CORRELATION BETWEEN MAGNETIC PROPERTIES AND PERMEABILITY: RESULTS FROM A NEW CASE STUDY IN THE NORTH SEA

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ABSTRACT

A new case study on a siliciclastic North Sea shoreface reservoir has shown correlations between magnetic susceptibility, paramagnetic clay content and permeability, consistent with previous work. The previous work looked at a shoreface reservoir in a different field and utilised conventional core plugs 1 inch diameter by 1.5 inches long. The new study has undertaken magnetic measurements at two different scales: probe sensor magnetic susceptibility (on the scale of a few millimetres) for high resolution measurements on slabbed core, and coil sensor magnetic susceptibility measurements on larger 1.5 inch diameter by 3 inch long plugs. The probe and plug magnetic measurements gave very similar profiles with depth within the same cored interval. The raw magnetic susceptibility measurements from the probe and plug data picked out the main reservoir intervals very well. The processed results showed strong correlations between magnetically derived illite content and permeability. Moreover, the correlations were very similar to those in the previously studied North Sea shoreface reservoir in a different field. The results suggest there may be specific relationships between magnetic susceptibility, clay content and permeability for this type of reservoir, and validate our previous suggestions that magnetic susceptibility measurements can rapidly and non-destructively predict key petrophysical parameters (clay content, permeability) at various scales on recent or historical core samples.

INTRODUCTION

A previous study (Potter, 2007) demonstrated a strong correlation between magnetically derived illite content and permeability using 1 inch diameter by 1.5 inch long core plugs in shoreface reservoir intervals in a North Sea oilfield. The new study presented here is on another siliciclastic shoreface reservoir in a different North Sea field, and utilized 1.5 inch diameter by 3 inch long plugs and slabbed core. One of the objectives was to see whether the relationship between magnetic properties and permeability was similar to that obtained in the previous study. Another objective was to see whether the two different scales of measurement in the new study gave comparable results. The volume of investigation of the slabbed core readings is much smaller than that of the plugs. Most of the signal (over 50%) from the probe sensor measurements on the slabbed core comes from a rectangular area 0.15 x 0.41 inch and depth of response of about 0.04-0.08 inch.

METHODS

Magnetic susceptibility measurements were made on the core plugs and slabbed core in a 50.4 m interval of the reservoir. For the core plug measurements we used a Bartington MS2C coil sensor of aperture diameter 1.77 inch (4.5 mm) with an MS3 meter. A background reading was first made with the MS2C sensor empty prior to each plug measurement. Each plug was then positioned coaxially inside the MS2C sensor coil (the mid point along the length of the plug being coincident with the mid point of the sensor thickness) and a magnetic susceptibility measurement was taken. The values were converted to mass magnetic susceptibility by dividing by the bulk density (using the weight and volume of the plugs). The illite content was then derived from the magnetic susceptibility results using equations given in Potter et al (2004) and Potter (2007). The illite content profile with depth was then compared with the air permeability (Klinkenberg corrected) profile. For the slabbed cores we used a Bartington MS2E sensor with an MS3 meter. After a background reading, the sensor was placed on the flat surface of the slabbed core to measure the volume magnetic susceptibility. Measurements were taken at 10 cm spacing down the core. The illite content was then derived from the magnetic susceptibility results using equations in Potter et al (2004) and Potter (2007).

RESULTS AND DISCUSSION

Figure 1 shows profiles of the mass magnetic susceptibility, the illite content derived from the magnetic susceptibility, and the measured air permeability (Klinkenberg corrected) values with depth for a suite of 1.5 inch diameter horizontal core plugs from a Jurassic North Sea shoreface reservoir. The illite profile with depth closely follows the permeability profile, i.e. permeabilities are lower where illite content is high and vice versa. The relationship between the two parameters is further exemplified by Figure 2, which shows a crossplot between the measured air permeability (Klinkenberg corrected) values and the illite content derived from the mass magnetic susceptibility measurements for the core plugs shown in Figure 1. There is a reasonably good correlation between the two parameters with the power regression coefficient of determination $R^2 = 0.62$. We have also used an empirical correlation between magnetically derived illite content and permeability from previous work (from Figure 2 of Potter, 2007) in another North Sea shoreface reservoir in a different field to predict the permeability of the core plugs in the present study. Figure 3 shows a crossplot of the predicted (calculated) versus measured air permeability (Klinkenberg corrected) values for the core plugs in Figures 1 and 2. It shows a quite good correlation between the two sets of permeability values derived from independent means, with the power regression coefficient of determination $R^2 = 0.62$.

