The use of X-Ray Fluorescence for Sequence Stratigraphy and Geomechanics of Shale

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Summary

Methods and results from 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 in optimizing and improving hydraulic fracturing of shales.

Four different mudstone facies associations were studied; two are siliciclastic and two are carbonate. The relationships between different XRF derived elemental compositions have helped define sedimentary successions that elegantly complement sedimentologic core descriptions and shed light on the sedimentary processes of deposition. Thus, as an example among many, manganese in combination with calcium in the Montney Formation can distinguish between specific carbonate lithofacies. Zirconium seems to be by far the best indicator of variations in siliciclastic input and has proved to be outstanding at outlining prograding clastic facies associations and/or parasequences.

Additionally, cross-correlations have been established between elemental compositions and geomechanical properties from cores or from wireline logs. Some of these correlations are revealed together with the analytical tools and methods used.

Introduction

X-Ray fluorescence is an increasingly popular tool to better understand shale composition and properties. A series of extensive data sets, using various emitting sources (molybdenum, tungsten and copper), from cores and cuttings have been integrated with sedimentological facies descriptions and rheological properties from logs or core. XRD data has been used to complement the analysis and consolidate some of the findings.

The study

The study encompasses four different mudstone facies associations, of which two are siliciclastic or hybrid and two are carbonate. The relationships between different XRF derived elemental compositions have helped define sedimentary successions that elegantly complement core descriptions and shed light on the inferred sedimentary processes of deposition. Thus, as an example among many, manganese in combination with calcium in the Montney Formation can distinguish between bioclastic tempestite and carbonate rich hemipelagic sequence top firmground facies (Fig.1). Zirconium is the best indicator of siliciclastic detrital input and has proved to be outstanding at outlining prograding clastic facies associations and/or parasequences (Fig.2). Silicon from XRF is less useful than Zirconium, as both tectosilicates and phyllosilicates (micas and clays) are rich in silica. Zirconium is associated with the quartz-feldspar-mica detrital components rather than the clay mineral component.

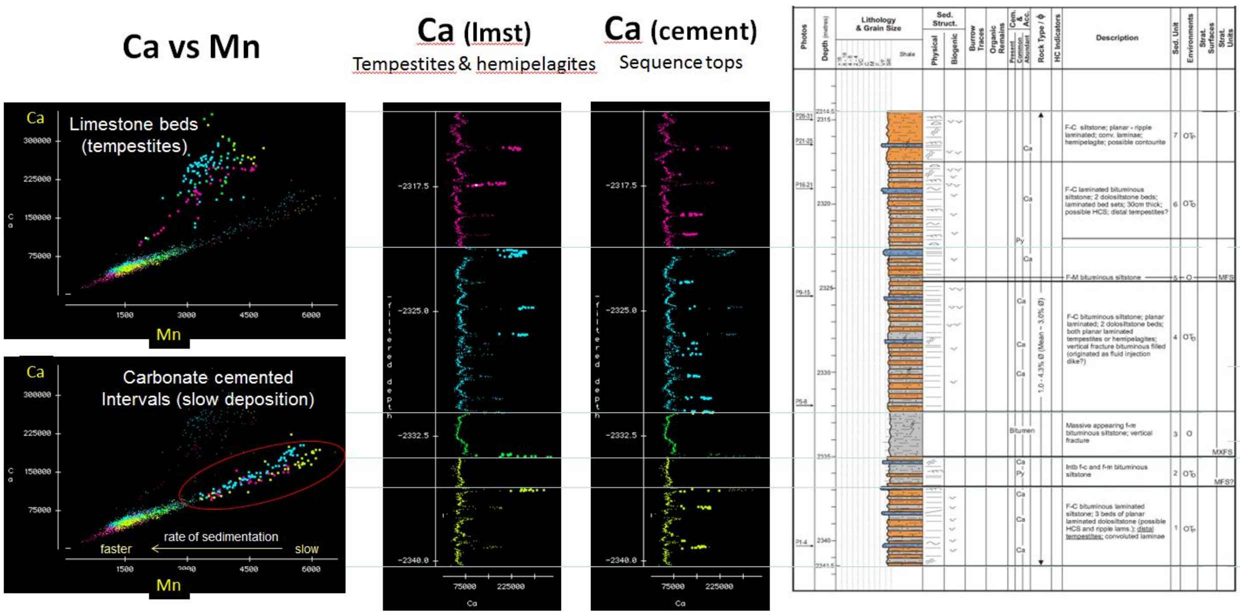

Fig.1 The use of Calcium vs Manganese XRF compositions to refine sedimentological interpretations. Note the correlation of thicker detrital siliciclastic facies (grey) and carbonate facies (blue) to specific XRF compositional signatures.

