RAPID ESTIMATION OF HYDRAULIC FLOW UNIT PARAMETERS RQI AND FZI FROM MAGNETIC MEASUREMENTS IN SOME SHOREFACE RESERVOIRS

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ABSTRACT

Petrophysical analysis of reservoirs often involves calculating key hydraulic flow unit parameters, such as the reservoir quality index (RQI) and the flow zone indicator (FZI), from core porosity and permeability measurements. The purpose of the present study was to see whether there were correlations between these hydraulic unit parameters and magnetic susceptibility measurements on core plugs from two oil wells in shoreface reservoirs in the North Sea. Good correlations could potentially allow future rapid estimation of RQI and FZI from magnetic measurements long before the conventional core porosity and permeability data normally becomes available. The main control on permeability in the two oil wells was illite clay, and the results showed good correlations between magnetically derived illite content (from the magnetic susceptibility measurements) and each of the parameters RQI and FZI in both wells. In one of the wells, where we had additional mineralogical data from X-ray diffraction (XRD), we obtained slightly improved estimates of the magnetically derived illite content by correcting for the presence of pyrite. This in turn led to slightly better correlations with RQI and FZI than the raw uncorrected values. Significantly poorer relationships were observed between XRD derived illite content and each of the parameters RQI and FZI. This may in part be because XRD is generally regarded as a semi-quantitative technique, whereas the magnetic method is extremely sensitive at quantifying the mineral components if the mineralogy is known. Also the XRD analyses required powdered samples that were much smaller than the core plugs used for the magnetic measurements, and therefore were not volumetrically identical to the core plug scale. The magnetic method is very rapid, non-destructive, easy to undertake and inexpensive. The good relationships generated in this study demonstrate its potential usefulness for rapidly estimating the hydraulic flow unit parameters RQI and FZI in these shoreface reservoirs. These measurements potentially allow field development decisions to be made at an earlier stage (before the conventional porosity and permeability data become available) in future cases in similar reservoirs, and this may have associated economic benefits.

INTRODUCTION AND METHODOLOGY

Recent studies have shown correlations between magnetic susceptibility, clay content and key petrophysical properties such as permeability [1,2]. The purpose of the present study was to see if rapid, non-destructive magnetic susceptibility measurements also correlate with the key hydraulic flow unit parameters reservoir quality index (RQI) and flow zone indicator (FZI). These parameters were first proposed by Amaefule et al [3] as a means of splitting a reservoir into quantifiable hydraulic flow units, and the methodology has been widely adopted in the industry. All samples in a particular hydraulic flow unit have similar values of FZI, which is related to porosity and permeability as follows:

$$\mathrm{FZI} = \mathrm{RQI} / \Phi_z \qquad (1)$$

where RQI is the reservoir quality index ($= 0.0314 \sqrt{\{K/\Phi_e\}}$ where K is the permeability and Φ_e is the effective porosity), and Φ_z is the pore volume to grain volume ratio ($= \Phi_e/1-\Phi_e$). The present study determined the FZI and RQI values for several hundred core plugs from the conventional core porosity and permeability data in two wells (Well 2 and 2a) containing shoreface reservoirs in a North Sea oilfield. The FZI and RQI values were then compared to the illite content derived from magnetic susceptibility measurements on the identical conventional core plugs. These measurements were obtained using a Molspin magnetic susceptibility bridge. Each measurement, which requires a background reading followed by a core plug sample reading, can be acquired in about 5 seconds. Thus many samples can be measured extremely rapidly. Assuming a simple mixture of quartz and illite (which was a reasonably good assumption according to our XRD data), then following the procedure of Potter et al [1,4] the fraction of illite, F_I, is given by:

$$F_I = (\chi_Q - \chi_T) / (\chi_Q - \chi_I) \qquad (2)$$

where $(1- F_I)$ is the fraction of quartz, and χ_I and χ_Q are the magnetic susceptibilities per unit mass of illite and quartz (15×10^{-8} m^3 kg^{-1} and -0.62×10^{-8} m^3 kg^{-1} respectively). In Well 2a we were also able to compare XRD derived illite content with RQI and FZI. The XRD data was acquired using the Siroquant technique, which quantifies clay and non-clay minerals in one run.

