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SEM Fabric Analyses of the Montney Formation: An Aid to Determination of Reservoir Properties.

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Summary

SEM fabric analyses are time consuming and relatively expensive; however, these analyses yeild valuable insight into the fabric controls of reservoir properties. Analyses of samples from the Montney Formation indicate that the pressence and amounts of dolomite, quartz and K-spar cements exhibit strong contols on porosity, permeability and mechanical properties. Information gained from the fabric analyses is then used to determine these reservoir properties through parameterization of specific mineral interaction algorithms using high resolution XRF data.

Introduction

XRF Solutions have employed X-Ray Fluorescence (XRF) techniques to analyse more than 30 Montney Formation cores during the past 5 years. We have created algorithms based on theoretical models to determine mineralogy and reservoir properties from the XRF data. Parameterization of these algorithms is accomplished through multivariate optimization of the XRF determined values with available laboratory and well log data. The Montney Formation is the most heterogeneous and complex unit we have encountered.

Exploitation of the Montney Formation reservoir, as with many unconventional reservoirs, is largely done using horizontal wells. XRF analyses of horizontal well cuttings provide a cost effective means for obtaining high resolution (5-10 m spacing) elemental data. Algorithms created from core allow determination of mineralogy and reservoir properties from these data. We have analysed more than 50 horizontal wells in the Montney Formation and find strong correlations between the reservoir properties (porosity, permeability and rock mechanics) of near wellbore rocks with drilling, completions and production data. We theorize that these reservoir properties are a function of the minerals present and the fabrics of those minerals.

Here we focus primarily on fabrics in the Montney Formation, especially the distinction between detrital grains and cements. SEM analyses of samples from the Montney Formation can be used to not only determine the amounts of different minerals present, but also if these minerals are present as detrital grains or cements. The distribution of quartz, dolomite and K-spar cements within the Montney Formation appear to exhibit a first order control on reservoir property variation.

Theory

We employ a semi-empirical specific mineral interaction model to determine reservoir properties such as porosity, permeability and the mechanical properties Young's Modulus and Poisson's Ratio (Spencer and Weedmark, 2015). Equations are set up in a similar manner to those used by Harvie, Moller and Weare (1984) and Spencer, Moller and Weare (1990) to parameterize the specific ion interaction model developed by Pitzer (1973) for complex electrolyte solutions. The fundamental equation is:

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

Where RP is a reservoir property such as porosity, Young's Modulus or Poisson's Ratio; alpha is a function of the reservoir property; DV is the detrital volume of a mineral in the rock, CV is the cement volume of a mineral in the rock and RV is the recrystalized volume of a mineral in the rock; the beta, gamma and theta terms are fabric coefficients. These fabric coefficients are fit to empirical data following, similar to the approach of Spencer, Moller and Weare (1990) who use phenominological coefficients to determine the thermodynamics of the interaction of complex brines and minerals. The equation is solved for all minerals i and j in the rock. The model has been successfully applied to different formations ranging from the McMurray oil sands to the unconventional Duvernay and Montney formations.

Elemental data obtained from XRF analyses are useful in determination of a chemical stratigraphy. However, geoscientists and engineers are more familiar with mineralogy rather than elemental composition. Further, our theoretical approach to reservoir properties relies on mineralogy. We have developed normative mineral algorithms to convert the elemental data to mineralogy (Spencer, Weedmark and Besplug, 2016). Comparison of our XRF determined mineralogy and XRD determinations (115 samples from four different labs) for four Montney wells are shown in Figure 1.

