Lessons From High-Resolution Continuous XRF on Stratigraphy and Geomechanics of Shale*

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Abstract

Methods and results from high resolution x-ray fluorescence studies on mudstone units from the Western Canadian Basin and eastern Canada show how a simple tool can be of great value for constructing a stratigraphic framework, complementing and refining sedimentological descriptions, as well as for optimizing and improving hydraulic fracturing of shales. Acquisition of continuous XRF was performed at a centimeter scale on cores and every five meters in cuttings and covered four different shale/mudstone facies associations; two from siliciclastic origin and two from carbonates. The various studies collected more than 110,000 samples from cores.

The relationships between different XRF-derived elemental compositions have helped define sedimentary successions that elegantly complement sedimentological core descriptions and shed light on some sedimentary processes of deposition. Among numerous findings of various kinds, our study shows that the relationship calcium/manganese in the Montney Formation can clearly define more than twenty chemostratigraphic units and distinguish between specific carbonate lithofacies and calcite-cemented horizons and can be used as a proxy for sedimentation rate. Obvious shifts in Ca/Mn trends are used to distinguish between sedimentary packages; the polarity of the shift reflecting sedimentary processes and sequence stratigraphy / system tracts.

Extensive statistical analysis of elemental composition against geomechanics has demonstrated that each newly defined chemostratigraphic unit has the better relationship/regression than any combination of adjacent packages; i.e., Rsquare is always higher for a single package than for any possible combination, including the underlying and/or overlying units. Both XRF and XRD data clearly demonstrate that single formulae are not adequate to predict brittleness; e.g., in some units such as the Duvernay using XRD, a tectosilicate (quartz + feldspars + plagioclase) cut-off of 40% has to be applied prior to establishing a relationship between mineralogy and Young's Modulus.

Similarly at a larger scale and based on stratigraphy, the Upper Montney needs to be analyzed separately from the Middle/Lower Montney if any meaningfull results are to be expected. Basin and field-wide XRF-based correlations have been satisfactorily established and can be used for steering, unit selection for stimulation and frac placement analysis.

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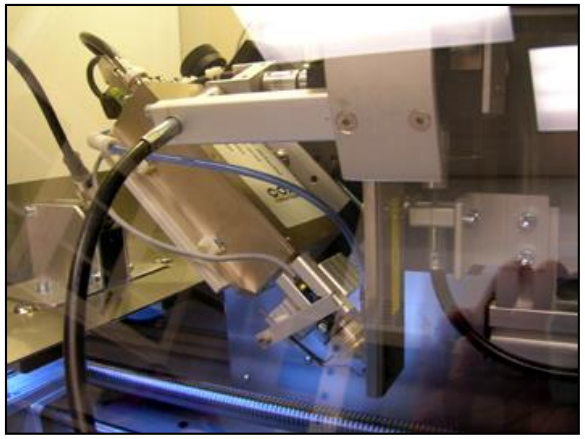
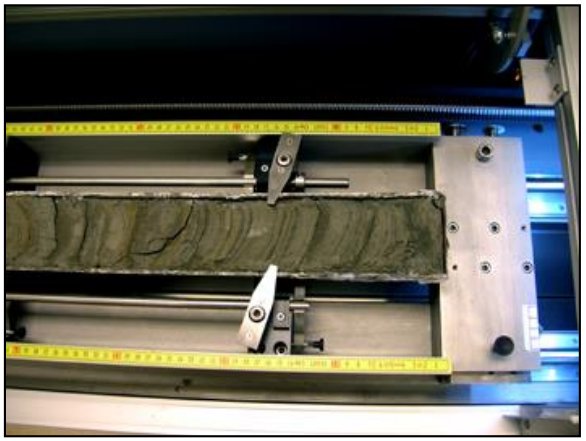
Talk Outline

- Introduction to XRF
- Vertical profiles using single and combined elements
- Learnings from other cores in Middle and Lower Montney
- Chemostratigraphy
- XRF vs Geomechanics
- Conclusions

The ITRAX Equipment

Precision = 100 microns





Two emitting beam options: Molybdenum and Chromium

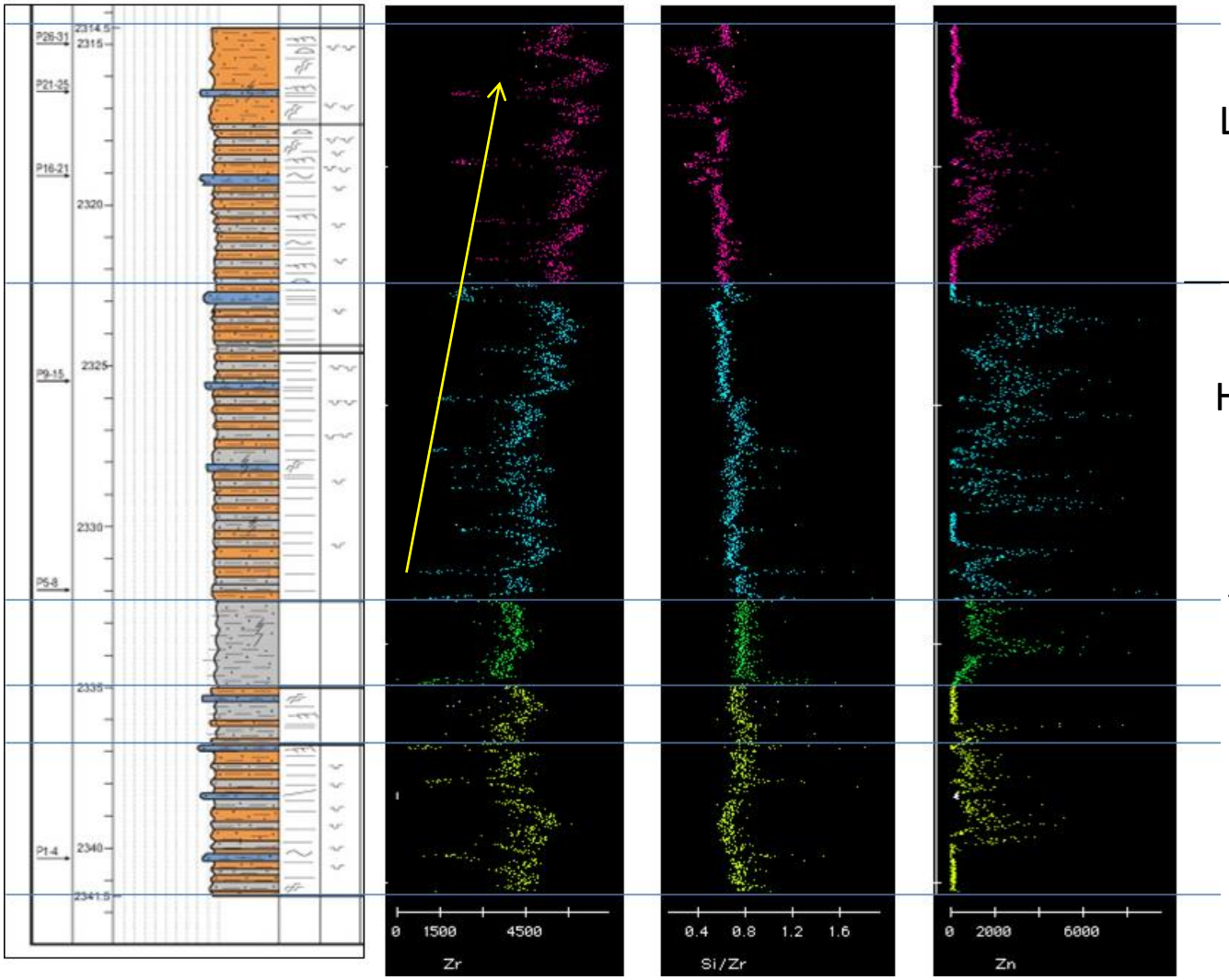
Single element trends

and

Combined element trends

Montney Fm

Well 1 Core 1



Low Zn

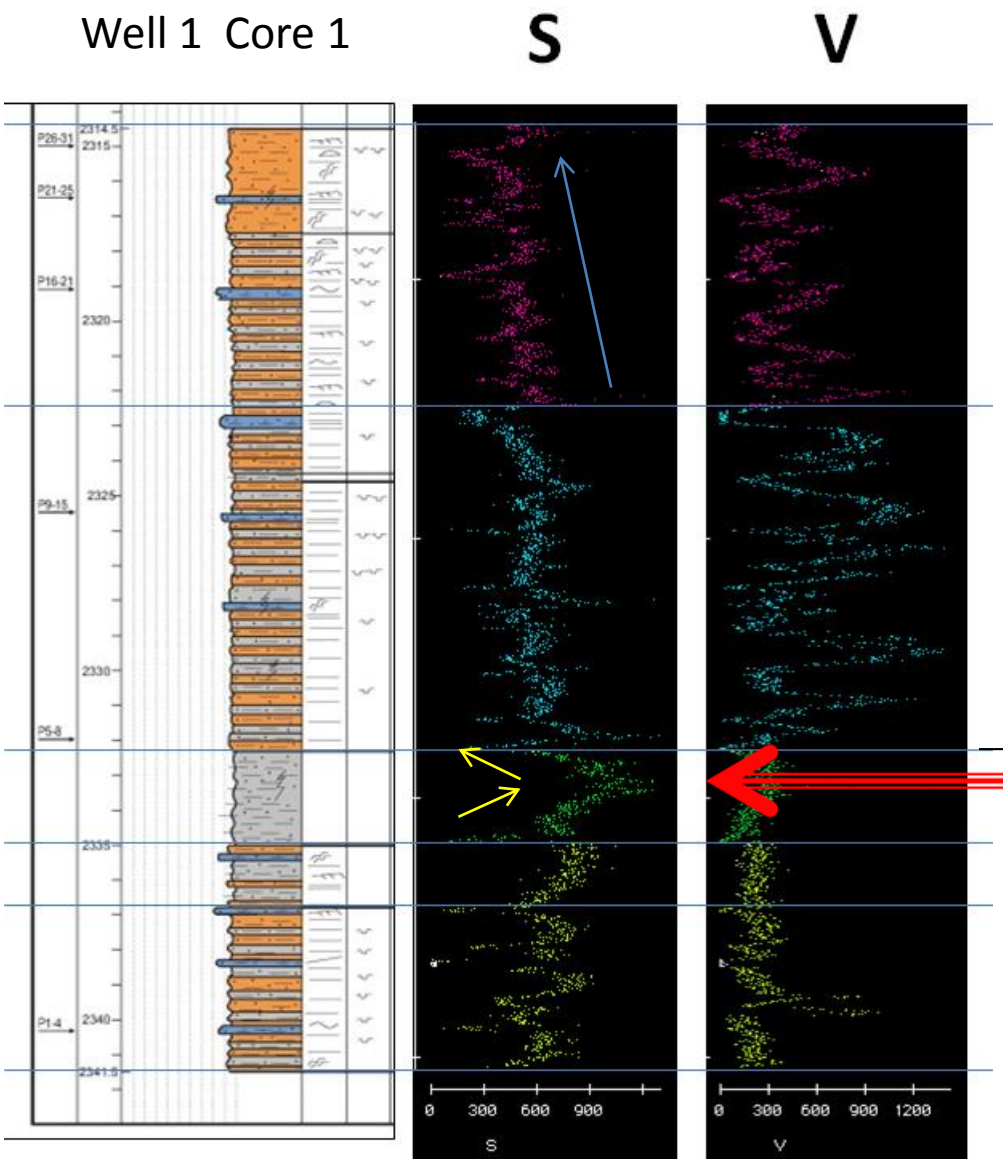
High Zn

Coarsening-upward sequence shown by Zr

2700 measurements (one per cm)

