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Comparison of Three New Portable Magnetics and Miniperm Probes for Permeability Prediction

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Abstract— The use of magnetic susceptibility and minipermeameter probe measurements for core analysis are among the recently developed techniques in petroleum reservoir evaluation. Probe measurements are rapid, cheap and non destructive compared to other conventional methods of core analysis. Low sensitivity magnetic susceptibility probe, high sensitivity magnetic susceptibility probe and air minipermeameter probe measurements were carried out on 45feet of slabbed core obtained from a shoreface reservoir. The result from the measurements were analysed and compared. The magnetically derived illite content from both magnetic probes correlated with probe permeability. High illite content indicates low permeability and low illite content indicates high permeability. The low sensitivity magnetic probe was found to be better than the high sensitivity magnetic probe in terms of correlation of magnetically derived illite content with probe permeability. Carrying out two magnetic susceptibility measurements using probes with high and low sensitivity could be a possible way of detecting natural cemented zones.

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Index Terms— Magnetics,Minipermeameter,Permeability,Portable,Probes,Reservoir,Susceptibility.

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1 INTRODUCTION

THe efficient exploitation of oil and gas and management of petroleum reservoir requires good knowledge of the geology of the particular reservoir. The knowledge required is obtained from the analysis of vast subsurface data gotten from both down-hole measurements and laboratory measurements on core. Despite efforts by industry and academia the acquisition and traditional analysis of core remains very expensive and time consuming. Besides the cost and time setback inherent in conventional core analysis, there are geological, petrophysical and geostatistical issues involved with routine (RCAL) core analysis and special (SCAL) core analysis [1].

Recently, other sampling strategies and measurements have been developed amongst which are the probe permeability and probe magnetics. These techniques involve cheap rapid core screening carried out at high resolution and in most cases measurements are non-destructive, thereby eliminating the need for cutting plugs. New probes that will enable better measurements and the further development of these techniques are being designed and produced continually.

Magnetic susceptibility is the ratio of the intensity of magnetisation to the applied magnetic field strength. Generally materials are paramagnetic, diamagnetic or ferromagnetic (ferro - and ferrimagnetic). Materials with positive susceptibility (X) such that (1+X) >1 are called paramagnetic materials. In the situation where susceptibility (X) is negative such that (1+X) < 1 the material is said to be diamagnetic. Ferromagnetic materials differ from paramagnetic and diamagnetic materials in that they have very high positive susceptibility such that they are able to retain their magnetic field. The measurement of magnetic susceptibility is achieved by quantifying the change of force felt upon the application of a magnetic field to a substance. For liquid samples it is measured from the dependence of the natural magnetic resonance (NMR) frequency of the sample on its shape or orientation. Ivakhnenko and Potter in 2004 successfully used other methods to measure fluid susceptibility, for example, Sherwood Scientific Magnetic Balance (MSB) Mark I and Magnetic Properties measuring System (MPMS2) SQUID magnetometer [2]. The susceptibility values of common reservoir rock/ minerals and fluids as summarised by Hunt et al in 1995 and Potter et al in 2004 is given in table 1[3] and [4].

The main factors controlling permeability in clean sandstone include: grain size, shape, sorting, packing, degree of consolidation, cements (quartz overgrowth, barite etc) and fractures. Additionally in muddy sandstone clay content (especially permeability controlling clays like illite or chloride) also control permeability while in shales the major factors controlling permeability are increased clay content (especially illite and chlorite), decreased quartz grain size and anisotropy [5]. Mikkelsen et al in 1991 and Vernik in 2000 also affirm that permeability depends on the amount of clay minerals like illite, chlorite and kaolinite present in a sample [6] and [7]. It has also been reported that the presence of illite can bridge pore space and create microporous rims that considerably reduces permeability with little effect on porosity [8] and [9].

