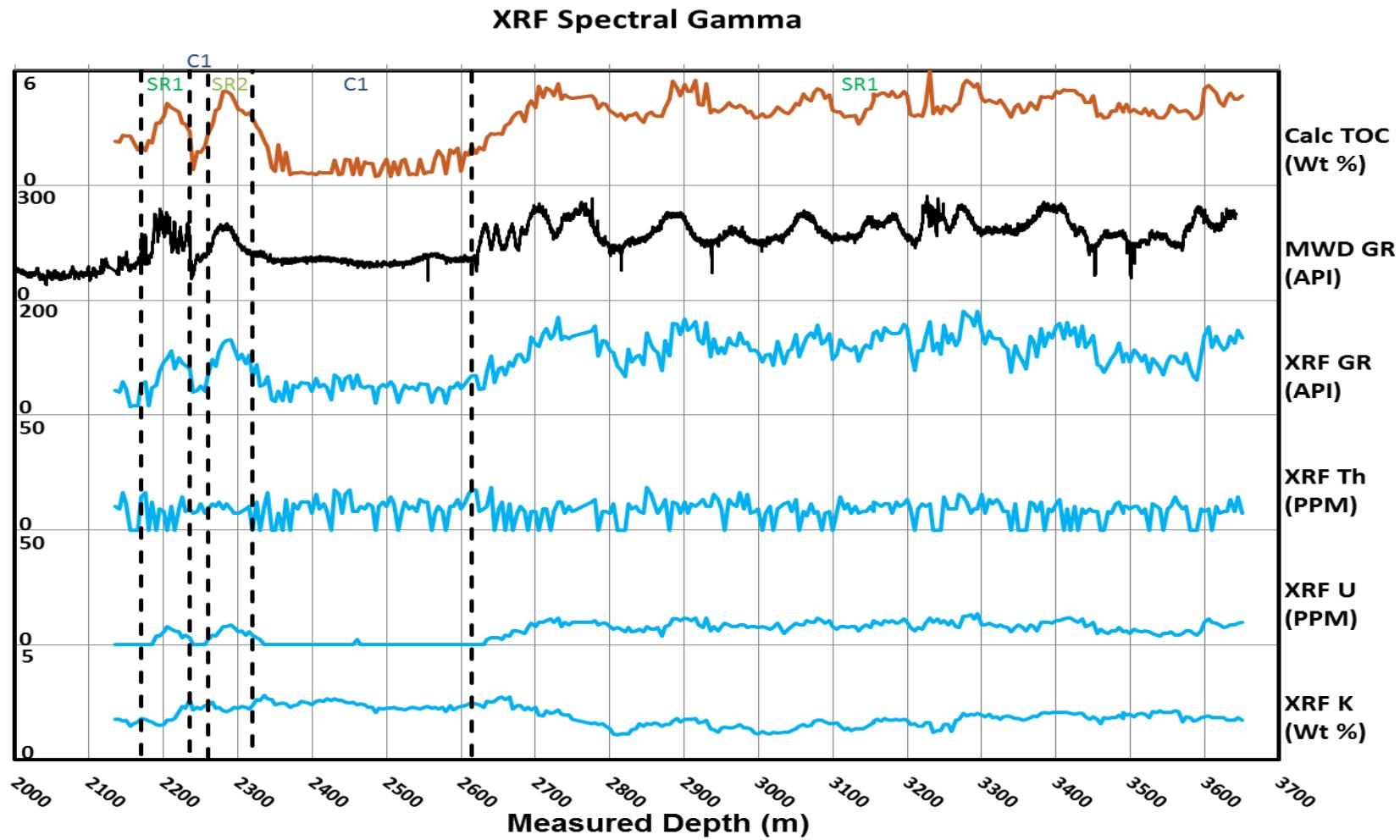


Applying an XRF Model (Duvernay)

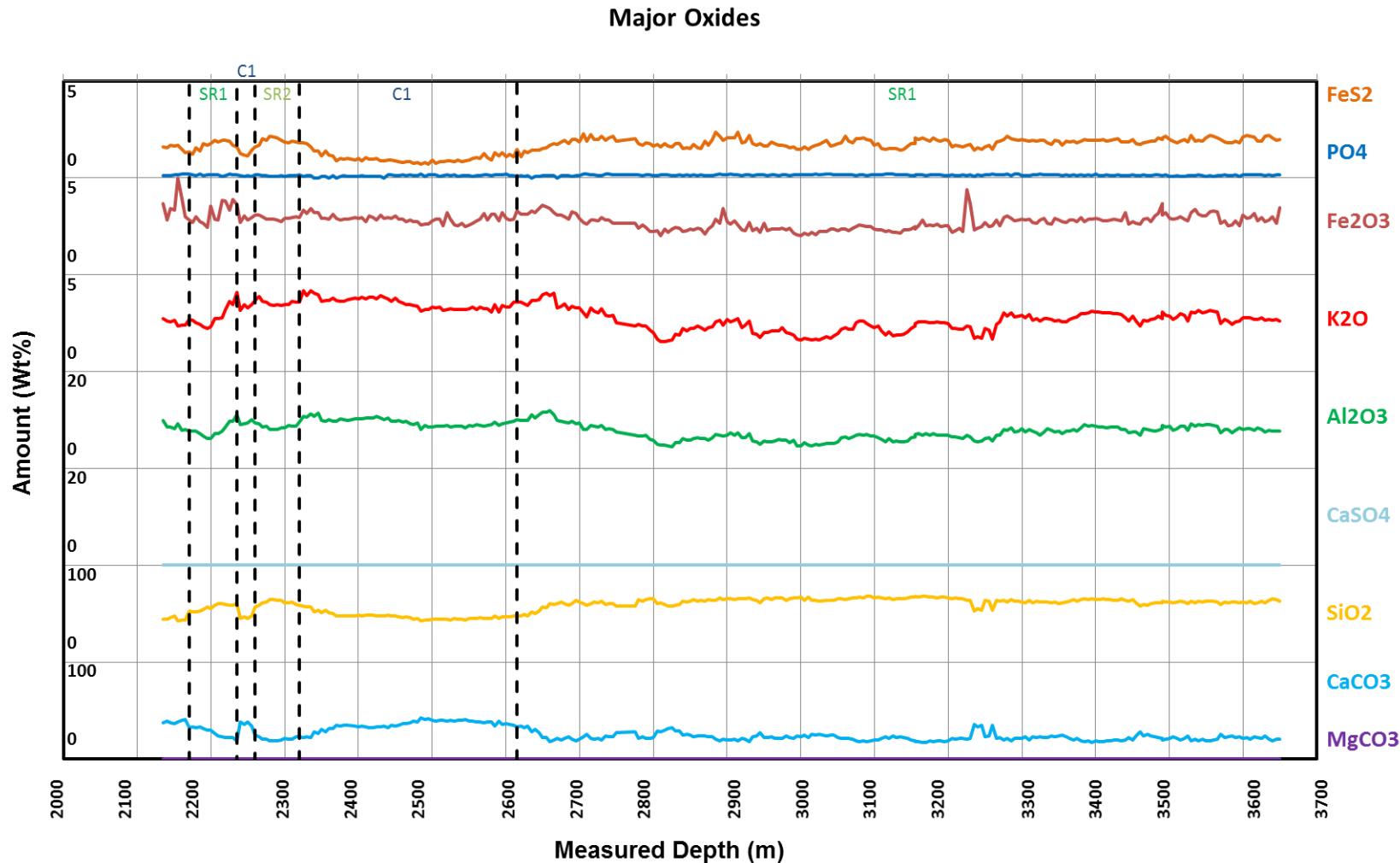