Montney Fm

Well 1 Core 1



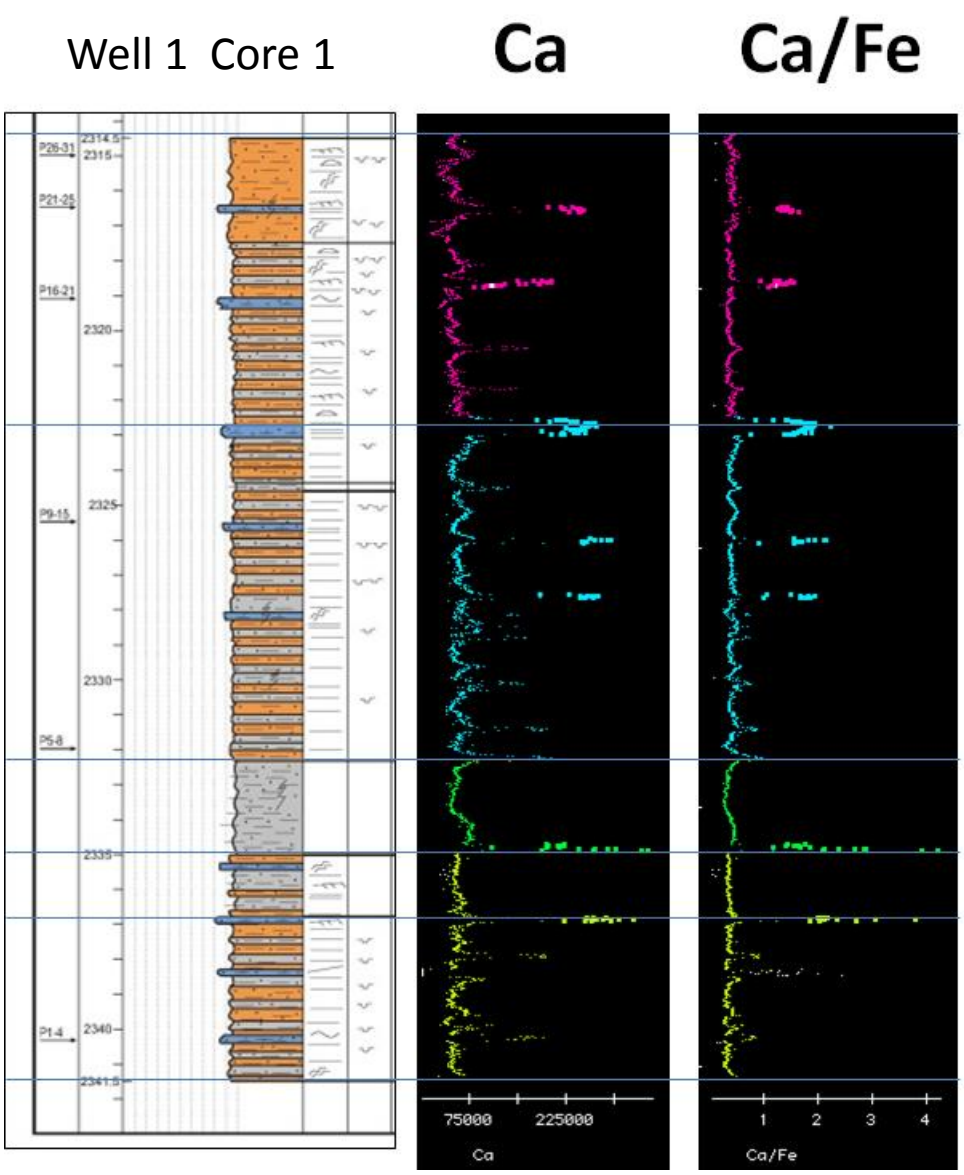
Very nice

Vanadium

small-scale

trends

Maximum Flooding Surface expressed by very high Sulfur



Perfect match between

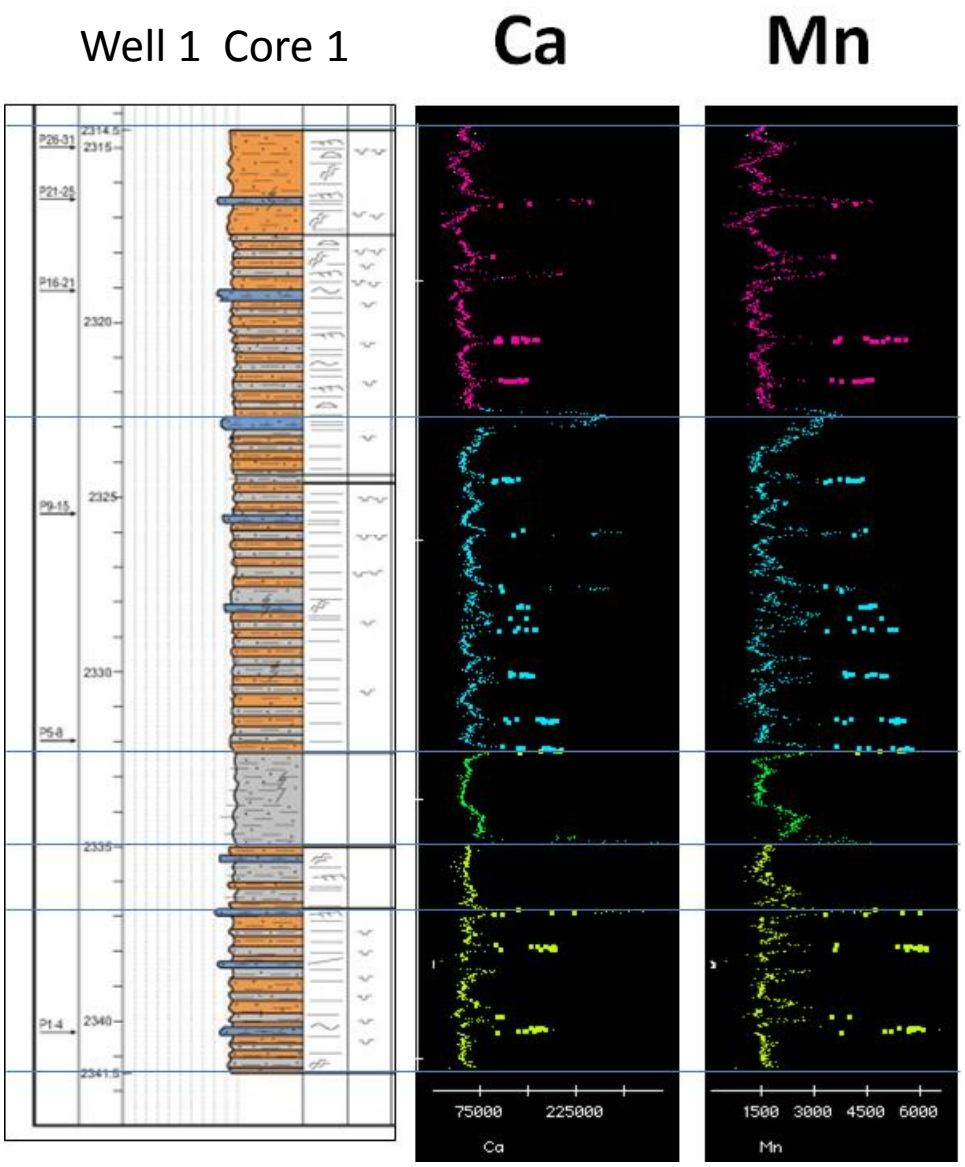
described limestone bed

and

high Calcium/Iron ratios

Montney Fm

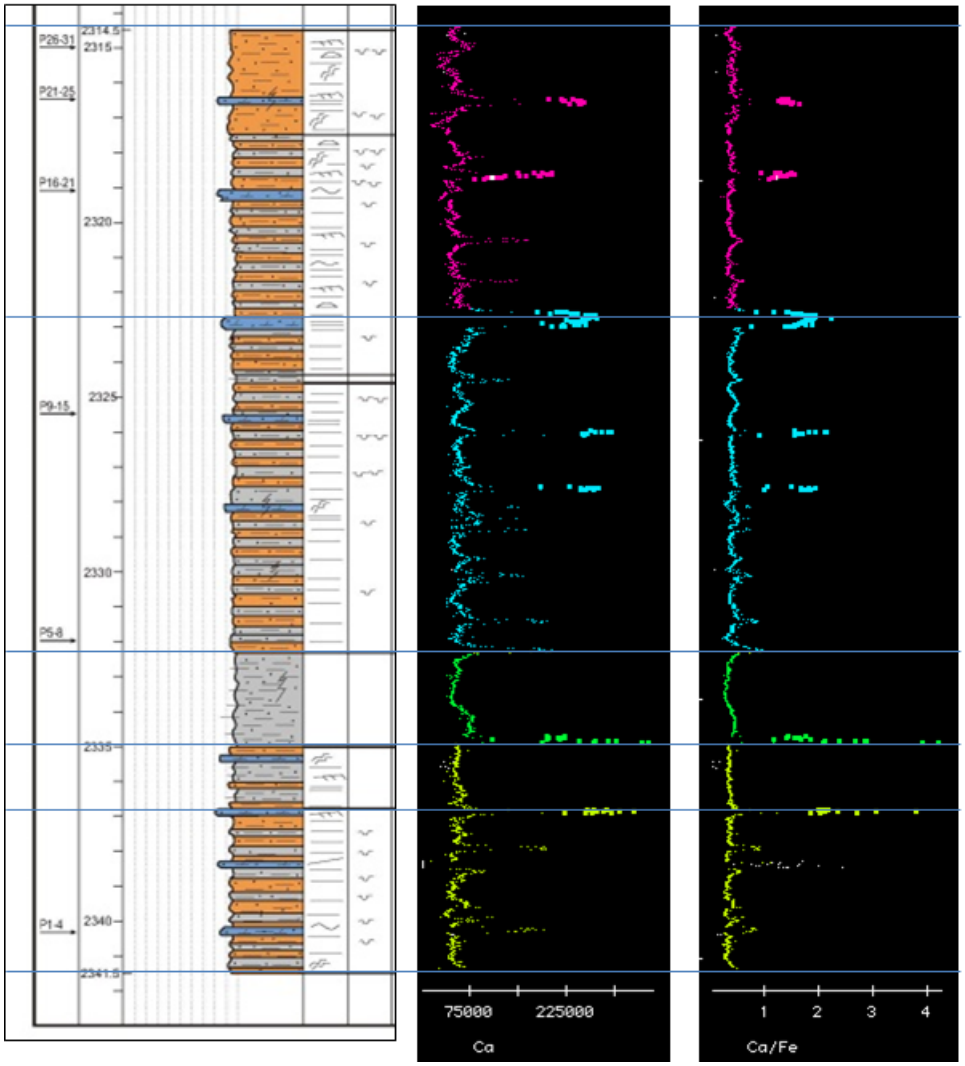
Well 1 Core 1

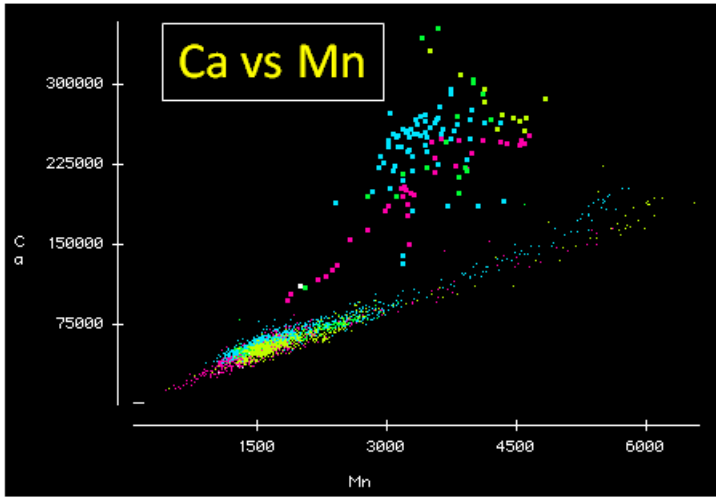


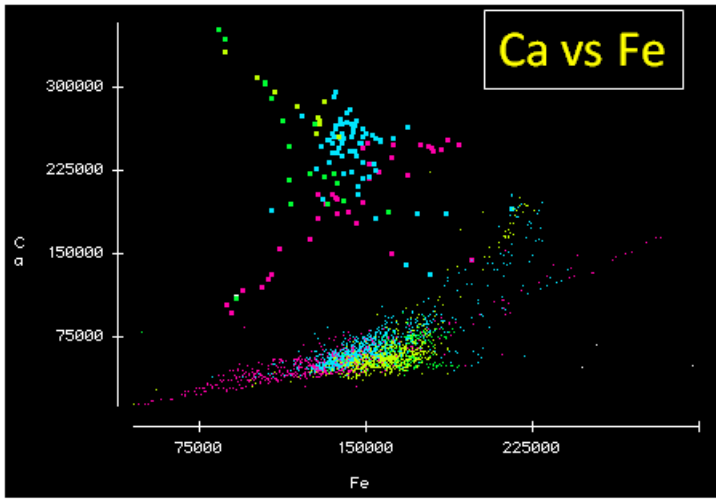
Very high Manganese units associated with fairly high Calcium

