Well log cluster analysis and electrofacies classification: a probabilistic approach for integrating log with mineralogical data.

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Introduction

Understanding reservoir mineralogy is critical to quantify the effect of the matrix on well log response for petrophysical analysis. Identifying mineralogical variations associated with sequence stratigraphy may also facilitate well to well correlation. Furthermore, quantifying the mineralogy is becoming increasingly important to estimate key properties like TOC and brittleness from logs in unconventional reservoirs. The most reliable source of information on the mineral makeup of a reservoir comes from direct measurements on core or cutting samples. However, due to the scarcity of cores and the limited vertical resolution of cuttings, well log data are ultimately necessary to propagate mineralogical information at higher resolution over the entire zone of interest along a wellbore. Consequently, a proper integration of well log data with mineralogical data derived from core or cuttings is paramount. This integration is challenged by the variable vertical resolutions and sampling rates of these different types of data, which result in a non-linear relationship between them. In this paper, we explore an innovative approach using well log cluster analysis and electrofacies probabilities for integrating quantitative mineralogy measurements from cores and cuttings with conventional well log data.

Theory and Method

The purpose of well log cluster analysis is to look for similarities/dissimilarities between data points in the multivariate space of logs, in order to group them into classes also called electrofacies (Euzen et al 2010). An electrofacies represents a unique set of log responses which characterizes the physical properties of the rocks and fluids contained in the volume investigated by the logging tools. The first step of the method involves the selection of training samples corresponding to intervals of known characteristics. Traditionally, electrofacies are calibrated on core interpretation to ensure their consistency with the geological facies. These training samples are used to define the typical log response of each electrofacies and then to predict their occurrence from logs where core is not available. This prediction is done by computing the probability of each data point to belong to each defined electrofacies (Fournier, 1997). The data points are then automatically assigned to the electrofacies with the highest probability.

The originality of the present approach is twofold: (1) electrofacies are defined and calibrated based on quantitative mineralogical data and (2) electrofacies probabilities and average mineralogy are used to compute modal mineralogy from conventional logs. Quantitative modal mineralogy (relative proportions of minerals) provides an ideal type of data on which to calibrate electrofacies because it is objective information reflecting actual physical properties of the rock (as opposed to geological interpretation). In this method, electrofacies are calibrated on training samples corresponding to representative lithofacies based on their mineralogy, measured on cores. A probability curve is then generated from the logs for each electrofacies. Finally these probabilities are multiplied by the average modal composition of each electrofacies and summed to compute mineral proportions.

Application

The method was tested on a 300 m thick interval of Westphalian continental deposits in a vertical well from the Schooner field, located in the Southern North Sea. Samples were obtained from public domain core and cuttings archives at the BGS storage facility in the UK whilst wireline data for these released wells were purchased from a data repository. Modal mineralogical data were collected from both core and cutting samples using QEMSCAN; an advanced mineral analysis and mapping technique comprising SEM coupled with energy dispersive X-ray spectrometry. Cluster analysis and electrofacies classification were performed using a multi-disciplinary 1D data processing and editing tool (Easytrace, Euzen et al 2011). Electrofacies were defined in order to account for the full range of mineralogical variation in the data, mainly comprising differing amounts of quartz, illite/smectite, chlorite, kaolinite and dolomite. Training samples were selected to reflect end-members containing the highest proportions of one or several minerals. The electrofacies probabilities were computed using Gamma Ray, Neutron Porosity, Density and Sonic logs. The selection of the training samples and the modal composition of the electrofacies were iteratively adjusted to improve the fit between measured and computed mineralogy (Fig. 1).

Discussion

The preliminary results of this study suggest that the use of well log cluster analysis and electrofacies probabilities may provide a simple and effective way of integrating quantitative data derived from core or cuttings with conventional well log data. The method may be used to quantify mineralogy in between cored intervals or in neighboring wells where coring has not been undertaken. In this case however, due to the sensitivity of the method, a careful normalization of logs must be done in order to minimize variations related to log acquisition. Another application consists in defining electrofacies in wells where only cuttings samples are available. In this case, the QEMSCAN software is used to group individual cuttings particles into populations (or lithotypes) based on mineralogical and textural attributes. The training samples are then selected by identifying the log signature of the representative lithotypes within the sampled intervals. This approach could be of wide practical benefit because both cuttings samples and conventional well logs are readily available and common data in many wells.

