Introduction

The giant Valhall oil field was discovered in 1975 and is one of the major chalk fields in the Central Graben petroleum system. It is located on the Lindenes Ridge, a Late Cenomanian to Oligocene inversion anticline. The Upper Cretaceous chalk reservoir is overpressured and contains a more than 200 m column of undersaturated oil, producing from the Tor and Lower Hod formations. A combination of overpressure and early petroleum charge are thought to be the main factors that lead to preservation of high porosities in chalk reservoirs (Brasher and Vagle 1996), the former being the main porosity preservation process in the Valhall Field (Munns 1985). Petroleum system modelling demonstrates that the Mandal and Farsund formations in the present-day fetch area of Valhall were not mature for oil generation during the early stages of the field’s burial.

Produced oils are of early maturity and were sourced by the Upper Jurassic marine shales, namely either the Mandal, Farsund and/or Haugesund formations, which have a cumulative thickness exceeding 1500 m in the Valhall fetch area. In order to gain a better understanding of the field’s filling history and the migration dynamics across the field a detailed oil-oil and oil-source rock correlation study was initiated.

Samples & Methods

Petroleum system modelling was conducted to constrain the thermal history of the reservoir and the timing of petroleum generation and expulsion in the Valhall fetch area (Figure 1). To understand the migration and charging mechanisms, i.e. to constrain the relative timing of the first charge and subsequent mixing with the main charge across the field, this study combines spatial PSA information with organic geochemical characterisation of the produced oils, reservoir core and source rock extracts.

The sample set contains eight DST oil samples from the Valhall crest and flanks as well as from the Hod East and West fields and ten corresponding Upper Cretaceous chalk reservoir core samples, including three samples from shallow Cenozoic formations above the Valhall main reservoir. Reservoir core extracts rather represent the initial oil emplacement, while produced oils represent the main charge (Leythaeuser et al. 2007). All samples are analysed for their inventory in conventional biomarkers and polar heterocompounds (the latter with FT-ICR-MS). While GC-MS is more suited to detect relatively nonpolar compounds up to a molecular weight of ~500 Da, FT-ICR-MS in ESI (-) and APPI (+) modes extends the detectable range to more polar, acidic and aromatic substances that can be as large as 10,000 Da.

Using acidic NSO compounds, maturity evolution, migration distances and fractionation effects of oils and source rock extracts can be investigated (Mahlstedt et al. 2016, Oldenburg et al. 2014, Poetz et al. 2014, Ziegs et al. 2018). The full range of NSO compounds, including aromatic compounds, may be helpful for correlation studies. Biodegradation levels of early and main charges into the field are the main indications for the timing of oil emplacement (Figure 2).

Timing of reservoir filling as revealed by maturity vs. migration distance vs. biodegradation

Oil maturities in the Valhall and Hod fields vary between 0.70 and 0.76% Ro equivalent, based on MPI-1 and carbazole distributions. Slight variations in maturity indicators are used to estimate when the main charge in the individual compartments occurred. Saturated biomarker data of oils and core extracts suggest that the Hod field and Valhall southern flank oils are the least mature, while the Valhall crest and northern flank oils are more mature. Slight differences in maturity assessment based on saturate, aromatic and gasoline compounds point towards mixing of differently mature charges at specific reservoir locations (after Farrimond 2019).

Benzocarbazoles are susceptible to migration fractionation, and homologues with shorter alkyl chains are depleted from the oil upon migration, while compounds with longer side chains are relatively enriched in the free, producible oil phase (Ziegs et al. 2018). Distributions of alkylated
benzocarbazoles in individual reservoir oils suggest that the crestal Valhall oil has migrated over the shortest distance, while the northern flank oil has migrated over slightly longer distances than the southern flank oil. Furthermore, there are slight variations in the migration distances for the Hod East and West fields. Due to oil-rock interactions of the more polar compounds this concept cannot be easily applied to reservoir core samples.

25-norhopane was the first indication for biodegradation in Valhall oils. Subsequently, high abundances of naphthenic acids have been detected in the NSO inventory of oils and core extracts from shallow Cenozoic reservoir oils at reservoir temperatures below 80 °C, corresponding to
moderate biodegradation levels. Only slightly elevated abundances of naphthenic acids are found in the oil and reservoir core extract of the southern flank compartment, as well as in the reservoir core extracts at the Valhall crest, eastern flank, southern flank and northern flank, and point to an early charge that was biodegraded, while the main charge occurred later after the reservoir had crossed the 80 °C boundary.

![Biodegradation map](image)

**Figure 2 Biodegradation levels of the initial and main charges at different reservoir positions in the Valhall and Hod oil fields.**

Petroleum system modelling reveals that the Tor and Hod formation chalk reservoirs in the Valhall and Hod fields crossed the 80 °C threshold for biodegradation during the mid to late Miocene (isotherm in Figure 1B) when the Mandal and upper Farsund Formations were locally not mature enough to generate and expel significant amounts of petroleum. Thus, biodegraded petroleum points to early, pre-Miocene emplacement from another local source horizon, or from a more distant kitchen area. Reservoir core extracts represent the initial oil emplacement, while produced oils represent the main charge (Leythaeuser al. 2007). Detailed polar NSO geochemistry reveals that:

- The initial charge of the Valhall crest seems to have experienced mild biodegradation although locally highest mature, while the main charge (the free, producible oil) is non-degraded and thus has been emplaced post-Miocene.

- The southern flank core extract and oil seems to be slightly biodegraded. Short migration distances indicate local sourcing – potentially from deeper Farsund Formation strata?

- The Hod oils are the least mature (also true for the core extract in Hod East) and were emplaced post-Miocene due to lack of biodegradation. Different migration distances – the Hod West oil is shorter migrated than Hod East – indicate different regional source kitchens.
Correlation

The acidic and aromatic NSO inventory in the reservoir core extracts is generally rich in compound classes containing one to six oxygen atoms. Being potential biomarker precursor structures and not contained in the drill mud mixture, these compounds can be used for oil-oil and oil-source rock correlation based on their relative abundances. Initial results from the acidic NSO inventory of source rock extracts show an increase in these compound classes with stratigraphic age from Mandal to Haugesund Formations.

Conclusions

Slight variations in maturity, migration distances and biodegradation levels of produced oils and reservoir core extracts of the Valhall and Hod oil fields revealed by GC-MS and FT-ICR-MS indicate that the giant Valhall field seems to be filled from three different directions and sub-facies of early mature Upper Jurassic marine shale successions. Combining conventional biomarker approaches with novel polar NSO compound analyses, initially overlooked influences of mixing and biodegradation on differently mature charges could be confirmed. Oxygen-containing compounds as potential precursor structures of biomarkers are helpful in order to decipher oil-oil and oil-source relationships.

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References


