Geological Classification of Seismic-Inversion Data in the Doba Basin of Chad*

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Abstract

The investigated field in Chad produces from Lower-Cretaceous sequences in the Doba Basin. The reservoir units consist of interbedded sands and shales of different thicknesses, and the resulting variability in properties makes accurate characterization important for field development. The approach used in our characterization first involved a quantitative analysis of log data and rock-physics models. This analysis established relationships between geological properties of interest and elastic-rock properties that could be obtained from seismic inversion. The results of the rock-property analysis were then mapped onto the seismic attributes to produce a geologically classified volume. The first step was a statistical analysis of log-based elastic properties as they relate to other geological parameters. Significant shifts in impedance and vP:vS were observed between sand and shale points in the reservoir. For the sands, porosity also had an impact on the elastic properties. To incorporate multiple attributes, and to better identify classes of data, crossplots of the elastic attributes were used. Trends of both Vshale and porosity are evident on crossplots of P-impedance vs. vP:vS. These trends are roughly orthogonal, meaning that the two properties may be interpreted with some independence. Yet at the seismic scale, the thin nature of the sand/shale intervals (5-10m) is unlikely to be resolved, requiring the use of net-to-gross ratio rather than Vshale. A rock-physics model was calculated with different inputs for N:G and porosity so that the resulting trends could be used to guide the crossplot interpretation. The rock was modelled as a cemented, five-mineral composition, based on mineralogy from x-ray diffraction analysis. Variable N:G were modelled through a Backus average of the sand model and representative shale values. With the behaviour identified from log analysis and rock-physics modelling, seismic attributes from AVO inversion were crossplotted in the same manner as the well data. Classification of the zone of interest followed the trends defining low, medium, and high N:G. The highest N:G points were further divided into low-, medium-, and high-porosity classes. The resulting lithology volume proved to be a good indicator of net reservoir, showing variations in continuity and thickness that were confirmed by additional drilling. The classified volume was used to produce sand probability maps for input into a reservoir model.

Introduction

The investigated field in Chad produces from Lower-Cretaceous Sequences of the Doba Basin. The reservoir units consist of interbedded sands and shales of different thicknesses, and the resulting variability in properties makes accurate characterization important for field development.

Seismic data can be inverted to provide estimates of P-impedance, S-impedance, and density. These properties are arguably more useful than the reflection amplitudes, because they describe the reservoir quantitatively. However, reservoir quality, a geological property, is not typically governed by a single geophysical measurement. As an example, a low P-impedance may be associated with a high porosity zone, or it could be due to an increase in clay content. To resolve these ambiguities, multiple attributes must be considered

The approach used in our characterization first involved a quantitative analysis of log data and rock-physics models. This analysis established relationships between desired geological properties and multiple elastic rock properties obtained from seismic inversion. The results of the rock-property analysis were then mapped onto the seismic attributes in the crossplot domain to produce a geologically classified volume.

Well Analysis

Our examination of geological properties began with a statistical analysis of the sand and shale properties observed on log data. This step was used to identify elastic properties that are significant for reservoir characterization. The shale content of the rocks, as determined by Vshale measurements, shows a large influence on the elastic properties. Specifically, the P-impedance and vP:vS values change substantially as more shale is observed in the rocks. The porosity of the sands also had an impact on the elastic properties, although to a lesser extent than the lithology. Figure 1 shows the distribution of these elastic values in the reservoir zone.

To incorporate multiple attributes and to better identify geological classes of data, crossplots of the elastic attributes were used. Trends of both Vshale and porosity are evident on crossplots of vP:vS versus P-impedance. These trends are roughly orthogonal to one another, while oblique to the axes. This implies that Vshale and porosity may be interpreted with independence; yet each requires measurements of both elastic attributes.

For the 3D seismic survey, it is unlikely that the thin sand/shale intervals (5-10 m) can be resolved at the seismic scale. Figure 2 shows the log data for a well in the field, and the rapidly varying nature of the logs can be seen. Also shown on this figure are the blocked elastic properties created with a Backus average (Backus, 1962) over 30m, the approximate minimum wavelength of the seismic. It is clear from this blocking that the average properties for an interval are those that will affect the seismic data.