Montney Fm

Well 1 Core 1

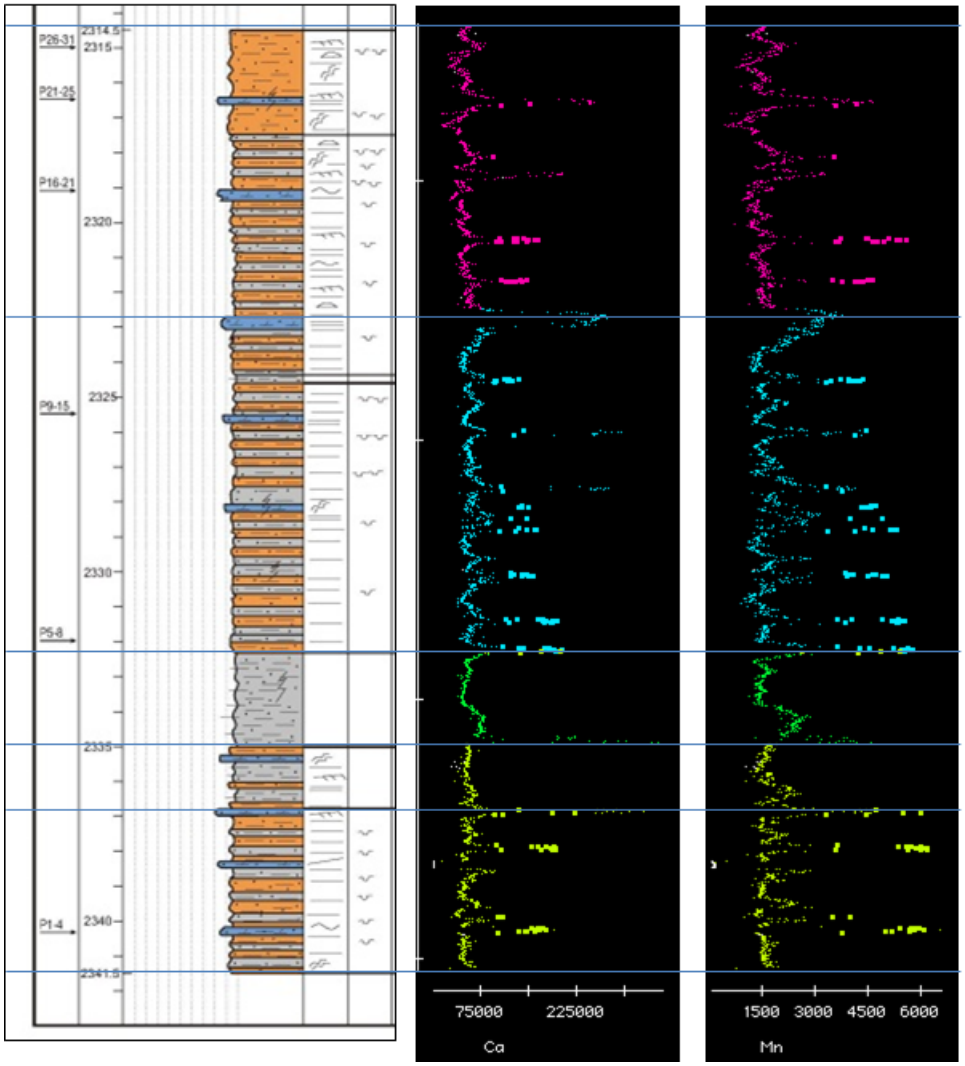


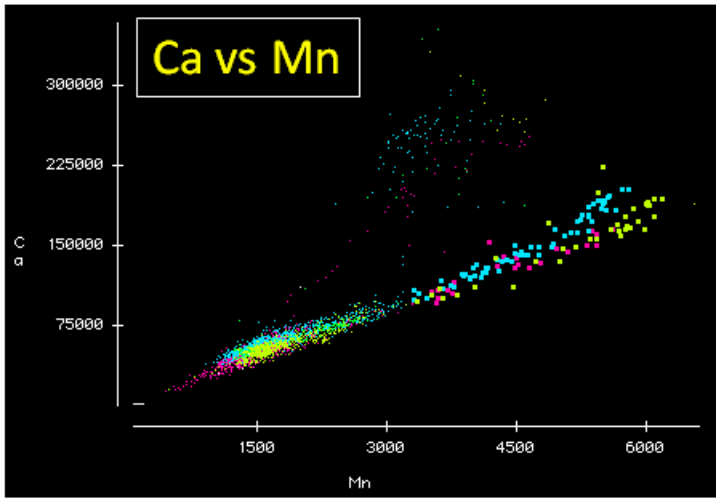


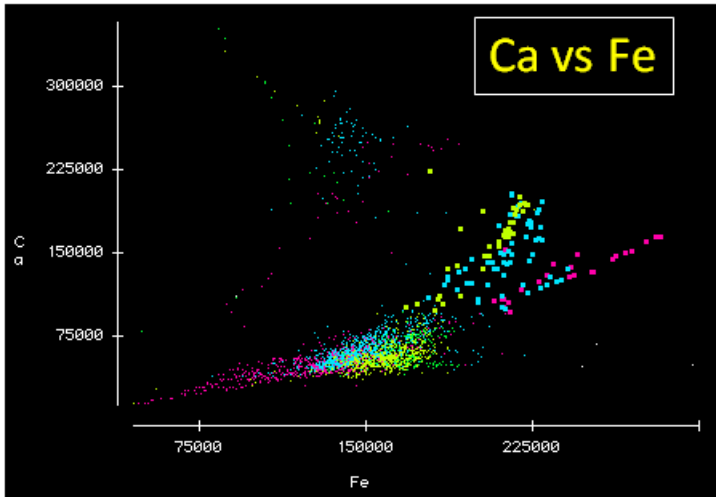


Montney Fm

Well 1 Core 1

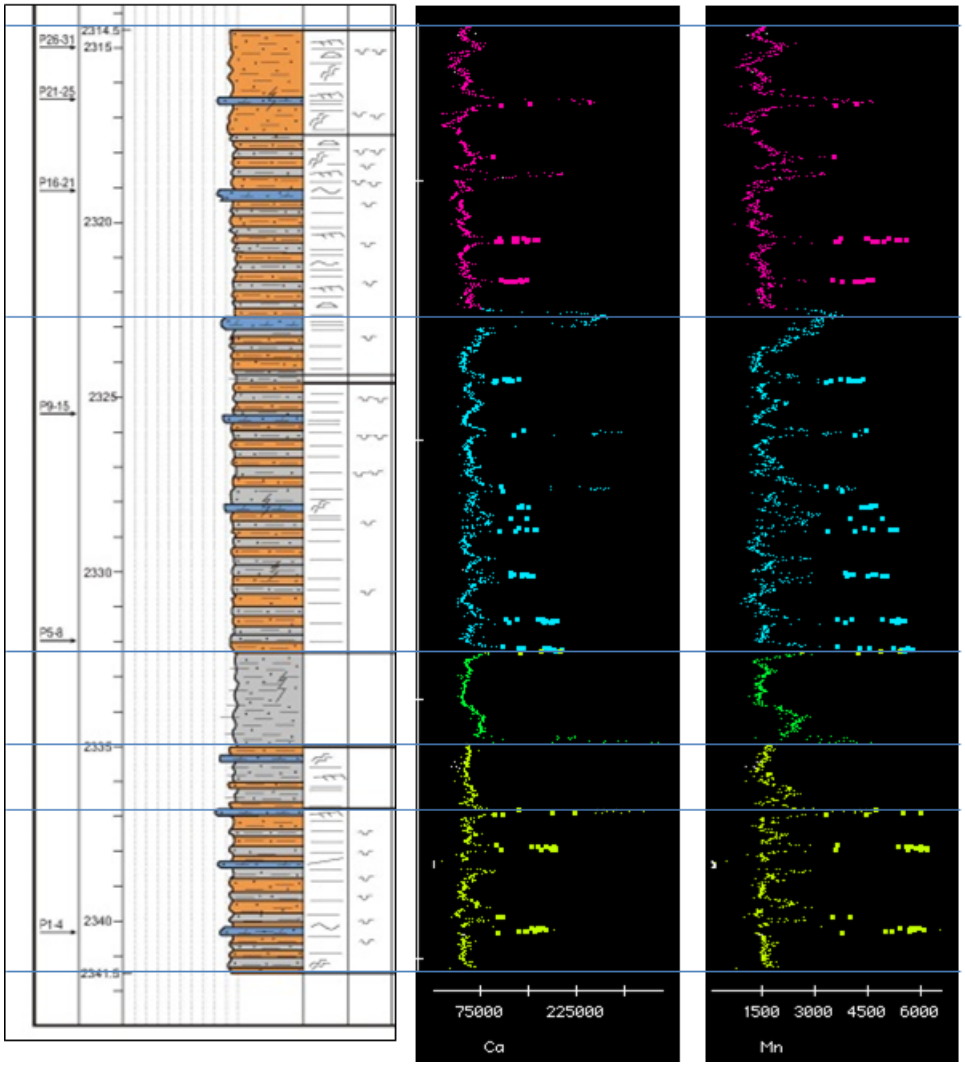




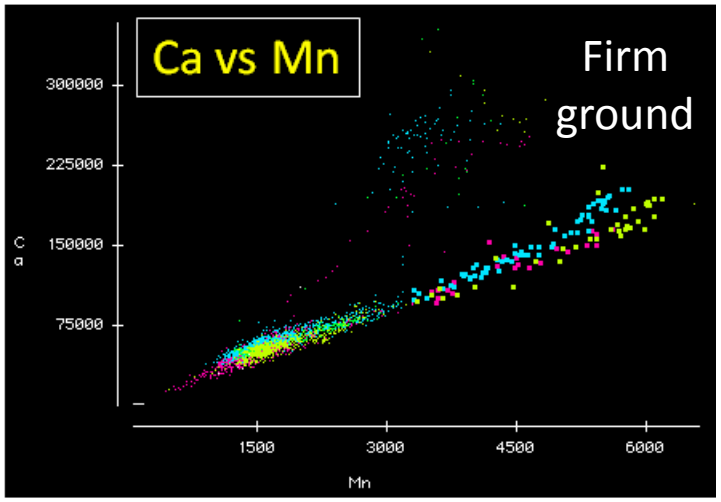


Montney Fm

Well 1 Core 1



Ca



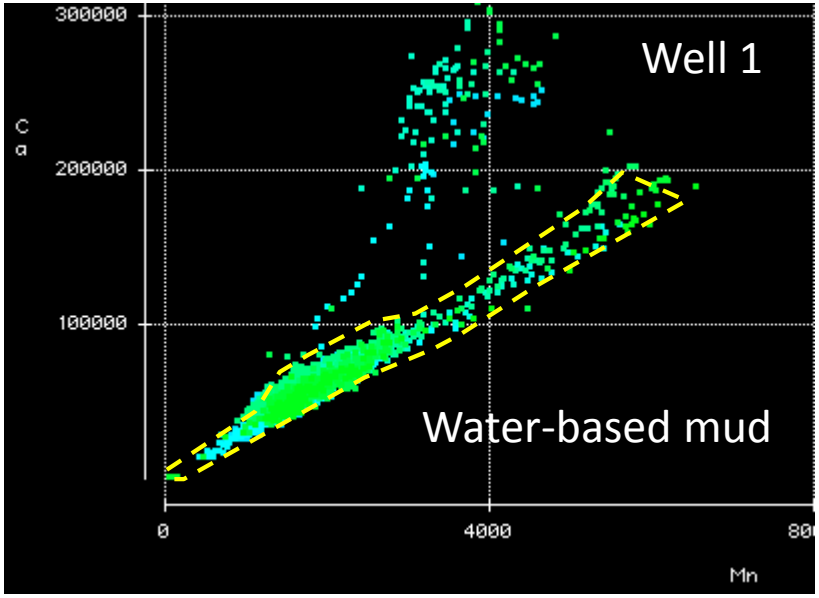
Mn

Fast ⟵ slow

Sedimentation rate

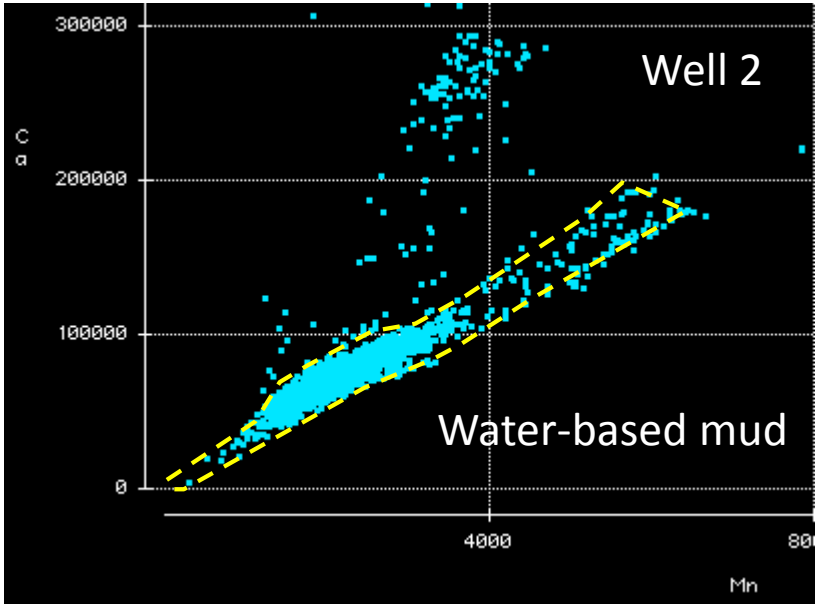
Trend

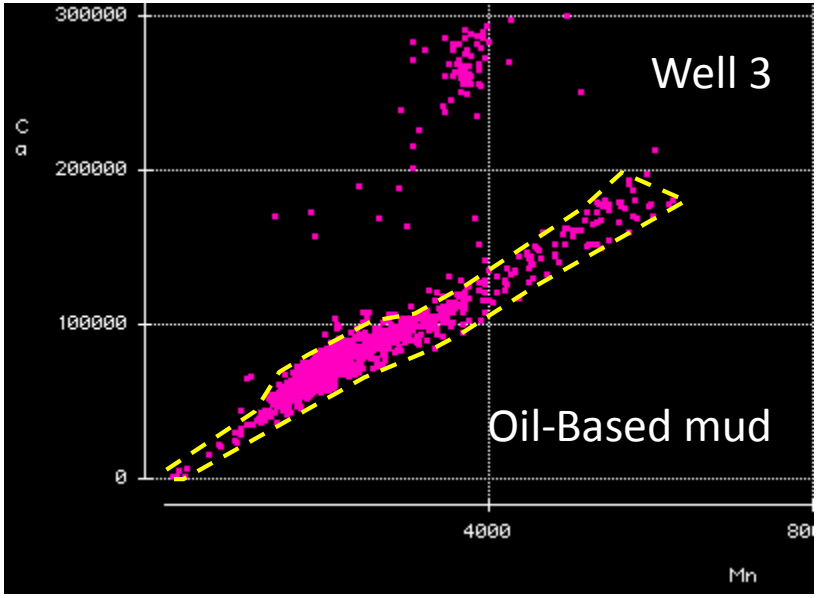
Normal water chemistry expression

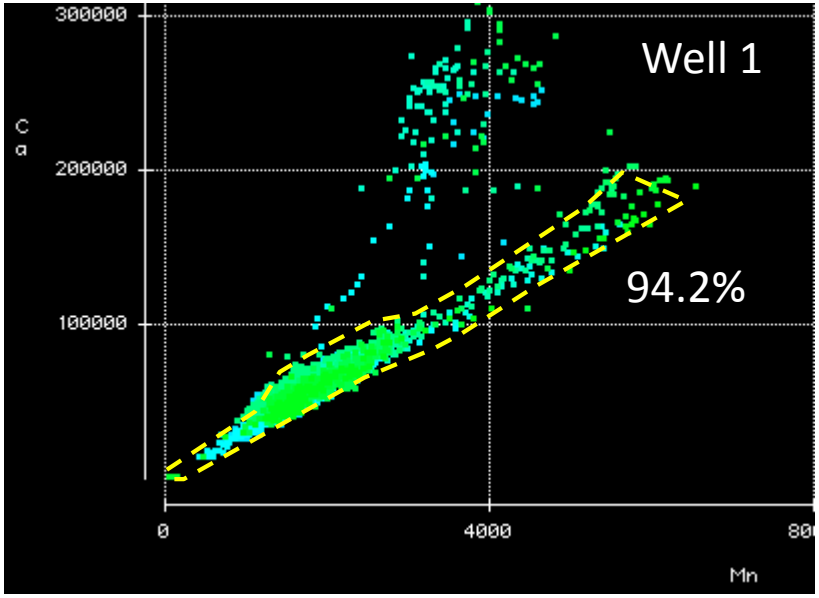