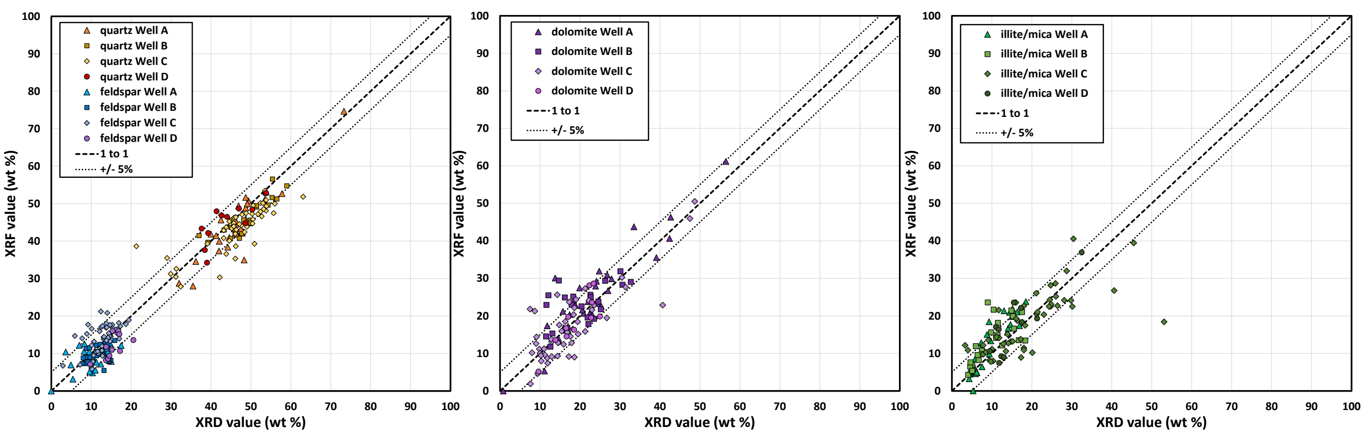

Figure 1. Comparison of XRF and XRD mineral determinations.

SEM Imagery

SEM grey-scale backscatter and corresponding false color element map images from a polished slab of the Montney Formation are shown in Figure 2. The sample is taken from core collected at 10-08-79-14W4 (British Columbia). The images contain rounded plagioclase grains (blue) that range from about 20 to 30 microns; there are also several quartz grains (yellow) with similar size and shape. In contrast to these grains with a detrital fabric, the dolomite (cyan) is much larger and exhibits a pore-filling cement fabric; there are also subtle differences within some of the dolomite masses that appear to define detrital cores. K-spar (magenta) also exhibits a void filling fabric and, like the dolomite, there are subtle differences within some K-spar masses that appear to define detrital cores. Several of the quartz grains are amalgamated with some exhibiting euhedral faces indicating a quartz cement component. Reservoir properties are strongly impacted by the amount and type of cements present. Most obvious visually is the reduction of porosity from the pore-filling cements. The degree and type of pre-compaction cements present in the Montney formation account for the preservation of porosity and brittle nature of this rock.

Three SEM grey-scale backscatter and corresponding false color element map images from polished slabs of the Montney Formation from core 12-19-060-23W5 are shown in Figure 3. The left hand images are from 2742 m, center from 2774 m and right from 2779 m. As in the example above, there are several quartz, plagioclase and K-spar grains that appear to exhibit detrital fabrics. These are less spherical and rounded than in the example above. These grains have similar ranges in size in all three samples; most are from 30 to 60 microns, with an averages of about 50, 40 and 45 microns in the three samples. The sample from 2742 m has the highest porosity (~6%), followed by the sample at 2779 m (~5%) and the sample at 2774 m (~3%).

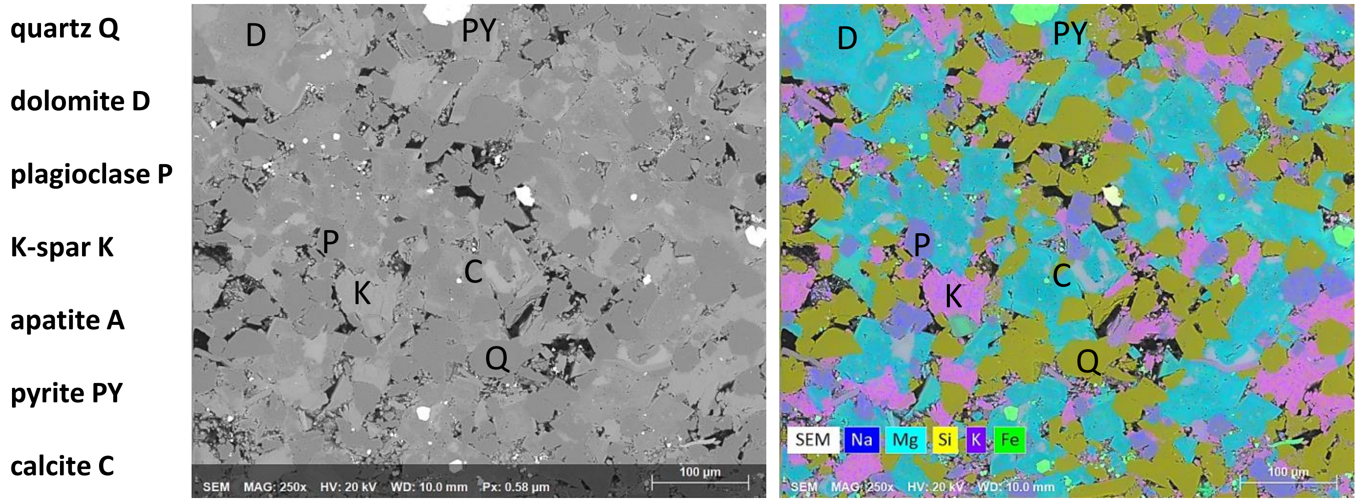

Figure 2. SEM grey-scale backscatter and corresponding false color element map image from a polished slab of the Montney Formation, core 10-08-79-14W4.

