

Rock physics and statistical well log analyses in marly chalk

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Analyses of the variations in porosity, clay content, and compressional velocity and modulus in marly chalk allow better interpretation of seismic data in terms of subsurface petrophysical parameters.

We present a study of variations in logging data from a marly chalk field. Our study includes log data of velocity, density, neutron-porosity, natural gamma-ray, and resistivity measurements.

In order to honor the various factors that interact to produce a suite of well log responses, we investigate the interdependencies using a multivariate principal component analysis (PCA). The main advantage of PCA is that no a priori information is required about the location, lithology, saturations, etc. to get an initial idea about the field. This means that PCA, even with only limited information, can help recognize trends in the data and separate lithology and saturation.

PCA is essentially a means of finding cross-correlations in a multidimensional data set. The simplest explanation of PCA is that it is a rotation of the multidimensional data cloud so that the maximum variability is projected on each pair-wise combination of the axes. Linear trends are fitted to the multidimensional data cloud to yield linear combinations of the original variables that can then be recombined to produce the original data set. Thus, the first principal component describes the

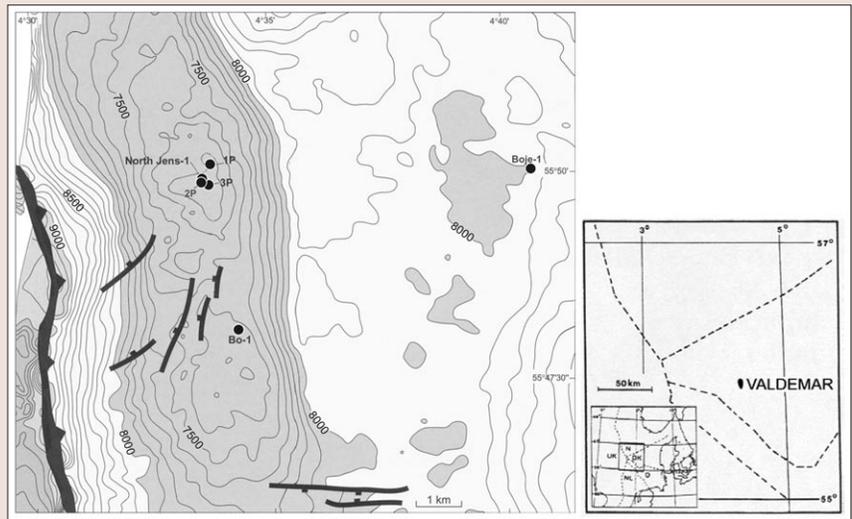


Figure 1. Location of the studied six wells in the Valdemar Field, Danish North Sea (modified after Jakobsen et al.).

Table 1. Wells used in the study

Well name	Well type	Fluid type	Mud type	Resistivity tool
BO	Exploration	Water	Water base	LLD, ILD
BOJE	Exploration	Water	Water base	LLD
NJENS	Exploration	Oil	Water base	ILD
VAL1P	Production	Oil	Oil base	ILD
VAL2P	Production	Oil	Oil base	ILD
VAL3P	Production	Oil	Water base	IDPH