Upper Montney
Comparison of XRF in 3 wells

Perfect match between wells





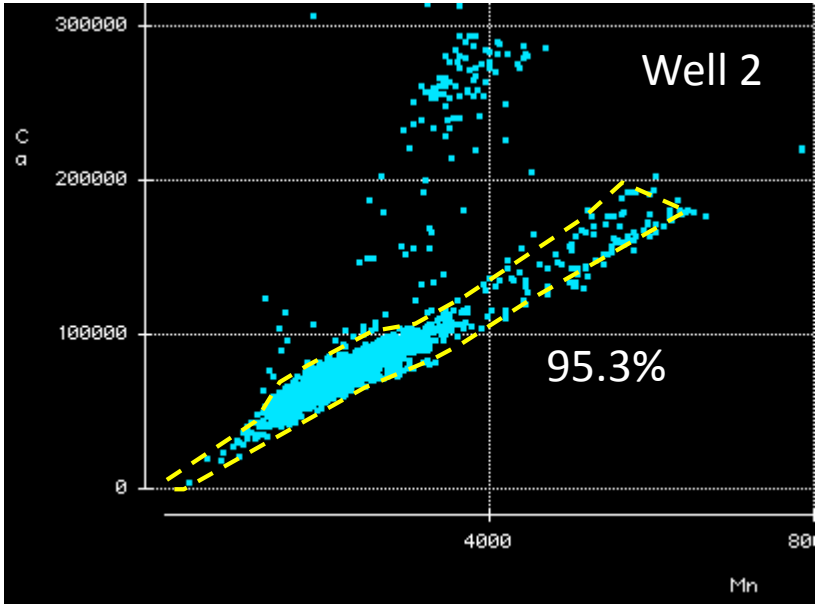


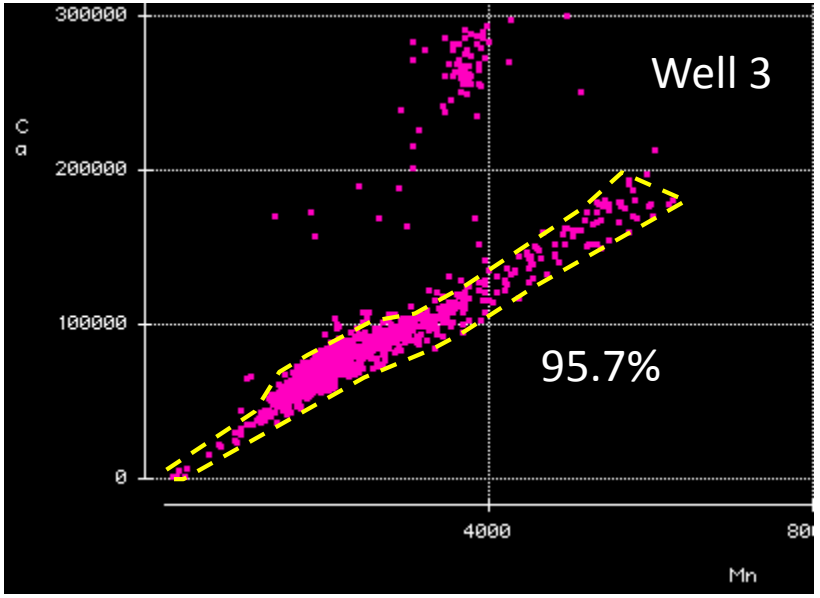
Upper Montney

Very similar percentages of :

Siliciclastics (94.2-95.7%)

Limestones (4.3-5.8%)



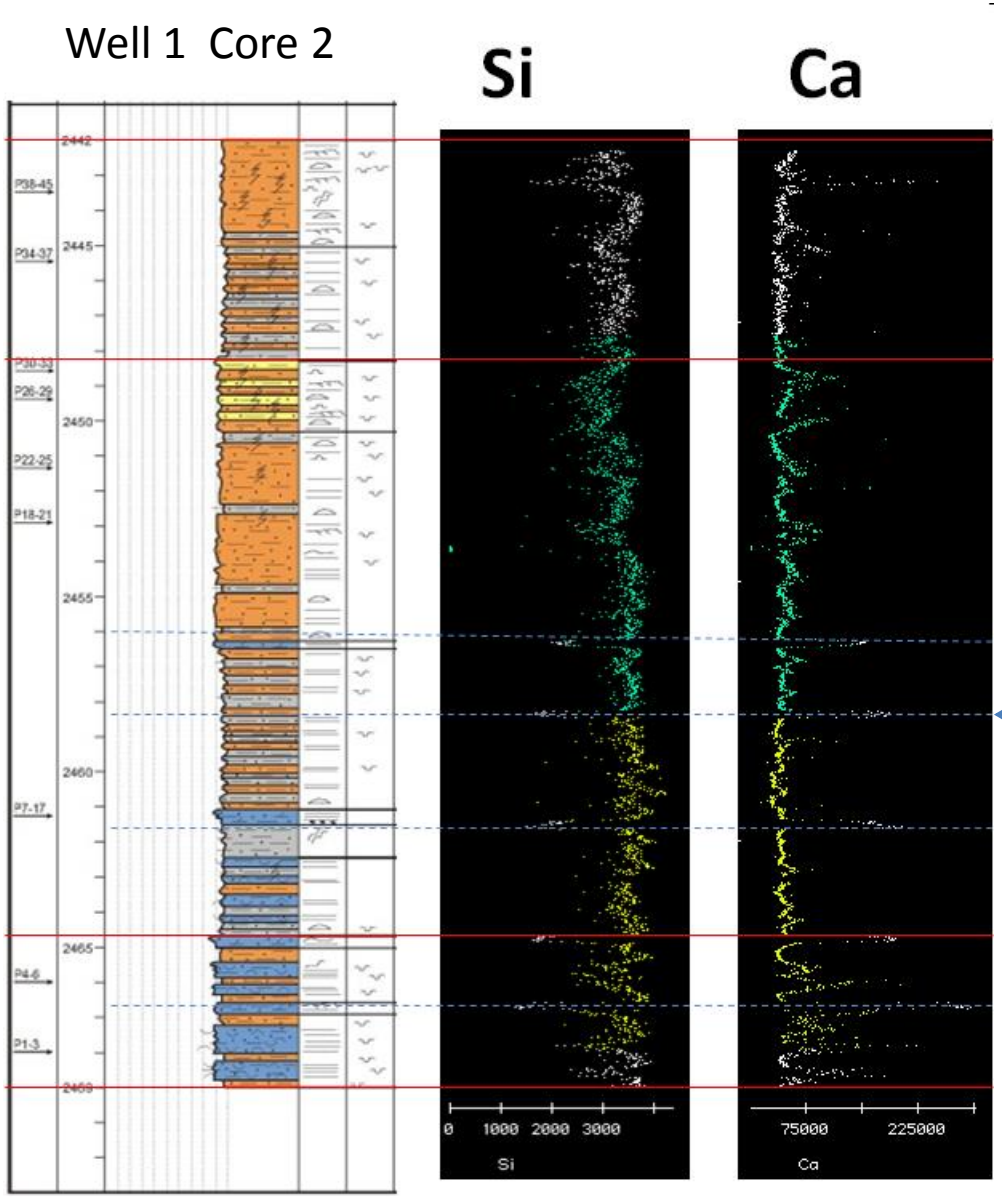


Some learnings from other cores

in

Middle and Lower Montney

Well 1 Core 2



XRF complementing a core descriptions

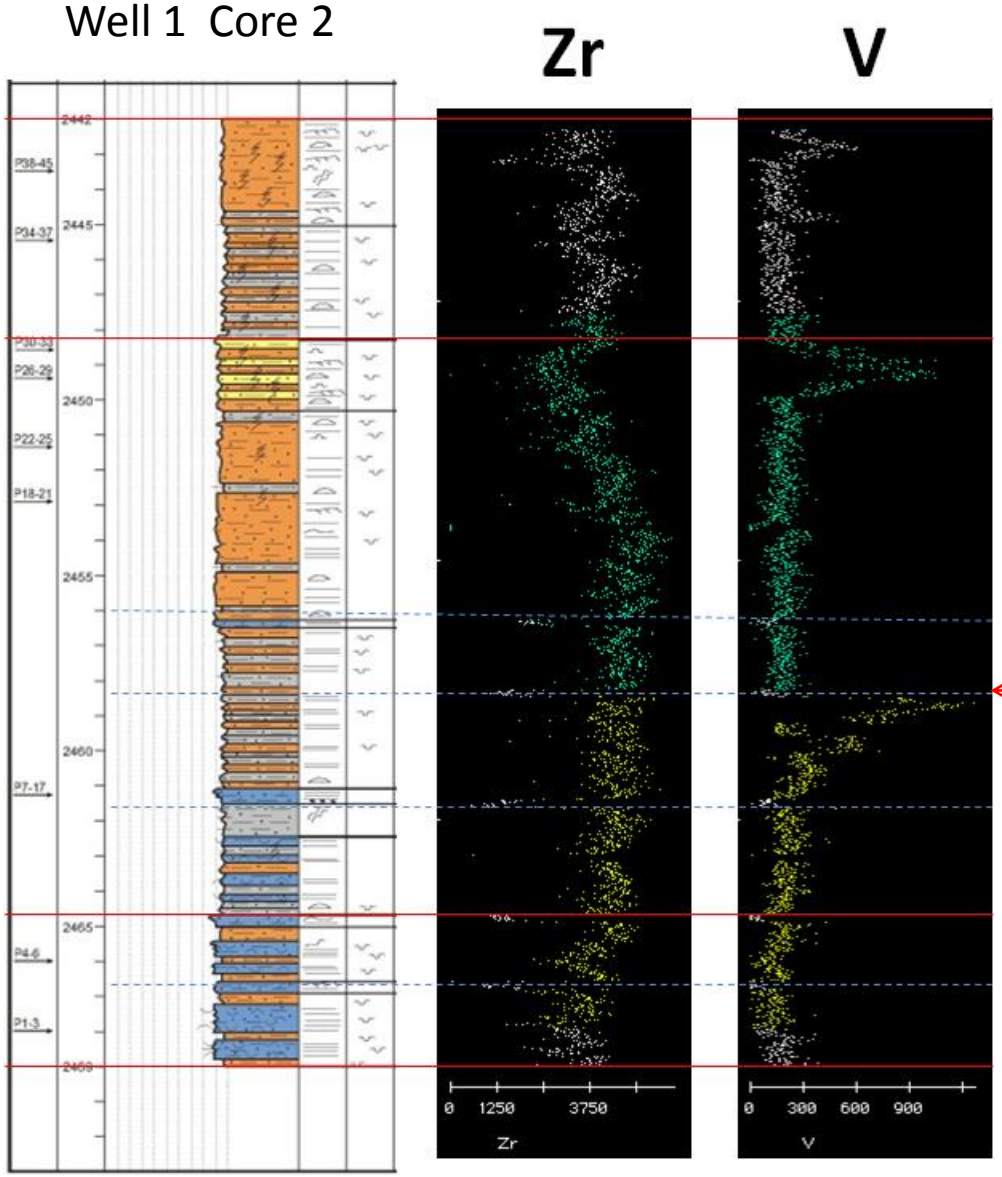
Low silica but described sdst

Missed carbonate bed

Much less carbonate beds than described why?