RESULTS AND DISCUSSION

Figure 1 shows crossplots of magnetically derived illite content against RQI (top) and FZI (bottom) for the nearly 300 core plugs in Well 2. The R^2 regression coefficients are relatively high (0.73 and 0.67 respectively) demonstrating good correlations between the hydraulic unit parameters and the magnetically derived illite content. The correlations might be expected given that a correlation was previously identified between permeability and magnetically derived illite content [1], and porosity is relatively constant. **Figure 2** shows crossplots of magnetically derived illite content (corrected for the presence of pyrite) against RQI (top) and XRD derived illite content against RQI (bottom) for the 87 core plugs in Well 2a. Whilst the R^2 regression coefficient is quite high (0.80) for the magnetic data, it is significantly lower (0.31) for the XRD data. A similar pattern is evident in **Figure 3**, which shows crossplots of magnetically derived illite content (corrected for the presence of pyrite) against FZI (top, with $R^2 = 0.76$) and XRD derived illite content against FZI (bottom, with $R^2 = 0.27$) for the 87 core plugs in Well 2a. Whilst XRD is good at identifying which minerals are present, it is a semi-quantitative technique, which may partly explain the poorer correlations with RQI and FZI. It may also partly be due to the XRD analyses requiring powdered samples that were much smaller than the core plugs used for the magnetic measurements, however, since the magnetic measurements indicate several samples with low illite content it seems unlikely that many of the XRD samples merely sampled the more illite rich zones. We have greater confidence in the magnetic measurements that are extremely sensitive to small amounts of illite clay (with uncertainties of less than ± 0.1%, compared to at least ± 0.5% for the XRD measurements). Note also that the differences between the magnetic and XRD values at low illite content appear exaggerated due to the logarithmic scale. There are also instances where the magnetic measurements give a higher illite content than XRD. This may partly be due to a very small amount of ferrimagnetic material in the samples (causing a slight overestimate in magnetically derived illite content), or that XRD may not see some very fine grained amorphous illite within the samples.

CONCLUSIONS

1. Good correlations exist between the hydraulic flow unit parameters (RQI, FZI) and magnetically derived illite content in Wells 2 and 2a. Hence, the magnetic method shows good promise for rapidly and non-destructively estimating the hydraulic unit parameters in this type of shoreface reservoir where porosity remains fairly constant and permeability varies with illite content.
2. Significantly poorer relationships were observed between the hydraulic flow unit parameters and the XRD derived illite content. This may be due to some of the reasons suggested in the Results and Discussion section. Unlike the XRD technique, which is more expensive and requires extra time for preparation, the magnetic method is rapid, sensitive, easy and less expensive for predicting the hydraulic flow unit parameters.
3. The correlations between the hydraulic flow unit parameters and magnetically derived illite content in Well 2a were very slightly better after the magnetic susceptibility results were corrected for the presence of paramagnetic pyrite (identified from XRD data).

ACKNOWLEDGEMENTS

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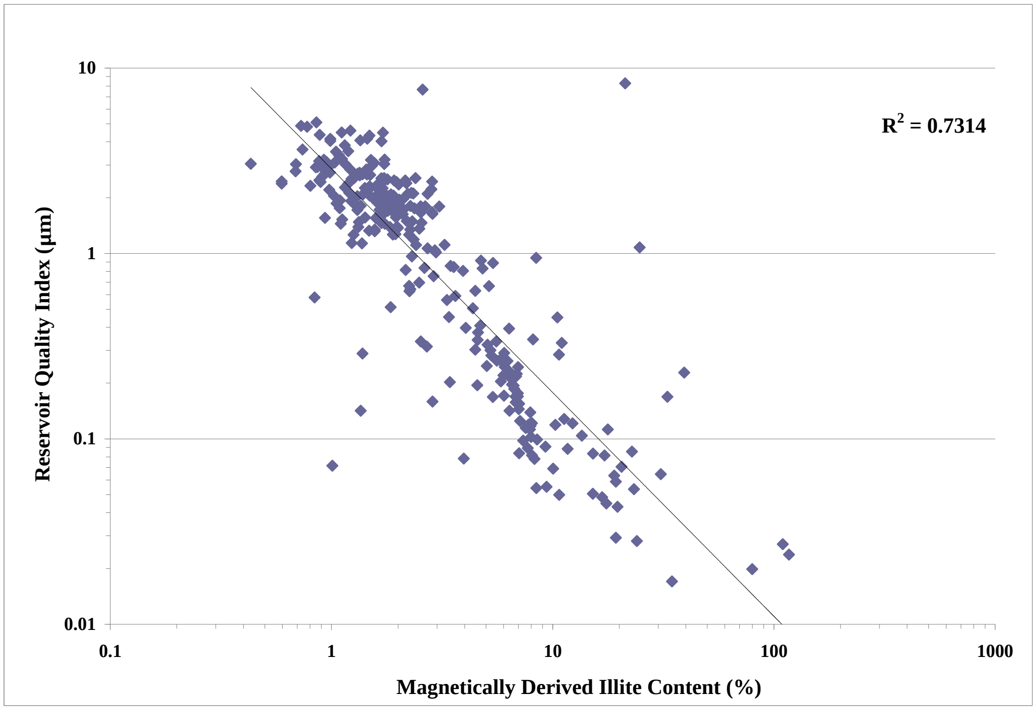


