Rock Physics and Stastical Well Log Analyses in Carbonates

Manika Prasad, Department of Geophysics, Stanford University, Casper Olsen, Ida Fabricius, Environment & Resources DTU, Technical University of Denmark, Kgs. Lyngby, Denmark*

Summary

Chalks and marl reservoirs may maintain high porosity at more than two kilometers of burial depths due to overpressure and the presence of hydrocarbons. As a result, formation stability is compromised considerably and wells are is danger of being lost. Analyses of the variations in velocity, attenuation, and static compression modulus in carbonates allow us to better interpret seismic measurements in terms of subsurface petrophysical parameters and to understand the failure and damage potential. We present a study of variations in dynamic moduli in various carbonate reservoirs. Our study includes log and laboratory data from velocity, porosity, permeability, and attenuation measurements.

Introduction

Chalks and marl reservoirs may maintain high porosity at more than two kilometers of burial depths due to overpressure and the presence of hydrocarbons. As a result, formation stability is compromised considerably and wells are in danger of being lost. Analyses of the variations in porosity, clay content, and compressional velocity and modulus in carbonates allow us to better interpret seismic data in terms of subsurface petrophysical parameters and to understand the failure and damage potential. We present a study of variations in dynamic moduli in various carbonate reservoirs. Our study includes log data of velocity, porosity, vshale, and resistivity measurements.

We present analyses of well logs from the region. The analyses using rock physics models and statistical principal component analyses allow us to better understand the reservoirs and to differentiate between the different response of oil-bearing and water-bearing wells. Thus, we find that the first three principal components can explain about 80% of the data. The oil-bearing wells can be separated from the water-bearing wells by examining the first three principal components. We also show how such statistical analyses can be understood and used to make more meaningful using rock-physics models.

Location

We analyzed well logs from the chalks, limestones, and marls from the Valdemar Field located in the central Graben in the North Sea (see Figure 1). The Valdemar field in the North Sea is a low relief marly chalk structure, sealed from the overlying Chalk by calcareous shale. Six wells were used for this study. Table 1 gives a summary of the wells used in the study.

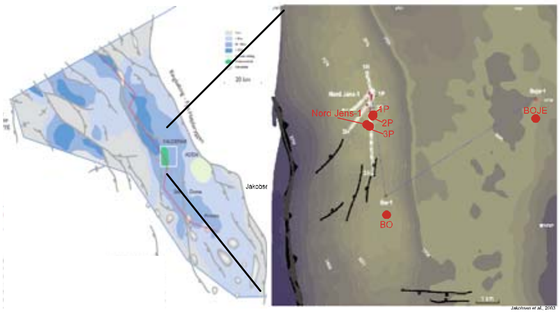

Figure 1: Location of the study area (left) and well location (right)

Table 1: Wells used in the study

Well name	Well type	Fluid type
BO	Exploration	Water
BOJE	Exploration	Water
NJENS	Exploration	Oil
VAL1P	Production	Oil
VAL2P	Production	Oil
VAL3P	Production	Oil

Raw Data from Well Logs

Figure 2 presents the well logs used in this study. We used Caliper (Cal), Gamma Ray (GR), Neutron Porosity (NPHI), LithoDensity (RHOB), Resistivity (RT), and Sonic Logs (DTP) for our analyses.

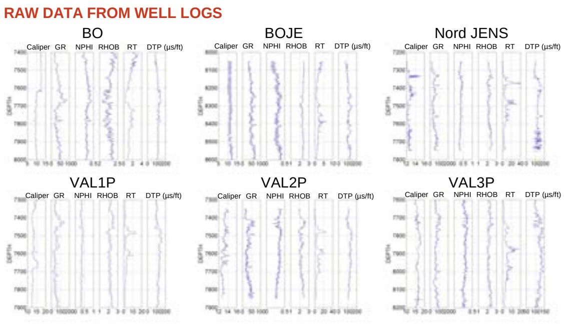

Figure 2: Raw data from the well logs

From the data presented in Figure 2, we do not observe any apparent differences between the oil and water wells. In this study, we examine the rock physics properties of the different wells. We use statistical Principal Component

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

Results

Rock Physics Relations: Figure 3 shows the rock physics relations derived for all the wells. In the plots of P-wave slowness (DTP) against porosity (NPHI), the symbols are color-coded by values of gamma ray logs (GR). Although, there is a correlation between DTP and porosity and GR, the scatter is quite large.