Figure 4 shows the high resolution probe magnetic susceptibility results on the 50.4 metres of slabbed core from the same interval as the plugs in Figure 1. The left profile of Figure 4 shows the raw volume magnetic susceptibility measurements, and the middle profile shows the illite content derived from the magnetic susceptibility measurements. The profiles look very similar to those for the core plug data in Figure 1. The right hand diagram of Figure 4 shows two permeability profiles with depth. The black (diamond) symbols are the permeability values derived using the middle illite content profile of Figure 4 in conjunction with the regression equation from the core plug data in Figure 2. The other permeability profile (brown, square symbols) is the air permeability (Klinkenberg corrected) data for the core plugs from the right hand graph of Figure 1. The two permeability profiles closely match in a number of intervals, yet differ in some others. The differences could be due to the presence of other minerals (clays, natural cements etc), since we have assumed a simple quartz plus illite mixture throughout. These intervals would be obvious targets for further mineralogical characterisation by XRD or other techniques. The few XRD analyses we have so far indicate a dominant quartz plus illite/smectite system. However, there is XRD evidence of calcite at depth 4,103 m and of significant kaolinite and some chlorite at 4,114 m. The presence of these minerals (if they act as cements) might help to explain why the actual permeabilities at those depths (Figure 4) are lower than those predicted from our quartz plus illite model. The differences may also be partly due to the heterogeneity of the core. The slabbed core probe measurements reflect the high resolution magnetic susceptibility values over a vertical interval of just a few millimetres, whereas the core plug permeability results reflect a measurement over a much larger volume. Differences may also arise by our use of the regression line from Figure 2, which is not a perfect fit to the plug data.

CONCLUSIONS

1. The raw magnetic susceptibility results from the core plugs and the slabbed core pick out the potentially good conventional reservoir intervals very well (the low negative, dominantly diamagnetic values in the left hand profiles of Figures 1 and 4).
2. The magnetically derived illite content for the core plugs correlates well with the measured plug permeability values, and shows that the core is quite heterogeneous. Moreover, the plug permeability values predicted using an empirical relationship from a previous study in a similar type of reservoir (Potter, 2007) also correlate well with the measured values (Figure 3). This adds support to our idea that there are specific relationships between magnetic susceptibility and permeability for this reservoir type.
3. The slabbed core results show generally similar profiles to those of the core plugs. The predicted permeability profile for the slabbed core agrees quite well with the measured plug permeability profile, and potential reasons for any differences were discussed above.

REFERENCES

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Potter, D. K., 2007. Magnetic susceptibility as a rapid, non-destructive technique for improved petrophysical parameter prediction. *Petrophysics*, **48**, (issue 3), 191-201.

