IMPROVED RESERVOIR CHARACTERISATION USING NOVEL UNCONVENTIONAL CROSSPLOTS BETWEEN MAGNETIC SUSCEPTIBILITY AND DOWNHOLE WIRELINE LOG DATA

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This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Napa Valley, California, USA, 16-19 September, 2013

ABSTRACT

Laboratory based magnetic susceptibility measurements on core samples have recently shown strong correlations with various petrophysical parameters, particularly clay content and permeability. We have developed a series of crossplots similar in format to standard industry charts that relate magnetic susceptibility to various standard downhole wireline log data. This provides a further tool for improved petrophysical characterization using rapid, non-destructive magnetic susceptibility measurements (at ambient temperature) on drill cuttings or core in conjunction with the depth matched wireline log data. We show that the crossplot between magnetic susceptibility and the downhole spectral gamma ray log can help to readily identify and quantify the type of clays present in the formation, which can be particularly useful in unconventional reservoirs. Crossplots between magnetic susceptibility and bulk density allow the mineral contents and porosities of mixtures of matrix minerals and clay minerals (such as quartz and illite) to be rapidly quantified. The plots also provide a new template to identify and quantify the main reservoir matrix minerals and the porosity. An extension of these templates, that accounts for the temperature dependence of the magnetic susceptibility of paramagnetic minerals, can potentially be used for prediction and evaluation of petrophysical parameters *in situ* using borehole magnetic susceptibility logs in conjunction with other standard wireline logs. Magnetic susceptibility logs are rarely used, but are potentially very useful for clay content and permeability prediction downhole.

INTRODUCTION

Magnetic susceptibility measurements on core samples or drill cuttings have recently been shown to be a useful tool in rapid, non-destructive petrophysical analysis, particularly for estimating clay content and relating this to permeability and other SCAL parameters (Potter, 2007; Potter and Ivakhnenko, 2008). If this information is also used in conjunction with other standard data from downhole wireline logs it provides a further tool for rapid petrophysical analysis. We have therefore constructed some new crossplots similar in format to standard industry crossplot charts, such as Schlumberger charts, which relate magnetic susceptibility to some standard wireline log data like spectral gamma ray and bulk density. The new crossplots can be used with magnetic susceptibility measurements (at ambient temperature) undertaken at the wellsite on drill cuttings or in the laboratory using core samples (core plugs, slabbed core or whole core) to estimate clay content and other parameters. Paramagnetic clays, such as illite, can sometimes be a major control on permeability and other parameters (Potter, 2007). The crossplots can potentially help to rapidly relate the clay content data to estimate permeability and other petrophysical parameters via this “quick look” analysis in the appraisal phase, well before the actual core permeability and other data becomes available. With the advent of new borehole magnetic susceptibility devices these new crossplots can also be used as a further tool to estimate clays and other parameters straight from the downhole data. For downhole applications we have prepared magnetic susceptibility plots as a function of temperature, based on our recent work on the temperature dependence of magnetic susceptibility in paramagnetic minerals (Ali and Potter, 2012).

TEMPLATE CROSSPLOTS

Figure 1 shows a plot of spectral gamma ray (Th/K ratio) versus mass magnetic susceptibility (at ambient temperature) for mixtures of quartz plus different clay and other minerals as indicated. Each rectangle represents the range of values from 100% quartz to 100% of the relevant mineral indicated. Each rectangle starts at a mass magnetic susceptibility value of -0.62 x $10^{-8}m^3kg^{-1}$ (100% quartz).The range of values may be all negative (for diamagnetic quartz plus diamagnetic kaolinite), or become positive with increasing content of paramagnetic or ferrimagnetic minerals (e.g., the 100% quartz to 100% biotite range is from -0.62 x $10^{-8}m^3kg^{-1}$ to 98 x $10^{-8}m^3kg^{-1}$). The magnetic susceptibility values were compiled from a number of sources (Borradaile et al, 1990, and Hunt el al, 1995, primarily). The different types of clay occupy fairly well defined regions of Figure 1. Some ferrimagnetic heavy minerals can have extremely high magnetic susceptibility values, hence the upward pointing arrow in Figure 1.