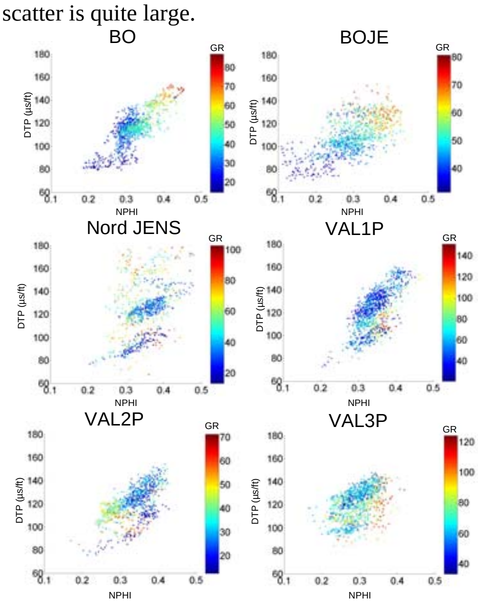

Figure 3: Porosity – DTP relations for all wells.

Principal Component Analyses: We made Principal Component (PC) analyses of all the wells using depth, gamma ray logs (GR), neutron porosity (NPHI), lithodensity (RHOB), shallow resistivity (RT), and P-wave slowness (DTP) as input parameters for our analyses. The PC 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.

Table 2: First, Second, and Third PC values based on depth, GR, NPHI, PHOB, RT, and DTP in the wells used in the study.

	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

From the Principal Component (PC) values in Table 1, we can distinguish between the correlations in the data set for the wells. Thus, 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 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 (Han et al., 1986; Prasad et al., 2002). The data in Table 2 suggests that there might be a depth dependence of the clay content. Also, the fact that NPHI has a large contribution but not RHOB implies a water saturation effect. Finally, the PC3 is describes by effects of mainly Depth, NPHI, and RT.

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

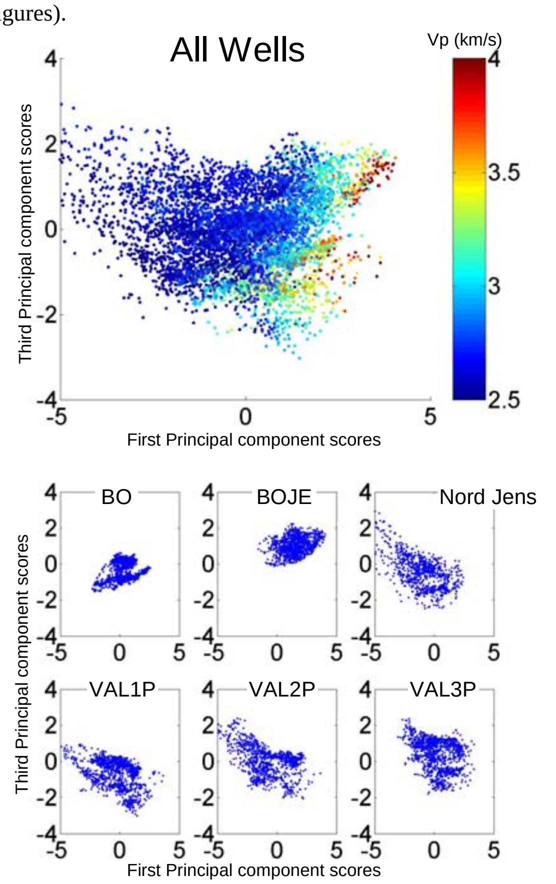

Figure 4: Relations between First and Third Principal Components for all wells (top) and each well (Bottom)

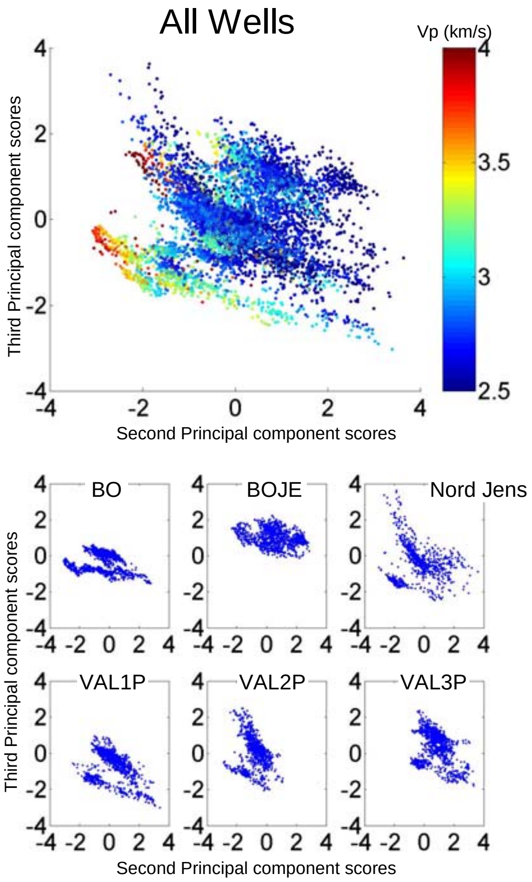

Figure 5: Relations between Second and Third Principal Components for all wells (top) and each well (Bottom)

Understanding Lithology: Figure 6 shows the results of principal component analyses on the well logs. The scatter in the 1st and 2nd 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 wells, both formations are water-bearing.