Rock-Physics Modelling

A rock-physics model uses inputs of mineralogy, fluid content, and rock architecture to define the theoretical elastic properties of the assembled parts. This allows distinct geological scenarios to be modelled, even if they were not encountered on well logs. Geological and engineering measurements are used as input to these models, and the results are calibrated with log and core data.

With respect to the mineralogy, the gross reservoir does not show a gradual transition between sand and shale layers, but rather exhibits more of a binary system of these two rock types; each occurs in different layer thicknesses. From a modelling perspective, this suggests that modelling a continuous range of clay content is not appropriate and that N:G is a more useful descriptor of the gross reservoir interval.

The sands were first modelled as a five-mineral composition of quartz, potassium feldspar, plagioclase feldspar, kaolinite, and chlorite. The mineral fractions were determined from x-ray diffraction (XRD) data, with these five minerals having the highest proportions. Mineral moduli and densities were obtained from Mavko et al. (1998) and Avseth et al. (2005). The rock was modelled with a fixed amount of cement, which was assumed to be calcite, based on the XRD analysis. To model the dry-frame elastic properties of the rock, a cemented-sand model (Dvorkin and Nur, 1996) was used.

Elastic properties of the saturating hydrocarbons were determined using the relationships of Batzle and Wang (1992), where the reservoir fluids were assumed to be in a single-liquid phase. Fluid analysis established the specific hydrocarbon properties. Finally, the dry-frame rock model was taken to saturated conditions using Gassmann fluid substitution (Mavko et al., 1998).

To accommodate a variable N:G, we followed the methodology outlined by Avseth et al. (2009). The shale properties were taken from log data where Vshale = 1. With sand properties modelled for a range of porosities, variable N:G were then modelled by performing a Backus average (Backus, 1962) of the two lithologies. This averaging was done at each porosity value, for N:G values from 0% to 100%.

Calibration of the rock-physics model is necessary to constrain parameters that have uncertain measurements. Figure 3 shows the calibration of the model with log measurements of P-wave velocity. This plot is useful for determining the amount of cement to use in the model, and whether to account for porosity changes using a sorting or diagenetic trend. A similar diagnostic was carried out using S-wave velocity. Figure 4 shows a rock-physics template in terms of vP:vS and P-impedance. Lines of constant N:G and porosity are displayed, and both the Vshale and porosity behaviour seen in the well data follow the template trends. This provides confidence in the predictive ability of the rock-physics model.

Classification of Seismic

Just as crossplots of well data were used to identify rock types of interest, the same crossplots of seismic data can be used to transfer these rock types onto the results of the AVO inversion. The shallower formations, mostly shales, were first excluded in the upper left corner of a vP:vS versus P-impedance crossplot. The zone of interest was then subdivided along the lines of the rock-physics template into classes of low, medium, and high N:G. Finally, the highest N:G points were further divided into low-, medium-, and high-porosity classes (Figure 5).

The resulting classified volume can be treated as any other seismic volume for interpretation and visualization purposes. The added advantage is that the classified volume synthesizes multiple geophysical attributes and displays geological classes that are more functional and intuitive. The classified volume was used to produce sand probability maps for input into a reservoir model.

Conclusions

Well analysis was carried out to determine how the elastic behaviour of the logs was distinguished by rock properties, and a theoretical rock-physics model was created to assist in this distinction. This analysis was the basis for assigning geological classes to groups of seismic attributes. The subdivision of the reservoir was based on both N:G and porosity. The resulting lithology volume proved to be a good indicator of net reservoir, showing variations in continuity and thickness that were confirmed by additional drilling.

Acknowledgements

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References Cited

Avseth, P., T. Mukerji, and G. Mavko, 2005, Quantitative seismic interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk: Cambridge University Press, 356p.

Avseth, P., A. Jorstad, A.-J. van Wijngaarden, and G. Mavko, 2009, Rock physics estimation of cement volume, sorting, and net-to-gross in North Sea sandstones: The Leading Edge, v. 28, p. 98-108.