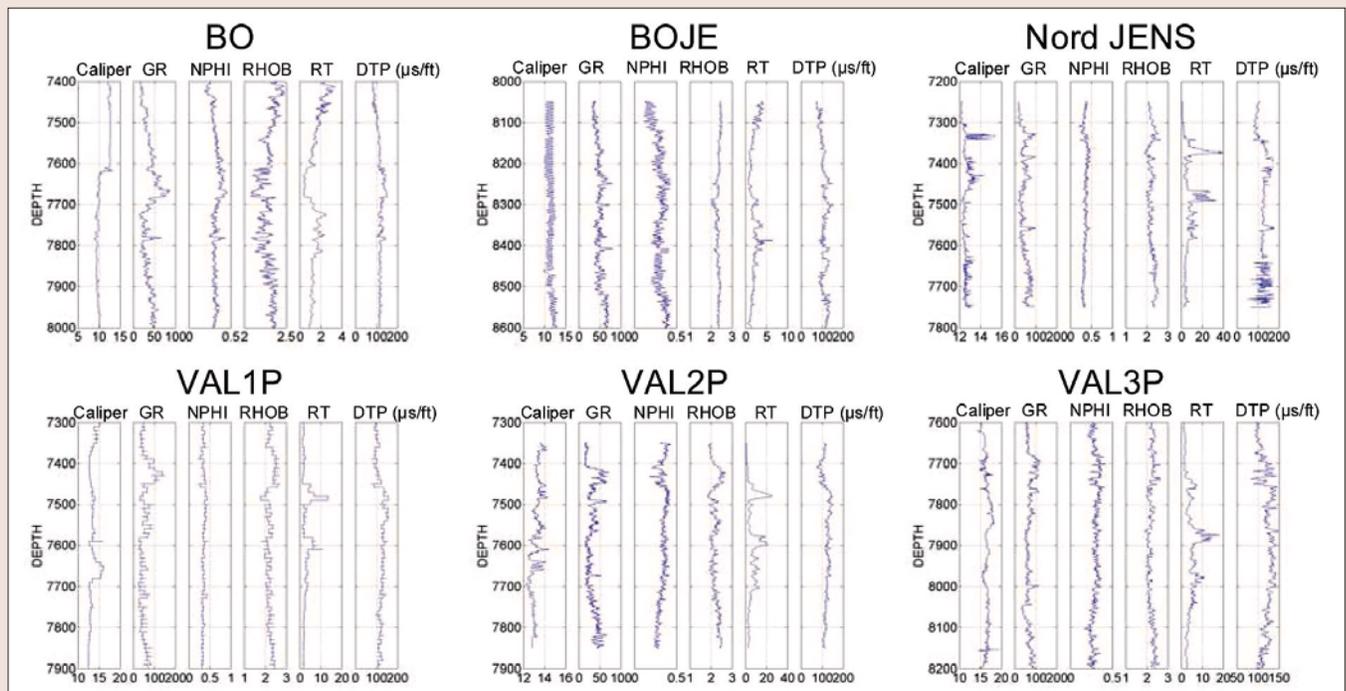


Figure 2. Raw data from the well logs.