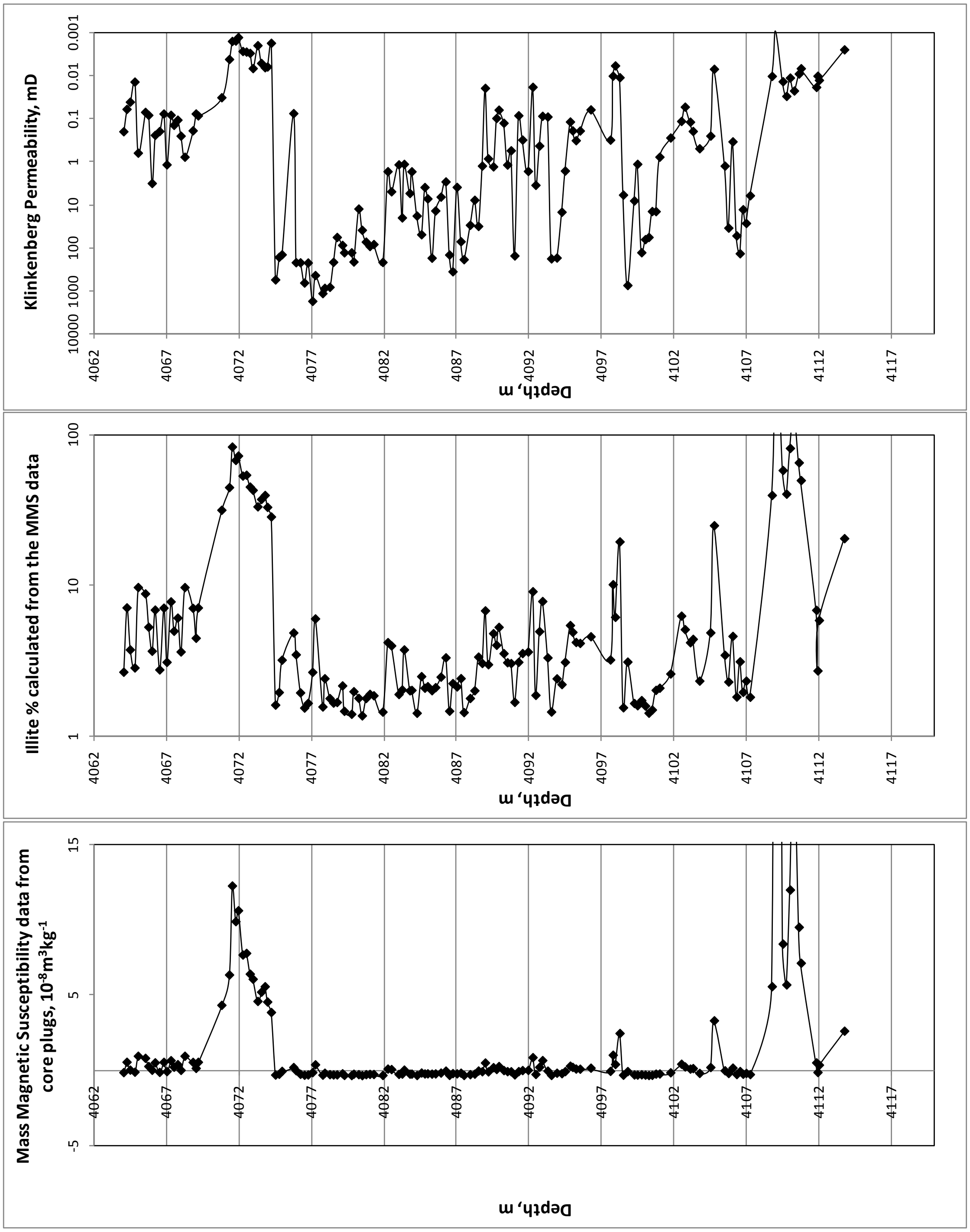

Figure 1. Raw mass magnetic susceptibility (left), magnetically derived illite content (middle), and Klinkenberg corrected air permeability (right) for 1.5 inch diameter by 3 inch long horizontal core plugs in a North Sea Jurassic shoreface reservoir interval.