Backus, G.E., 1962, Long-wave elastic anisotropy produced by horizontal layering: Journal of Geophysical Research, v. 67, p. 4427-4440.

Batzle, M., and Z. Wang, 1992, Seismic properties of pore fluids: Geophysics, v. 57, p. 1396-1408.

Dvorkin, J., and A. Nur, 1996, Elasticity of high-porosity sandstones: Theory for two North Sea data sets: Geophysics, v. 61, p. 1363-1370.

Mavko, G., T. Mukerji, and J. Dvorkin, 1998, The Rock Physics Handbook: Tools for Seismic Analysis in Porous Media: Cambridge University Press.

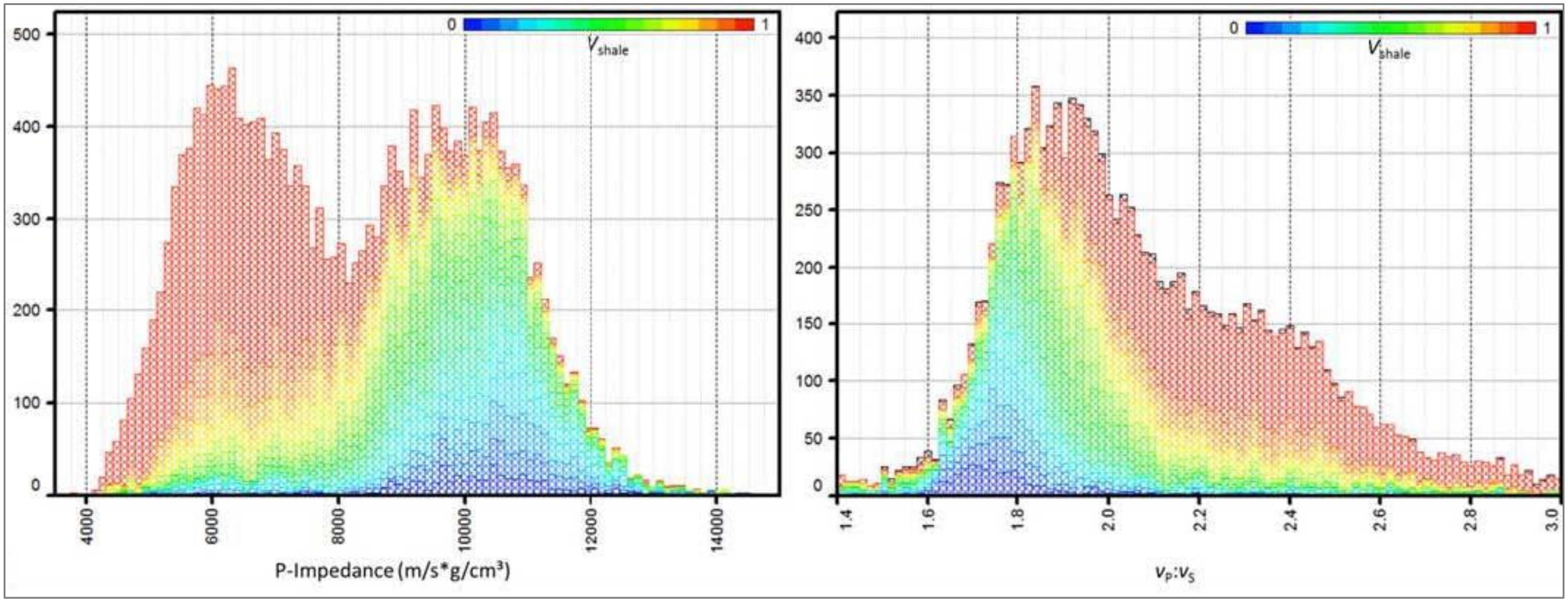

Figure 1. Distribution of P-Impedance and vP:vS for the reservoir interval. The data are coloured by Vshale, and it is apparent that lithology has a major influence on these two properties.