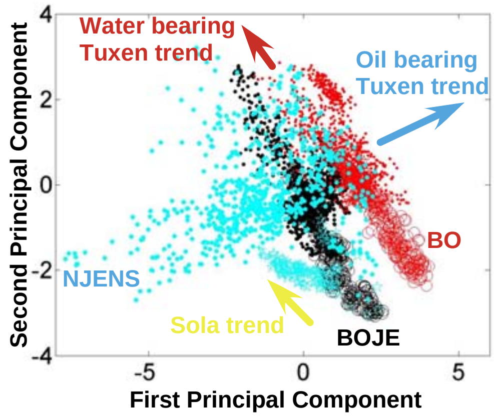

Figure 6: Crossplot of the First and Second Principal Components for three wells. Both water bearing wells, BO and BOJE show a similar trend (the Tuxen trend). The oil well (NJENS) shows a very different trend (the Sola trend).

Rock Physics Transforms for Velocity: Next, we calculated P-wave velocity for each well using the uncemented model from Dvorkin et al. (1999). The results of our calculations are shown as solid lines in Figure 7. The well log data for each well is shown as symbols 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. We will present the variations in rock physics models that need to be considered in modeling these carbonate lithologies and compare them to other existing models to identify a best scheme to make realistic predictive models of carbonate reservoirs.

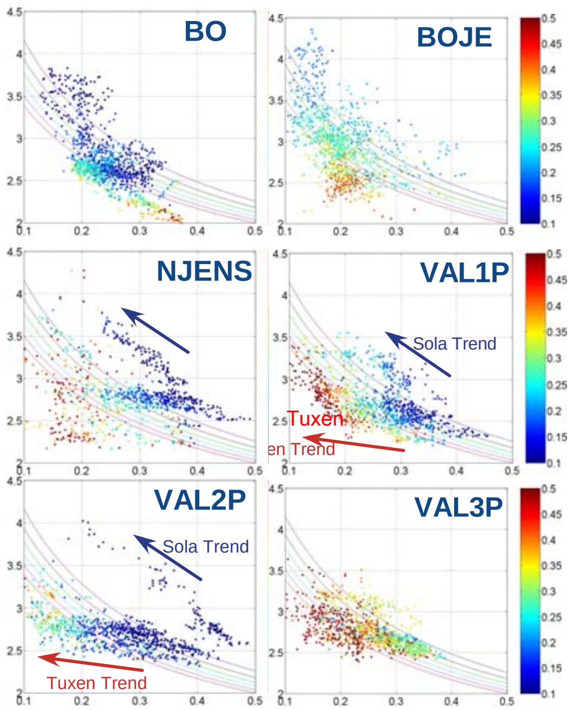

Figure 7: Relations between Second and Third Principal Components for all wells (top) and each well (Bottom)

Differentiating Fluids

To further examine the differences between the different 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, whereas oil-bearing wells have a positive-negative-negative sequence.

Table 3: Correlation coefficients between PC1-PC2, PC1-PC3, and PC2-PC3 for all wells. Water-bearing wells have a negative-positive-negative sequence, whereas oil-bearing wells have a positive-negative-negative sequence.

	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	Oil
VAL1P	-0.050	-0.448	-0.333	
VAL2P	0.181	-0.491	-0.215	
VAL3P	-0.149	-0.324	-0.294	

Conclusions

Our rock physics and statistical analyses of well log data from the Valdemar field in North Denmark show that:

1. The correlation coefficient patterns between oil- and water-bearing wells follow different schemes: Water-bearing wells have a negative-positive-negative sequence, whereas oil-bearing wells have a positive-negative-negative sequence.
2. The scatter in the 1st and 2nd 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 the principal component analyses, we can make different rock physics models: the Sola can be better approximated by the cemented contact model, whereas the Vp in the Tuxen formation matches the Uncemented Sediment Model by Dvorkin et al. (1999).

References

Dvorkin, J., Prasad, M., Sakai, A., Lavoie, D., 1999, Elasticity of marine sediments: Rock Physics Modeling: GRL, v. 26, no. 12, 1781-1784.

Han, De-hua , Nur, A., and Morgan F. D., 1986. The events of porosity and clay content on wave velocities in sandstones, Geophysics, 51, 2093-2107.

Prasad, M., Reinstaedler, M., Nur, A., Arnold, W., 2002, Quantitative acoustic microscopy: Applications to petrophysical studies of reservoir rocks: Acoustical Imaging 25, Kluver Publications.

Acknowledgements

Thanks to Finn Jacobsen, Helle Christensen, Tapan Mukerji, Mark Zoback for comments. The funding and data for this work was provided by the Maersk Oil and Gas Company, the SRB project, and DOE (Award No. DE-FC26-01BC15354).