Figure 2 shows crossplots of mass magnetic susceptibility (at ambient temperature) versus bulk density for mixtures of quartz and illite, and porosities of 0% to 40%. Extremely small percentages of illite can be quantified using these plots (bottom plot in Figure 2). We have constructed other crossplots for a number of other clays (chlorite, montmorillonite, kaolinite) with quartz or a carbonate matrix. For a paramagnetic mineral such as illite magnetic susceptibility decreases with increasing temperature (and therefore also generally with depth) according to the Curie law. Therefore similar plots to Figure 2 as a function of temperature, where the mineral lines would be shifted to the left, could be used to interpret wireline magnetic susceptibility and bulk density data. Alternatively, the temperature dependence could be shown on 3D plots. Figure 3 shows a 3D plot of mass magnetic susceptibility versus bulk density as a function of temperature for one specific example comprising a mixture of 9% illite and 91% quartz. The decrease in mass magnetic susceptibility with increasing temperature is clearly shown.

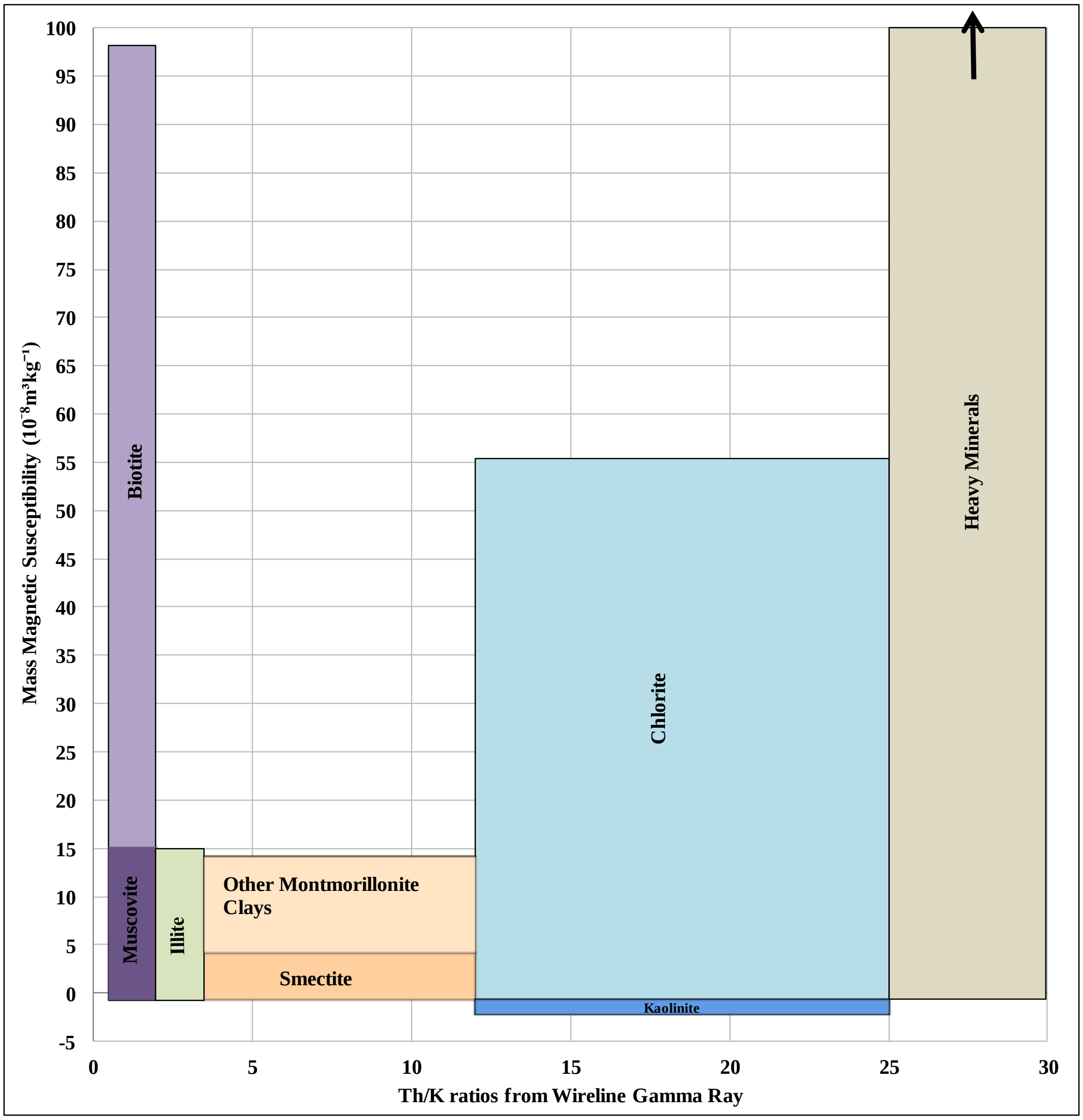

Figure 1. Spectral gamma ray Th/K ratio (taken mainly from Fertl, 1979, where Th is in ppm and K is in %) versus mass magnetic susceptibility (at ambient temperature) for mixtures of quartz plus different minerals as indicated. Each rectangle starts at -0.62 x $10^{-8}m^3kg^{-1}$ (100% quartz) on the mass magnetic susceptibility axis, and the rectangles represent the range of values from 100% quartz to 100% of the mineral indicated.

Figure 4 shows a mass magnetic susceptibility versus bulk density crossplot for the three main reservoir matrix minerals quartz, calcite and dolomite (in the same format as standard industry crossplots) and porosities of 0% to 40%. The mass magnetic susceptibility data was taken mainly from Hunt et al (1995). Also plotted on Figure 4 are results from some heavily dolomitized samples (provided by the Libyan Petroleum Institute) from a carbonate reservoir in Libya.