The power of XRF might be to help understand lithological changes in horizontal wells, especially in the absence of wireline logs. In ideal conditions, frac stages would encompass rocks with similar geomechanical properties; brittleness disparity could lead to some of the perforations being by-passed and volumes of rocks not stimulated. X-Ray fluorescence could “map” drastic lithological changes and could guide towards modified and improved completion designs.

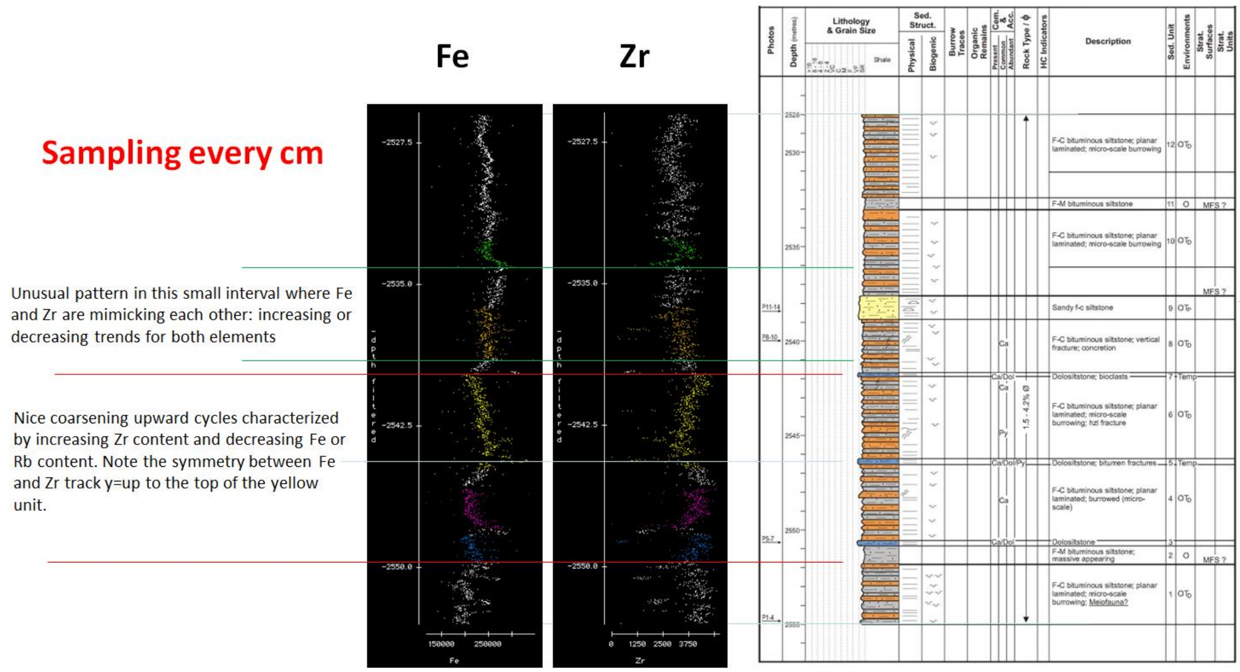

Fig.2 A view of some well-defined facies associations expressed by a combination of Fe and Zr as a complement to a sedimentologic core description. Note the close correlation of two of the three sedimentologically inferred marine flooding surfaces (MFS) to XRF compositional signatures.

Elemental compositions have been studied against various completion and mechanical parameters. These include Young's Modulus and Poisson's Ratio from core experiments or from logs, Leeb hardness, and completion parameters such as Initial-Shut-in-Pressures and breakdown pressures. Core to log shift assessment was a critical parameter in our integrated core study.