Duvernay Horizontal Well

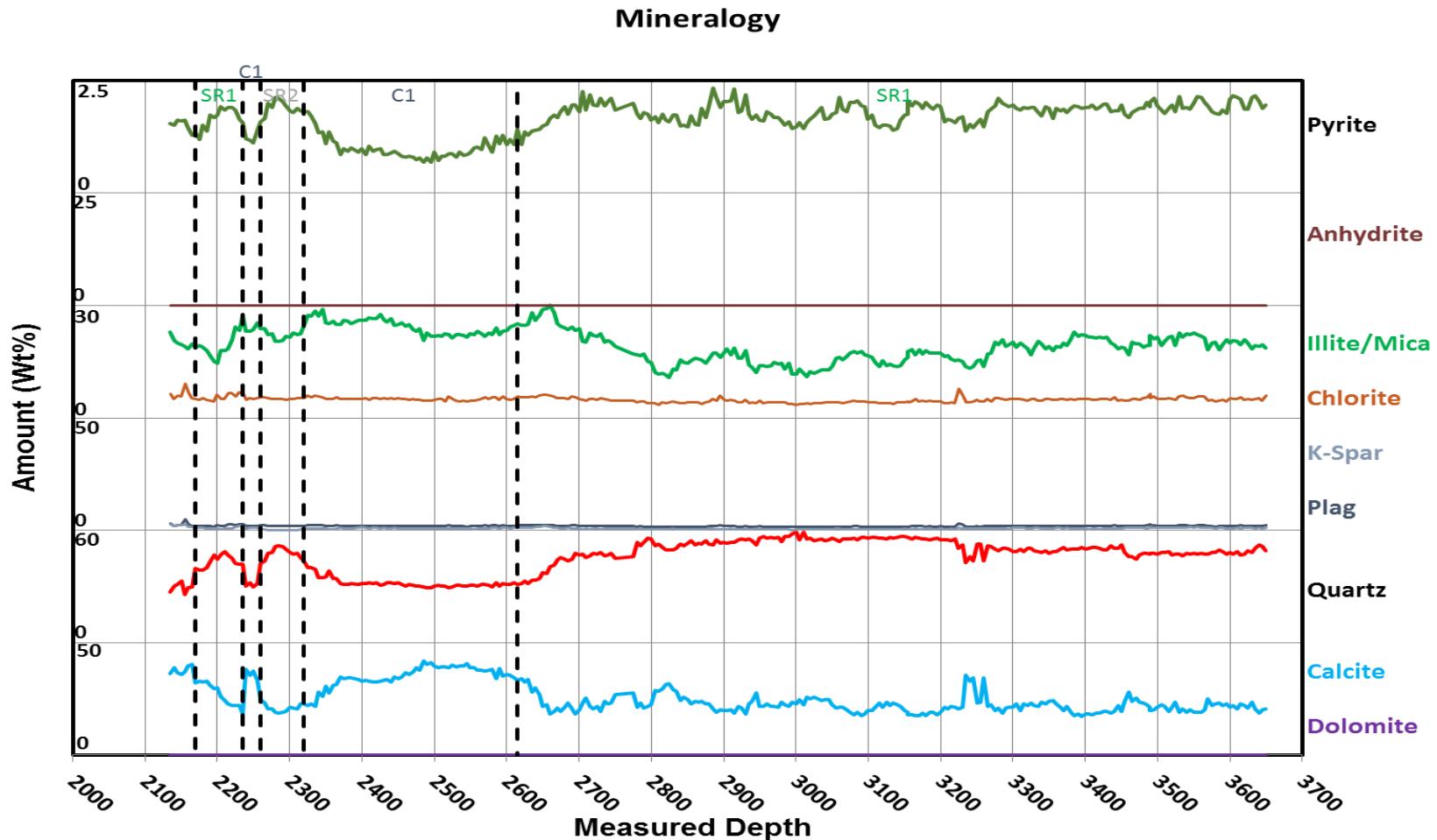
XRF Horizontal Logging (Duvernay)