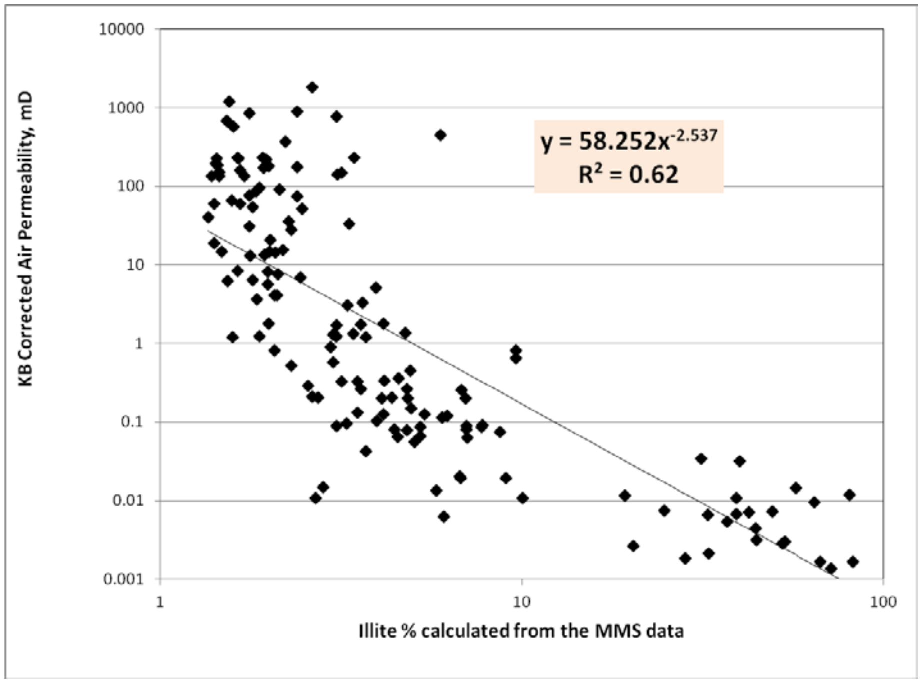

Figure 2. Crossplot of illite content derived from the magnetic susceptibility data versus the measured Klinkenberg corrected air permeability for the core plug results shown in Figure 1.

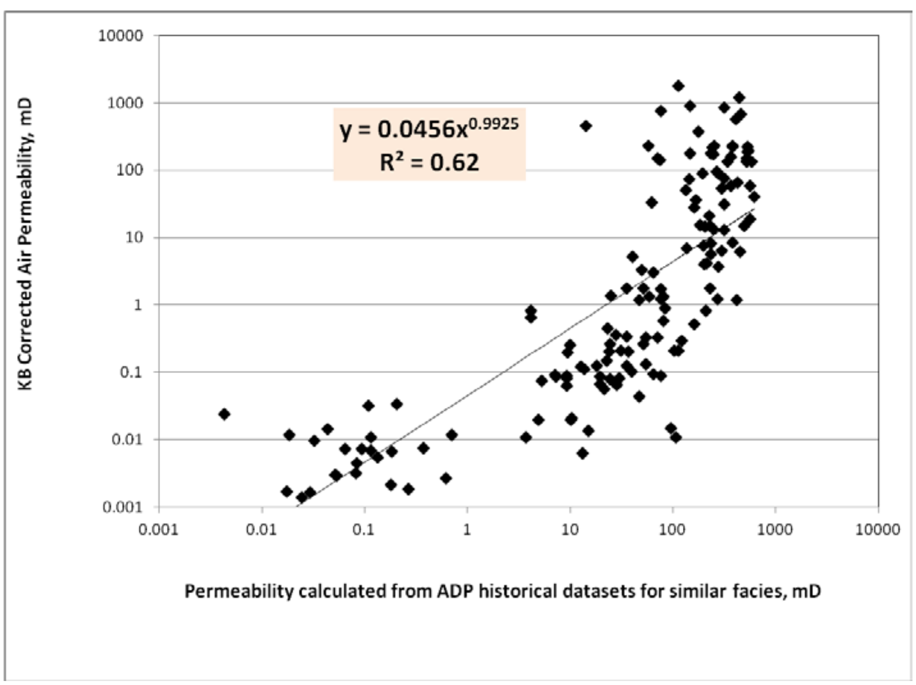

Figure 3. Crossplot of calculated versus measured (Klinkenberg corrected) air permeability values for the core plugs in Figures 1 and 2. The calculated values were derived using an empirical relationship (from Potter, 2007) between magnetically derived illite content and permeability for a similar type of reservoir.