Each mudstone facies shows some relationships between specific elemental compositions and geomechanical properties; i.e., in one of the carbonate mudrock formations, manganese and bismuth have the best but opposite correlations with frac parameters. In siliciclastic mudrocks, rubidium, chromium and titanium in addition to potassium and aluminum have very strong negative correlations with Young's moduli. In the Montney Formation, some of the distinctive elemental trends found in the Lower Montney do not continue into the Upper Montney (Fig.3).

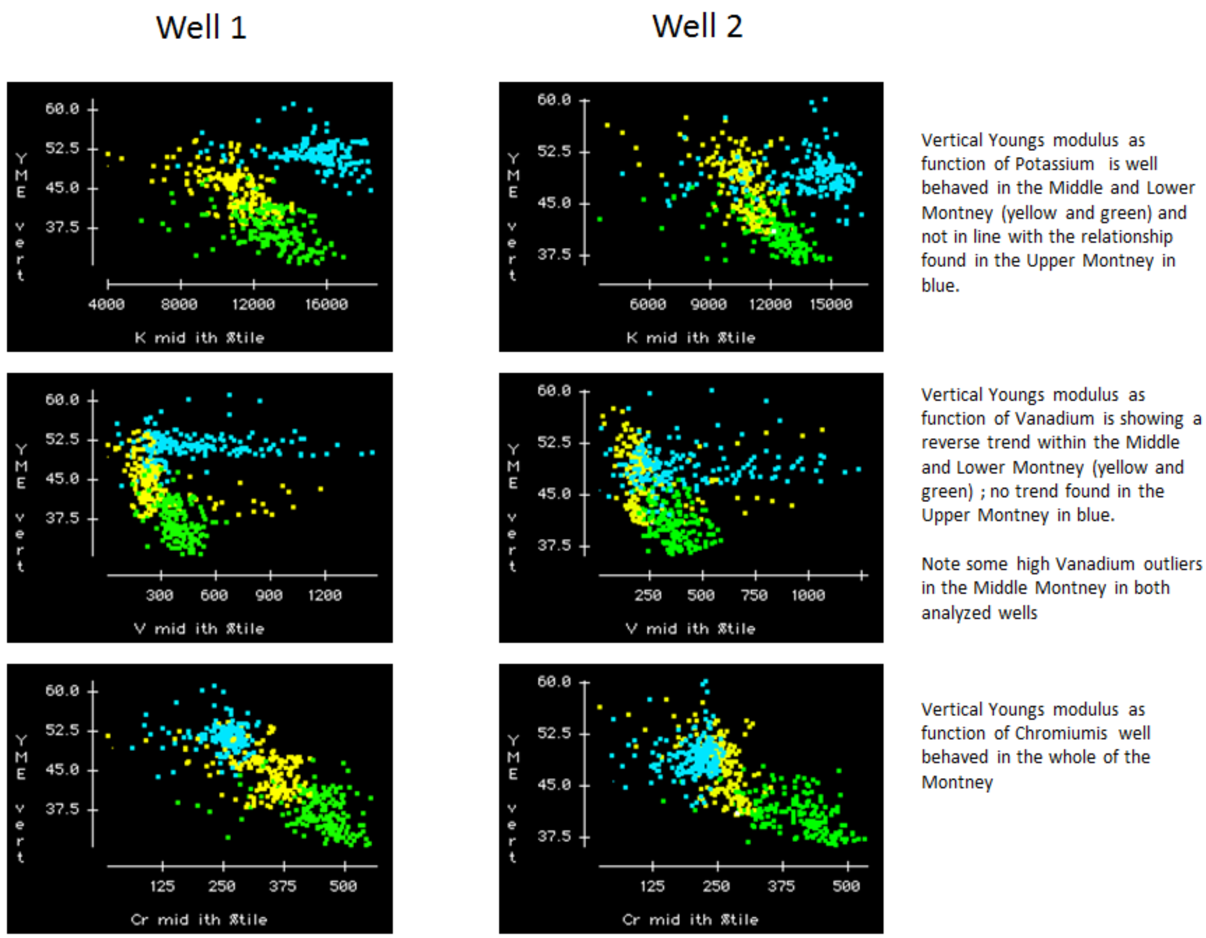

Fig. 3 XRF data from Montney cores in two wells against dynamic vertical Young's Modulus from logs.

