

Application of X-Ray Fluorescence (XRF) Analyses to the Characterization of Oil Sand Reservoirs

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Summary

X-Ray Fluorescence (XRF) analyses allow a large amount of data to be obtained from oil sands cores in a short amount of time, with minimal sample preparation and at low cost. XRF analyses provide highly precise, and if calibrated properly, accurate data on the bulk chemistry of a sample. The chemical data can be converted into forms more applicable to geoscientists and engineers, providing mineral compositions and reservoir properties.

Introduction

The bulk chemical composition of rocks are determined rapidly and at relatively low cost using X-Ray Fluorescence (XRF) analysis. Rock powders, cuttings, slabs or core faces can be analysed directly using this technique. Surfaces of slabbed oil sands core can be analysed directly using portable XRF instruments, eliminating the need to extract the bitumen from the sample prior to analysis. Elemental data obtained from the XRF analyses can be useful in determination of a chemical stratigraphy. However, geoscientists and engineers are more familiar with and work with mineralogy and reservoir properties rather than elemental composition. We have developed normative mineral and reservoir property algorithms to convert the elemental data into these more familiar forms.

Mineral and trace element distributions define chemical stratigraphic units and provide insight into variations in the source of sediments. The mineralogy and elemental data are also used to determine reservoir properties through a set of semi-empirical equations. Porosity values determined from mineral volumes obtained using the XRF data are compared with porosity determined from wireline logs and Dean-Stark analyses. Oil (bitumen) and water saturations obtained from the XRF data are compared to data obtained from Dean-Stark analyses. Several thousand oil sand samples have been analysed, porosities calculated and comparisons made to values from wireline logs. Fewer Dean-Stark analyses (several hundred) are available from this data set; these have also been compared with the XRF results. There is excellent agreement among the data sets.

Oil (bitumen) quality in terms of viscosity and sulphur content is also determined from the XRF data using semi-empirical algorithms. There are very few laboratory analyses of viscosity and sulphur content from samples in our XRF data base for comparison. These algorithms are therefore not as rigorous as we would like at this time.

Methods and Theory

XRF analyses are relatively straight forward. X-Rays of a given energy are accelerated toward the sample. The X-Rays penetrate the sample, encounter and excite elements. Each excited element gives off X-Rays with an energy distribution specific to the element as it returns to the ground state. These X-Rays are detected by the instrument. Essentially the data obtained are proportional to the number of atoms of a specific element present in the excited volume. We use two source beams at 8 and 45 Kev for excitation,

the higher energy beam penetrates the sample more deeply. The data obtained have a very high precision, that is if we analyse the same sample several times we get the same results. However, the instruments are not accurate; data obtained need to be calibrated to standards.

Once data are obtained and calibrated mineralogy is determined using normative mineral algorithms. A “specific mineral interaction” model is used to determine reservoir properties. The general formula is:

$$RP = \alpha(RP) + \sum \beta_i^0 DV_i + \sum \sum \beta_{ij}^1 DV_i DV_j + \sum \gamma_i CV_i + \sum \theta_i RV_i$$

Where RP is a reservoir property such as porosity, permeability, Poisson’s ratio, Young’s modulus, etc. $\alpha(RP)$ is a function of the reservoir property, β^0 , β^1 , γ and θ are fabric dependent phenomenological coefficients that vary as a function of T, P (depth) and rock composition. DV_i is the detrital volume fraction of solid phase i, CV_i is the cement volume fraction of solid phase i and RV_i is the recrystallized volume fraction of solid phase i.

Examples

We have tested our XRF based normative mineralogy algorithm against a relatively small mineral data base from X-Ray Diffraction (XRD) analyses. There is a general correspondence with random scatter and a systematic variation in the amount of clay present; the XRF analyses show consistently higher clay content in the bitumen saturated sands than do the XRD results. XRD analyses require the removal of bitumen from the sample prior to analysis; fines, clays, are lost during the bitumen extraction. We do not feel that a sufficient, high quality data base for the mineralogy of the oil sands exists, nor can one be obtained, from XRD analyses. We find better correspondence of our XRF mineralogy with point counts made from thin sections and area maps from SEM images; however, the data base is extremely small. Given the preparation time and expense of these analyses it is unlikely that a sufficient data base can be obtained from these techniques.