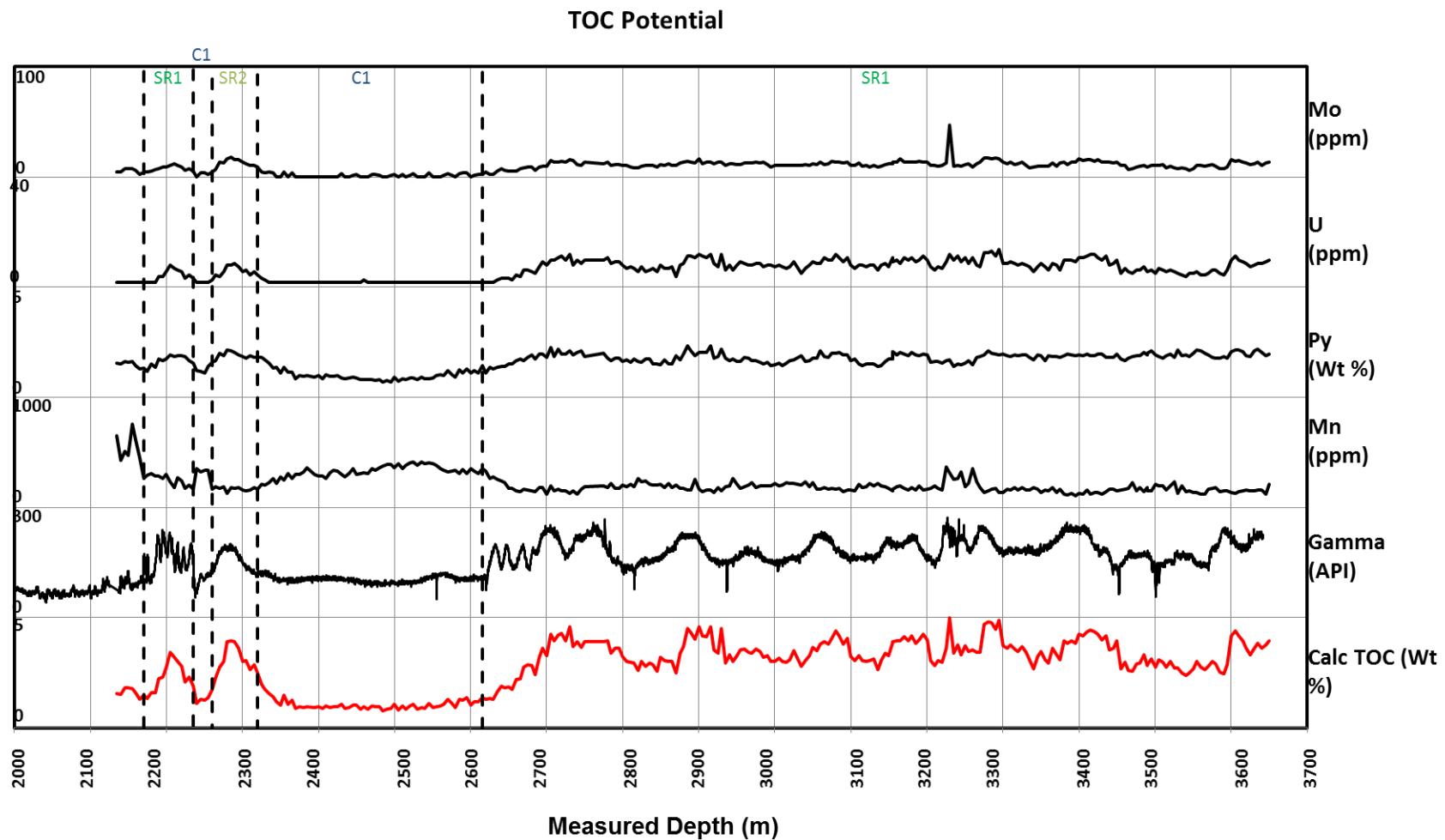
XRF Horizontal Logging (Duvernay)



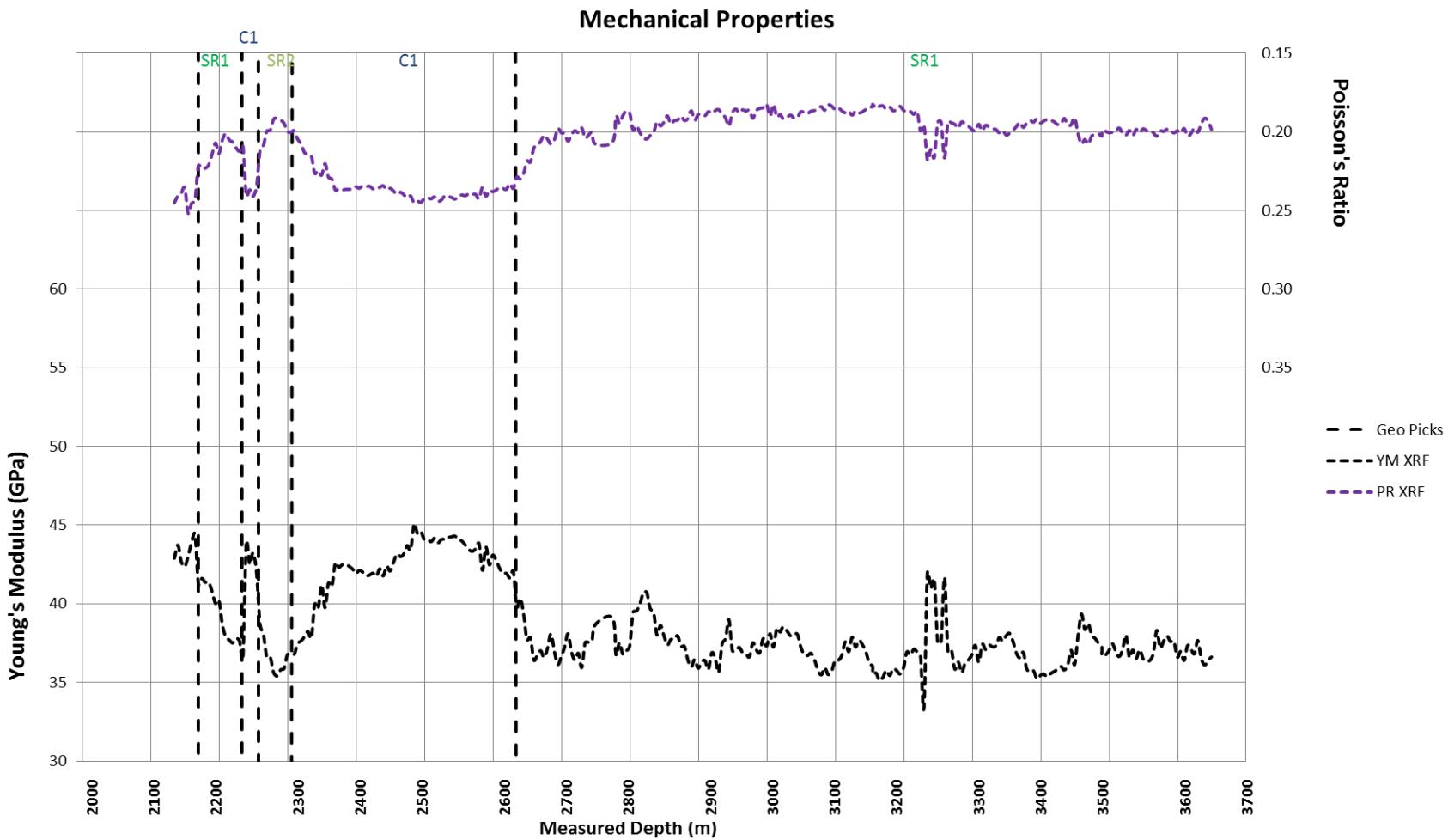