Considering the difference between the susceptibility of matrix minerals and permeability controlling clays, the sign of the raw magnetic susceptibility can be very useful for

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permeability and lithological zonations. Research in the past few years continuously show that excellent correlations exits between the net values of magnetic susceptibility and main permeability and lithological zones in a shallow marine shoreface Para-sequences as displayed in figure1 [10]; net susceptibility is generally negative in the high permeability clean sand units indicating the predominance of diamagnetic quartz and feldspar while in the low permeability muddy sand and shale units the net susceptibility has positive values indicating the higher percentage of paramagnetic illite clay and minor quantities of other paramagnetic and ferromagnetic minerals Processing the raw magnetic susceptibility into mineral content percentage provide even better correlation with key petrophysical properties. Potter et al in 2004 developed a formula for calculating the mineral fraction assuming a two-component system [10]. The total susceptibility from a sample is expressed as:

$$\mathbf{X_T = (F_I.X_I) + (1-F_I)X_Q} \qquad (1)$$

Where X_T = Total measured susceptibility, X_Q = Known susceptibility of quartz (from table1), X_I = Known susceptibility of illite and F_I is the fractional volume of illite which can also be expressed as:

$$\mathbf{F_I = (X_Q - X_T)/ (X_Q - X_I)} \qquad (2)$$

The above equations are true for both volume susceptibility and mass susceptibility and illite content calculated using equation 2 from magnetic susceptibility measurements correlates with X-ray Diffraction derived illite content as shown in figure 2. The calculation of mineral (illite) content can be extended to a whole range of other simple mineral mixtures for any given core material undergoing analysis, especially that magnetically derived illite content has been found to show very good correlations with horizontal plug permeability for a North Sea well [10]. Thus permeability in clean sand(corresponding to lower magnetically derived illite content) is expected to be higher than permeability in muddy sand (corresponding to higher magnetically derived illite content), however, this is not true for low permeability naturally barite- cemented regions [11]. The naturally barite cemented regions are undetectable by the magnetic susceptibility technique because barite that is a paramagnetic mineral has susceptibility approximately the same as the susceptibility of diamagnetic quartz.

Core analysis using core plug results gives incomplete information about the reservoir as such sampling might be biased. There is need to have sufficient samples that can give information about the reservoir at the lamina scale especially for heterogeneous reservoirs that are very difficult to manage. Corbett and Jensen in 1992 introduced the concept of sample sufficiency and developed rules-of thumb that help in estimating the optimum number of samples that will be needed [12].

Probe Permeability allows one to obtain practically sufficient number of samples that represent a particular core interval. Probe permeability is measured using minipermeameter probes that provide high resolution, rapid, cheap and non destructive way of measuring permeability. The high resolution data from minipermeameter are at the lamina scale and can identify small scale heterogeneity such that key features are more likely to be identified.

Probe measurement data are less sensitive to missing core and improves depth matching to wire line log data. Minipermeameter estimate local absolute permeability by flowing gas through tubes sealed against the surface of core sample. Minipermeter are of two types: steady state minipermeameters and unsteady state (or pressure decay) minipermeameters. A new portable unsteady state air probe has been used in this study. Research in previous years have shown that in many cases core plug permeability and probe permeability measurements give very similar values [13]. However in some North Sea examples the core plug permeabilities are higher than the probe permeabilities at comparable depths. The major reason for this variation is the fact that core plugs have been cleaned and dried whereas the slabbed core which is not cleaned has significant dried out hydrocarbons, which are causing a slight reduction in the measured probe permeability values.

Comparison of three new portable probes has been carried out in this paper. The probes include one low sensitivity magnetic susceptibility probe, one high sensitivity magnetic probe and a minipermeameter probe (Tiny Perm II). The probes were used to carry out measurements on 45feet long slabbed core recovered from a shoreface reservoir. The results gotten from the measurements were processed after which a thorough analysis of the result comparing the probes followed.