Montney Fm

Well 1 Core 2



Low Zr = low clastic input

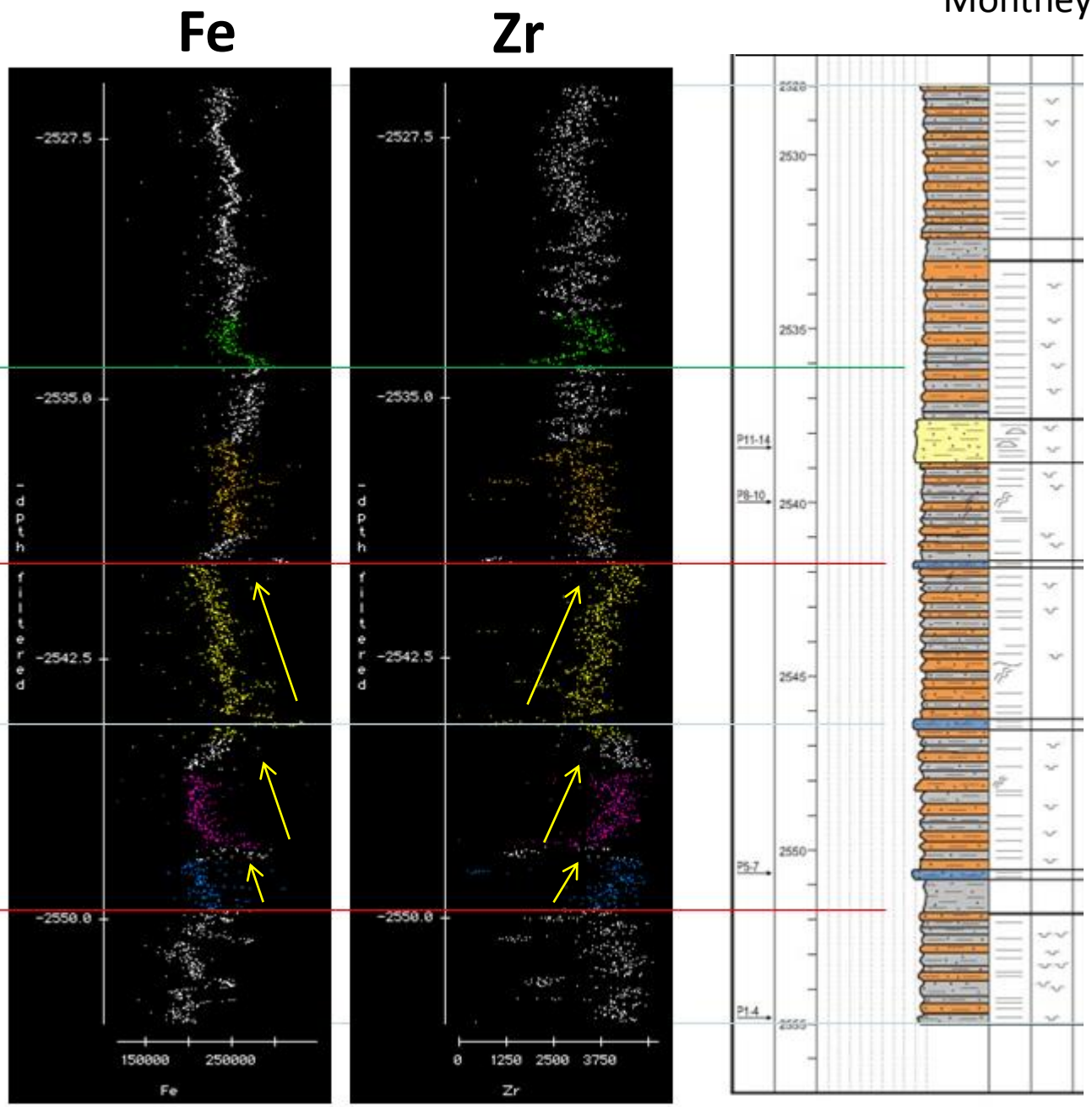
Unrecognized sequence boundary

Montney Fm

Well 1 core 3

Change in sedimentary patterns

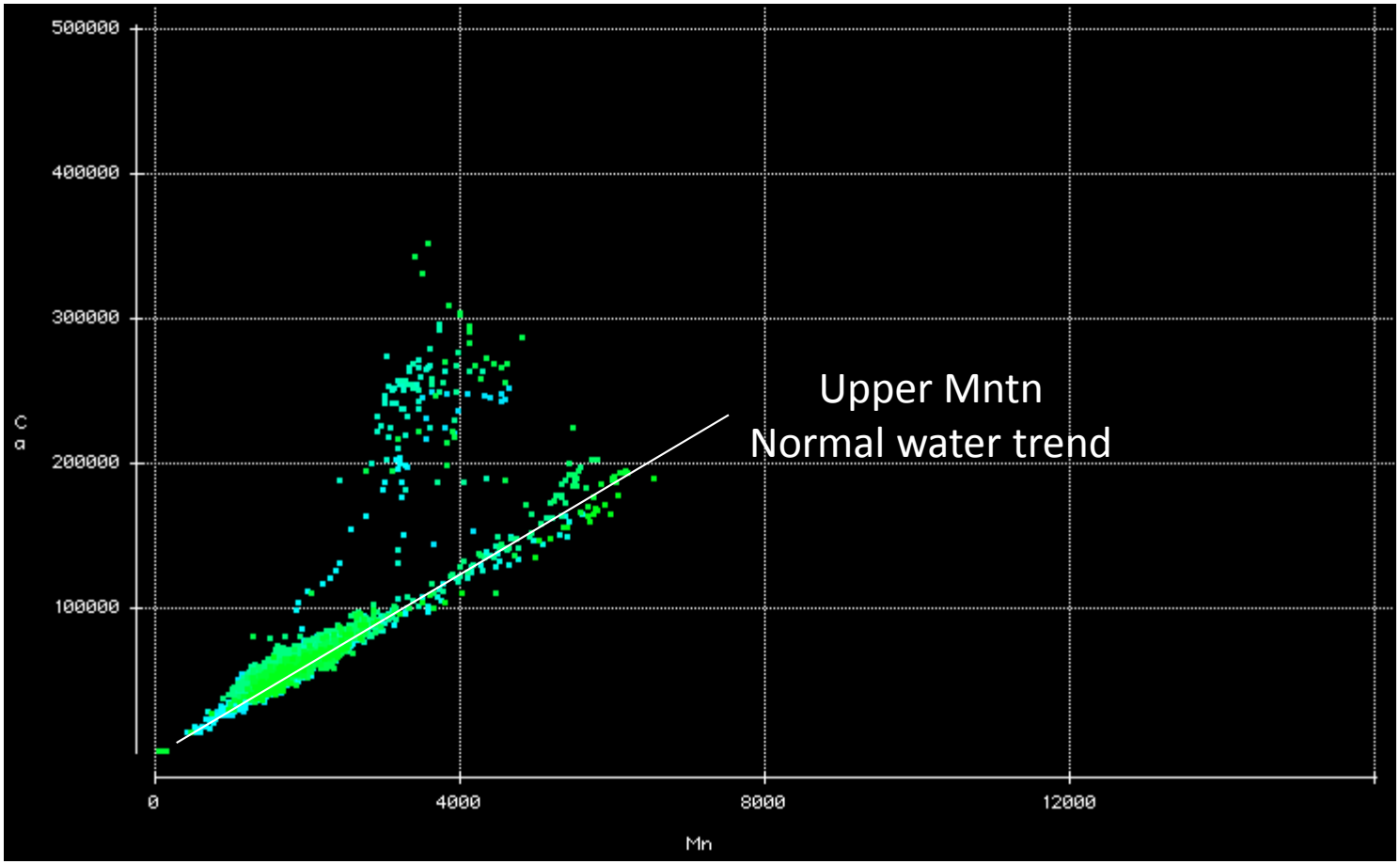
Well defined coarsening-up sequences



XRF Stratigraphic signature

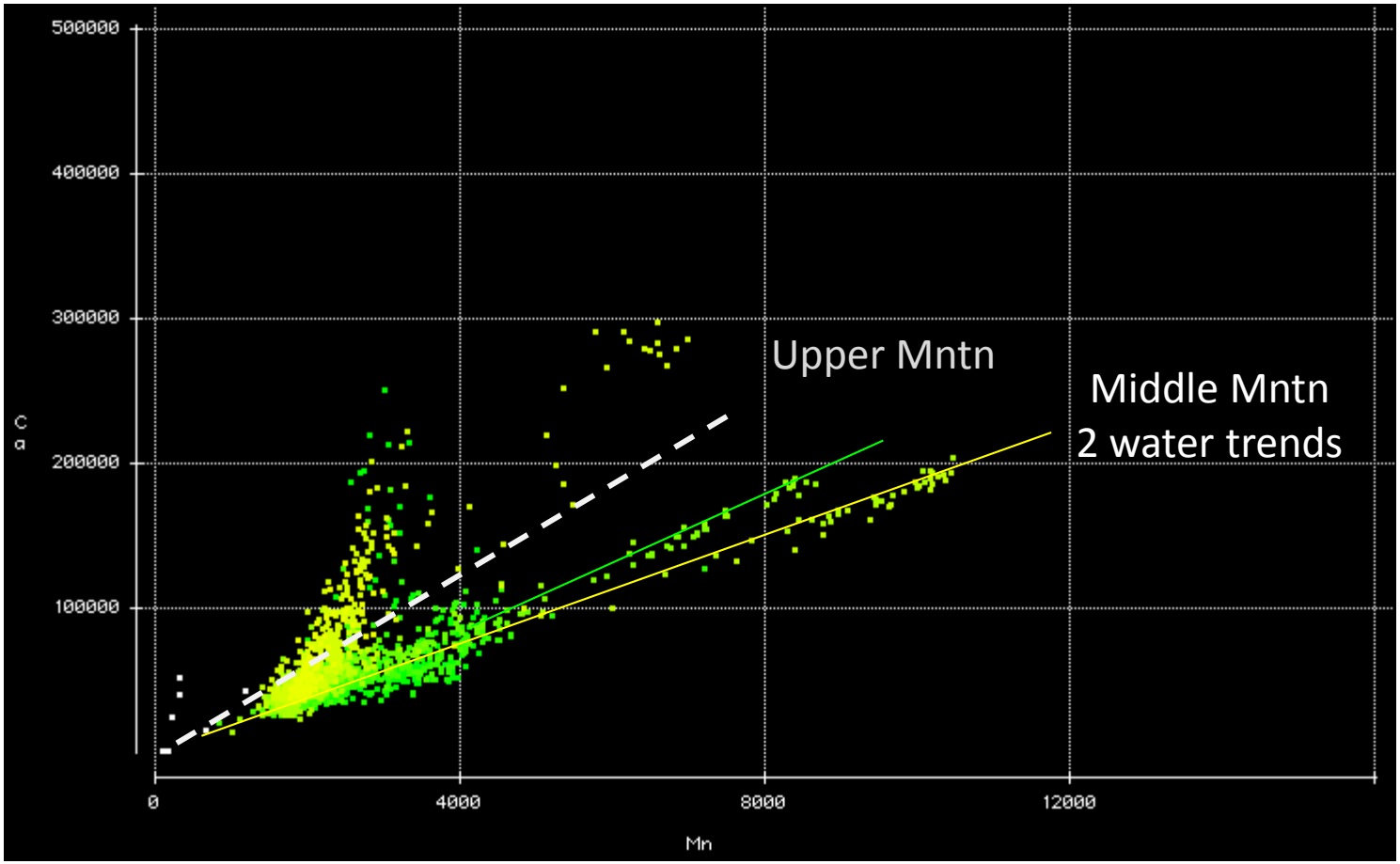
Montney Fm

Well 1 core 1



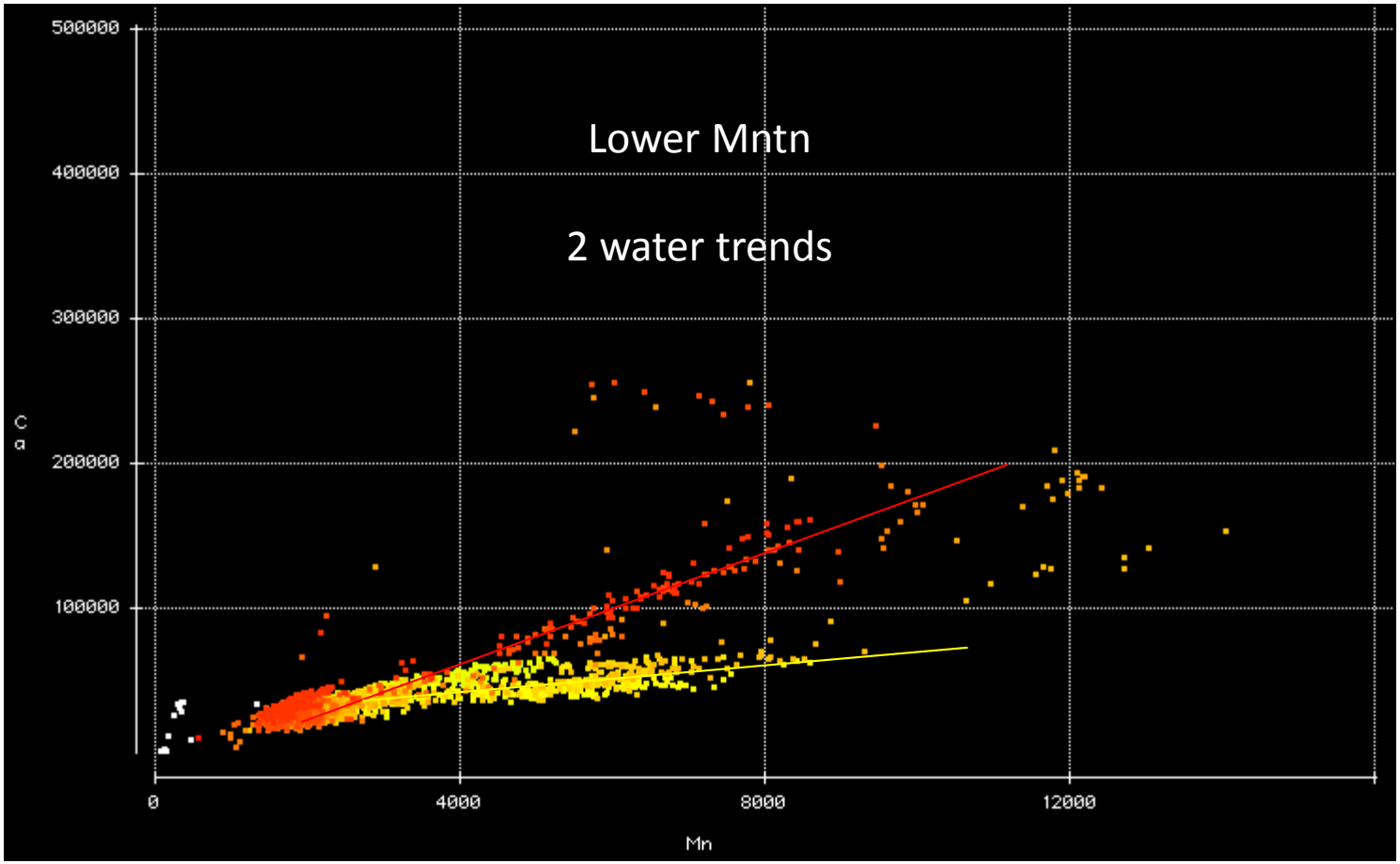
Montney Fm

Well 1 core 2

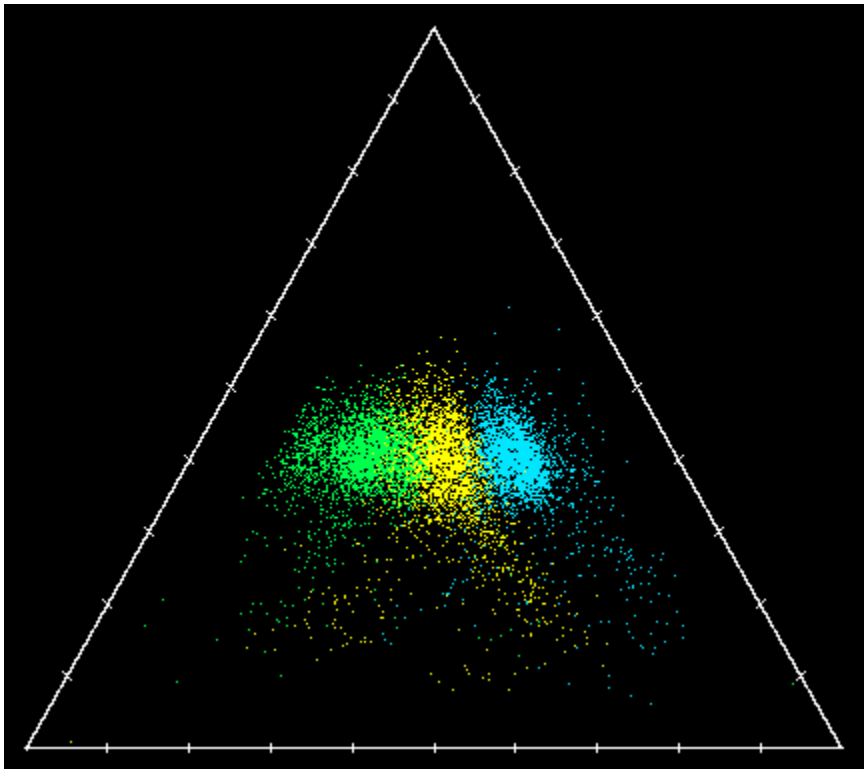


Montney Fm

Well 1 core 3



Ternary diagrams for well 1



Very distinct composition