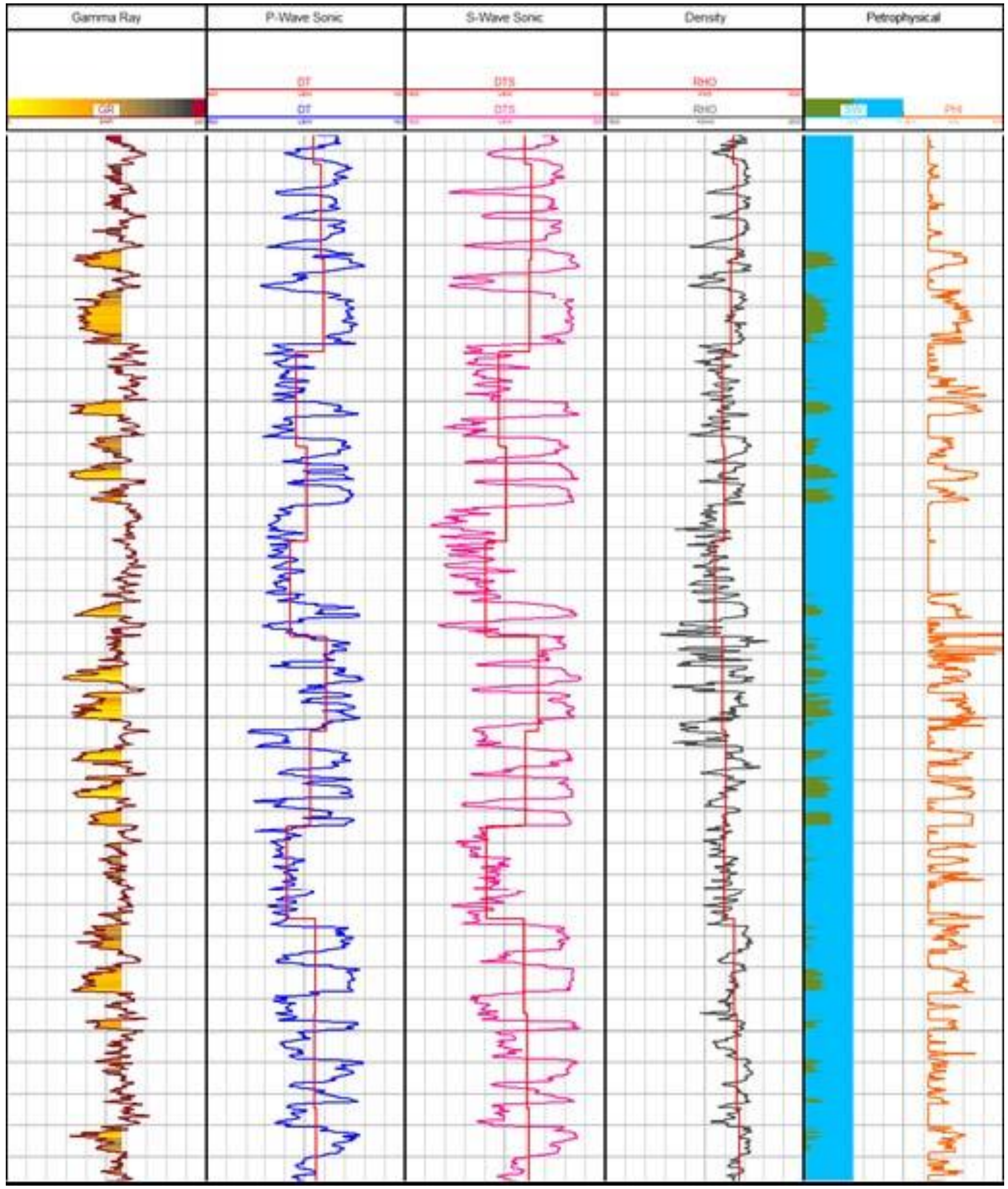

Figure 2. Representative well logs for the field. The gamma-ray log is coloured by Vshale, and the effects of lithology on the sonic data can be seen. The red, blocky curves on the sonic and density tracks show the effect of a Backus average with an effective length of 30 m. The vertical grid divisions are 10 m.