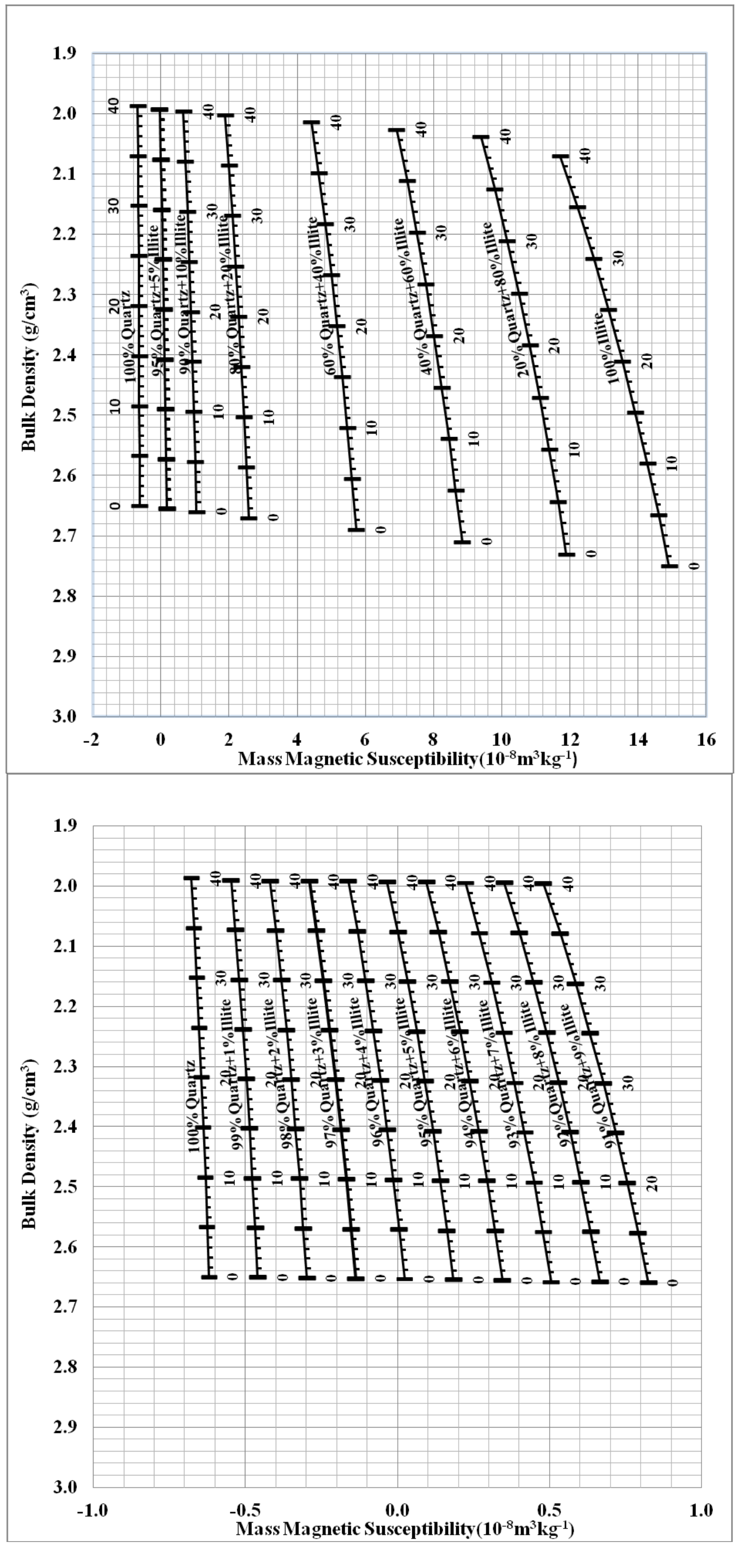

Figure 2. Crossplots of mass magnetic susceptibility (at ambient temperature) versus bulk density for mixtures of quartz and illite and porosities of 0% to 40%. The bottom plot is for very low illite contents.