Dynamic geomechanical properties derived from wireline logs have a very low vertical resolution compared to the data collected in our cored wells. XRF sampling is at 1cm spacing, compared to the 16cm sampling of the log derived Young's Modulus or Poisson Ratio.

Applying a median smoothing (type of spline fit) as an alternative to moving average greatly improves the quality of the fit between log or core derived rock mechanics and elemental composition. This is expressed graphically in figure 4 using potassium as a reference; the Rsquare values are based on all of the data from the two bottom cores (lower Montney). Potassium is not the element with the best correlation with Young's Modulus but it can be an excellent tool to outline sedimentary sequences, specifically facies associations and parasequences (similar patterns as with iron, see fig.2)

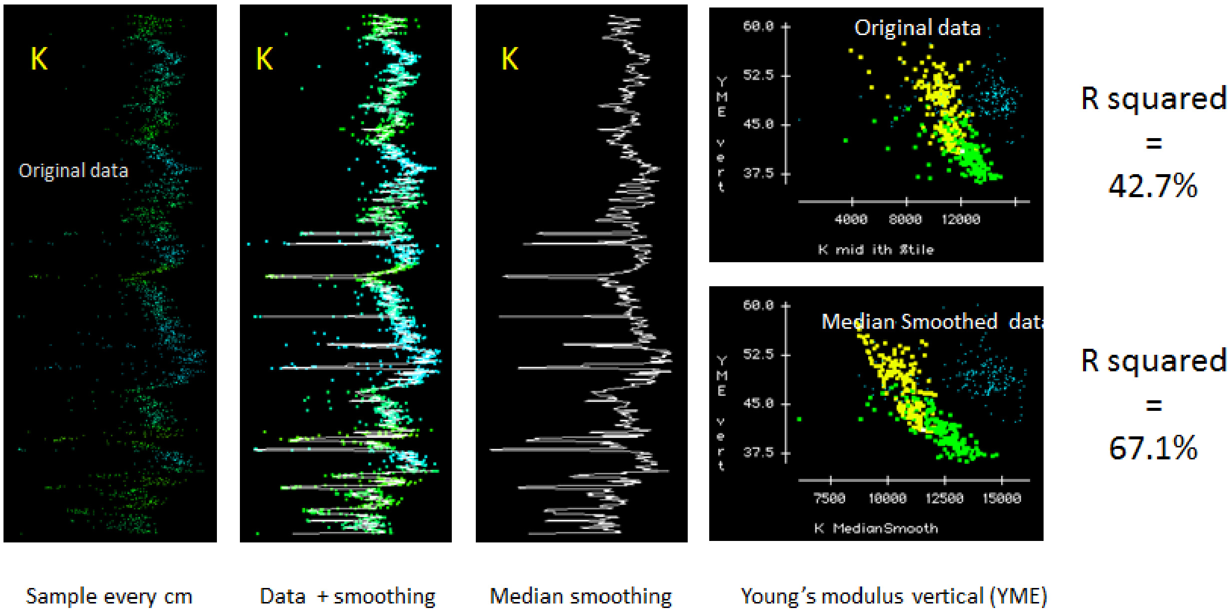

Fig.4 Vertical Young's Modulus versus Potassium before and after spline smoothing in well 2

The Leeb Hardness, another geomechanical parameter, has been well correlated to sulfur and potassium elemental compositions (Figure 5). Note that, as mentioned before, major differences are observed between the Upper and Lower Montney. Formulae between XRF and rheological properties derived out of real data need to be specific to the individual formations or members.