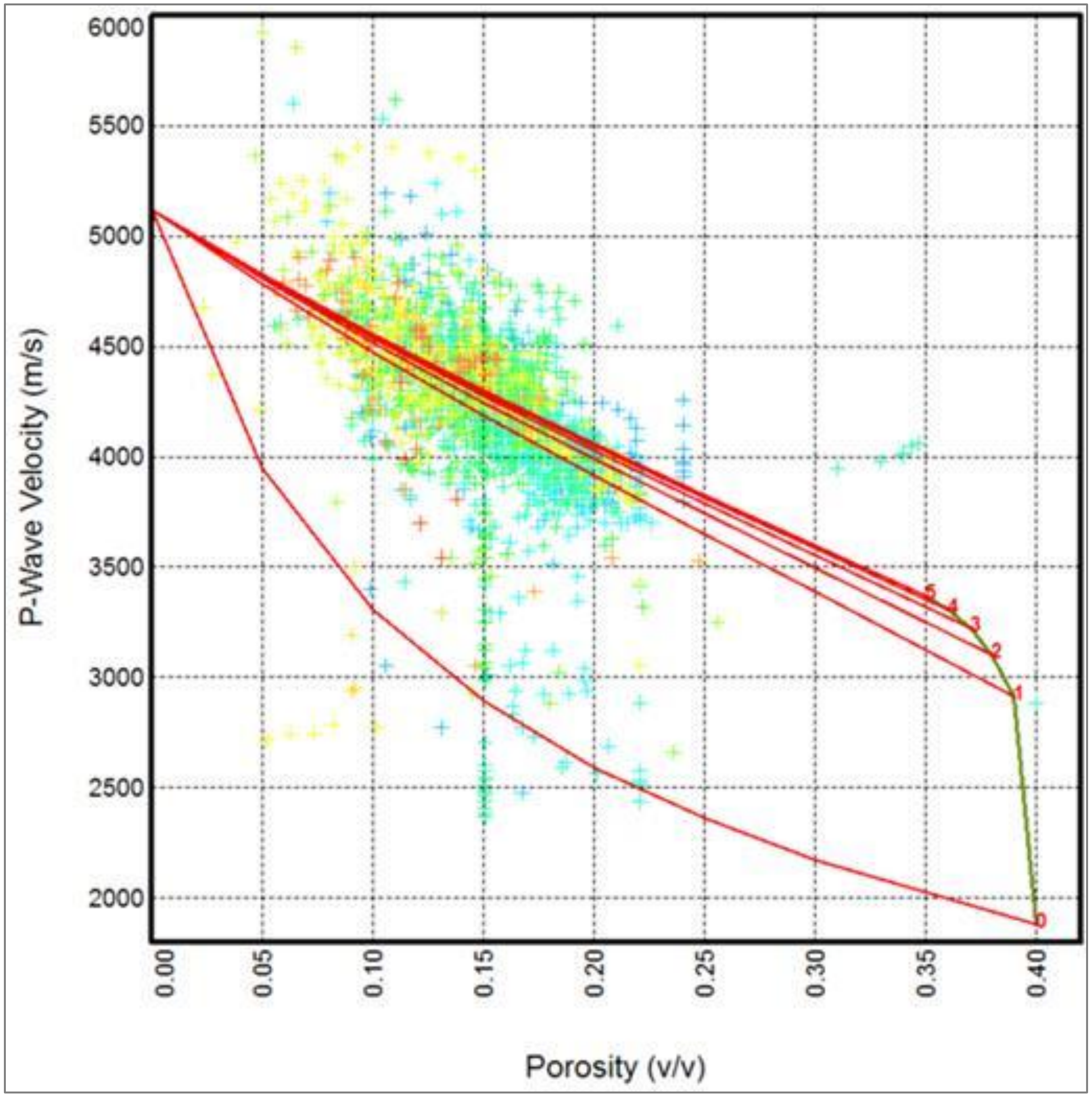

Figure 3. Calibration of the rock-physics model with well values of vP and porosity. Red lines correspond to percentage of cement in the model, ranging from 0- 5%.