TABLE 1
MAGNETIC SUSCEPTIBILITY OF COMMON RESERVOIR MINERALS AND FLUIDS *(AFTER [3] AND [4]).*

Type of Mineral	**Mineral**	**Susceptibility Per unit mass ($10^{-8}m^3$/ Kg)**	**Susceptibility per unit Volume (10^{-6}SI)**
Diamagnetic minerals	Quartz	-0.55	-13 to -17
	Calcite	-0.3 to -1.4	-7.5 to 39
	Orthoclasse Feldspar	- 0.49to -0.67	
	Kaolinite	-2.0	-50
Paramagnetic minerals	Illite	15.0	410
	BVS Chlorite	13.6	
	CFS Chlorite	52.5	
	Pyrite	2.0	35 to 5000
Ferromagnetic minerals	Magnetite	20,000 to 110,000	1,000,000 to 5,700,000

2 MATERIALS AND METHODS

The following instruments, equipment and other materials were used to carry out the analysis.

1. Bartington high sensitivity magnetic probe MS2E1.
2. Bartington low sensitivity magnetic probe MS2F.
3. MS2 display unit.
4. Standard calibration samples.
5. Connecting cables.
6. Vindum Engineering Inc. Tiny Perm II air minipermeameter probe.
7. 45 feet long slabbed core from a North Sea oil well.

The experimental procedure included the quality control (Q.C) of the core, magnetic probes measurement and minpermeameter measurement. The details are as follows

2.1 Magnetic Probes Measurement Procedure

The procedure started with Q.C. of the core with the aid of the pictures of the core before some sections were removed to ensure that the core sections were at the right depth and that the core had not been contaminated with particles of magnetic materials that will compromise the accuracy of the measurements. Then the core boxes were placed on a non-magnetic table and the cable was connected between the probes and the display unit positioned on a suitable plastic base.

The whole apparatus was then powered via an adaptor connecting the display unit and the mains power supply. After this, the tool was set to the c.g.s. unit because the calibration sample is in c.g.s unit and the sensitivity knob was set to 0.1 c.g.s. Then the equipment was switched on and allowed to warm up for a moment after which measurement began.

The first measurement to be taken was that of the calibration sample to ensure that the calibration of the probe was still valid; the background reading was taken by holding the probe to the air and taking the measurement which was noted, then the probe tip was placed on the calibration sample and another reading was taken. The true value of the sample is the difference between the measured value and the background (air) value, i.e.

Xv = probe reading – background reading (3)

The true value of measurement found from equation 3 above was compared to the standard known value of susceptibility of the calibration sample and the two values were the same confirming that the probe calibration was still valid and measurements could proceed. Then the probe tip was placed on the core section to be measured and measurement was taken at all measurable sections of the core. For every one foot of core measured the background reading was taken at the beginning and the end and averaged, and then the true value of susceptibility was found using (3). The instrument reading was automatically zeroed at the beginning of every measurement and the same procedure was used for both the high and low sensitive probes respectively.

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2.2 Minipermeameter Probe Measurement Procedure

The core was first positioned properly on the measurement table, and then the probe was set to commence measurements after connecting the pressure transducer to the microprocessor and control unit with the electric cable. The procedure out lined below was followed to take measurements:

1. Tiny Perm II was turned on, the plunger was pulled out fully until the screen was reading “Push+Hold”;
2. The rubber nozzle was pressed firmly against the core surface to be measured;
3. Then the plunger was depressed completely. Immediately the current vacuum and measurement status bar was displayed on the screen, the plunger was held in and the pressing of the nozzle to the core face continued until the vacuum reading was 0 and the status bar indicated that the measurement was completed;
4. The result displayed on the LCD screen of the microprocessor and control unit was recorded in the laboratory notebook;
5. The recorded Tiny Perm II result was cross-referenced to the calibration curve to obtain the absolute permeability at the core section measured;

The plunger was pulled out again and the procedure was repeated for each point of the core measured.

3 RESULTS AND DISCUSSIONS

3.1 Magnetically Derived Illite Content Distribution

The raw magnetic susceptibility values obtained from measurements using the low sensitive magnetic probe and high sensitive magnetic probe were converted into illite content using (2). Figure 3 shows a plot of magnetically derived illite content against depth for both the low sensitive probe and high sensitive probe. The plot shows the distribution of illite content at different depths of the core. Comparison of the profiles obtained from the two magnetic probes shows a reasonable correlation between the two sets of measurements. Generally the illite content obtained from the low sensitive probe measurement are a little higher than the illite content obtained from the high sensitive probe except at depth between 220ft-225ft. This exception could have arisen as a result of the presence of some natural cement or calcite whose susceptibility is close to that of quartz so the low sensitive probe could not capture the difference while the high sensitive probe did. This suggests that repeating magnetic susceptibility measurements using a lower sensitive probe can be helpful in resolving the difficulty posed by natural cemented zones in magnetic susceptibility measurements of core.