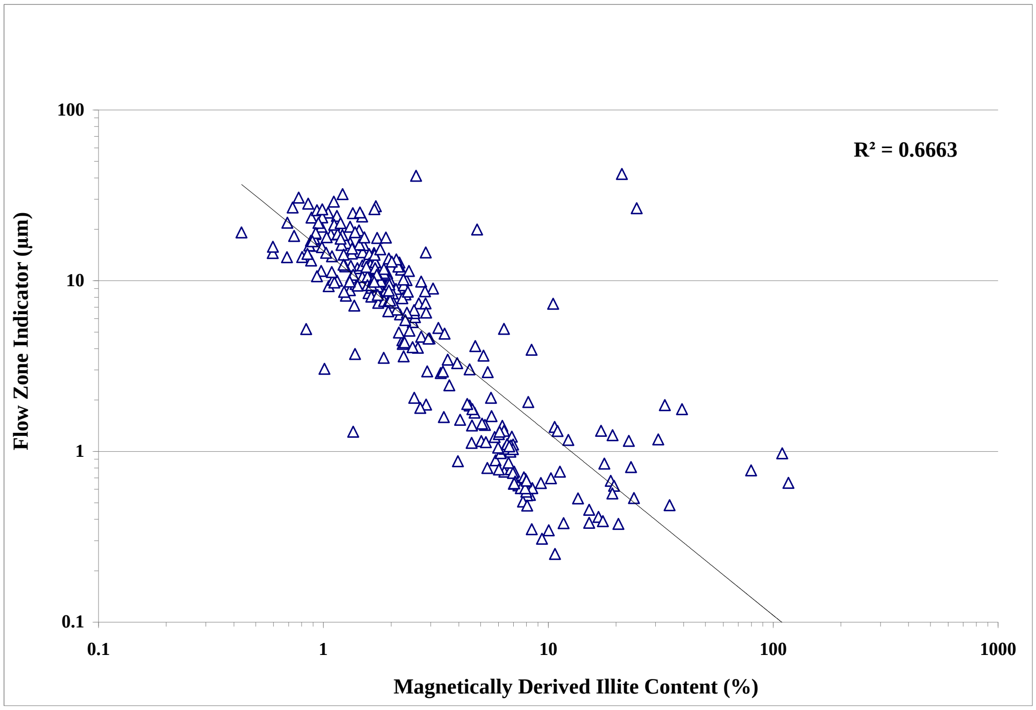
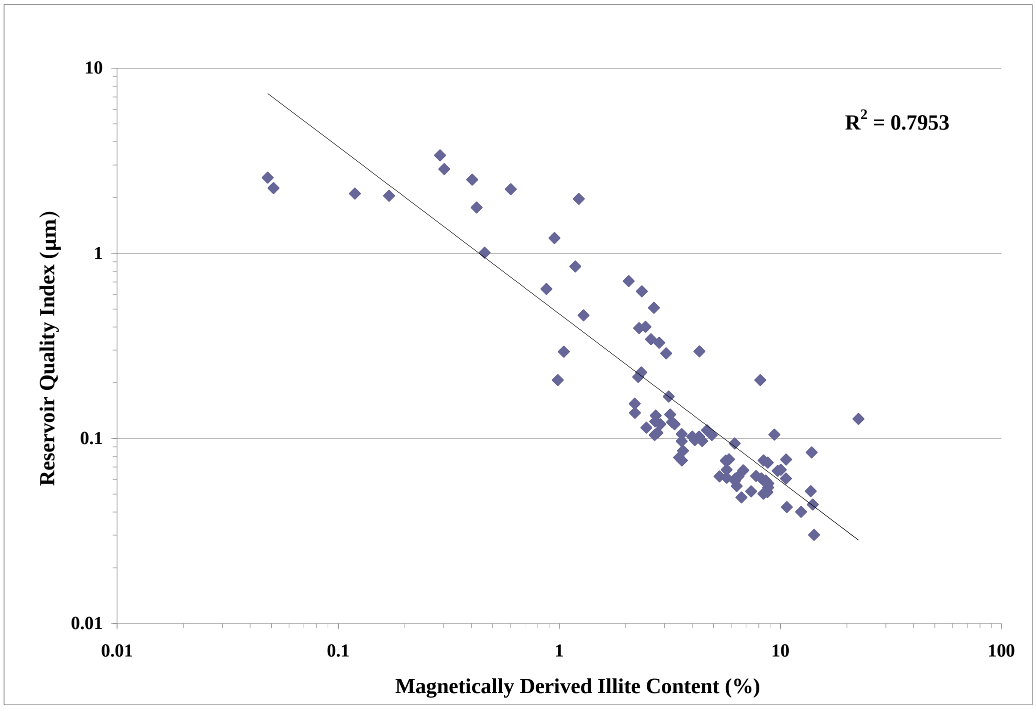