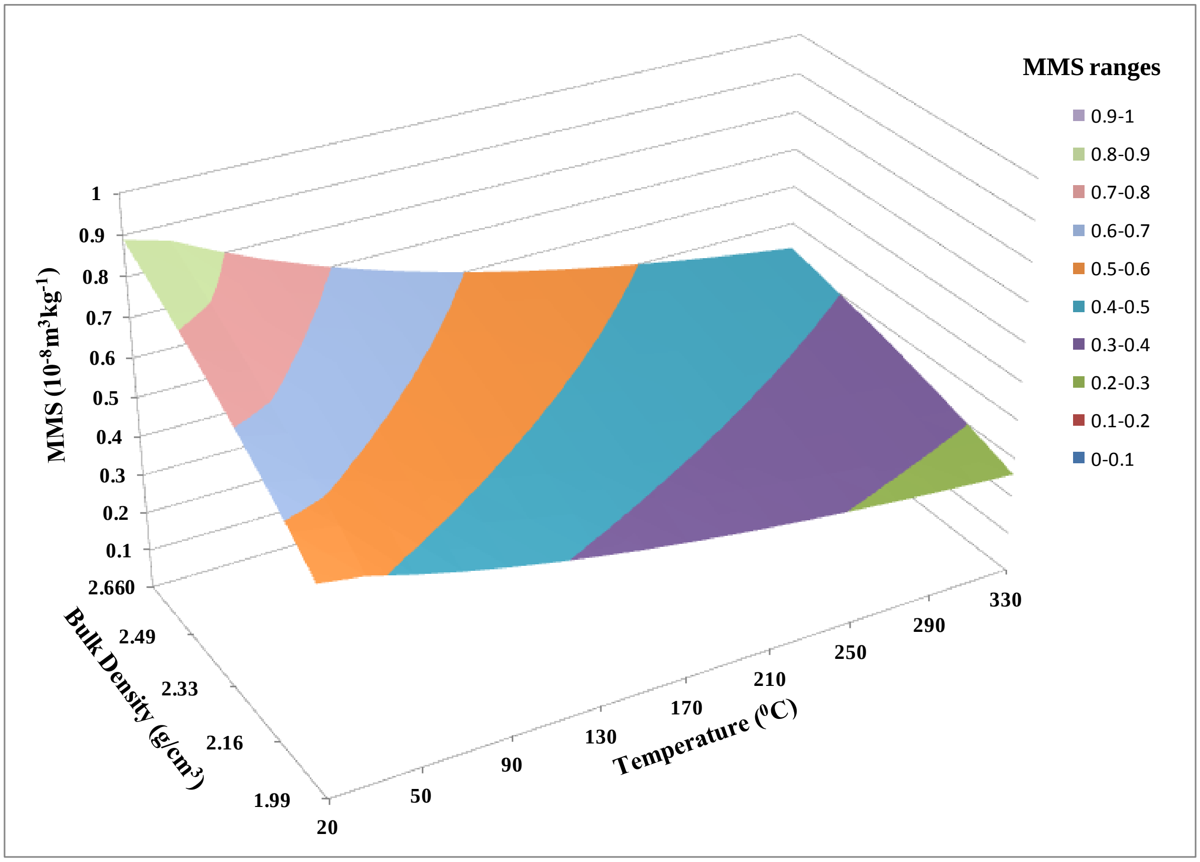

Figure 3. 3D plot of mass magnetic susceptibility (MMS) versus bulk density as a function of temperature for a mixture of 9% illite and 91% quartz. The MMS ranges in the legend have units of $10^{-8}m^3kg^{-1}$. For the specific mineral mixture and range of temperatures shown the MMS values spanned the ranges between 0.2 and 0.9 ($10^{-8}m^3kg^{-1}$).

CONCLUSIONS

A series of new template crossplots of magnetic susceptibility versus standard downhole wireline data provide a potentially useful tool for rapid petrophysical characterization using magnetic susceptibility measurements (at ambient temperature), on drill cuttings or core, in conjunction with wireline log data. The binary mineral mixture could first be determined from Figure 1, and then mineral contents and porosities could be determined from plots like Figure 