Using six elements arranged
in three common ratios

Upper Mntn

Middle Mntn

Lower Mntn

Ratios corrected to normalize their maxima

High Resolution Correlation

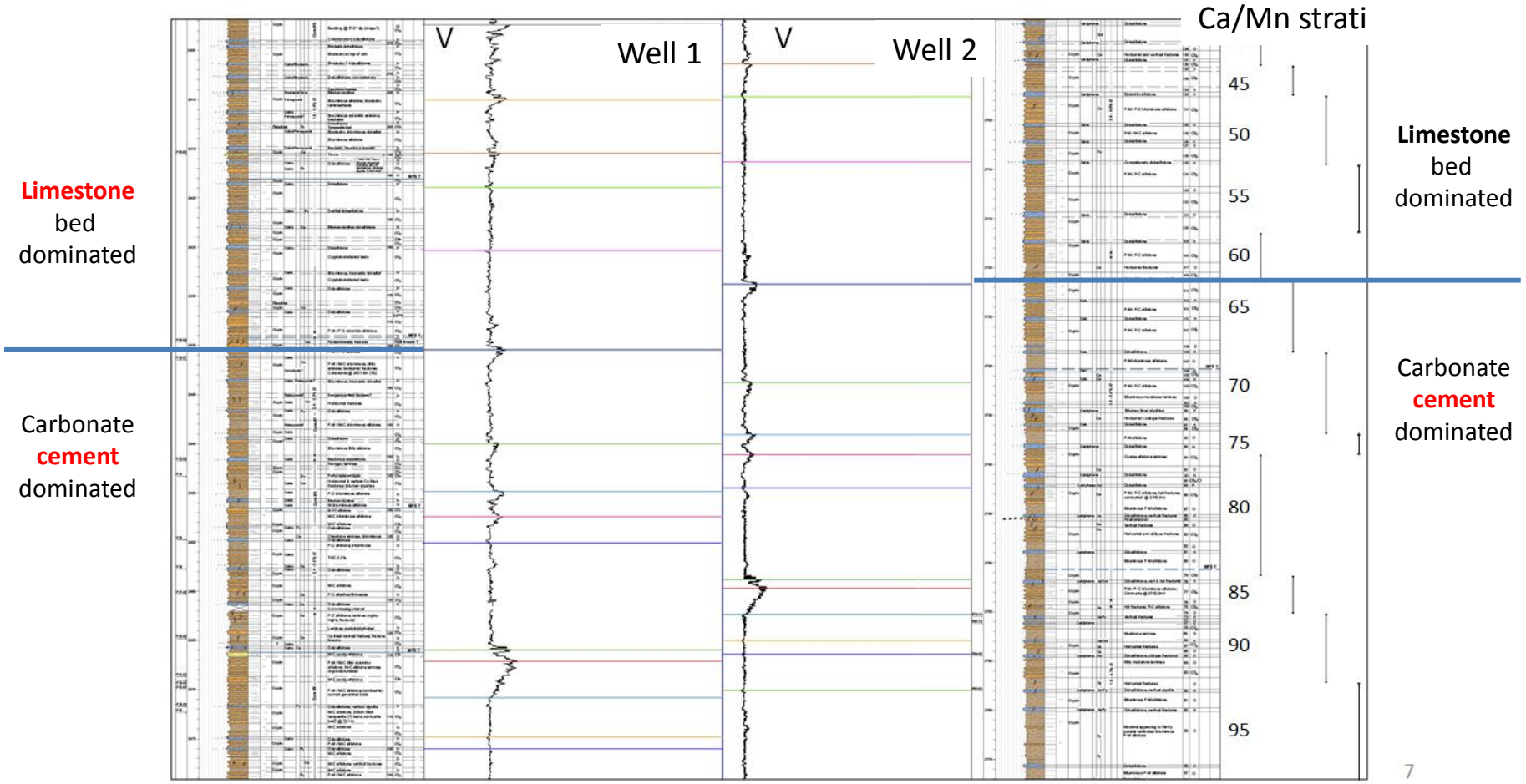
Based on

Ca/Mn stratigraphy

Montney Carbonate Middle Member

XRF based stratigraphy between wells some 7km apart

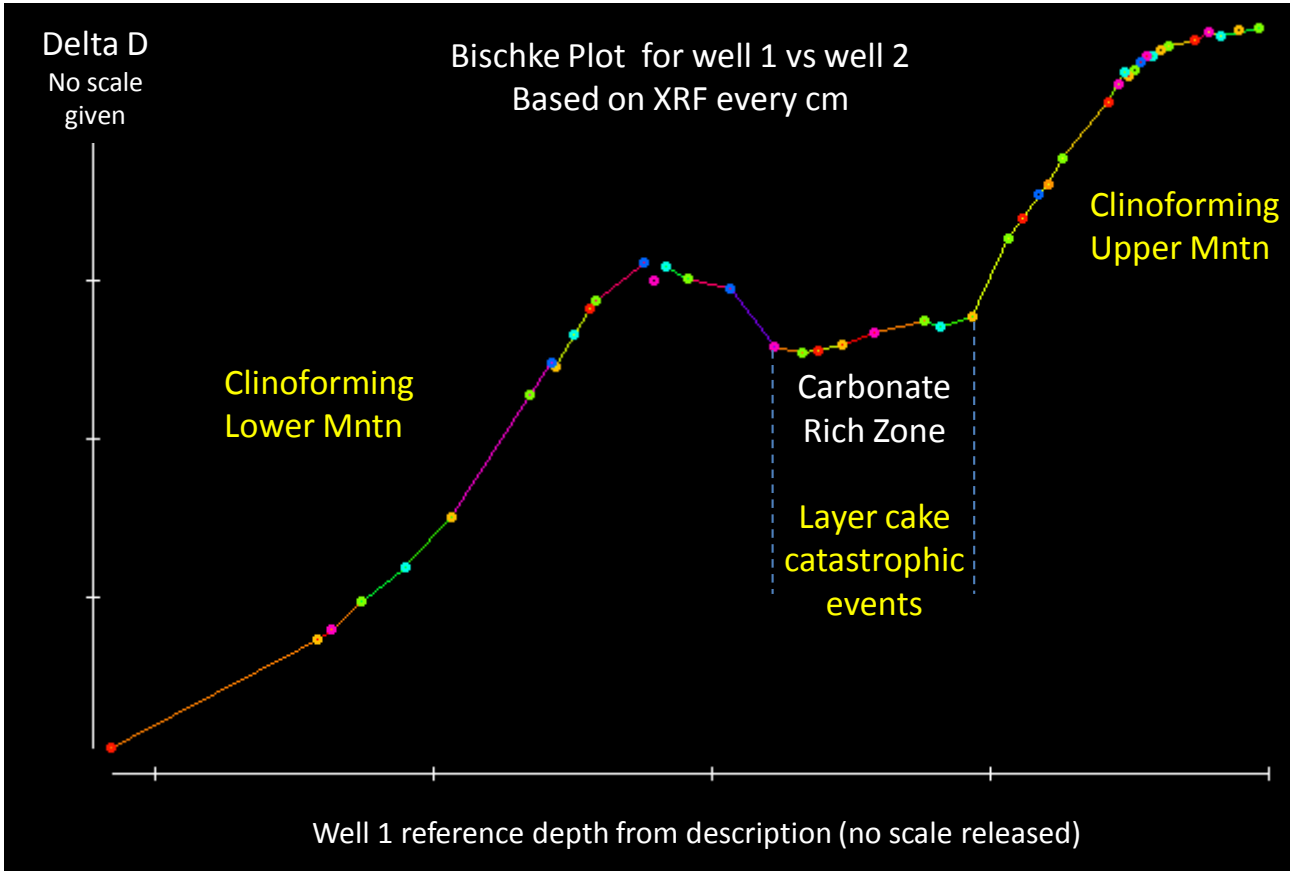
Correlation markers using Vanadium, Zirconium and Manganese XRF profiles



Montney Carbonate Middle Member

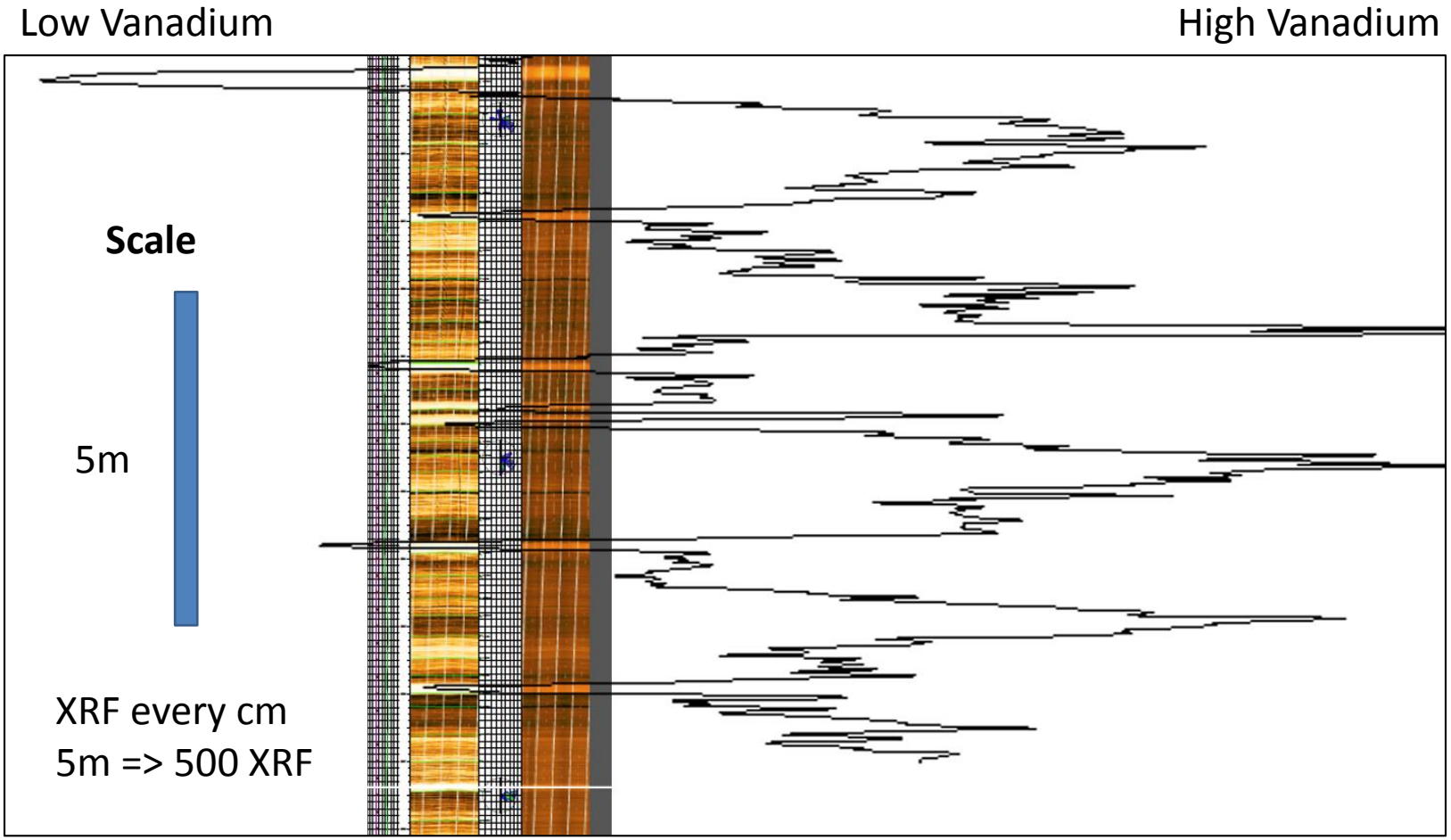
Genesis inferred from simple geometrical analysis