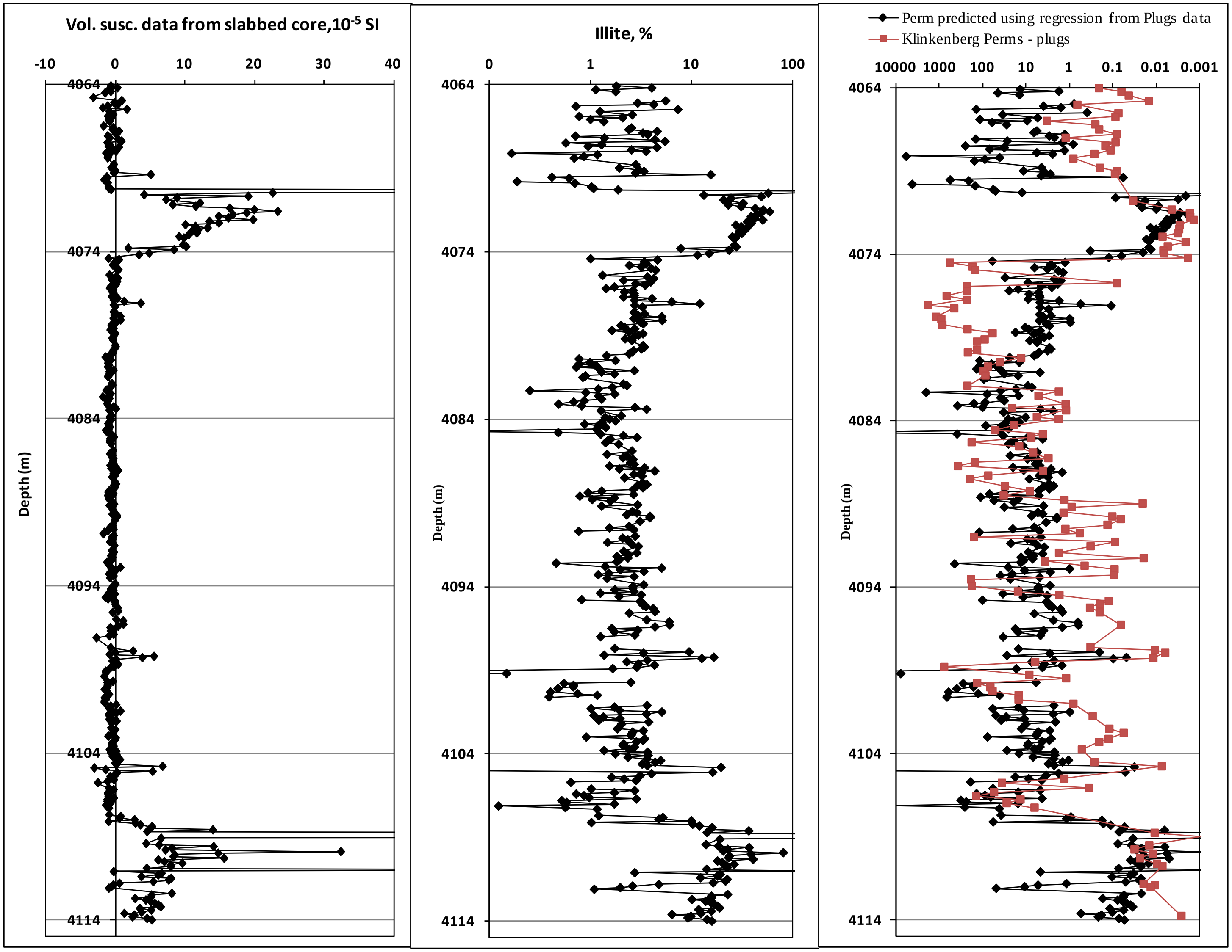

Figure 4. Slabbed core data: raw volume magnetic susceptibility (left), and magnetically derived illite content (middle). The right profile shows the predicted (black diamonds) permeability in mD from the slabbed core, and the measured Klinkenberg corrected air permeability values from the plugs in Figure 1. The predicted values were derived from the illite content above in conjunction with the regression equation for the core plugs in Figure 2.