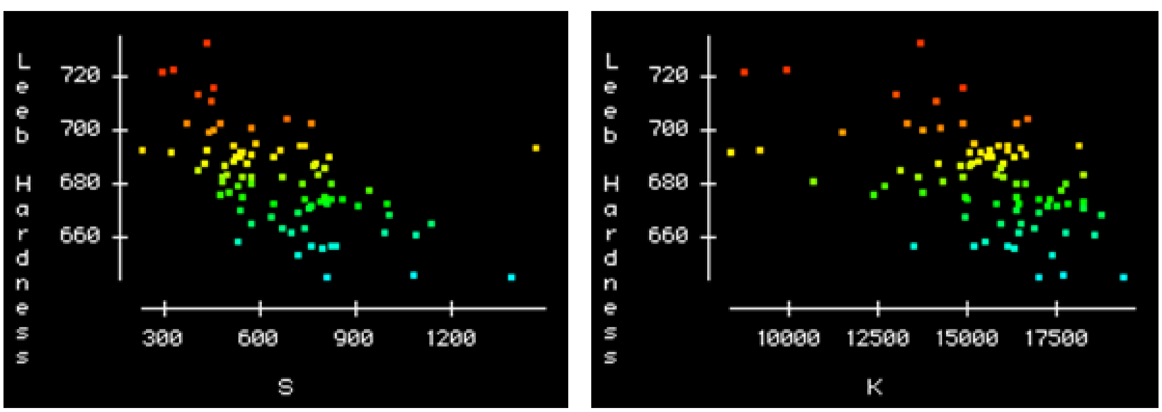

Fig.5 Leeb hardness versus Sulfur and Potassium in upper core of Well 1 (blue dots on figure 4)

Brittleness indices using XRD results, such as those found in the literature, should be used as a last resort. Thus, figure 6 shows that in a carbonate shale (mudstone) facies, the tectosilicate content nicely matches the Young's Modulus; however, two trends exist and a cut-off has to be applied to quartz-K feldspar-plagioclase content prior to applying any formula (40% for QFP in the example shown).

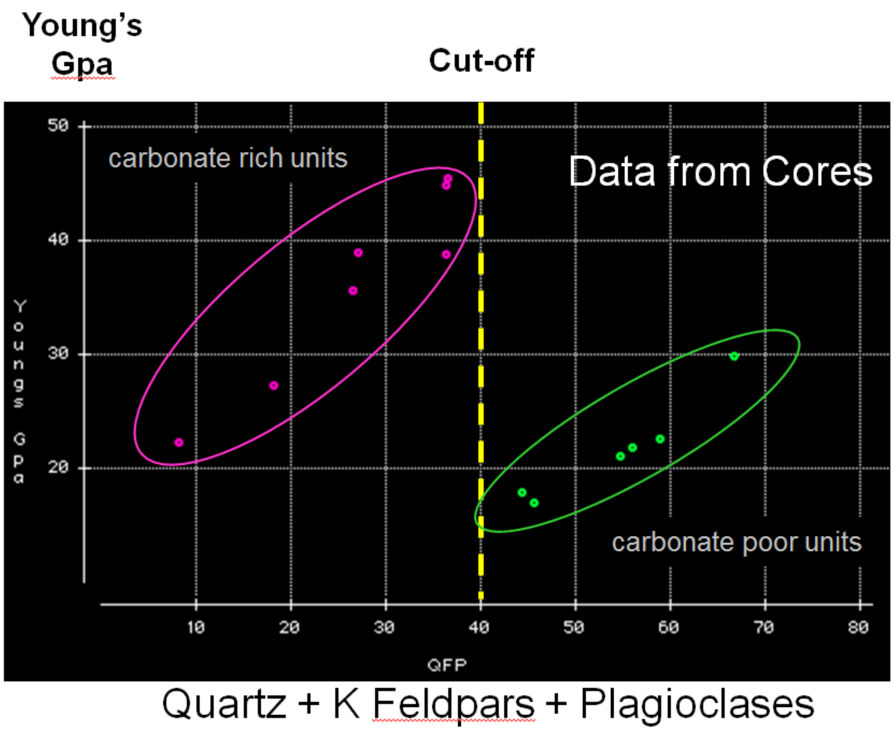

Fig.6 Two nice trends of XRD derived mineralogy against Young's Modulus from carbonate shale

Conclusions

From our study of various hydrocarbon producing mudrock formations, X-ray fluorescence seems to have a great potential as a complementary and diagnostic tool for sedimentology and geomechanics and could help save substantial capital expenditures in completion costs if applied appropriately.

It is important to keep in mind that formulae between XRF and rheological properties are specific to the individual formations or units under study. The same constraints are valid when dealing with XRD.

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