XRF Interpretation: Problems and Possibilities for the Montney

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Summary

Geochemical data acquired from X-Ray Fluorescence (XRF) analysis of horizontal well cuttings can be interpreted to gain an understanding of small scale lateral heterogeneity in unconventional reservoirs. Here we show XRF interpretations from the liquids rich Bigstone Montney field in Alberta. Elemental analysis from a large number of horizontal wells from the same clinoform are correlated with vertical cores to create mineralogical models. Difficulties in extracting lateral information from the analysis are discussed and solutions presented. Interpretation of results from normalized elemental values show smaller scale inter-well lateral heterogeneities and possible fracture related diagenetic changes. XRF interpretations of horizontal well cuttings have potential for increasing our understanding of the Montney Formation and other unconventional plays.

Introduction

The unconventional Montney play is extensively exploited using horizontal wells. Often only a few vertical wells are used to characterize large areas of a given field. While this is useful on a regional scale, rock properties and fluid types can be laterally heterogeneous within much smaller areas. These smaller scaled geological variations can affect productivity and reserve estimation within a field. Moreover, unconventional wells can have horizontal legs longer than three kilometers, allowing room for significant geological changes from well heel to toe.

Drilling records including rate of penetration (ROP), gas composition, and gamma ray data are regularly acquired and analyzed to understand lateral changes in a well. Unfortunately, ROP is often dependent on drilling rig decisions or bit condition, and therefore not a reliable description of rock properties. The drilling records of freed gas composition and gamma response give more useful, but incomplete, descriptions of the rock, and are often very sensitive to small vertical facies changes. Microscopic and visual descriptions of the cuttings are subjective and again inconclusive. Some horizontal wells have petrophysical logs such as density or resistivity in their horizontal legs. There is considerable added expense and delay in acquiring these data. In addition, the logging of horizontal wells also risks damaging or even losing the well bore. Seismic data processed for rock property description often do not have the resolution needed to make meaningful contributions to the understanding of smaller scaled changes. All of these problems make it difficult map and predict lateral rock property variations in a field.

XRF analysis of cuttings can help alleviate this gap in our data. XRF analyses yield quantitative elemental compositions of rock forming elements and minerals as well as and trace elements chemistry. With proper correlation to core mineralogy and regional geology, the elemental data can be used to determine minerology and determine lateral changes of rock properties. Trace element information can also provide lateral information of subsequent diagenetic changes. This understanding of lateral variations can lead to changes in drilling or completions even within the length of a well bore.

Horizontal XRF Cuttings Analysis

XRF analysis of drill cuttings can be processed to determine the minerology and reservoir properties throughout the horizontal well bore. XRF is a rapid, non-destructive, low cost, technique with no risk to the wellbore. Most previous work on horizontal cutting analysis has emphasized the benefits of using XRF to help understand the vertical position of well trajectories, utilizing the chemical changes that occur vertically above and below target formations. This is very useful for geo-steering while drilling and for analysis of where a drilled well's trajectory is located stratigraphically. In this study, we attempt to understand lateral changes in the formation. These changes could be due to depositional environment, or to later diagenetic changes possibly as a result of hydrothermal fluids flowing along the formation or vertically through fractured corridors, or to some other geological phenomena.

The data base for this study include XRF analyses of cuttings analyzed every 10 m from more than 25 horizontal wells in the Montney Bigstone Field. In addition, we performed XRF analysis of the core and cuttings from three vertical wells in the area. As a quality control step, a prediction of the gamma was made using the XRF derived quantities of radioactive elements, K, U and Th. Excellent correlations between the XRF gamma prediction and actual gamma recorded during drilling gives confidence that the XRF analyses give reasonable estimations of the rock, and that the samples are registered at the correct depth (Fig 1). The elemental analysis show that most of the gamma response is due to potassium, with only minor contributions from thorium and uranium.

XRD and SEM thin section analysis were performed on several samples from the vertical core through the Montney. The results were correlated with the core XRF, and a mineralogical model was created that relates elemental abundances to the mineralogy. Displays comparing the derived mineralogy of the horizontal wells along the well trajectory demonstrate some variability in mineralogical content. A ternary diagram shows that the all wells tend to cluster at around the same proportion of the rock forming minerals (Fig 2). This result was expected, as all the wells are targeting the same Montney clinoform.

