# UNDERSTANDING RESERVOIR CONTINUITY IN THE MID TO LATE JURASSIC LAMINARIA FORMATION, AUSTRALIAN TIMOR SEA, BY INTEGRATING CORE AND LOG DATA

Duncan Barr* and Russell Gray**

*Core Laboratories Australia Pty Ltd
**Core Laboratories (U.K.) Limited

## INTRODUCTION

A recent study, conducted by Core Laboratories for Woodside Energy Ltd and their joint venture partners, establishes the lateral continuity of reservoir sandstones in the Middle to Late Jurassic Laminaria Formation, located in the Australian Timor Sea (Figure 1). The primary objective of the study was to determine the areal distribution of reservoir facies based on existing core from key wells in the area. A secondary objective was to investigate the reserves and production potential of several thin, high permeability sandstones observed near the top of the formation.

Most of the reservoir sandstones were found to be laterally continuous, including the upper, thin sandstones at the top. Based on this work, subsequent modelling of the reservoir has yielded a significant increase in probable oil recovery.

## DATA BASE

A total of twelve wells were included in the study, nine of which had been extensively cored. Data used in the study included high resolution biostratigraphy, detailed sedimentological core descriptions, ichnofacies profiles, routine core analysis data, and wireline logging information.

## SEDIMENTOLOGY OF THE LAMINARIA FORMATION

The Laminaria Formation consists of six major facies, which are interpreted to have been deposited in a shallow marine environment (Barr et al, 2001). These facies are arranged in a series of coarsening upward cycles, starting in poor quality heterolithics and argillaceous sandstones, coarsening upward into the fine to medium grained, good quality sandstones that dominate the formation. These good quality sandstones are believed to have been deposited as sand banks.

Thin, high permeability medium to coarse grained sandstones are also observed; these are thought to represent storm sands. Several thin conglomeratic layers occur on the tops of coarsening upward cycles, and are believed to have formed as transgressive lag deposits. These conglomeratic layers can be traced laterally right across the study area, making them important correlative markers. Pebbles within these conglomeratic beds consist of sandstone intraclasts.

## SEDIMENTOLOGICAL CORRELATION

A basic correlative framework for the study was provided by biostratigraphy, and was used as an underlying control for the sedimentological correlation. Establishing the hierarchy of bedding surfaces from core descriptions and subsequent integration of wireline log profiles made it possible to trace these facies groups across the study area.

Most of the reservoir sandstone consists of the high quality sand bank facies: fine to medium grained, massive to cross-bedded sandstone. This facies occurs in the upper portions of coarsening upward cycles and was found to form laterally extensive blankets. The thinly bedded storm sandstones are also laterally extensive, with many forming sheets that extend right across the study area. However, at the top of the formation, several of these thin sandstones appear to be confined to the Northwest of the study area, pinching out towards the Southeast.

## HYDRAULIC UNITS AND IDENTIFICATION OF THIN SANDSTONES

Hydraulic unit analysis was used to assist the sedimentological correlation, especially within the uppermost five to ten metres of the formation, where core coverage was limited (Barr, 2000). The thin, high permeability sandstones located in this part of the formation are interbedded with thin shaly layers, making them difficult to identify from the gamma ray log alone. However, with the help of hydraulic Unit analysis, these sandstones could be readily identified from logs in uncored intervals.

Hydraulic Units were derived using the term FZI, which was calculated from a modified form of the Kozeny-Carmen equation (Equations 1 and 2). Using both cluster analysis and histogram techniques, a total of eight Hydraulic Units (or "bins") were defined. Total porosity and Klinkenberg permeability (both measured at net overburden conditions) were used for this calculation.

A "learning" data set was built, consisting of the profile of Hydraulic Units determined from core analysis data, together with wireline log values. Wireline log curves included in the learning set were gamma ray, sonic and neutron-density porosity. Bayesian mathematics were then applied to this data set to predict Hydraulic Units in uncored wells and zones (an explanation of Bayes' theorem is provided by Swan and Sandilands, 1995). Peak deconvolution was not attempted.

Permeability was predicted by applying the modified Kozeny-Carmen equation (Equation 2) to the predicted profile of Hydraulic Units, substituting clay-corrected neutron-density porosity for core porosity. The resulting profile of predicted Hydraulic Units was used to reinforce facies identification in uncored zones, while the profile of predicted permeability was used to establish their production potential.

A measure of the success of the Hydraulic Unit approach in predicting permeability is provided by a cross-plot of predicted permeability against actual permeability for well Vidalia-1, using a "learning" data set built up from six other wells (Figure 2). Compare this cross-plot with those for permeability predicted from a single, straight-line porosity-permeability correlation (Figure 3) and with permeability predicted from correlations derived from each of the six facies encountered (Figure 4). Note how the Hydraulic Unit-based prediction provides a high degree of agreement over the whole data set, while the facies and single-line correlations fail to predict permeability adequately in higher and lower quality rocks.

## APPLICATION OF THE STUDY

Subsequent simulation modelling based on this study has resulted in a significant increase in estimates of ultimate recovery factor from existing completions. The field is currently in production and is performing in accordance with predictions.

## CONCLUSIONS

- Permeability in thin sandstone layers can be reliably predicted using the Hydraulic Units method.
- Reservoir facies were found to be laterally extensive and show blanket-like to sheet-like geometry, thus providing for large drainage radii.
- Thinly bedded, high permeability sandstones near the top of the formation can be counted as potential pay, but may act as thief zones. Some of these sandstones are confined to the North-western portion of the study area.
- Thin, conglomeratic sheets are important correlative markers that are interpreted to have formed as transgressive sheets.