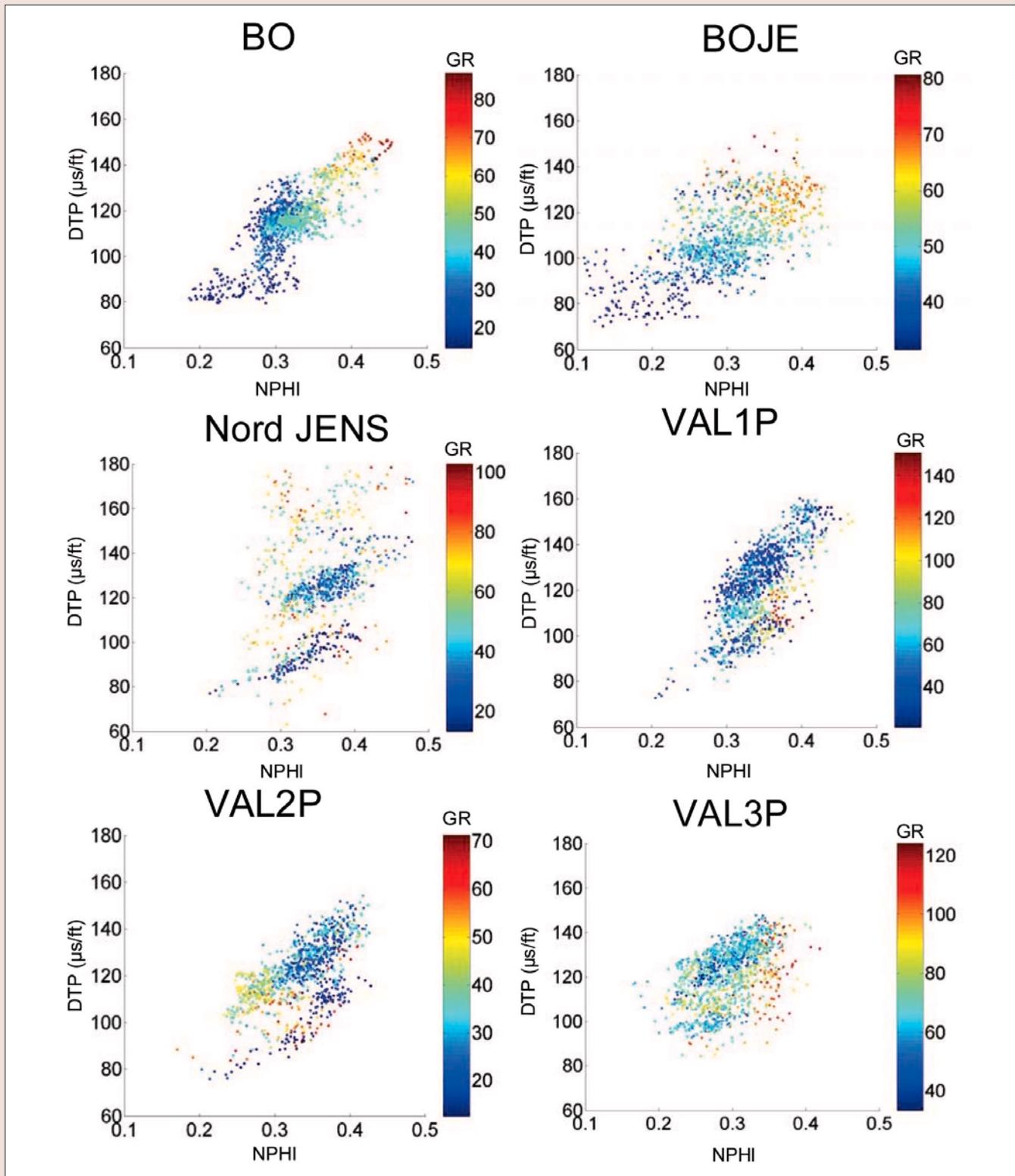


Figure 3. The relationship between porosity (NPHI) and P-wave slowness (DTP) for all six wells. Color coding is given by the GR response. Warmer colors indicate higher GR; cooler colors indicate lower GR. BO and BOJE are water wells; all others are oil-bearing.

maximum amount of variation in the data set. The second principal component describes the second largest data variability orthogonal to the first principal component and so on. The main advantage of PCA is reducing data dimensionality while retaining as much information as possible. Generally, the first three principal components describe almost 80% of the data.

Data acquisition. We analyzed well logs from the chalks, marly chalks, marl, and claystones of Valdemar Field in the central graben of the North Sea (Figure 1). The field is a low-relief marly chalk structure, sealed from the overlying chalk group by calcareous claystone. Six wells were used for this study, two water-bearing and four oil-bearing. One oil-bearing well is an exploration well drilled with high overpressure. The other oil-bearing wells are producing. Table 1