We feel a better test of our algorithms is with the match to porosity data. We have analyzed over 7000 sample points from oil sands cores using XRF at the time of writing this abstract. All of these cores have density porosity values from wire line logs. This larger data base provides for a much better test of the algorithms. The XRF porosity values are derived from the “specific mineral interaction” model which employs the normative mineral determinations from the XRF data. Porosity values obtained from the “specific mineral interaction model” are sensitive to the mineralogy, particularly in the amount and type of clay minerals present. Therefore, we feel that comparison of the XRF derived porosity values with those obtained from wire line logs is the best available means to test our mineralogy determinations. The XRF data are from analyses of discrete, centimeter diameter points; whereas the log data average a rock volume. As a result we can analyze a relatively small shale clast or thin lamina within a sand body, which may not be seen in the log data. The different scales of the analyses in the two data sets can lead to mismatches. Considering these differences we obtain an excellent match of the wire line log derived porosities and our XRF determined porosities as exemplified for the data from three cores in Figure 1.

We have also developed algorithms for determination of the amount of bitumen present in a sample. The X-Ray signals from light elements, such as carbon, are attenuated in air and cannot be detected using portable XRF instruments (Mg is the lightest element we can detect with our instruments). However, S and trace elements contained in the bitumen can be used to determine the amount present in a sample. The bitumen content of samples from the three cores above determined using the XRF data are shown in Figure 2. These analyses are from 1 centimeter diameter spots within the core. As in the case of the porosity analyses above, data are from a range of sample types including individual shale clasts, shale lamina and beds, and bitumen saturated or clean sands. The high frequency variations in the amount of bitumen present are a result of the analysis of these different lithologies in close proximity to one another.

