MAGNETIC SUSCEPTIBILITY OF DRILL CUTTINGS IN A NORTH SEA OIL WELL: A RAPID, NON-DESTRUCTIVE MEANS OF CHARACTERIZING LITHOLOGY

[1]Arfan Ali, [2]David K. Potter and [3]Andrew Tugwell
[1]Shell UK Limited, Aberdeen, UK
[2]Department of Physics, University of Alberta, Edmonton, Canada
[3]Advanced Downhole Petrophysics Limited, Aberdeen, UK

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in St. John's, Newfoundland and Labrador, Canada, 16-21 August, 2015

ABSTRACT

Magnetic susceptibility measurements provide a non-destructive method to rapidly characterize drill cuttings at the wellsite or laboratory. Our previous studies on core plugs, slabbed core and whole core have demonstrated that magnetic measurements can identify lithological variations, estimate mineral content, and correlate with key petrophysical properties (such as permeability) and with downhole gamma ray data. In the present study volume magnetic susceptibility measurements were undertaken on drill cuttings from a North Sea oil well using a portable low field magnetic susceptibility sensor. The values were then converted to mass magnetic susceptibility by dividing by the bulk density of each sample. The results clearly indicated the main lithological zonations in the well, and provided estimates of basic mineral type (diamagnetic versus paramagnetic or ferrimagnetic) significantly quicker and cheaper than undertaking XRD measurements. The magnetic results also showed a correlation with the downhole LWD (logging while drilling) gamma ray profile. Interestingly, the correlation was the opposite way round to that observed in most other reservoirs we have studied. However, this provided additional mineralogical information for the well in the present study. Normally a low gamma ray signal (e.g., in a clean sandstone interval) would give a low or negative magnetic susceptibility due to diamagnetic quartz, whereas a high gamma ray signal (e.g., in shale) would give a higher magnetic susceptibility signal due to paramagnetic clays etc. In the present study many of the low gamma ray sandstone intervals exhibited a higher magnetic susceptibility signal, which indicated that there are additional paramagnetic and/or ferrimagnetic minerals present in those intervals in addition to the main diamagnetic matrix mineral (quartz). These additional higher magnetic susceptibility minerals can, for example, be due to a strongly paramagnetic mineral such as siderite, small amounts of a ferrimagnetic mineral such as magnetite or the canted antiferromagnetic mineral hematite. These minerals can affect the permeability, and may explain why productivity has been lower in this well.

INTRODUCTION

Drill cuttings have generally been a highly under utilized resource in the petroleum industry. Apart from some exceptions, such as the Darcylog^{TM} method to determine permeability [1] and porosity from drill cuttings, there have been very few published studies that have derived mineralogical or petrophysical properties from drill cuttings. Our previous magnetic susceptibility work on conventional core plugs [2], slabbed core [3,4] and whole core [5] proved fruitful in demonstrating correlations between magnetic susceptibility, mineralogy (especially clay content) and key petrophysical properties such as permeability. For instance, our work on North Sea oilfields [2,3] showed strong correlations between magnetically derived illite content and permeability. The present paper describes how magnetic susceptibility measurements on drill cuttings can rapidly and non-destructively identify mineralogical / lithological variations. In the present study we made 421 measurements from 157 bags of drill cuttings from a North Sea oil well. We were told by the operating company that there was an issue in this well, in that the oil production was lower than expected compared to other wells in the same field. We were therefore asked to see if the drill cuttings measurements might provide a possible reason for the lower production.

METHODS

The drill cuttings measurements were performed at Iron Mountain in Dyce, Aberdeen, UK. The sample boxes containing bags of drill cuttings were arranged in order of depth (**Figure 1 (a)**). Each sample bag contained drill cuttings from a particular depth interval. 10cc plastic vials were used as sample pots and were filled with randomly selected "spoonfuls" of cuttings from each sample bag (**Figure 1 (b)**). Volume magnetic susceptibility measurements were undertaken on the vials containing the drill cuttings using a small portable low field Bartington MS2B magnetic susceptibility sensor connected to laptop via an MS3 meter (**Figure 2**). Each sample vial containing drill cuttings was also accurately weighted. Volume magnetic susceptibility measurements were then simply converted into mass magnetic susceptibility as follows:

$$\chi = \kappa / \rho \qquad (1)$$

where χ is the mass magnetic susceptibility, κ is the measured volume magnetic susceptibility, and ρ is the bulk density of the drill cuttings in the vial. The advantage of using mass magnetic susceptibility is that it removes any small effects due to porosity, which can affect the volume magnetic susceptibility measurements. This includes the intrinsic porosity of the individual drill cuttings and also the "porosity" between individual drill cuttings. This ensures that drill cuttings with an identical mineralogy will give exactly the same mass magnetic susceptibility value (whereas they would give different volume magnetic susceptibility values if the amount of those cuttings is different in each sample vial). During the measurement procedure a calibration sample was also measured every hour to check whether there was any drift in the sensor.

RESULTS AND DISCUSSION

The results showed that the mass magnetic susceptibility was positive throughout the 9,000 ft section of the well. Moreover, an analysis of the magnetic results with the LWD (logging while drilling) gamma ray data (**Figure 3**) shows that the sandstone intervals identified by the low gamma ray sections (shaded yellow on the gamma ray log) have anomalously high mass magnetic susceptibility values (shaded yellow on the mass magnetic susceptibility data). This was very unexpected, since pure quartz sandstone should have a very low, negative mass magnetic susceptibility (since quartz is diamagnetic). The large positive mass magnetic susceptibility values immediately tell us that there are additional paramagnetic and /or ferrimagnetic minerals contained within the sandstones. Possible candidates for these minerals are siderite (a strongly paramagnetic iron carbonate), the ferrimagnetic mineral magnetite, or the canted antiferromagnetic mineral hematite. The additional minerals in the sandstone intervals are not likely to be paramagnetic clays such as illite or chlorite, otherwise they would have given a much higher gamma ray signal. Whilst there was no X-ray diffraction (XRD) data available in this well, there was XRD data for just 10 samples from another well in the same oilfield. The XRD data indicated average values of around 85% quartz, around 4% K-feldspar, 1-2% plagioclase, 1-2% pyrite, around 6% kaolinite (which is diamagnetic) and only trace amounts of illite. No evidence for siderite was seen in this data. Of course the XRD data from the other well may not necessarily be representative of the mineralogy in the present studied well. However, it seems more likely that the observed high mass magnetic susceptibility values are due to a mineral like magnetite or hematite. Small amounts of these minerals would not necessarily be readily identified by XRD, yet would give the observed high magnetic susceptibility values.

The additional minerals identified by the magnetics in the sandstone intervals may have important implications for the petrophysical properties. We have previously demonstrated [6] that small amounts of fine-grained hematite, for instance, can have a very dramatic effect on reducing the permeability. The additional minerals in the sandstones may therefore help to explain why the well in our present study was not as good a producer as other wells in the same oilfield. It is also important to be able to readily identify additional paramagnetic and ferrimagnetic minerals, since nuclear magnetic resonance (NMR) log data can be significantly affected by these minerals.

CONCLUSIONS

1. The drill cutting measurements gave generally high positive mass magnetic susceptibility values in the sandstone intervals (low gamma ray). This is very unusual since pure quartz sandstone is diamagnetic with a low, negative magnetic susceptibility. The magnetic measurements demonstrated that there must be significant additional paramagnetic and/or ferrimagnetic minerals in the sandstone intervals. Potential candidates could be the paramagnetic mineral siderite, the ferrimagnetic mineral magnetite, or the canted antiferromagnetic mineral hematite.

2. The presence of these additional minerals in the sandstones is likely to affect the permeability of the sandstones, and this may in turn be responsible for the lower productivity that has been observed by the operating company in this well.
3. The study demonstrated that magnetic measurements on drill cuttings provide a rapid means of identifying of mineralogical variations over large intervals and are a potentially important supplement to XRD data.

FUTURE WORK

Either high field magnetic susceptibility or magnetic remanence measurements would enable us to determine whether the additional minerals in the sandstones were due to, for instance, small amounts of magnetite or hematite (note that XRD would not necessarily be helpful in this respect). Also it would be useful to undertake magnetic susceptibility measurements on drill cuttings in one of the good producing wells in the same field. If we obtained a normal diamagnetic signal in the sandstones of the good producer then it would be further evidence to suggest that the additional minerals identified in the present well were responsible for its lower productivity. We are waiting for permission from the operating company to undertake these extra studies.