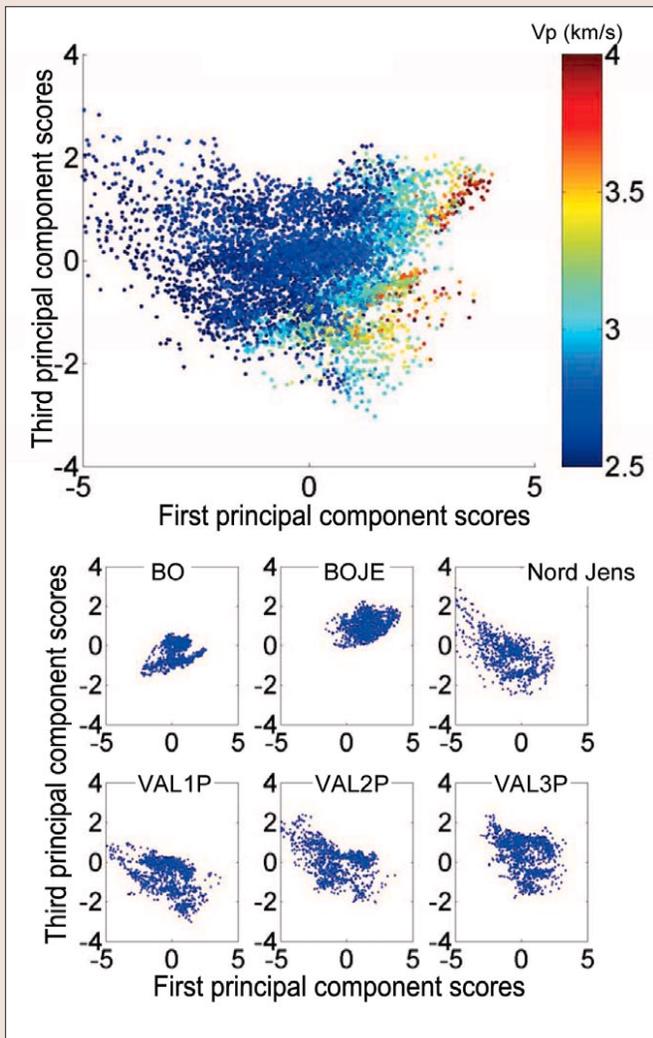


Figure 4. Relations between first and third principal components for all wells (top) and each well (bottom).

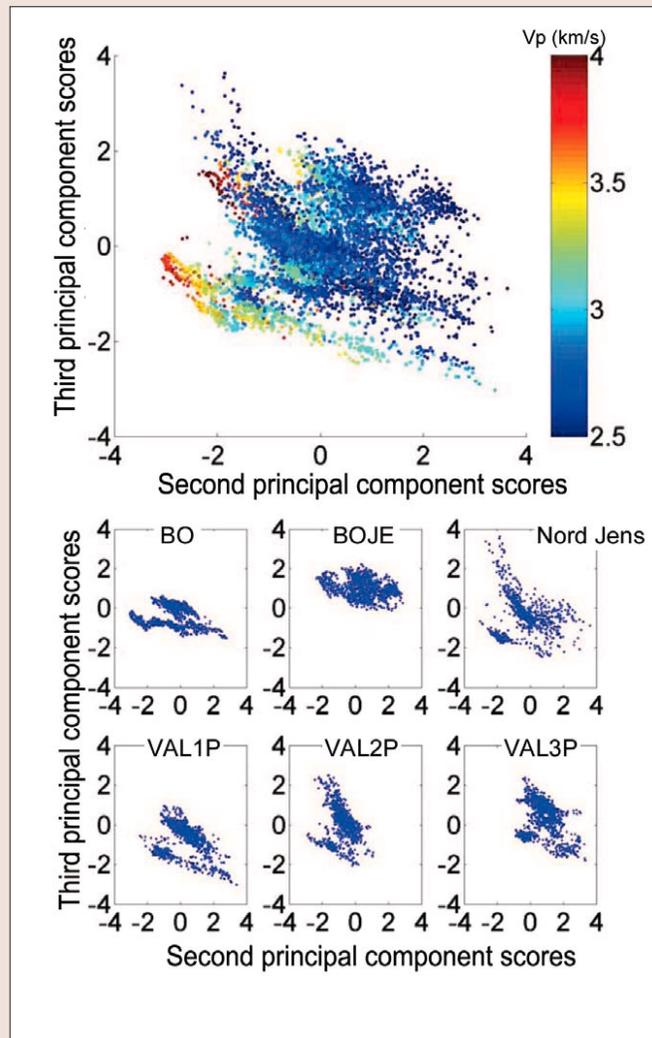


Figure 5. Relations between second and third principal components for all wells (top) and each well (Bottom)

