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Controls on Cementation in a Chalk Reservoir

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Summary

In this study, we identify different controls on cementation in a chalk reservoir. Biot's coefficient, a measure of cementation, stiffness and strength in porous rocks, is calculated from logging data (bulk density and sonic P-wave velocity). We show that Biot's coefficient is correlated to the water saturation of the Kraka reservoir and is partly controlled by its stratigraphic sub-units. While the direct causal relationship between Biot's coefficient and water saturation cannot be extended for Biot's coefficient and porosity, a correlation is also identified between the two, implying that some degree of pore filling cementation occurred in Kraka (Alam, 2010). Lack of correlation between Biot's coefficient and Gamma Ray (GR) indicates that the small amount of clay present is generally located in the pore space, thus not contributing to frame stiffness. While there was no compositional control on cementation via clay, we could infer that stratigraphy impacts on the diagenetic process.

Introduction

The estimation of Biot's coefficient is essential in predicting settlement of a reservoir undergoing depletion, estimation of the drilling window (the difference between fracture formation pressure and the pore fluid pressure) and magnitude of lateral stresses. The coefficient α is inversely proportional to the degree of cementation in a sedimentary rock and for a given mineralogy, and has been found to correlate with strength and stiffness parameters such as compressional and shear modulus, yield strength and creep (Alam et al., 2010).

In this study, we identify different controls on cementation in a chalk reservoir. Biot's coefficient is calculated from logging data (bulk density and sonic P-wave velocity). We show that Biot's coefficient is correlated to the water saturation of the Kraka reservoir and is partly controlled by its stratigraphic sub-units. While a direct causal relationship cannot be established between Biot's coefficient and porosity, a correlation is also identified between the two, implying that some degree of pore filling cementation occurred in Kraka (Alam, 2010). Lack of correlation between Biot's coefficient and Gamma Ray (*GR*) indicates that the small amount of clay present is generally located in the pore space, thus not contributing to frame stiffness.

Materials and Methods

The Kraka Field is located in the southern part of the Danish North Sea. The slightly elongated domal structure can be stratigraphically divided into two main formations: Danian (lower Paleocene) and Maastrichtian (upper Cretaceous). The chalk is characterized by high porosities (up to 45%) and low matrix permeabilities (up to 5mD), locally enhanced by subvertical fractures, especially close to the ridge of the reservoir. Most of the oil in place is located in the Danian part of the reservoir, and water saturation is generally high (above 20%).

Petrophysical logs and cores from wells located in the Kraka field were used to calculate water saturation (*Sw*) by Archie (resistivity and porosity) and to assess the presence of clay in the reservoir (*GR*). Formation fluid pressure measurements (RFT) were used to estimate in-situ fluid densities needed to calculate density derived porosity. Core porosity and Klinkenberg permeability data were measured by Boyle's law Helium expansion and N_2 flow respectively and depth shifts we performed to match wireline depth. Results were used to calculate Archie's cementation exponent *m* (Olsen et al., 2008), an input in the water saturation equation. Characteristic grain size was also determined from core data using the equation introduced by Kozeny (1927), which derives permeability, *k*, as function of porosity, φ, specific surface area normalized to pore volume, *S/V* and a constant *c*.

$$k = c\,\frac{\varphi}{(S/V)^2} \quad . \tag{1}$$

The factor *c* (close to 0.25 in the present case) accounts for lack of contribution from a major part of the pore space due to a shielding effect (Mortensen et al. 1998). Assuming spherical grain shape, grain diameter, *d*, is defined as:

$$d = \frac{6\sqrt{k}(1-\varphi)}{\sqrt{c}\,\varphi^{\frac{3}{2}}} \quad . \tag{2}$$

Where k is the Klinkenberg permeability.

Biot (1941) introduced the effective stress coefficient α that describes to which extent the pore pressure P_p in a porous material under drained conditions counteracts the elastic deformation of the frame.

$$\sigma' = \sigma - \alpha P_p \;, \tag{3}$$

Where σ is the stress due to the overburden, and σ' is termed the effective stress.

The P-wave modulus of the saturated rock M can be calculated by:

$$M = \rho V_p^2 \tag{4}$$

Where ρ is bulk density and V_p, the propagation of a purely elastic wave through a saturated porous rock. The dry modulus is reached by applying the approximated Gassmann substitution (Mavko, 1998):

$$\frac{M}{M_{min} - M} \sim \frac{M_{dry}}{M_{min} - M_{dry}} + \frac{M_{fl}}{\varphi(M_{min} - M_{fl})} \tag{5}$$

And Biot's coefficient is approximated by:

$$\alpha \sim 1 - \frac{M_{dry}}{M_{min}} \tag{6}$$

Where M_{dry}, M_{min} and M_{fl} are the P-wave moduli of the dry rock, the mineral, and the pore fluid, respectively. M_{fl} is estimated by mixing the modulus of the water and hydrocarbon phases according to the Voigt average, assuming a water-wet reservoir (Katika et al., 2017).