3.2 Correlation between Magnetically Derived Illite Content Profile and Permeability Profile

It was stated earlier that illite content controls permeability, to confirm this, the magnetically derived illite content profile obtained from the magnetic probe measurements were compared with the permeability profile obtained from the minpermeameter probe measurements. Comparing the magnetically derived illite content profile and the probe permeability profile shows that a good correlation exits between the two profiles. The high illite content at the top and bottom sections correlates with the low permeability at the top and bottom section, equally the low illite content at the middle section correlates with the high permeability in the middle section as shown in fig. 4. This correlation confirms what has been reported earlier by Potter in 2004 and Potter in 2007 for other silliclastic formations in the North Sea that very good correlation exist between magnetically derived illite content and horizontal plug permeability [10] and [11]. Thus magnetic susceptibility measurements can provide an alternative or complementary method for predicting permeability. This method is fast, less expensive, rapid and non destructive.

However, the regression coefficient between the magnetically derived illite content and probe permeability is not too good because the probe permeameter (Tiny Perm II) tool is not measuring the same volume as the magnetic probes tool. The magnetic probe measures a volume of 39.9mm^3 while the probe permeameter measures a volume of about 100-900mm^3. Also the probe measurements might not have been taken at exactly the same depth as a result of error due to parallax thus introducing small scale depth shifting issue. Additionally the effect of porosity on volume susceptibility would also have contributed to the poorer regression coefficient. It is also important to know that the physics of measurement for the magnetic probe and the minipermeameter are different and could also affect the regression coefficient.

3.3 Comparison between Low Sensitivity Magnetic Probe and High Sensitivity Magnetic Probe

The main aim of this paper is to compare the three new portable probes used for measurement in this project. Having confirmed that magnetically derived illite content can be used to predict permeability it is necessary to compare the two new magnetic probes to know which is most suitable for permeability prediction.

Fig. 5 shows the correlation between low sensitivity magnetic probe magnetically derived Illite content and minipermeameter permeability, while figure 6 is the correlation between the high sensitivity magnetic probes magnetically derived Illite content and minipermeameter permeability. The low sensitivity probe Illite content gives a better correlation with permeability than the correlation between the High sensitivity probe Illite content and permeability. This means that the low sensitivity magnetic probe is better than the high sensitivity magnetic probe for permeability prediction.

The high sensitivity probe gave poorer correlation with permeability because its use is not completely compatible with the simple two component system of illite and quartz used for determining magnetically derived illite content outlined in (2). It is able to record slight differences in susceptibility as a result of the presence of other permeability controlling clay minerals other than illite. Previous X-ray diffraction performed on the core shows that besides illite and quartz that are the main minerals in the core, there are other clay minerals like pyrite, mica and kaolinite in small quantities [14]. Unlike the high sensitivity probe that gives a complex profile, the low sensitivity probe can not differentiate between small differences in susceptibility but rather upscales the susceptibility thus subscribing to the simple two component system of illite and quartz given in (2).

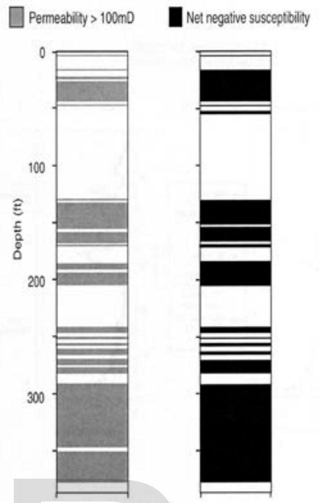

Fig. 1. Correlation between Net Susceptibility Values and Main Permeability and Lithological Zones in a N. Sea Oil Well *(From [10])*.

