New suite of modified laboratory procedures and dedicated software for the effective integration of the core analysis and wireline data sets

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Core analysis data is considered one of the cornerstones of formation evaluation by believers in core data, whether users or providers. However, there seems to be a general consensus that more could be done with core data, both in the scope of petrophysical data provided and how it is used. With recognition of this a suite of methods has been put together that provide an extended core data set, and software designed expressly for the interpretation of core data.

This extended data set is designed for use only in hydrocarbon bearing reservoirs and data has been gathered from a number of Australian oil and gas reservoirs. The software allows firstly an independent core based reservoir interpretation, and secondly direct integration and correlation of the core and wireline log data sets and their interpretations. In order to illustrate the core/log integration capabilities of the package a simple case study is presented

The Data Set

Historically there appears to have been a gap in the services provided by core analysis laboratories. Routine core analysis (RCA) provides core plug measurements such as porosity, permeability, fluid saturations, grain density and whole core gamma at high sample frequency and low cost. However, the data has limited interpretative capability, for example poor to questionable determination of the saturation height function, and unreliable quantification of shaliness. On the other hand special core analysis (SCAL) provides a wide range of data such as capillary pressure, electrical properties, CEC and relative permeability, with high interpretive capability. However, the data is usually obtained at low sample frequency, due mainly to the cost and time associated with gathering the data.

The ‘new’ data set was designed to compliment the current (RCA) data set, and significantly extend the interpretative capability of the data set. The additional measurements performed are total, effective and furnace porosity, capillary pressure curve, surface area, core plug spectral gamma and a sample description. The new data set fills the gap that currently exists between RCA and SCAL data, by providing significant interpretative capability at high sampling frequency in a reasonable time frame. To achieve these features the bulk of the measurements are performed on an off-cut of the original RCA plug. The methods used, are in most cases modifications of existing methods to account for the smaller sample volume, and to shorten the turn-around time without compromising the quality of the results. Table 1 provides a summary of the analysis suite along with a brief description.

Measurement	Technique	Whole Plug	Offcut
Total porosity	Oven dry at 105^oC		√
Effective porosity	Humidity dry at 55% RVP		√
Furnace porosity	Bake at 650^oC		√
Capillary pressure	Ambient air/brine porous plate equilibrium		√
Surface area	Polar molecule adsorption		√
Spectral gamma		√	
Sample description		√	√

Table 1 – Summary of laboratory measurements.

The Software Module

The computation of core-based or core-enhanced petrophysical interpretations has been hampered by the lack of availability of software designed exclusively for modeling core data. Most petrophysical packages are decidedly log centric, which has limited the effective integration of core and log data. Much core data processing is performed using spreadsheets with inherent data integration and transfer limitations.

To redress the balance a core interpretation module has been generated within a main-stream log analysis software package. This makes available the same functionality for processing and interpreting core data as is currently available for processing and interpreting log data. The result is that core analysis becomes a truly parallel formation evaluation discipline and the end result is far more easy and effective use of core data. The core data processing module provides the user with tools for interpretation and integration of core analysis data with wireline log data. The major components of the core data processing module are described below.

Corrections

- using regression functions to correct porosity and permeability values from ambient to overburden conditions
- correcting fluid saturation data to overburden conditions accounting for fluid formation volume changes, pore volume changes and oil bleeding
- estimation of non-Darcy flow effects (gas slippage and inertial resistance factor) from published empirical algorithms
- calculation of total gamma from core spectral gamma measurements
- vertical smoothing of core data to match log resolution

Capillary Pressure

- curve-fitting of sample capillary pressure data using a least squares fit to a hyperbolic function
- calculation of a Leverett J-function for particular reservoir zones
- estimation of initial fluid saturations from either the hyperbolic curve-fit or from the J-Function, assuming that fluid-rock properties and the free water level are known and that the reservoir is in capillary equilibrium. Estimation of residual fluid saturations from empirical relationships

Resistivity

- correction of CEC data to Qv
- estimation of Qv from surface area data based on a calibrated relationship between surface area measurements and wet chemistry or multiple salinity derived Qv measurements

Permeability

- verification of intrinsic permeability models (Schlumberger K3 chart and Dual Water model)
- estimation of relative permeability using empirical algorithms.

Heterogeneity

- estimation of permeability heterogeneity using either Dykstra-Parson's coefficient, Lorenz coefficient or the coefficient of variation.

Characterisation –

- calculation of various rock characterisation parameters for correlation with permeability such as; displacement pressure, pore throat sorting, Swanson Parameter and the pore throat size at a particular saturation
- 2-group discriminant analysis for facies prediction.

Case study

A well called Heavy has had a probabilistic petrophysical interpretation performed over the reservoir zones. This technique minimizes the error associated with log reconstruction based on iterating mineral and fluid volume for a given depth. The volumes solved for in the model were: quartz, dolomite, orthoclase, illite, kaolinite, chlorite, zircon, oil, bound water, and free water. The presence of these mineral components was confirmed by XRD, petrography and wireline crossplots.

After the initial evaluation had been produced, the next step was to incorporate the core data in order to test the validity of the interpretation. Ambient capillary pressure measurements were performed on a suite of plugs along with overburden measurements of porosity and permeability.

Using the core module the ambient core data was corrected to overburden conditions and a J-function determined for the reservoir using measured capillary pressure data. This J-function was then used to predict the vertical distribution of fluids through the reservoir assuming capillary equilibrium. A comparison of core and log data is shown in Figure 1. The depth plot highlights the fact that the log analysis is predicting optimistic porosities over much of the reservoir, and that the water saturations predicted by logs are significantly higher than those predicted from capillary theory.

