Chalk stiffness: Distribution in the Maastrichtian unit of the Dan Field

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Introduction

Stiffness is an important parameter in hydrocarbon exploitation: It governs elastic deformation during depletion of reservoirs and can be correlated to peak strength of core plugs, when pore collapse takes place. From the related property, seismic impedance, porosity maps are sometimes derived from seismic data, impacting estimation of OIP, permeability and other parameters. Based on petrophysical log data and core measurements we derived seismic impedance logs and assessed trends between porosity and stiffness across the reservoir. We found that in the Maastrichtian chalk of the North Sea Dan field, the chalk located at the crest of the reservoir is softer than the chalk located at the flanks of the field, even considering the same porosity and saturation state. We speculate that earlier hydrocarbon filling on the crest of the reservoir might have delayed cementation between the chalk particles which can have led to loss in porosity due to elastic strain or pore collapse.

Setting

The Dan chalk field. Lying in the southern part of the North Sea Central Graben, the Dan field is part of a number of structures induced through salt tectonics called the "Salt Dome Province" which also includes the Ekofisk field. The Dan field is a structural dome divided by a large SW-NE striking fault, itself intersected by several minor faults which are thought to locally enhance its low matrix permeability. Most of the oil produced in Dan field comes from the Maastrichtian chalk of the Tor Formation; the chalk mineralogy of this chalk is almost exclusively calcite.

Methodology

Petrophysical logs and core data. Compressional seismic impedance (*Ip*) was derived from logs via a fluid substitution procedure, because during logging, the region probed by density and sonic logs is flushed by mud filtrate. In order to assess the *Ip* of the virgin zone we did these calculations:

Porosity and saturation of the invaded and the uninvaded zone. Density porosity was calibrated to core porosity based on calcite grain density and by adjusting fluid density. In wells drilled with water based mud, we found that the fluid density corresponds to residual oil saturation (S_{oir}) of 0.2, whereas for wells drilled with oil based mud, the fluid density corresponds to irreducible water saturation (S_{wir}) of 0.2. The saturation of the uninvaded zone was then calculated by Archie's equation from the resulting porosity and deep resistivity.

Fluid substitution. Due to the difficulty in assessing residual gas saturation and the large impact that relatively low gas saturation (5%) has on fluid modulus, wells which penetrate the Tor Formation in the gas cap were not included in this study. Modulus of oil was calculated based on compositional analysis (Dashti and Riazi, 2014), whereas brine modulus was estimated according to Batzle and Wang (1992). The resulting fluid moduli in invaded and uninvaded zone were estimated by a Voigt model. The Iso-frame model (*IF*) was used to estimate the shear modulus and the drained rock bulk modulus K_{dry} based on invaded zone data, and to estimate the compressional modulus of the uninvaded zone.

Results

Seismic impedance, *Ip* was plotted against density porosity (Figure 1a). Water saturation, one of the controlling parameters of stiffness provides the input for colour mapping. In order to probe the influence of hydrocarbon filling time, we compared the stiffness of the oil leg of different wells by fitting a linear curve to the scatter (figure 1b) and finding the *Ip* for a normalized porosity of 25%. These values are plotted in the map of the top Maastrichtian in the Dan field (Figure 1c).

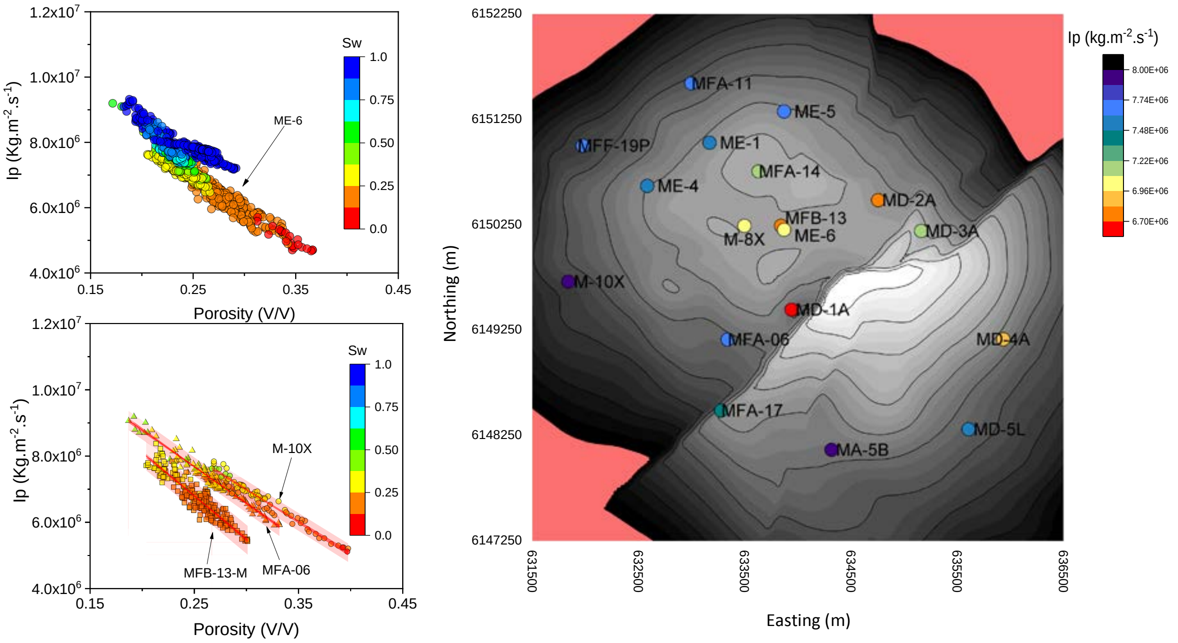

Figure 1: a) IP vs. Porosity vs. in ME-6. b) Ip vs. Porosity in the oil leg of 3 wells. c) Normalized Ip for porosity of 25% in the top part of the oil leg of 18 wells in the Dan field

Discussion

We found that for a given porosity and oil saturation, chalk that is located off structure is stiffer than chalk located at the crest of the reservoir. This off structure chalk was probably filled by oil later and hence it appears that the presence of oil hampered the contact cementation of the chalk, but it could also indicate partial pore filling cementation in off structure chalk and elastic deformation of the crestal chalk. Such behaviour could explain the apparent lack of depth related porosity reduction in the Maastrichtian chalk of the Dan field: although it may be pore-filling to some degree, enhanced cementation that took place due to the easier access to the calcium rich pore water effectively stiffened the rock frame. The softer frame of the rock first invaded by oil by contrast underwent elastic strain. Some degree of pore collapse in the oil leg is indicated by the observation of Jorgensen (1992). He identified abundant zones with compaction bands (then erroneously identified as hairline fractures) in the oil saturated upper units of the Maastrichtian chalk. He also observed that these become less frequent and eventually disappear in the lowermost water saturated units.

Acknowledgements

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References

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