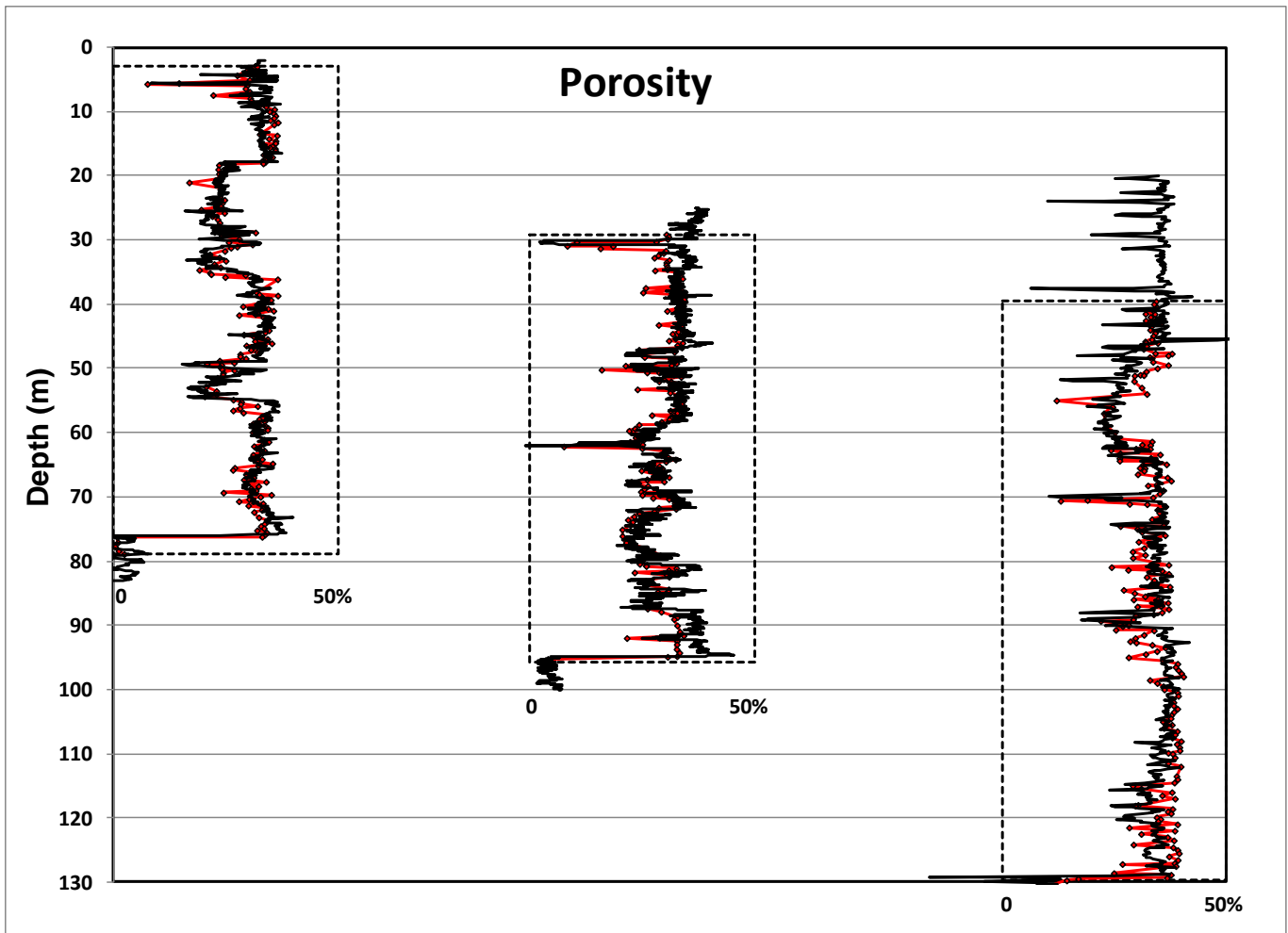


Figure 1. Porosity. Porosity values determined from XRF analyses of three oil sands cores (connected red diamonds) are compared to corresponding values from wire line logs (black curves). Cored intervals are outlined in dashed boxes. There are about 200 XRF points for each core.

Data from Dean-Stark analyses of these same three cores are also displayed in Figure 2 as black triangles for comparison. These measurements are from a volume of material, several, to a few tens of centimeters each. A single sample may contain variable amounts of bitumen saturated sands and shale that does not contain bitumen. Although the two sample sets are somewhat different in their make up, there is still an overall good correspondence among the two data sets.

We are also working on determination of the bitumen quality from the XRF data set. Results to date are not as good as we would like, but do show promise. For instance, our determination of the S content of relatively high quality bitumen is in good agreement with a handful of laboratory determined values. However, our determination of the S content of low quality, highly degraded bitumen appears to be much too high. Further work to understand where the S is in the degraded intervals is in progress. Likewise, we are able to determine bitumen viscosity which match laboratory data for some cores, but the same algorithm applied to others does not yield satisfactory results.