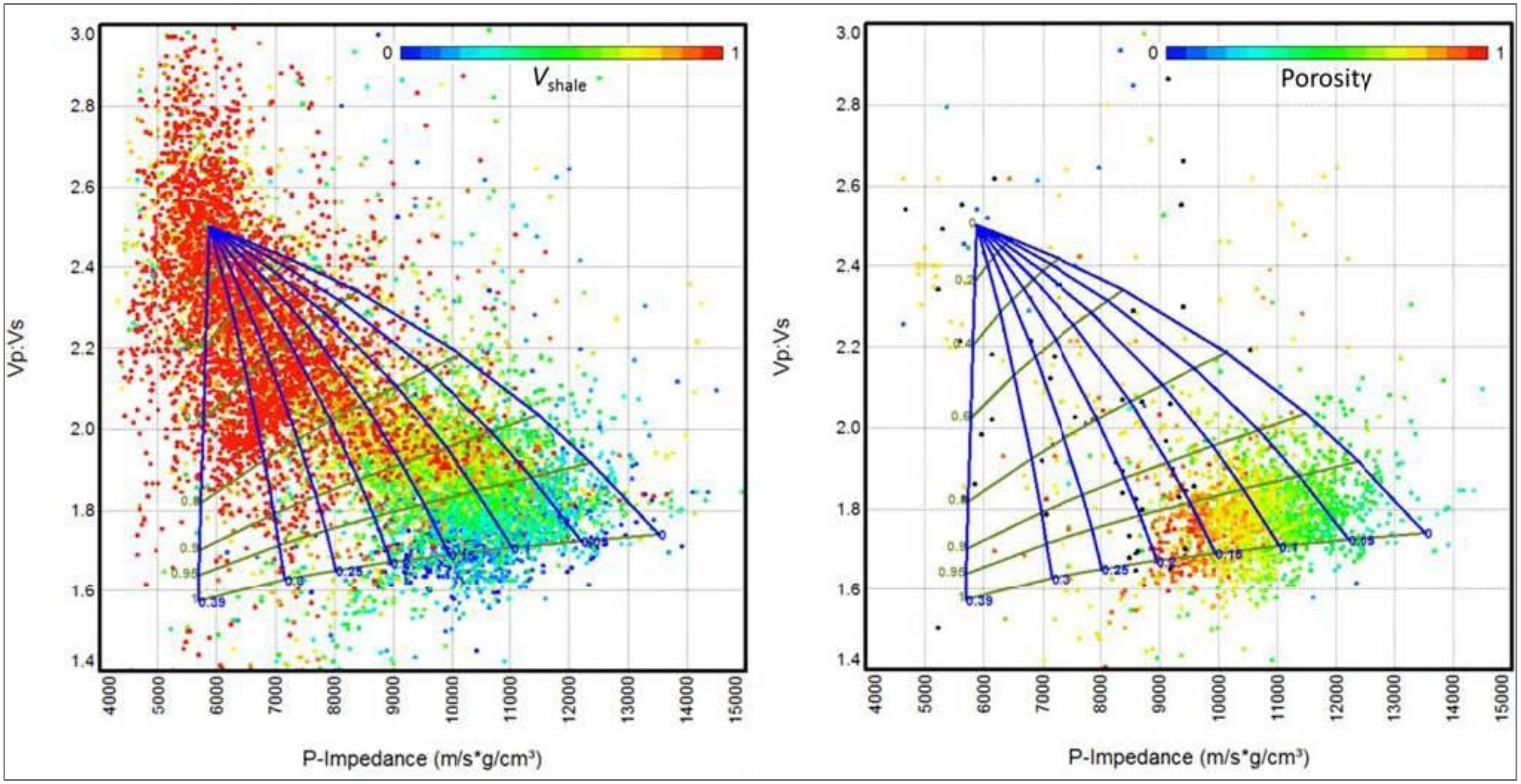

Figure 4. Rock-physics templates in the vP:vS versus P-impedance domain. Blue lines connect points of constant porosity, and green lines connect points of constant N:G. There is good correspondence with the Vshale and porosity trends observed on well data.