Using Bischke Plots



See previous plot for XRF vs core description

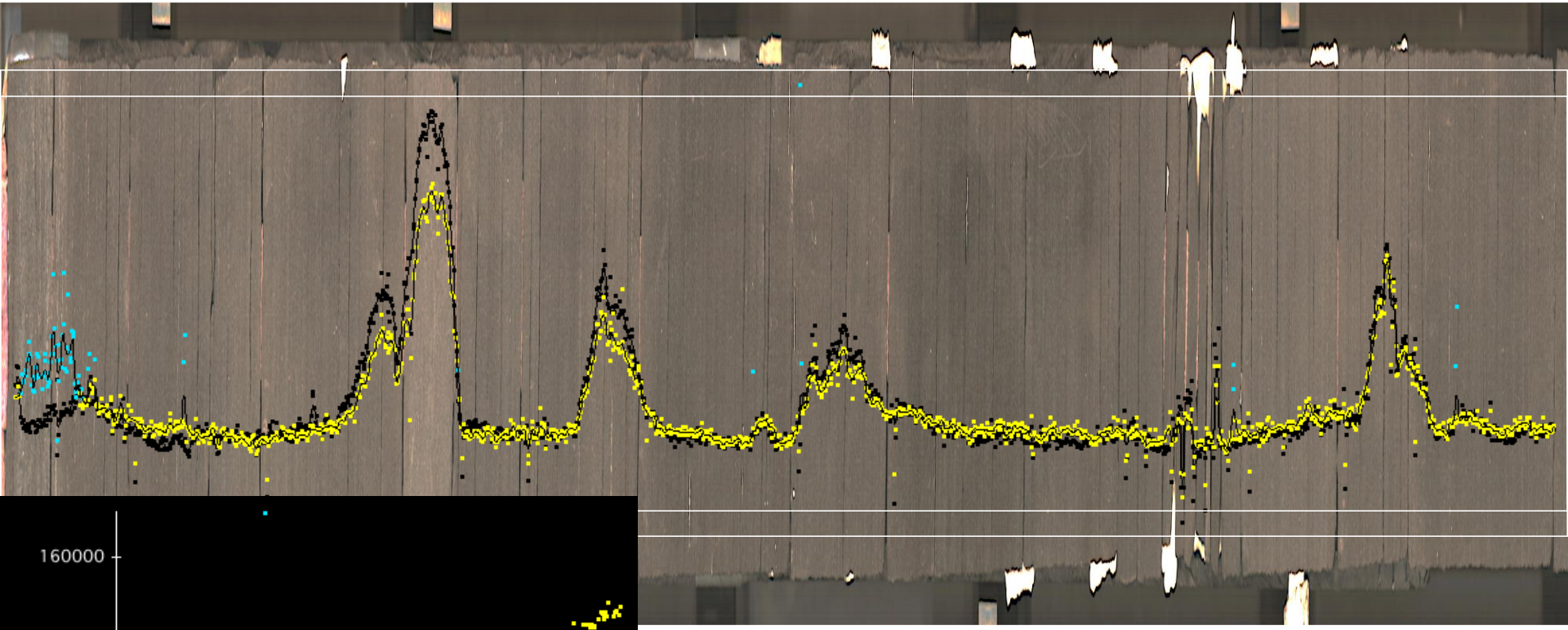
Vanadium from XRF versus Microresistivity from Image Log

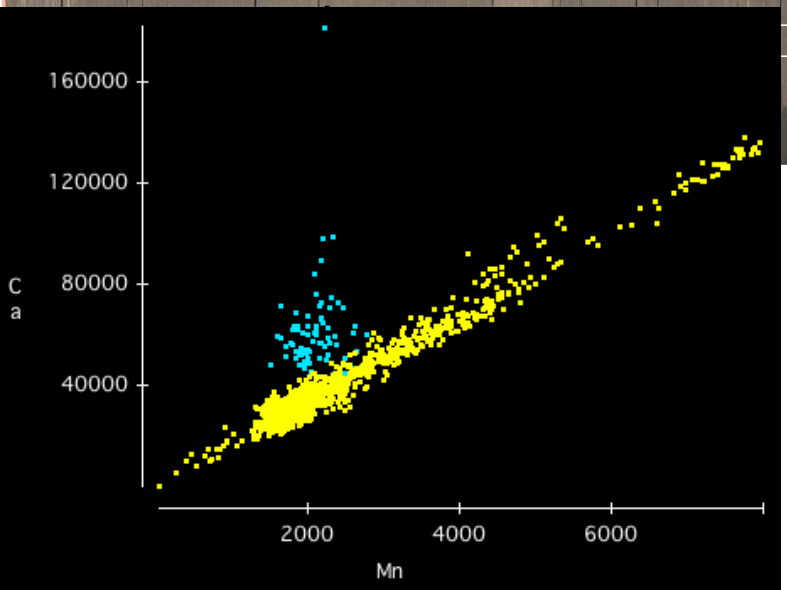


Just an example: 25 more elements can be compared with microresistivity

XRF run on 1.5m slab 1500 measurements (XRF every mm)

Mn (black dots)





Core width = 4 inches

Ca (yellow dots)

Calcium and Manganese are mimicking each other

There is no limestone bed, the top 5 cm is a limy shale (blue dots)

The higher the amount of Mn (and Ca), the slower the sedimentation

Limestone and limy shale have Ca/Mn higher than background water chemistry

Vanadium vs Grey Scale vs Core Photo

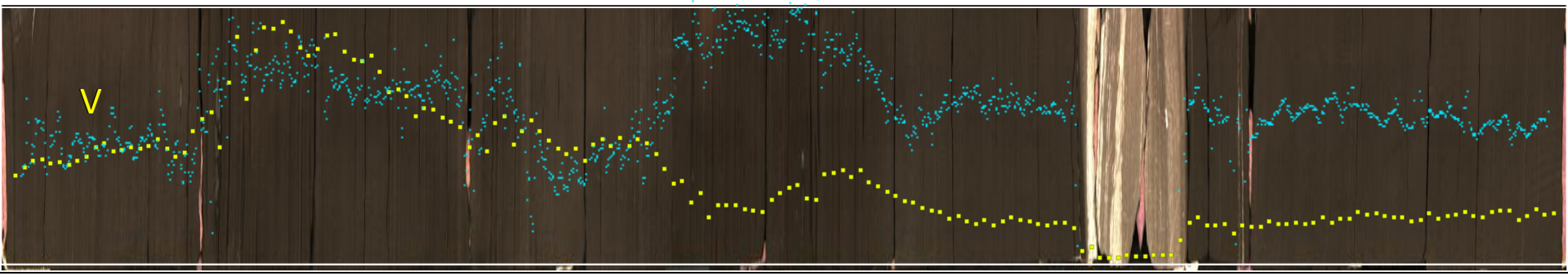
1 XRF/cm

slab C1-19 1.77 m => 177 XRF measurements (yellow)

256 Shades of grey in Light blue (3500 blue points)

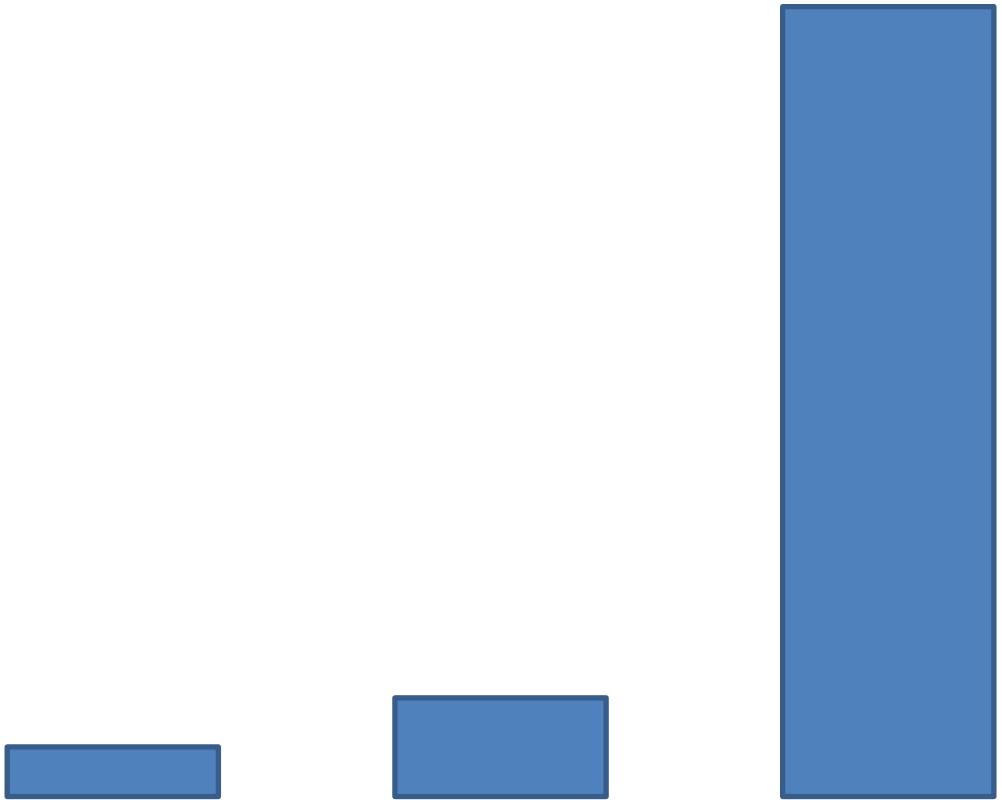
slab C1-21 1.73 m => 173 XRF measurements (yellow)

256 Shades of grey in Light blue (3500 blue points)



XRF vs Geomechanics

Resolution issues



XRF

1 cm

Core Gamma

2 cm

Geomechanics
Log-Based
16 cm

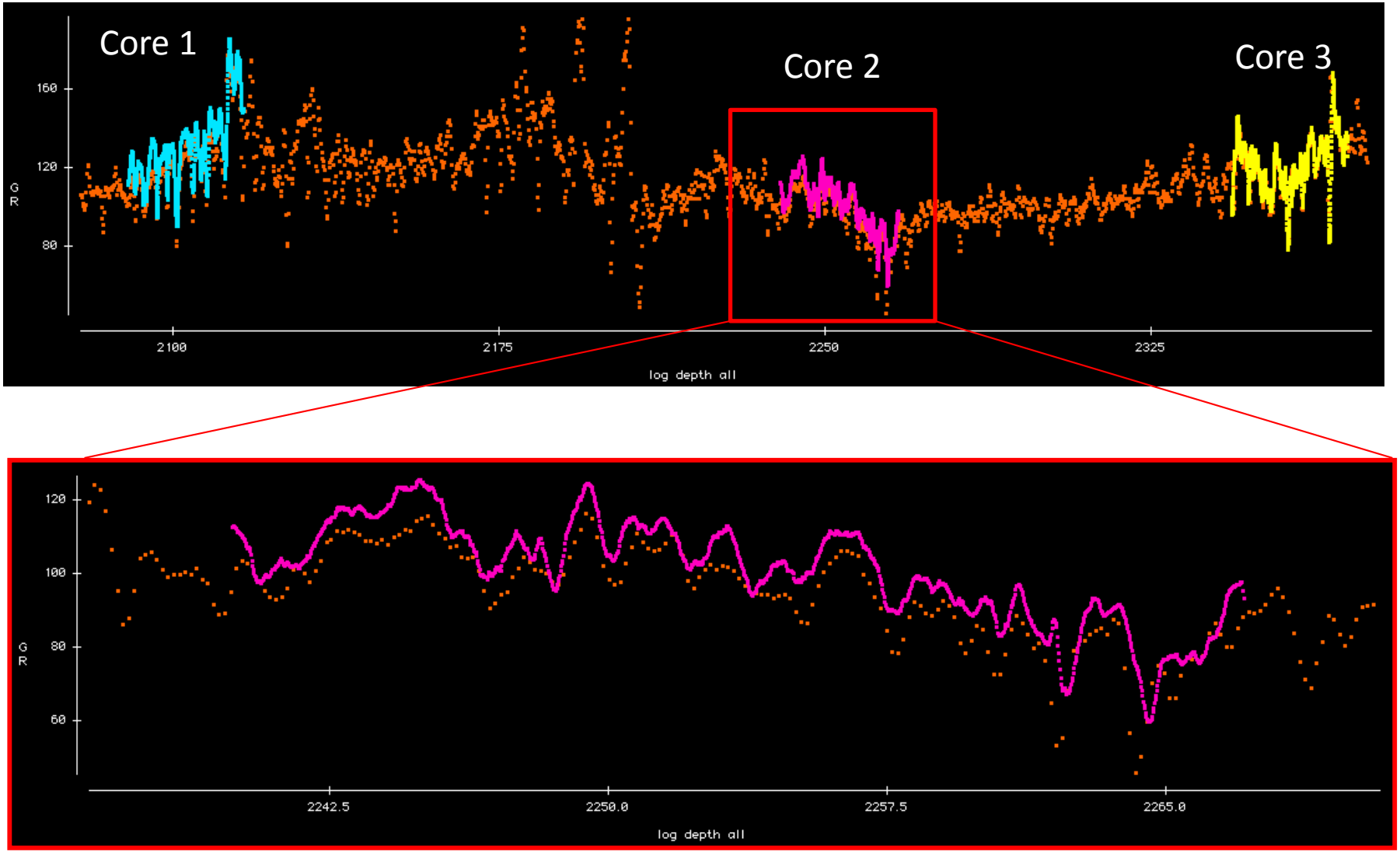
Solution:

Statistics:

Box Plots & mid%iles

Core shift in well 2

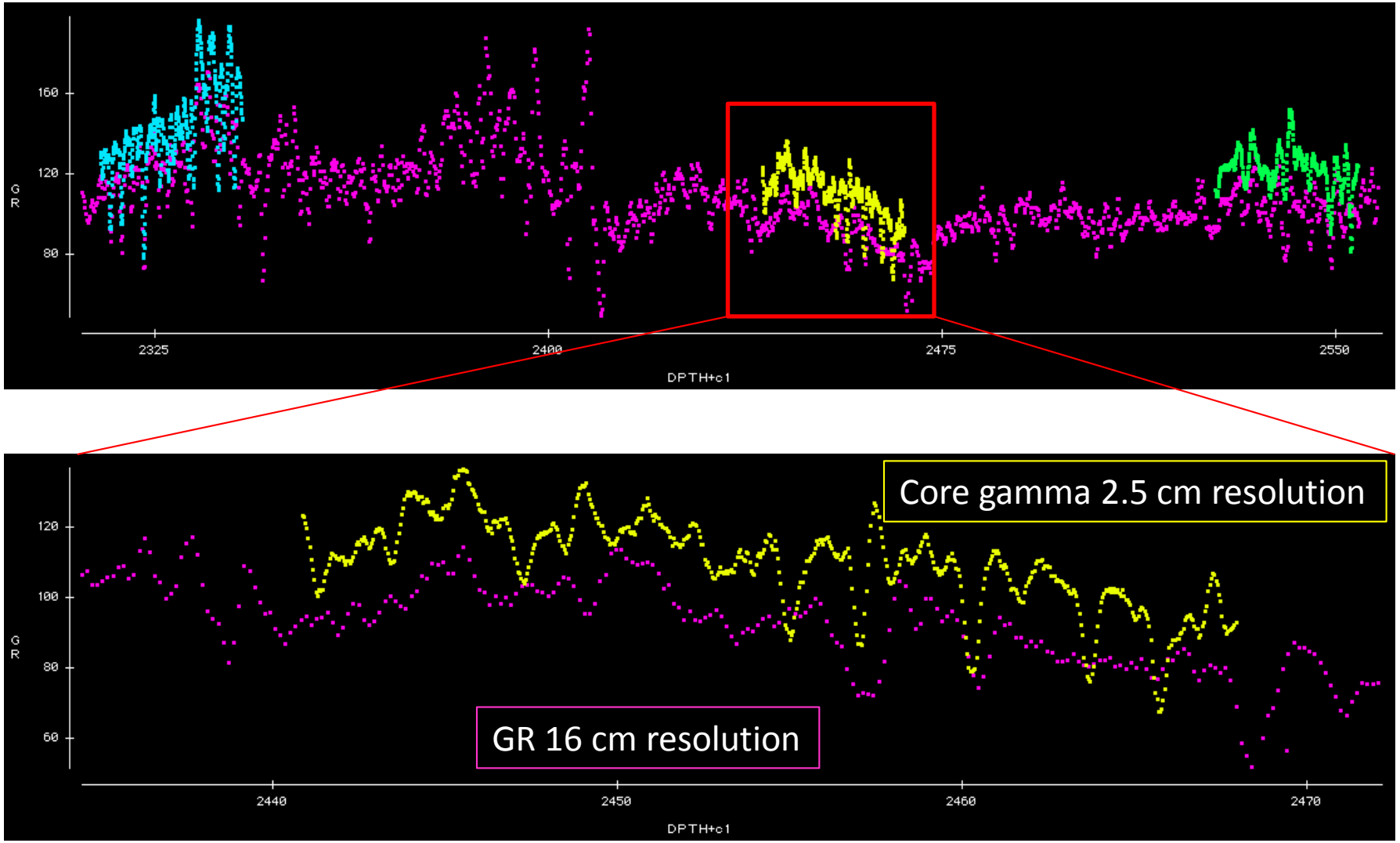
Montney Fm



Good quality match in all three cores

Montney Fm

Core shift issues in well 1

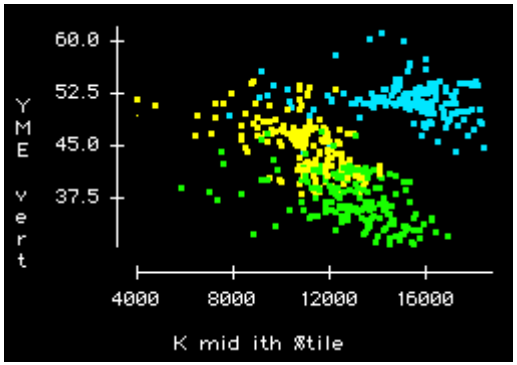


Low-quality match in all three cores

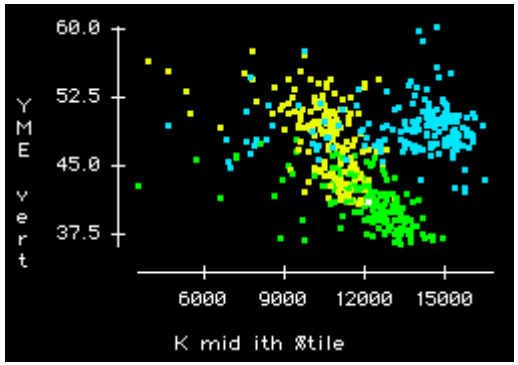
Montney Fm

Using Box Plot Statistics: e.g., median

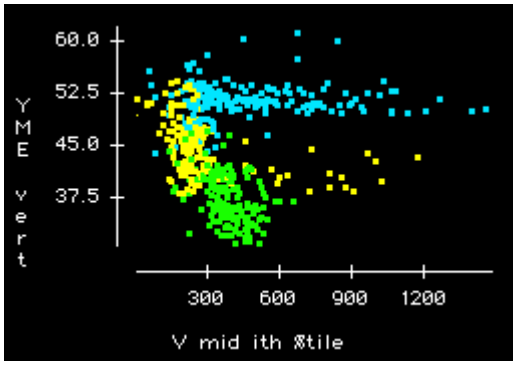
Well 1

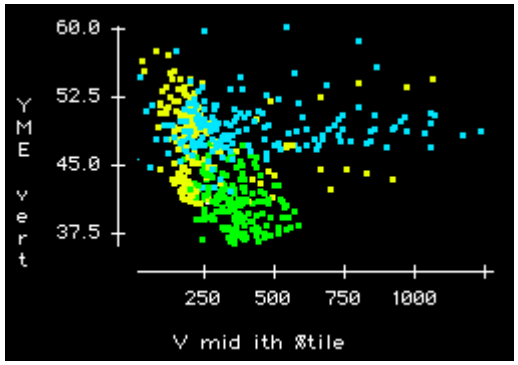


Well 2

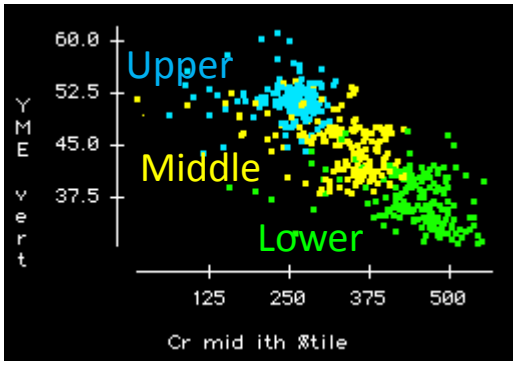


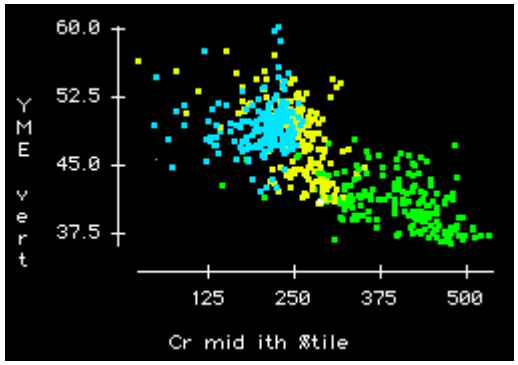
Vertical Young's Modulus is very well represented by the single element Potassium Middle and Lower Mntn





Vertical Young's Modulus is well represented by the single element Vanadium Middle and Lower Mntn

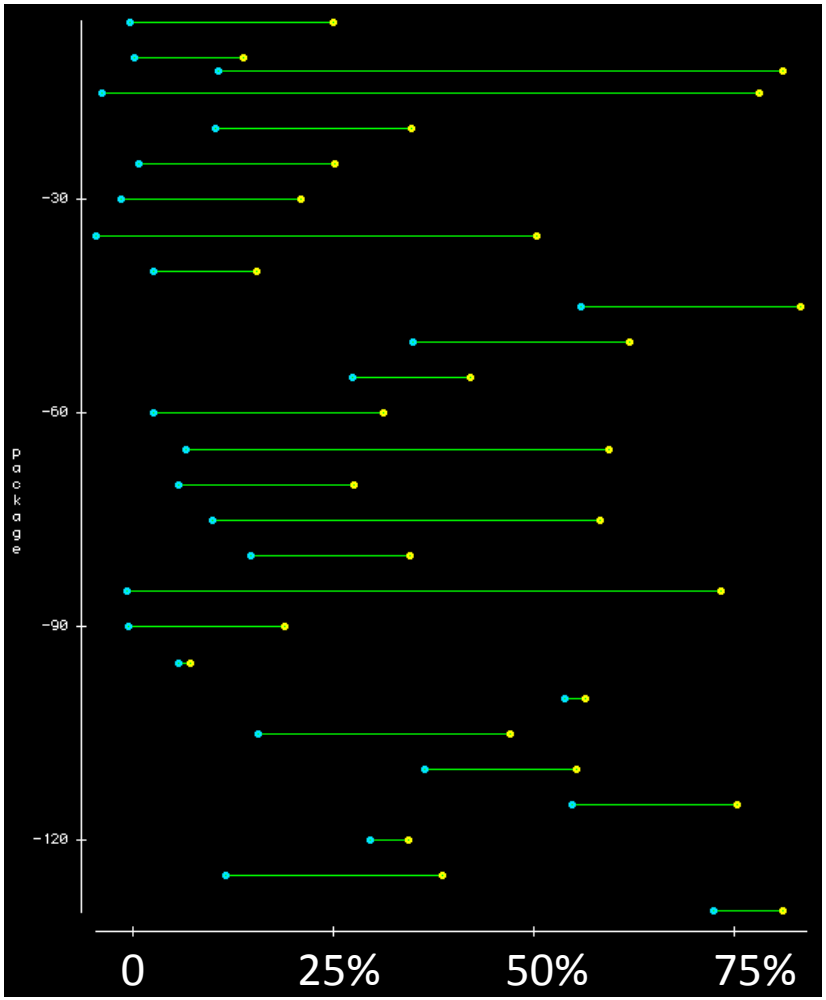




Vertical Young's Modulus is best represented by a decrease of the single element **Chromium**

Brittleness Prediction from XRF

Ca/Mn Units



R Square

K

Fe, V, Ni, Cu, Zn, Rb

Important finding:

Every combination of successive units has a worse correlation than the individual Ca/Mn-based units

Conclusions

- XRF delivers repeatable results that can be used for
  - Solid basis for correlation
  - Complement to sedimentology description
- Single and multiple elemental compositions
  - Can predict brittleness in well defined packages or units
  - Can be used to optimize frac design in horizontal wells
- Ongoing work to better understand Ca/Mn in the Montney shale