Figure 1. Crossplots of magnetically derived illite content against RQI (top) and FZI (bottom) for the nearly 300 core plugs in Well 2. The cause of the two samples that exhibit "illite" contents just over 100% is most likely due to the samples containing extremely small amounts of ferrimagnetic material.



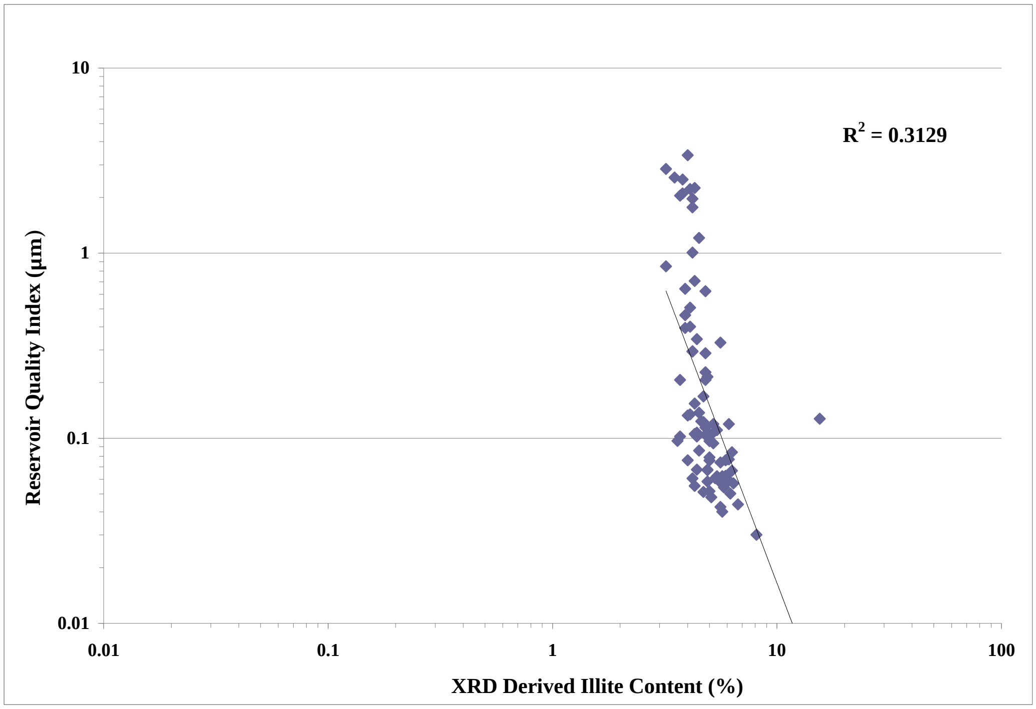
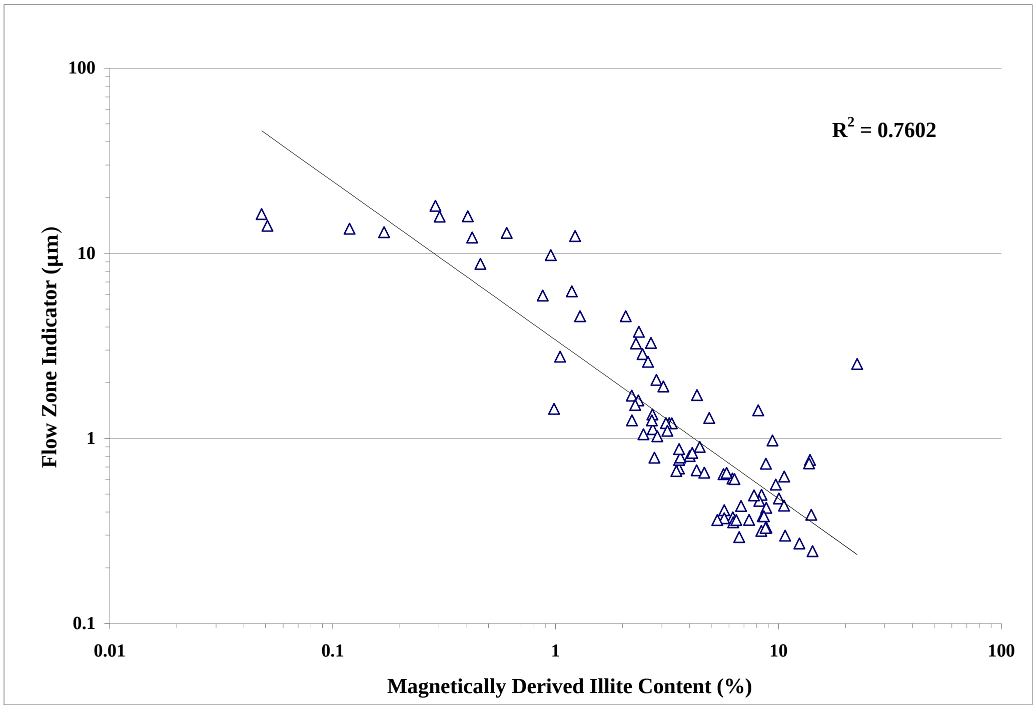