REFERENCES

1. Lenormand, R., Bauget, F., Ringot, G., 2010. Permeability measurement on small rock samples. *2010 International Symposium of the Society of Core Analysts*, Halifax, Nova Scotia, Canada. Paper SCA2010-32 (12 pages).
2. Potter, D. K., 2007. Magnetic susceptibility as a rapid, non-destructive technique for improved petrophysical parameter prediction. *Petrophysics*, **48** (issue 3), 191-201.
3. Ali, A., Potter, D. K. and Tugwell, A., 2014. Correlation between magnetic properties and permeability: results from a new case study in the North Sea. *2014 International Symposium of the Society of Core Analysts*, Avignon, France. Paper SCA2014-077 (6 pages).
4. Agbo, B. C. and Potter, D. K., 2014. Novel high resolution probe magnetic susceptibility and comparison with wireline gamma ray and grain size in an Albertan oil sand well. SEG Technical Program Expanded Abstracts: pp. 2590-2594. doi: 10.1190/segam2014-1140.1.
5. Potter, D. K., Ali, A., Imhmed, S. and Schleifer, N., 2011. Quantifying the effects of core cleaning, core flooding and fines migration using sensitive magnetic techniques: implications for permeability determination and formation damage. *Petrophysics*, **52** (issue 6), 444-451.
6. Potter, D. K., Ali, A. and Ivakhnenko, O. P., 2009. Quantifying the relative roles of illite and hematite on permeability in red and white sandstones using low and high field magnetic susceptibility. *2009 International Symposium of the Society of Core Analysts*, Noordwijk aan Zee, The Netherlands. Paper SCA2009-11 (12 pages).

Figure 1. (a) Bags of drill cuttings arranged in order of their depth in the well. (b) Samples of drill cuttings being put into the vials for measurement.

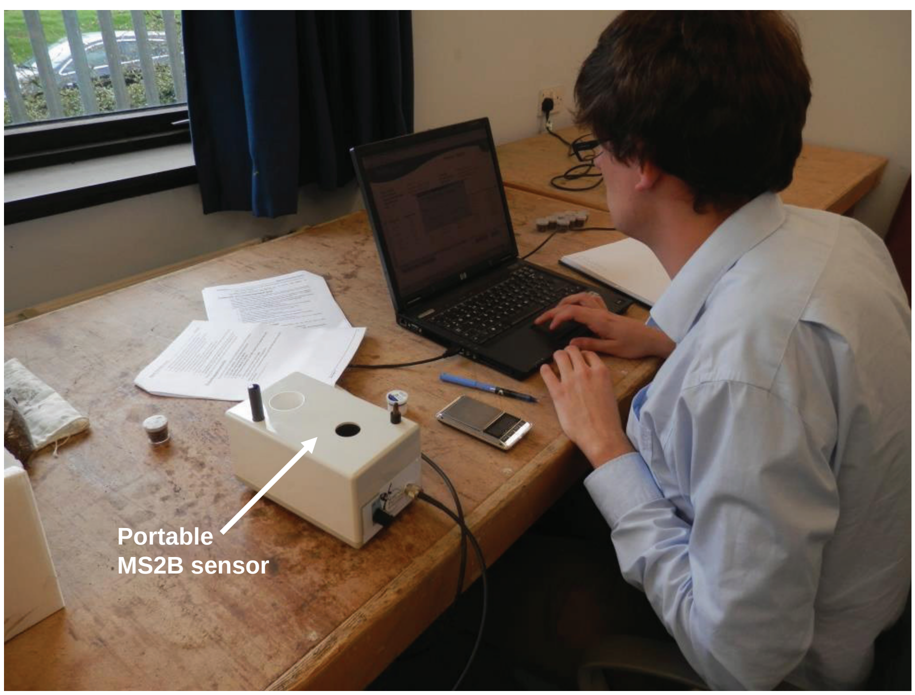

Figure 2. View of the portable MS2B magnetic susceptibility sensor, connected to a laptop.