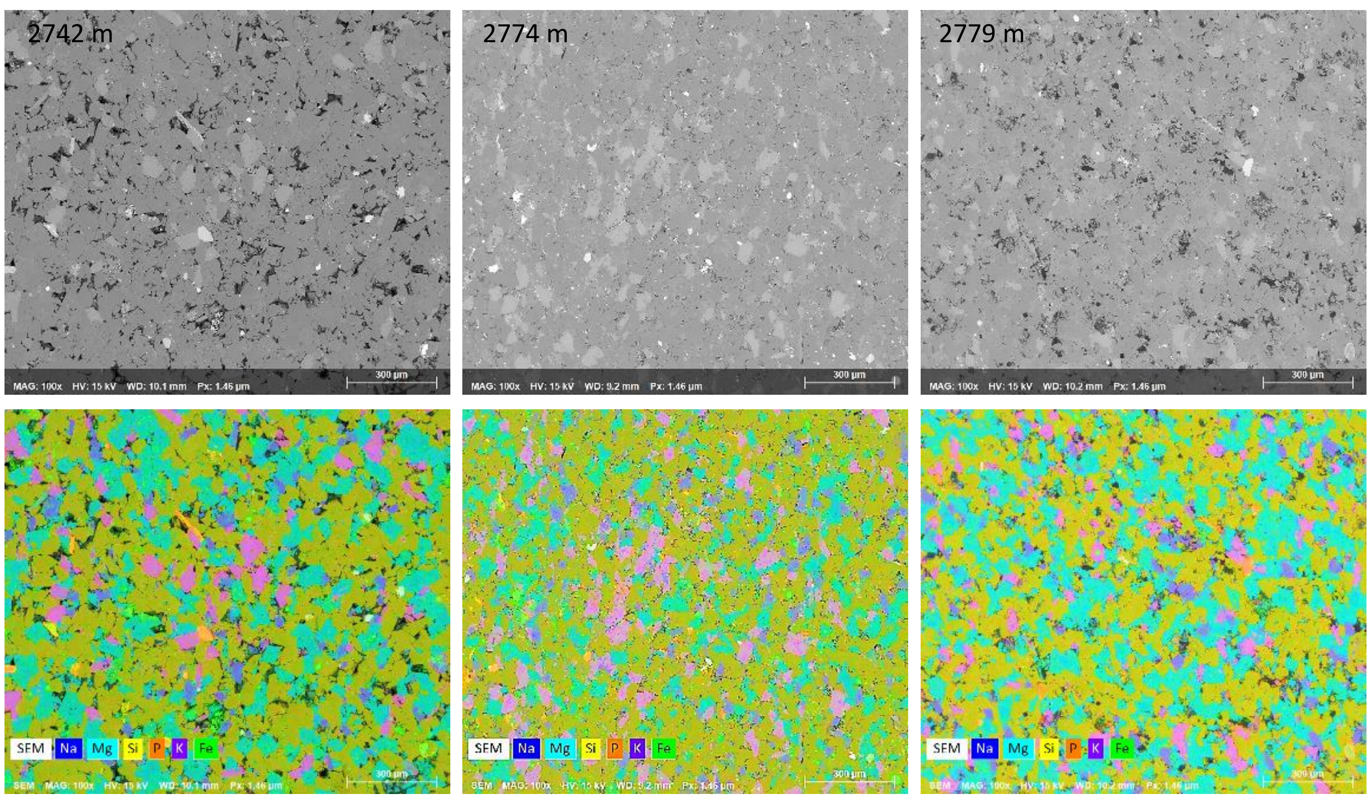

Figure 3. SEM grey-scale backscatter and corresponding false color element map images from three polished slabs of the Montney Formation, core 12-19-060-23W5.

Dolomite in all three samples exhibit void-filling fabrics; these are more abundant in the two higher porosity samples. Although all three samples contain both quartz and K-spar masses that also exhibit void-filling fabrics and/or euhedral terminations; these are far more extensive in the low porosity sample.

These pore-filling cements appear to have formed prior to any significant compaction and inter-grow with one another. Chemical and thermal conditions required for the growth of these cements along with the pre-compaction fabrics indicate an early diagenetic hydrothermal system. Strontium isotope data obtained from dolomite in 22 Montney Formation samples, from core collected at the 10-08-79-14W6 and 2-19-79-14W6 locations, have high radiogenic values in comparison to carbonates from Triassic seawater. Those seawater carbonates have 87Sr/86Sr that range of 0.7075 to 0.7082 (compilation by Veizer), whereas dolomites from the Montney Formation range from 0.7106 to 0.7127.