Results and discussion

The interpretation of the stratigraphic units based on grain size and calculated values of Biot's coefficient and water saturation can be observed in Figures 1 to 4.

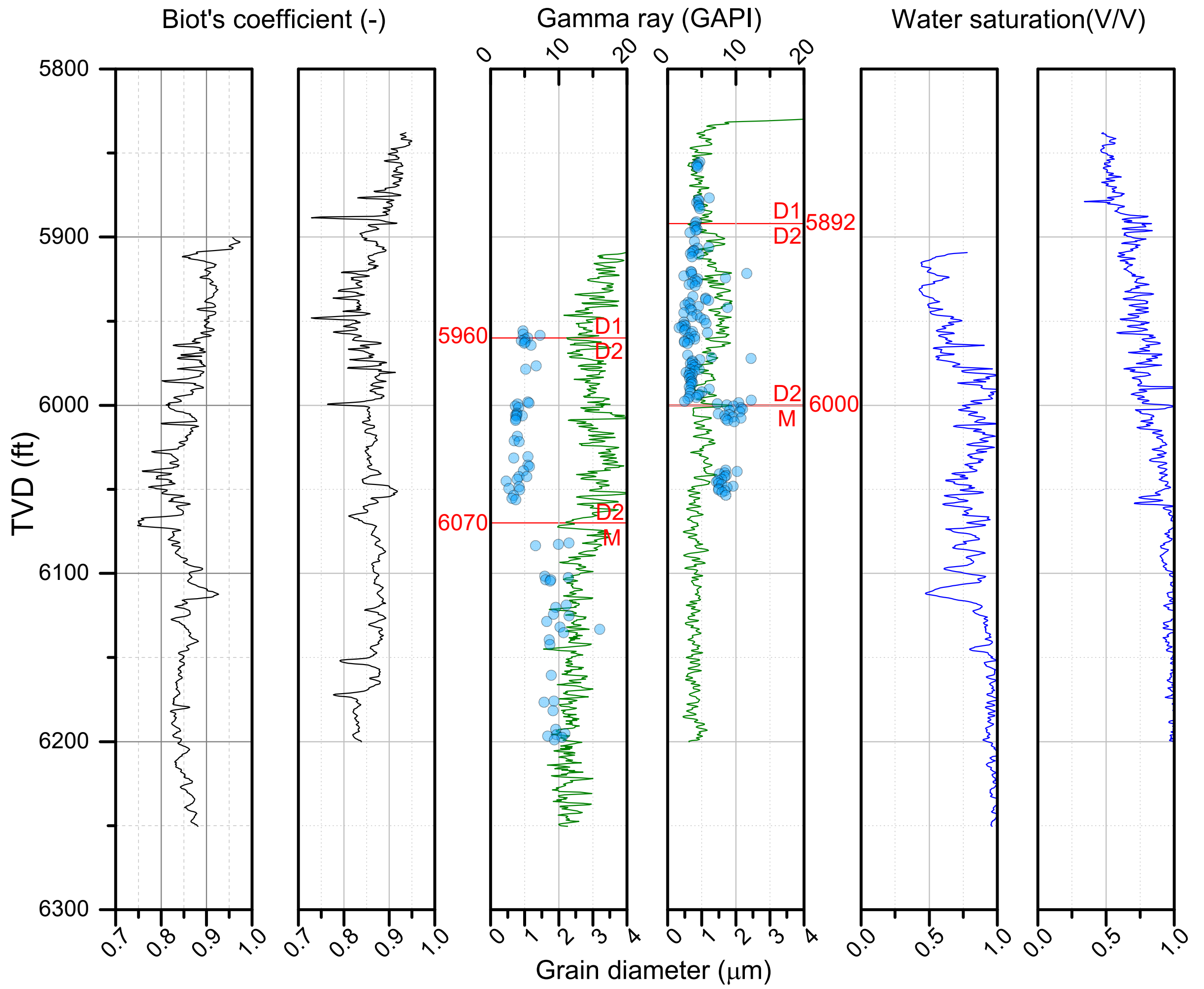
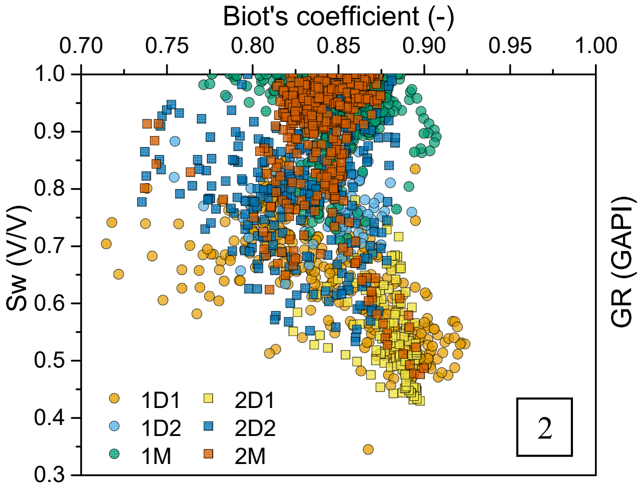
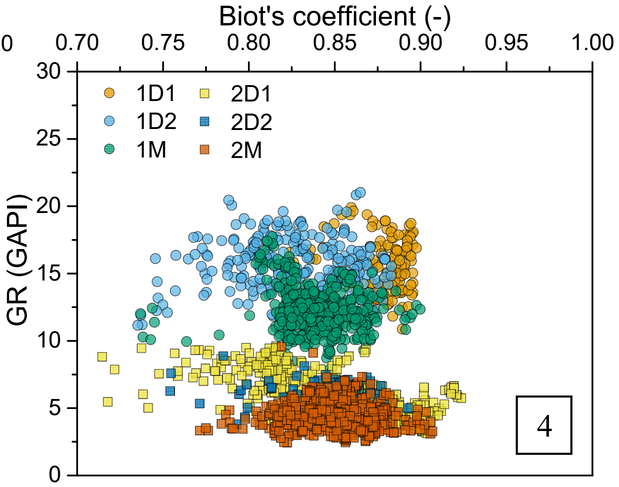
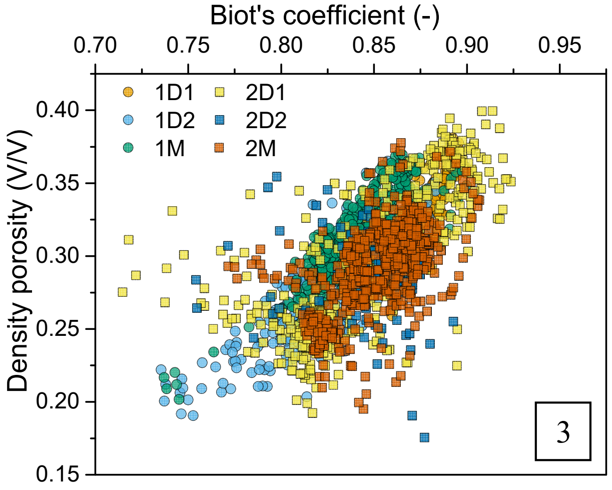