XRF Horizontal Logging (Duvernay)



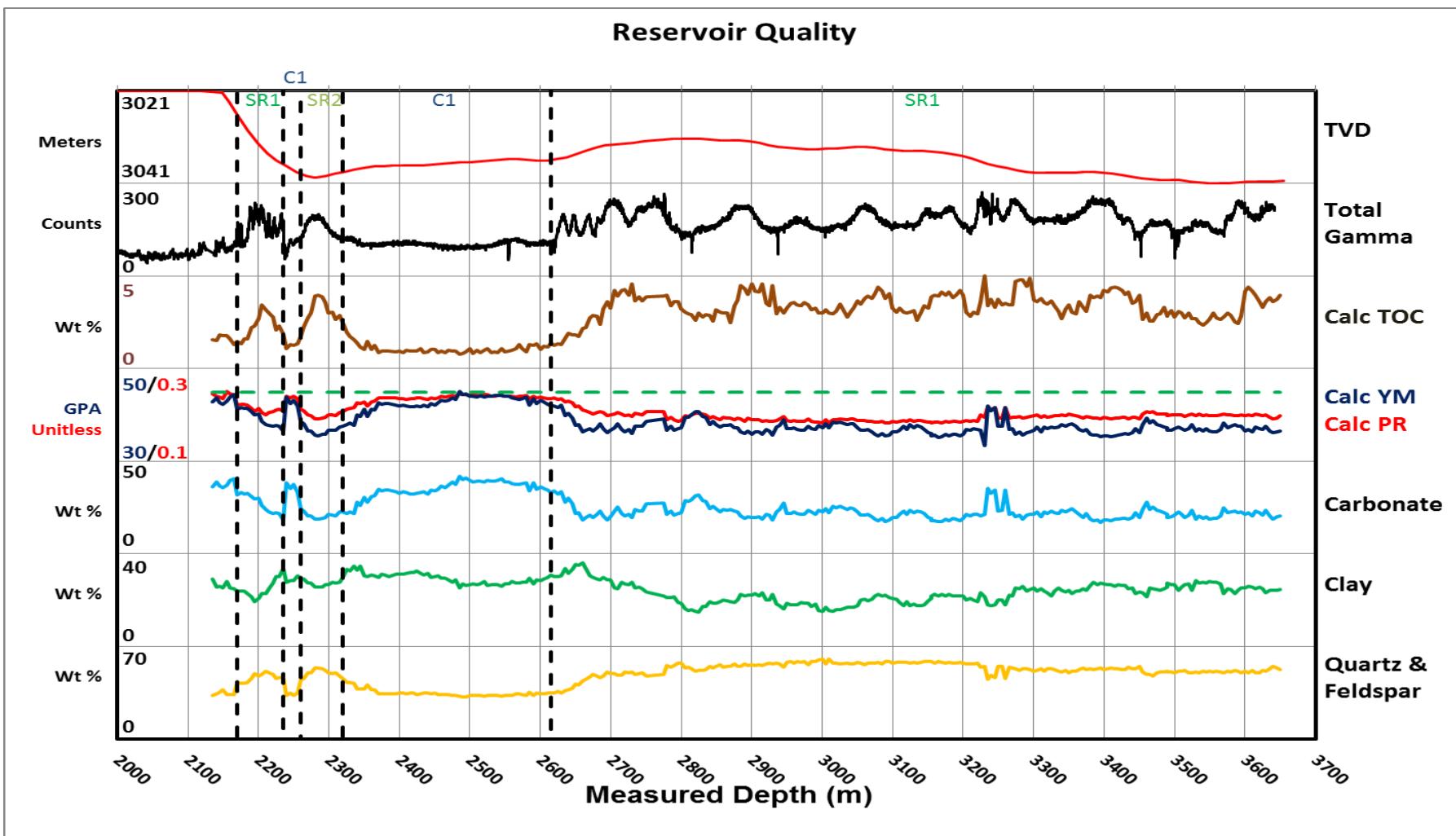
XRF Horizontal Logging (Duvernay)