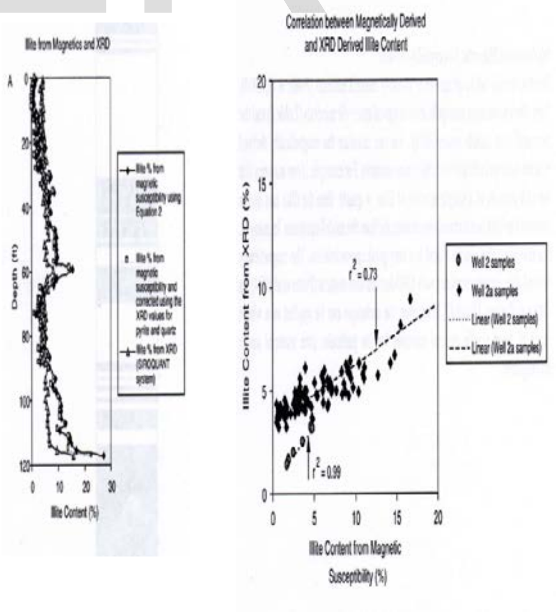

Fig. 2. Showing Good Correlation between Magnetically Derived Illite Content and XRD Derived Illite Content (from [4]).

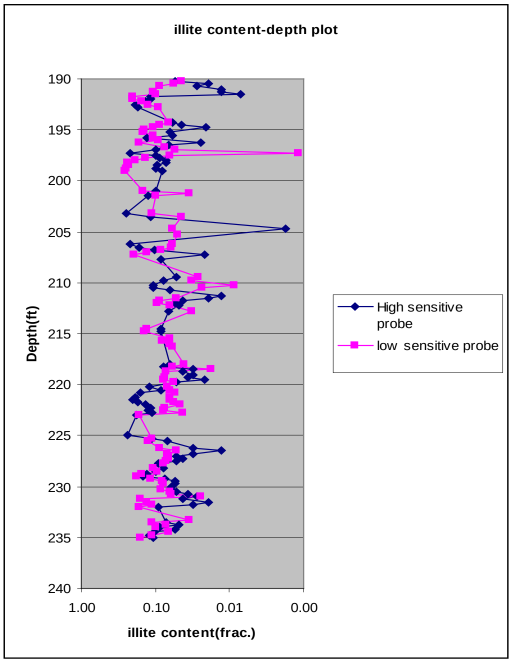

Fig. 3. Magnetically Derived Illite Content against Depth Plot from High Sensitive and Low Sensitive Magnetic Probes Measurements.

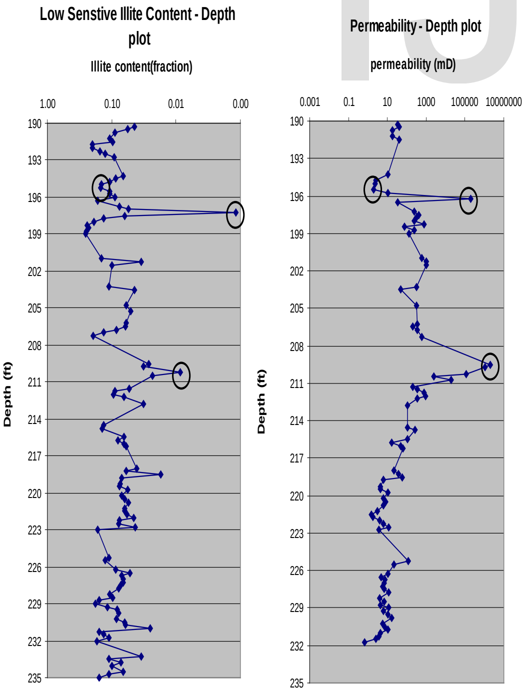

Fig. 4. Correlation between Magnetically Derived Illite Content Profile and Permeability Profile.