## REFERENCES

Amaefule, J.O., Altunbay, M., Tiab, D., Kersey, D.G., and Keelan, D.K., “Enhanced reservoir description: using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells”, *SPE 26436* (1993).

Barr, D.C., “Reservoir description of the Mid to Late Jurassic Laminaria Formation: Laminaria/Corallina Area, Timor Sea”, *SPE 64285* (2000).

Barr, D.C., Kennaird, A.F., Fowles J., Marshall, N.G., and Cutten, V.L., “Determining reservoir continuity in the Laminaria Formation by integrated geological study”, *APPEA Journal* (2001), p. 415-427.

Swan, A.R.H., and Sandilands, M., *Introduction to Geological Data Analysis*, Blackwell Science, Oxford 1995, p. 50.

## ACKNOWLEDGEMENTS

The authors wish to thank Woodside Energy Ltd, their joint venture partners, and Core Laboratories for permission to publish this paper.

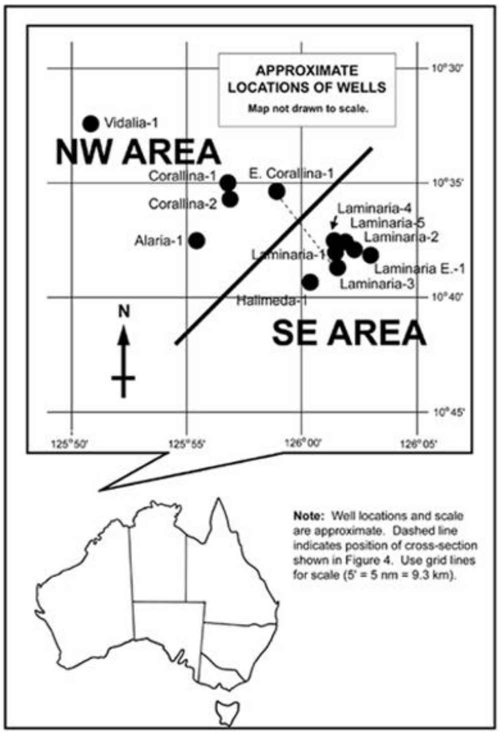



**Figure 1.** Location map of study area.

$$k = \frac{\phi_e^3}{(1-\phi_e)^2}\,\frac{1}{(F_s \tau^2 S_{gv}^2)}$$

**Equation 1:** Generalised form of Kozeny-Carmen relationship, where $k$ is permeability (md), $\phi_e$ is effective porosity (fraction), $F_s$ is shape factor, $\tau$ is tortuosity and $S_{gv}$ is surface area per unit grain volume ($\mu m^{-1}$). With the Hydraulic Unit approach, the right-hand side of the equation is solved without the need for laboratory measurements of shape factor, tortuosity and surface area (Amaefule et al, 1993).

$$FZI = RQI / PHIZ$$

where:

$$RQI = 0.0314 * (k / \phi_e)^{0.5}$$

$$PHIZ = \phi_e / (1 - \phi_e)$$

**Equation 2:** Modified form of the Kozeny-Carmen relationship. Hydraulic Units are defined by FZI.

**FIGURE 2. MEASURED PERMEABILITY vs PERMEABILITY PREDICTED FROM HYDRAULIC UNITS, VIDALIA-1**

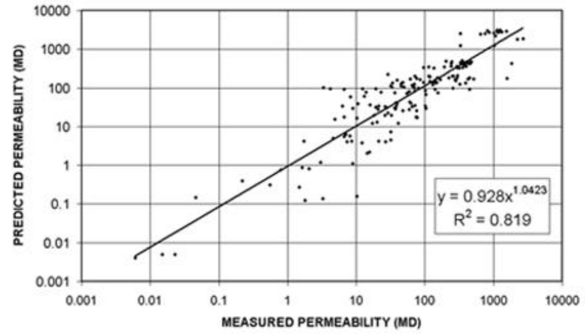



**FIGURE 3. MEASURED PERMEABILITY vs PERMEABILITY PREDICTED FROM POROSITY-PERMEABILITY PLOT, VIDALIA-1**

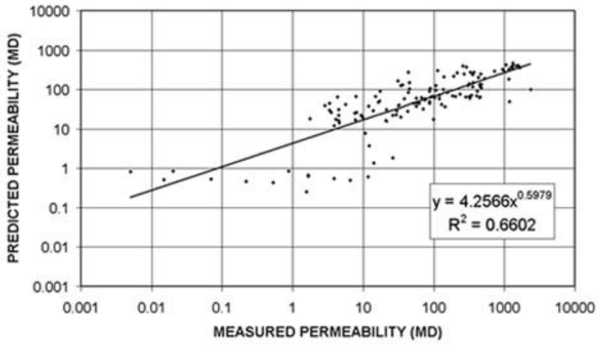
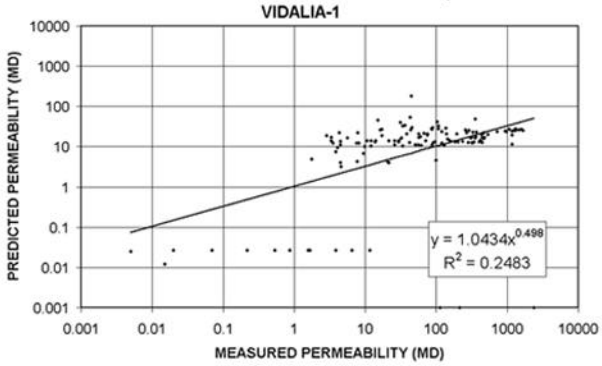



**FIGURE 4. MEASURED PERMEABILITY vs PERMEABILITY PREDICTED ACCORDING TO FACIES, VIDALIA-1**






back to contents