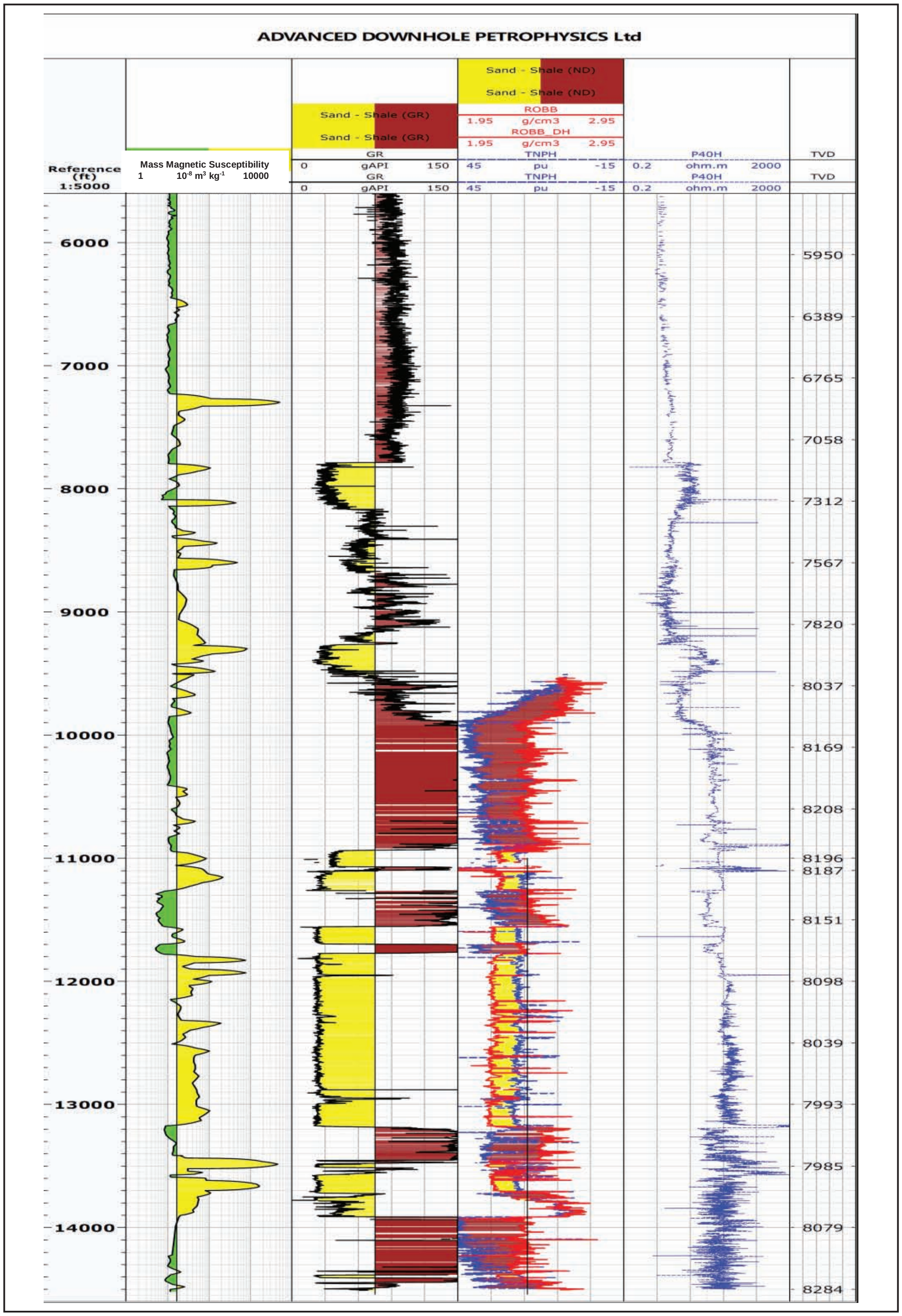

Figure 3. Mass magnetic susceptibility results for 421 measurements over 9,000 ft are shown in the left hand column (scale runs from 1–10,000 x 10^{-8} m^3 kg^{-1}). An arbitrary cut-off (green/yellow) is given at around 17 x 10^{-8} m^3 kg^{-1} to compare easily with the low gamma ray (yellow) values in the adjacent column.