Conclusions

Information obtained from the SEM analyses give a skeleton picture of the mineralogy and reservoir properties in the Montney Formation. Data obtained from six samples of the 12-19-060-23W5 core are displayed in Figure 4. These data are compared to values determined from 537 XRF analyses of this core. The XRF algorithm was created from parameterization of previous XRF data sets with XRD, wireline and laboratory determinations. The XRF determinations allow the heterogeneity of the well to be assessed at high resolution. The strong correlation between the SEM and XRF data sets give added confidence that both mineralogy and reservoir properties derived from the XRF analyses can be applied to horizontal wells.

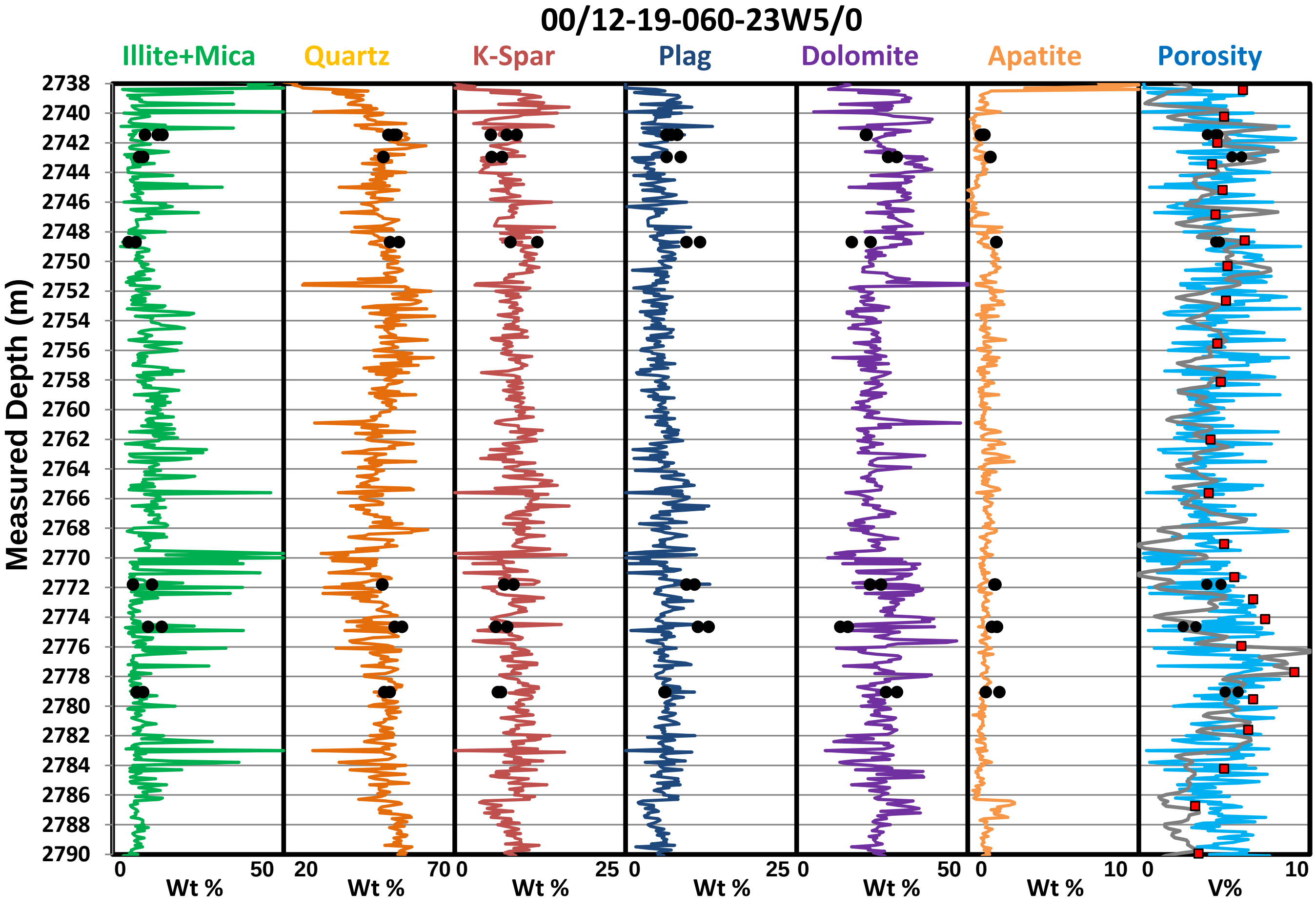

Figure 4. Comparison of SEM data (black circles) for six samples of the Montney 12-19-060-23W5 core with XFR determined values (colored curves). The DPhi porosity curve (grey) and laboratory porosity data (red squares) are also shown for comparison.

Acknowledgements

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