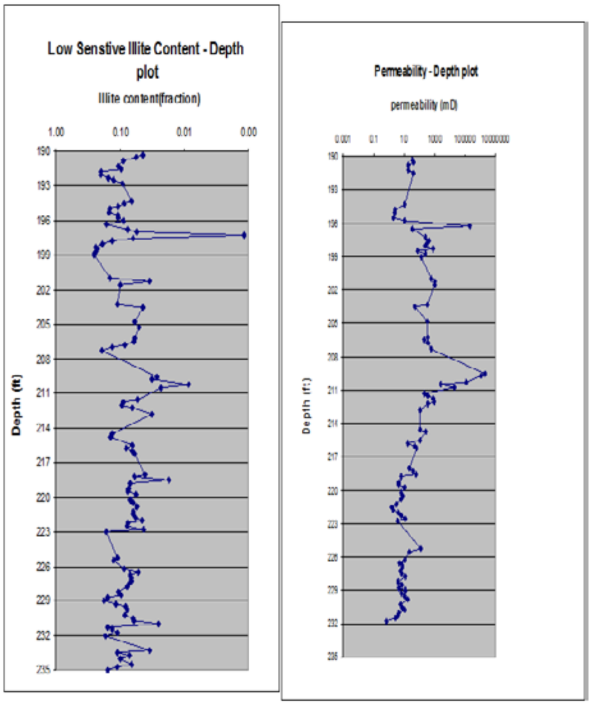

Fig. 5. Correlation between Low sensitivity magnetic Probe Illite Content and Minipermeameter Permeability.

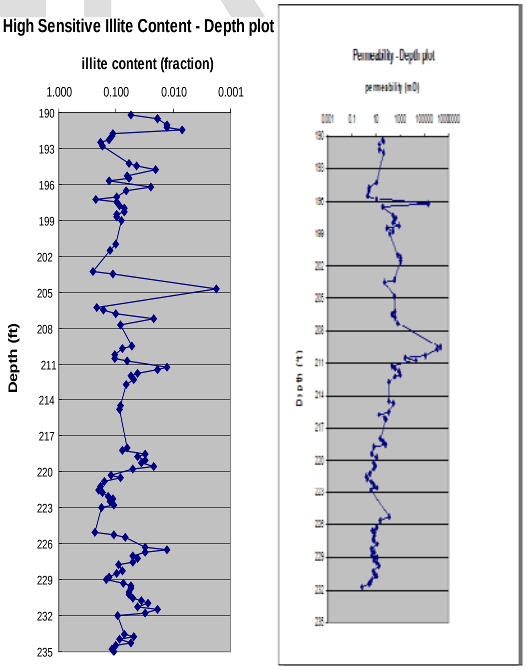

Fig. 6. Correlation between High sensitivity magnetic Probe Illite Content and Minipermeameter Permeability.

4 CONCLUSION

The oil well used in this study has low permeability zones at the top and bottom regions while the middle section of the core has high permeability.The amount of illite in the oil well is concentrated at the top and bottom sections of the cored interval while the middle section of the cored interval has a lower amount of illite content. Both low sensitivity magnetic probe and high sensitivity magnetic probe gave magnetically derived illite content that correlated with probe permeability. Thus magnetic probes can be used in a rapid, cheap and non-destructive way to predict permeability.

The low sensitivity magnetic susceptibility probe is better than the high sensitivity magnetic susceptibility probe in terms of correlation with permeability. In the absence of routine core analysis data, the low sensitivity probe can be used to predict permeability for quick decision making. It may be unnecessary to spend energy and resources to design and construct higher sensitivity magnetic probes for the purpose of permeability prediction. The simple two component (illite and quartz) system of determining magnetically derived illite content may not be completely compatible with high sensitivity probe measurement in cases where there are other clay minerals in the core.

Finally, repeating magnetic susceptibility measurements using a different sensitivity probe may be helpful in detecting calcite and/or natural cemented zones in a core. Plotting the magnetically derived illite content against depth for both high sensitive and low sensitive magnetic probes on the same graph will produce a profile that could be used for detecting the natural cemented or calcite zones. These zones will have the two profiles crossing each other with a noticeable separation between the low sensitive probe magnetically derived illite content-depth profile and the high sensitive probe magnetically derived illite content-depth profile.

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