__Figure 1__ Logs (GR) and derived measurements (Biot's coefficient, Sw and Grain diameter) for wells 1 and 2 (left and right) in the Kraka field. Two stratigraphic units are highlighted for the Danian formation (D1 and D2) and one for the Maastrichtian, based on grain diameter. Biot's coefficient is largely unaffected by changes in GR indicating that clay has little (if any) influence on cementation.







***Figures 2, 3&4** Biot's coefficient plotted respectively against Sw, porosity and GR: Stratigraphy does influence cementation in Kraka, though not through clay content (evidenced by the lack of correlation between Biot's coefficient and GR). The relation between porosity and Biot's coefficient indicates that in this reservoir pore-filling cementation lead to porosity reduction.*

The stratigraphic units indicated in Figure 1 (track 2) determined by grain diameter analysis coincide with subtle but noticeable changes in *GR*, reflecting the small size of *GR* emitting clay particles. Comparing the *GR* and Biot's track in Figure 1 and observing Figure 4 it is clear that there is no compositional control on Biot's coefficient via clay, since no correlation is observed between the two. Nevertheless, small silica particles found especially in the lower Danian could contribute to increasing levels of *Sw*. A strong correlation is observed between cementation and *Sw*, seen as an inverse correlation between Biot's coefficient and *Sw* in Figure 1 (tracks 1 and 3) and Figure 2. A direct correlation between porosity and Biot's coefficient (Figure 3) shows that cementation of the chalk leads to a decrease in porosity.

It has been shown that early accumulations of oil in chalk reservoirs prevent cementation, either by inhibiting pressure solution of calcite (Rabinowicz et al., 1985) or increasing the tortuosity of the water phase, which leads to slowing diffusion and/or reducing ion mobility (Fabricius, 2007). This is certainly the case for Kraka, as we can see that the presence of high levels of water saturation promotes grain cementation in the reservoir. It is also interesting to note that though stratigraphy does not directly control cementation it influences the ensuing diagenetic processes. This is evidenced by the different cementation trends found for each stratigraphic interval (Figure 2) where the slope of the linear fit between Biot's coefficient and *Sw* differs between units, especially between Danian and Maastrichtian datasets.

Conclusions

Based on petrophysical log and core data from two wells in the Kraka field, this study provides insights on what governs the cementation process in a chalk reservoir. We found that water saturation was the most significant control on cementation: a good inverse correlation between Biot's coefficient and *Sw* was found for both wells and a causal relationship can be established between these two parameters. We also showed that cementation in Kraka lead to a decrease in pore volume, thus the good agreement between Biot's coefficient and porosity. While there was no compositional control on cementation, we could infer that stratigraphy impacts on the diagenetic process.

Acknowledgements

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