2. Extending the crossplots to take account of the temperature dependence of paramagnetic minerals allows the crossplots to be used with borehole magnetic susceptibility measurements at reservoir temperatures in conjunction with other wireline log data.

ACKNOWLEDGEMENTS

We thank the Libyan Petroleum Institute for providing the dolomitized carbonate samples.

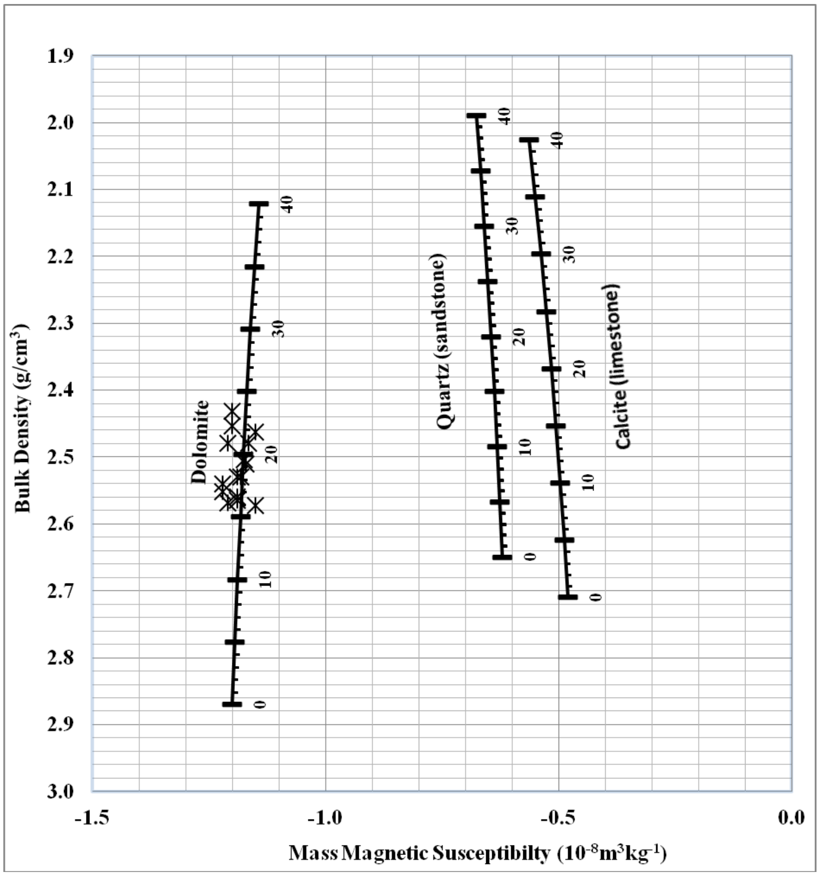

Figure 4. Mass magnetic susceptibility versus bulk density crossplot for the three main reservoir matrix minerals quartz, calcite and dolomite and porosities of 0% to 40%. Also shown are results (star symbols) from some heavily dolomitized samples from a carbonate reservoir in Libya (measured values have uncertainties of ± 0.1 g/cm^3 bulk density and ± 0.1 x 10^{-8}m^{3}kg^{-1} mass magnetic susceptibility).

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