Table 2. First, second, and third PC values

	PC1	PC2	PC3
Depth	0.2851	0.3970	0.7423
GR	0.1513	0.7268	-0.2189
NPHI	-0.4728	0.2661	-0.3649
RHOB	0.5432	0.0435	-0.1738
RT	-0.4049	-0.2087	0.4644
DTP	-0.4618	0.4448	0.1485

Table 3. Correlation coefficients

	PC1-PC2	PC1-PC3	PC2-PC3	Fluid
BO	-0.742	0.341	-0.186	Water
BOJE	-0.821	0.325	-0.265	
NJENS	0.049	-0.659	-0.173	
VAL1P	-0.050	-0.448	-0.333	Oil
VAL2P	0.181	-0.491	-0.215	
VAL3P	-0.149	-0.324	-0.294	

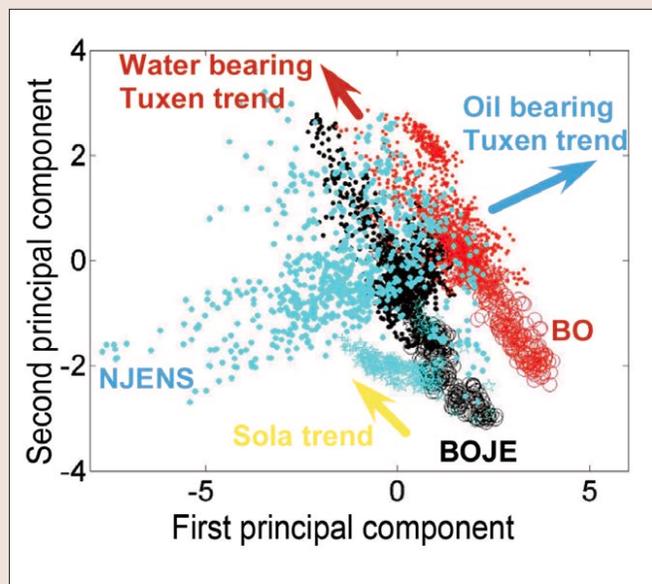


Figure 6. Crossplot of the first and second principal components for three wells. Both water-bearing wells, BO and BOJE show a similar trend (the Tuxen trend). The oil well (NJENS) shows a very different trend (the Sola trend).