It is important to have a good understanding of the regional depositional environment and subsequent diagenesis in order to interpret local lateral changes in horizontal wells with XRF. Studies of the Montney and analysis of nearby cores show that at Bigstone, the Montney is a series of stacked clinoforms deposited in a shoreface to near offshore environment. After lithification further diagenesis created a relatively tight condensate reservoir. Tectonic and differential compaction events are expected to have created natural fracture systems, some of which still may be able to transport fluids. At Bigstone, the top of a clinoform called locally the Montney D1 has relatively good characteristics for porosity, permeability and thickness. This is the major target for horizontal drilling in the field, and the main target of the horizontal wells used in this project. Initial production from a horizontal Bigstone well is commonly over 1000 BOED with over 100 bbl/mmcf condensate after ninety days; these are considered good wells for this play.

Horizontal wells are not uniformly horizontal. This is because they follow a particular facies or structural dip and also because of difficulties in keeping a drilling bit in a particular facies; a drilled horizontal well trajectory has many undulations. These bumps and valleys cause the well to encounter vertical changes in facies, especially in thinly bedded formations like the Montney. If the trajectory of our horizontal wells stayed in the same lithological facies vertically, the variation on the recorded gamma ray is expected to be minor. This is seldom the case with the recorded gamma ray logs or the XRF predicted gamma ray. This continuous vertical change in facies creates complications with lateral elemental analysis. Rocks with a different mineralogical composition also show different compositions of trace elements. The challenge when trying to interpret lateral rock property changes is to remove the "noise" of these vertical facies changes.

Examples of Lateral Change from Bigstone

One way to account for this vertical change is to normalize the elemental data. Zinc is a good element for determining the presence of hydrothermal fluid flow, as it can be deposited as zinc sulfide. In the Montney, zinc also is associated with finer grained lithofacies that have greater amounts of micas and illite clays. These micas and clays contain substantial amounts of potassium. By normalizing the zinc abundances to that of potassium, the effect of vertical lithological variations can be somewhat alleviated. Figure 3 shows the zinc abundance in ppm through the Bigstone area. Figure 4 shows the zinc abundance normalized to potassium. The well to the east has higher water cuts and hydrogen sulfide levels attributed to fracturing providing a conduit to deeper Paleozoic waters. Zinc anomalies are present in two places on the well trajectory. To the west, a series of wells show what could be a halo of zinc deposition from a hydrothermal plume passing through the Montney. Quartz and carbonate overgrowths from hydrothermal fluids occlude permeability and impact stimulation of the reservoir. Other normalization methods and elements can provide new interpretations and insights.

Conclusions

XRF analysis of horizontal well cuttings is a safe, reliable and inexpensive technique providing a large amount of information along the horizontal trajectory of a well. By accounting for the vertical facies elemental variations that are prevalent in horizontal well trajectories, we can extract an image of smaller lateral variations. Interpretations of these leads to a better understanding of local, lateral variations. At Bigstone, zinc anomalies point to areas with hydrothermal overprints. Ideally, drilling and completions operations can be optimized using this new subsurface understanding.

Acknowledgements

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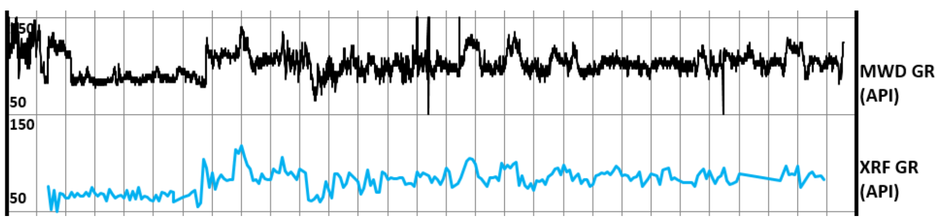

Figure 1. Gamma from drilling record (MWD GR) and XRF predicted gamma (XRF GR). MWD GR has many spikes and zeros from instrument noise, and many more samples. In general, the XRF GR correlates with MWD GR change at the correct locations and close to the correct magnitude.

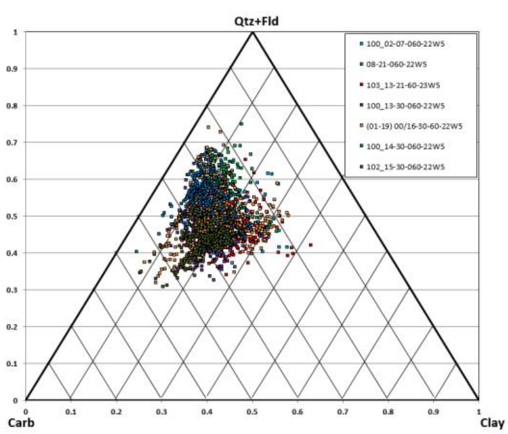

Figure 2. Percentages of major rock forming minerals of Bigstone Montney clustering at around the same percentages on ternary diagram.