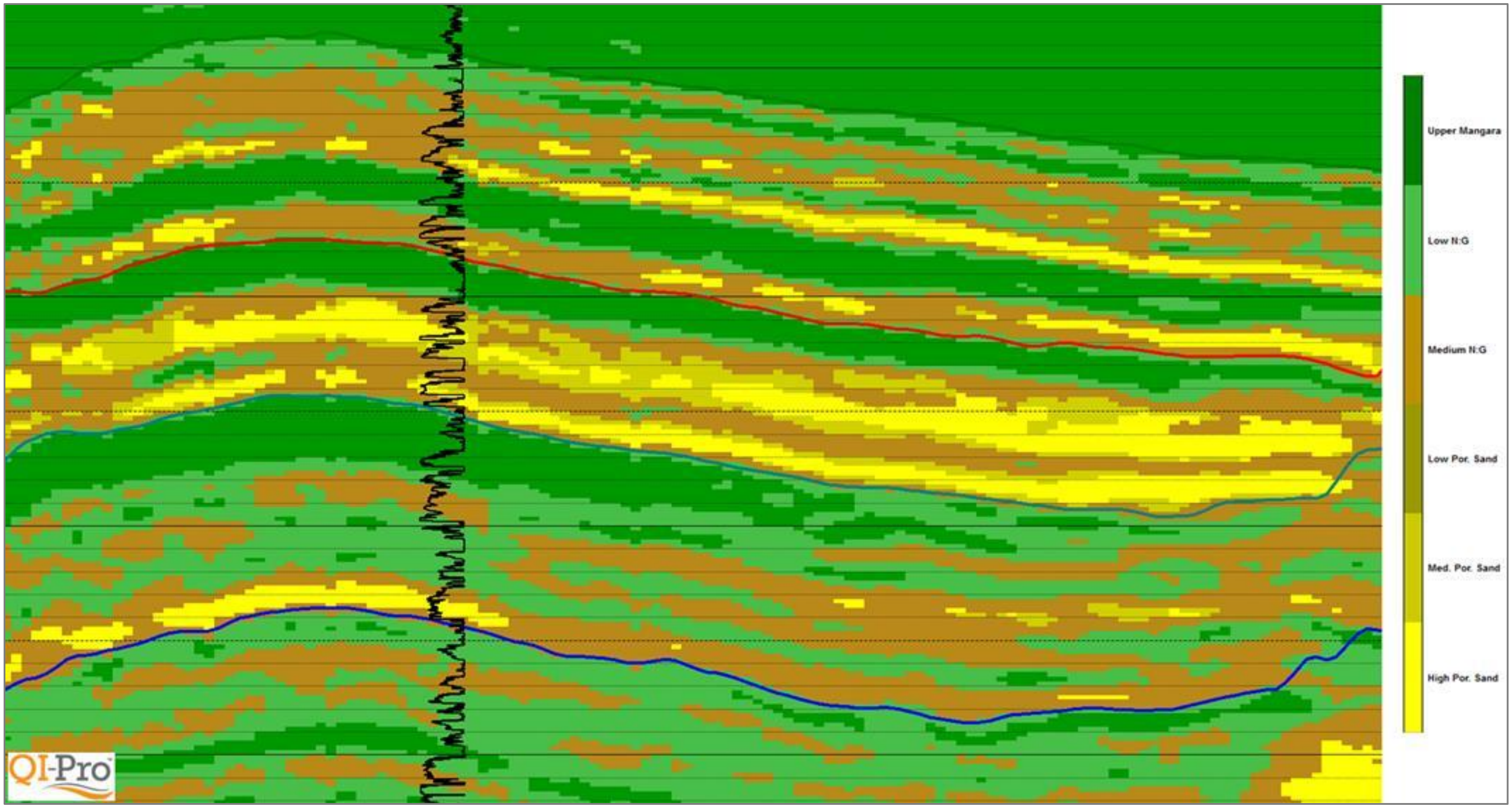

Figure 5. Classified seismic section showing areas of shale/low N:G (green), medium N:G (brown), and high N:G sands (yellow). A Vshale log is shown for correlation purposes.