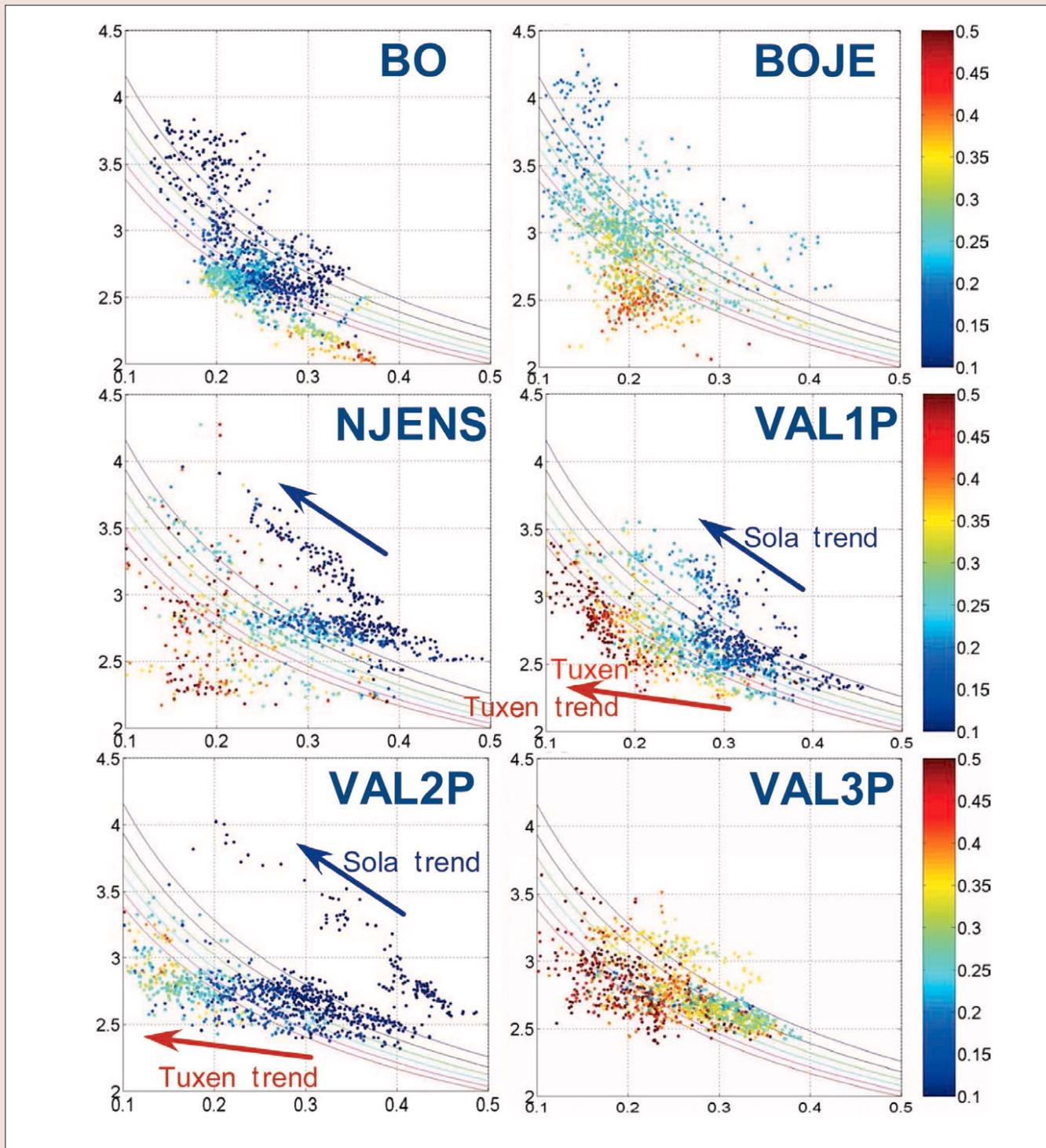


Figure 7. The relationship between neutron-porosity and velocity for all the wells. The well log data are color-coded by clay content as calculated from the gamma ray logs. The solid lines are velocities calculated with the uncemented model from Dvorkin et al. for calcite-clay mixtures from 100% calcite to a 50-50% calcite-clay mixture.

summarizes the wells in the study. In Table 1, LLD = deep laterolog, ILD = deep induction log, and IDPH = deep phasor induction tool. In BO, LLD was used from 6600 to 7600 ft and ILD from 7600 to 8398 ft.

We used caliper, gamma ray (GR), neutron porosity (NPHI), lithodensity (RHOB), deep resistivity (RT), and sonic logs (DTP) for our analyses (Figure 2).

The data in Figure 2 do not indicate any apparent differences between the oil and water wells. Therefore, we examined the rock physics properties of the different wells

and used PCA to improve the rock physics models in an attempt to understand the various correlations between the different parameters, and to examine the differences between oil-bearing and water-bearing carbonate formations in the wells.