Figure 2. Crossplots of magnetically derived illite content against RQI (top) and XRD derived illite content against RQI (bottom) for the 87 core plugs in Well 2a. The magnetically derived illite content was corrected for the presence of small amounts of pyrite (identified from XRD). This made only a slight difference to the regression, since the R^2 value for the uncorrected data for the top figure was 0.7933.



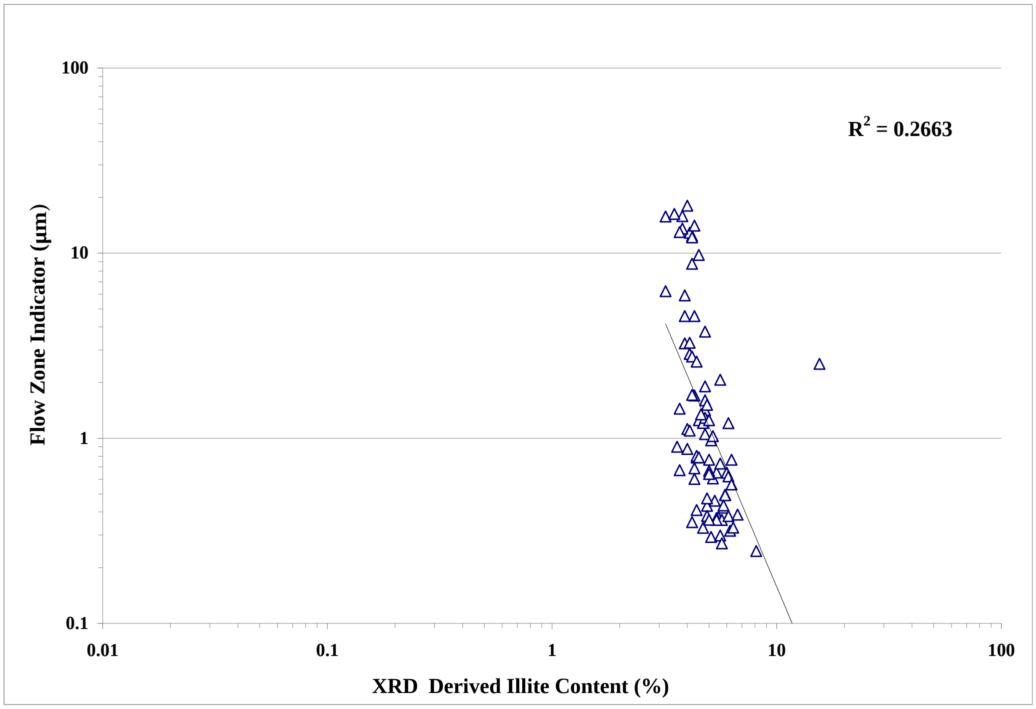


Figure 3. Crossplots of magnetically derived illite content against FZI (top) and XRD derived illite content against FZI (bottom) for the 87 core plugs in Well 2a. The magnetically derived illite content was corrected for the presence of small amounts of pyrite (identified from XRD). This made only a slight difference to the regression, since the R^2 value for the uncorrected data for the top figure was 0.7579.