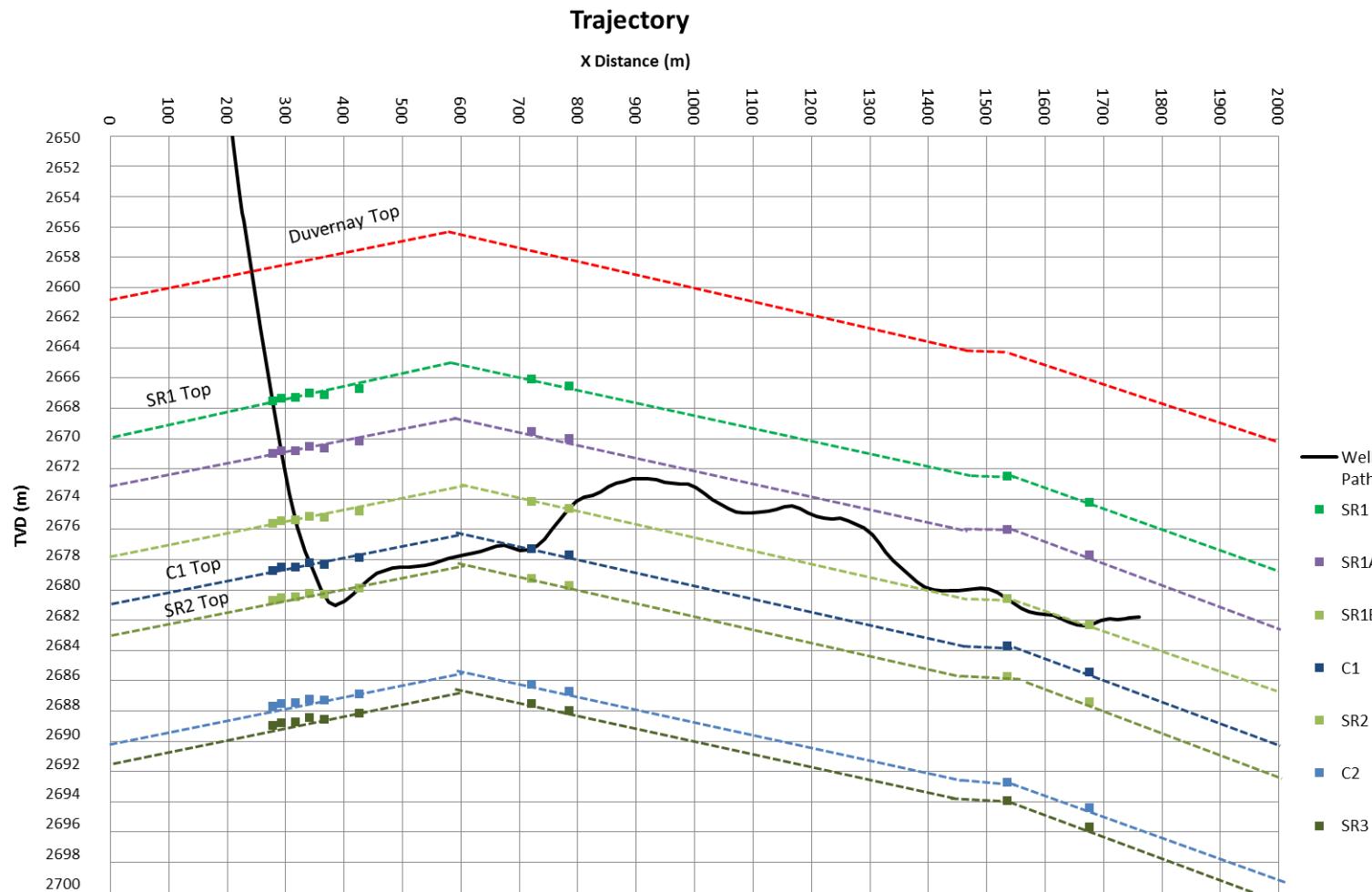
XRF Horizontal Logging (Duvernay)



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 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
 - <http://cspg.insinc.com/cspgtlwebcast-dunn09232014/> (Slides 31-36)

Questions?



chemical solutions to geologic problems

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