Results. Figure 3 shows plots of P-wave slowness (DTP) against neutron porosity (NPHI); the symbols are color-coded by values of gamma ray logs (GR). These are raw data and have not been corrected for different fluid saturations

and the effects of clay on the log response. Even in the uncorrected data, the log sections with higher GR also show larger DTP and NPHI values. However, this correlation between DTP, NPHI, and GR is obscured by the large scatter in the data.

We made principal component analyses of all wells using depth, gamma ray logs (GR), neutron porosity (NPHI), lithodensity (RHOB), deep resistivity (RT), and P-wave slowness (DTP) as input parameters. The analyses were made on all wells together and on each well separately. Table 2 gives the values of the first three principal components for all wells.

The PC values in Table 2 let us determine the correlations in the data for the wells. It is apparent that NPHI, RHOB, DTP, and RT (saturation) play a major role in PC1. NPHI and DTP have a negative correlation with RHOB—as porosity increases, slowness also increases and density decreases.

The main contributions in PC2 are from GR and DTP with some minor effects of NPHI, depth, and RT. GR has a positive correlation with DTP. As clay content increases, slowness also increases. This observation is consistent with the laboratory data on sandstones that show a decrease in acoustic velocities with increasing clay content. The data in Table 2 suggest a possible depth dependence of the clay content. Also, the fact that NPHI has a large contribution but RHOB does not implies a water saturation effect. Finally, PC3 is impacted mainly by depth, NPHI, and RT.

Figures 4 and 5 present our PC analyses of all wells together (top figures) and each well separately (bottom figures).

Figure 6 shows the principal component analyses on the well logs. The scatter in the first and second principal components for NJENS can be better understood by separating the trends for the water-bearing Sola Formation and the oil-bearing Tuxen Formation. In BO and BOJE, both formations are water-bearing.

Next, we calculated P-wave velocity for each well using the uncemented model from Dvorkin et al. The results of our calculations are shown as the solid lines in Figure 7. The well-log data for each well are color coded by clay content as calculated from the gamma ray (GR) logs. The solid lines in Figure 7 were calculated for calcite-clay mixtures from 100% calcite to a 50-50% calcite-clay mixture.

To further examine the differences between the fluids in the wells, we investigated the correlations between the PCs of each well. Table 3 shows the correlation coefficient values. The correlation coefficient patterns between oil- and water-bearing wells follow different schemes. Water-bearing wells have a negative-positive-negative sequence and oil-bearing wells have a zero-negative-negative sequence.

Conclusions. Our rock physics and statistical analyses of well log data from Valdemar Field in the Danish North Sea show:

- 1) The correlation coefficient patterns between oil- and water-bearing wells follow different schemes. Water-bearing wells have a negative-positive-negative sequence and oil-bearing wells have a zero-negative-negative sequence.
- 2) The scatter in the first and second principal components for NJENS can be understood by separating the trends for the water-bearing Sola Formation and the oil-bearing Tuxen Formation. In BO and BOJE wells, both formations are water-bearing.

- 3) Using PCA, we can make different rock physics models and determine which is most appropriate. In this study, Sola can be better approximated by the cemented contact model but Vp in Tuxen Formation matches the uncemented sediment model by Dvorkin et al.

Acknowledgments: Thanks to Finn Jakobsen, Helle Foged Christensen, Tapan Mukerji, and Mark Zoback for comments. Some data for this work were provided by the Mærsk Oil and Gas AS.

Suggested reading. “Elasticity of marine sediments: rock physics modeling” by Dvorkin et al. (*GRL*, 1999). “The effects of porosity and clay content on wave velocities in sandstones” by Han et al. (*GEOPHYSICS*, 1986). “Characterization and zonation of a marly chalk reservoir: the Lower Cretaceous Valdemar Field of the Danish Central Graben” by Jakobsen et al. (*Petroleum Geoscience*, 2004). *Quantitative Acoustic Microscopy: Applications to Petrophysical Studies of Reservoir Rocks* by Prasad et al. (*Acoustical Imaging 25*, Kluwer, 2002). **TJF**

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