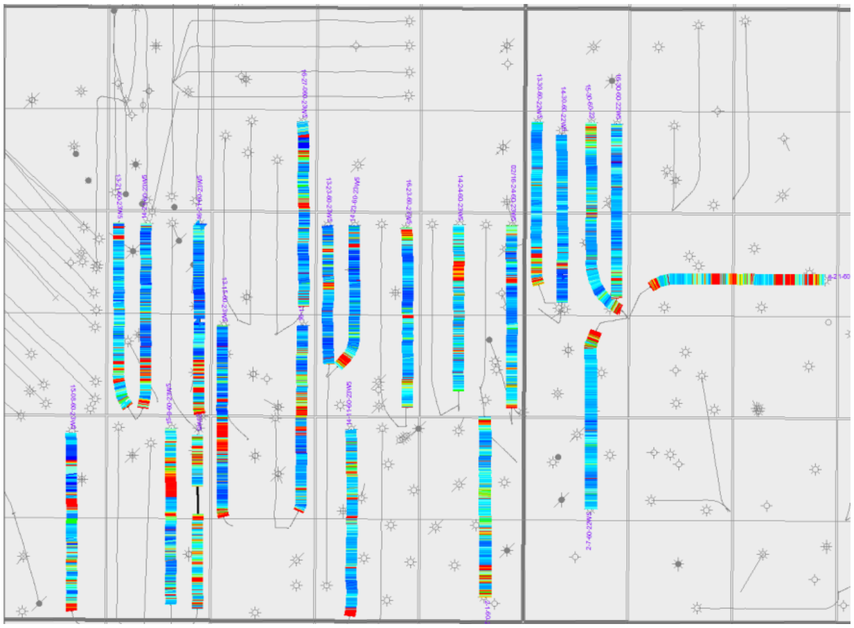

Figure 3: Zinc abundance in ppm at Bigstone

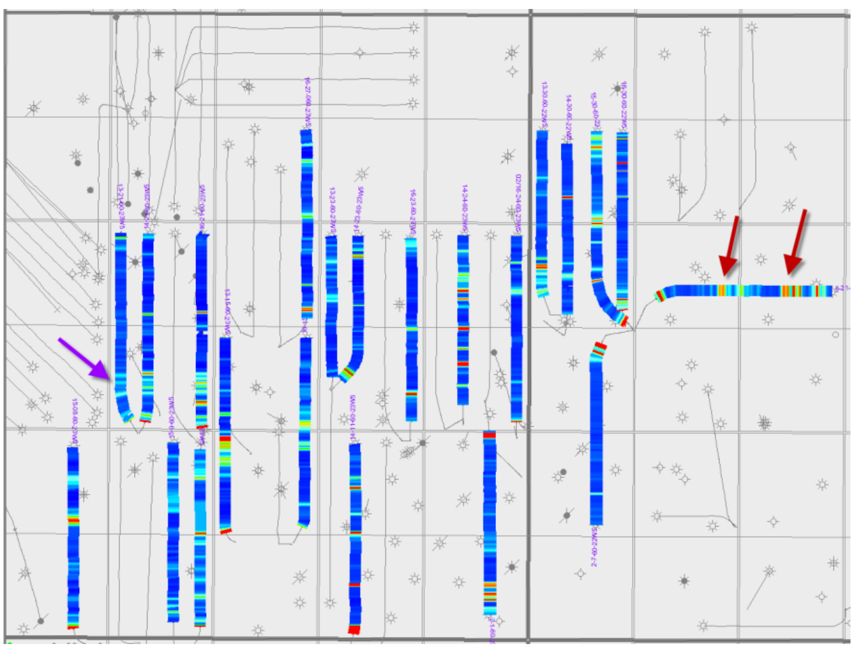

Figure 4. Zinc abundance normalized to potassium abundance. Red arrows point to interpreted hydrothermally alteration from Paleozoic fractures. Water inflow was shut-down in this well with a plug before the eastern arrow. The purple arrow points to a suspected hydrothermal plume that created a halo of zinc sulfides.