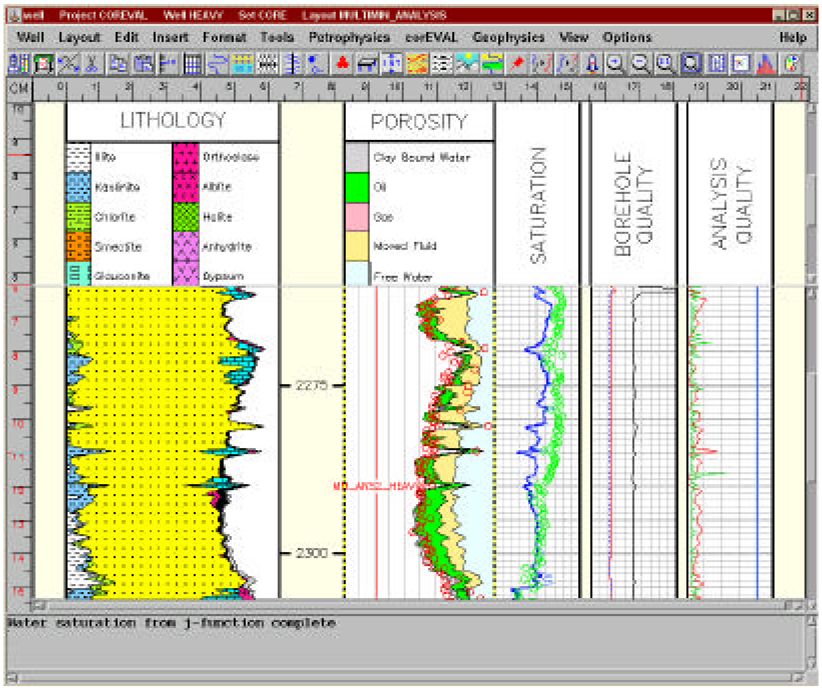

Figure 1 – Comparison of probabilistic and core data based interpretations showing inconsistencies between log and core predicted porosity and water saturation.

A second optimizing model was built with the same mineral volumes as in the first, however this time the core values for overburden porosity and predicted water saturation were treated as input logs. This second model was used in place of the first wherever a value for core water saturation was available. A comparison over the core interval is shown in Figure 2. It can be seen that the when the model was made to match the core porosity and water saturation, the result showed a much poorer quality of reconstruction (from the analysis quality curve). This has provided the interpreter with more information from which to assess the validity of the optimizing model.

For this particular interpretation two scenarios would seem possible, (1) the reservoir fluids are in capillary equilibrium and therefore the original optimizing model that was created is in error, or (2) the original model is correct and the reservoir is not in capillary equilibrium (i.e. the reservoir is partially depleted).

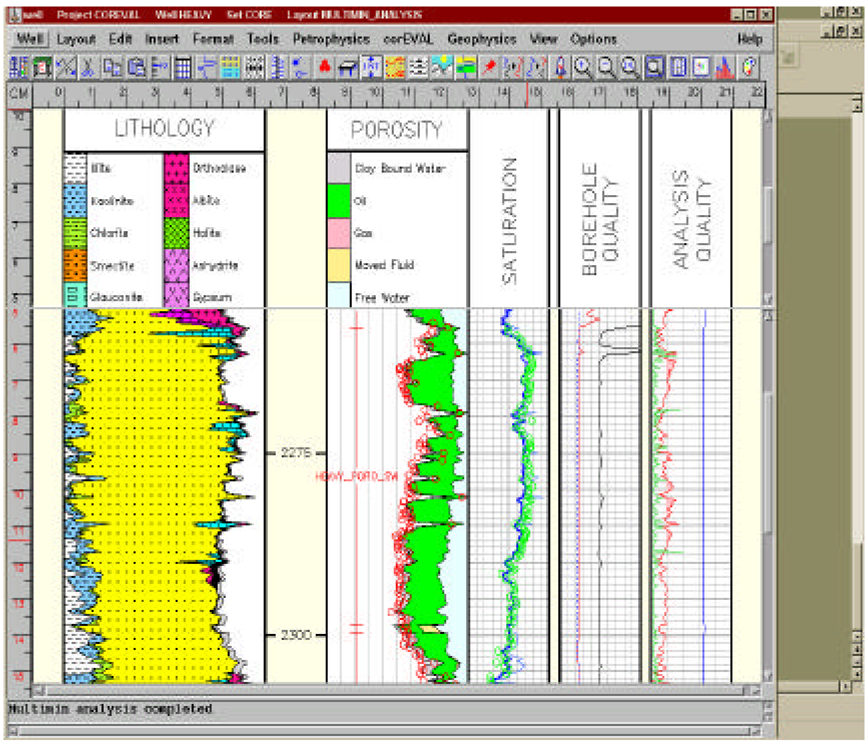

Figure 2 – Probabilistic model results after using J-function water saturations and core porosity to test the validity of the model. This resulted in a significant reduction in the quality of the reconstruction.

Summary

The effective integration of core and log data is dependent on having sufficient high quality data with adequate interpretive capability, and having the right software tools for performing the integration. These tools have been developed and used by the authors to enhance the usefulness of available core data and to decrease the uncertainty associated with a petrophysical evaluation.