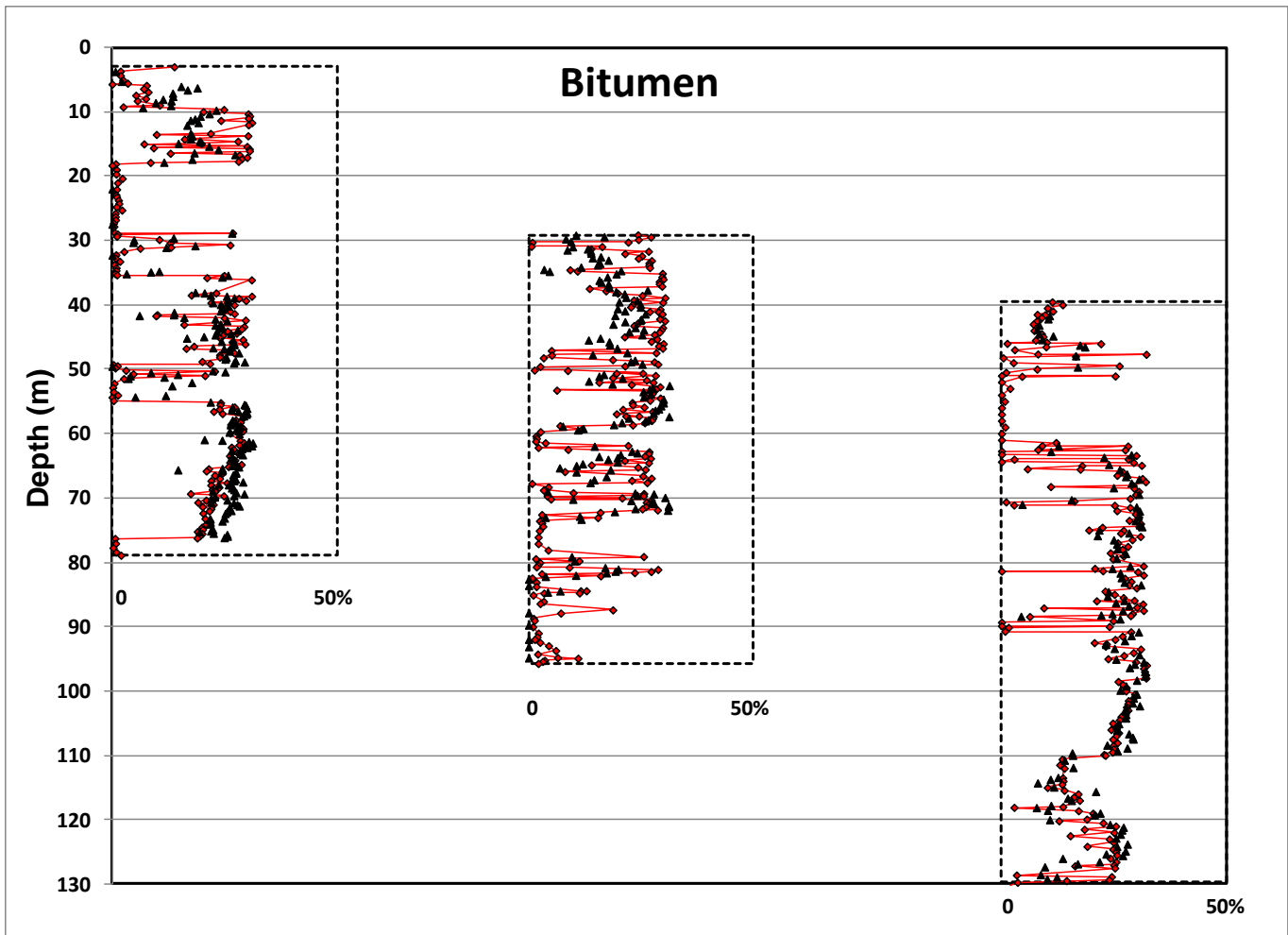


Figure 2. Bitumen Content. Bitumen content determined from XRF analyses of three oil sands cores (connected red diamonds) are compared to corresponding values from wire line logs (black triangles). Cored intervals are outlined in dashed boxes. There are about 200 XRF points for each core.

Conclusions

X-Ray Fluorescence (XRF) analyses allow the collection of up to 200 high quality data points to be obtained from oil sands cores in a single day with minimal sample preparation. XRF analyses provide highly precise, and if calibrated properly, accurate data on the bulk chemistry of a sample. The chemical data can be converted into forms more applicable to geoscientists and engineers, providing mineral compositions and reservoir properties in a timely and cost-effective manner.

Acknowledgements

We thank a company that wishes to remain anonymous for permission to use the data presented here.