In the application presented in this paper we have applied the proposed method to derive a mineralogical log, but this approach might also be applied to other types of quantitative information. For instance, our method could be used to compute TOC or brittleness logs in shale reservoirs.

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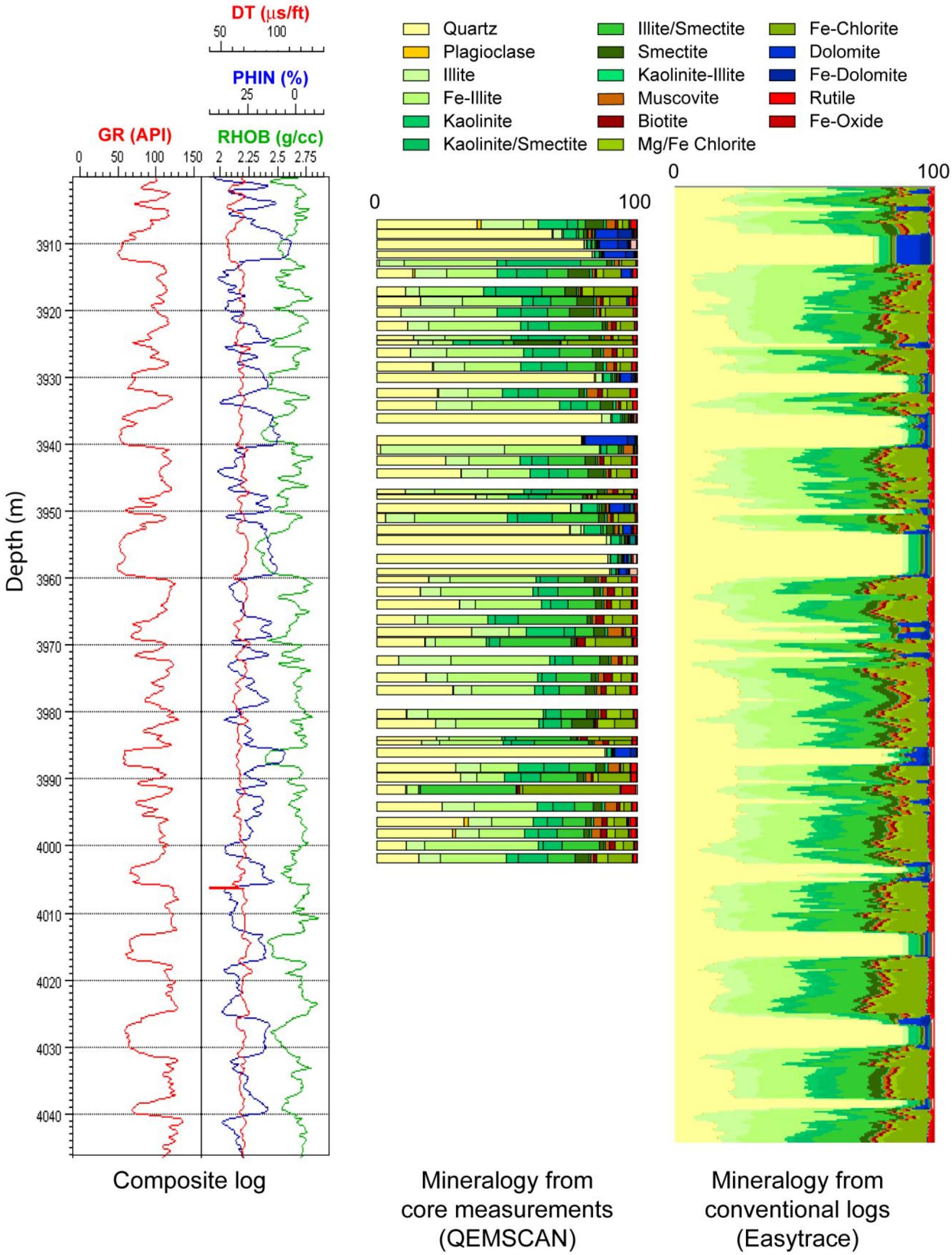

Figure 1: Comparison of modal mineralogy measured on core with modal mineralogy derived from logs.