5 Geochemistry of greater Ekofisk crude oils

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Detailed analyses of bulk properties and of molecular composition by gas chromatography and gas chromatography–mass spectrometry of 30 oils from the greater Ekofisk area including Hod, Valhall, Eldfisk, Edda, Ekofisk, West Ekofisk, Albuskjell, Northwest Tor, and Tor fields show the following.

The major differences among the oils are due to maturity, which decreases systematically by field along a NW–SE trend as follows: Albuskjell > Northwest Tor, Tor, West Ekofisk > Ekofisk, Edda, Eldfisk > Valhall, Hod. These maturity variations could be due to differences in the degree of thermal stress experienced by the source rocks, to thermal alteration in the reservoirs, or to some combination of these two factors.

Minor, but definite, source differences exist which are not distributed systematically by field. The oils fall in the following order of increasing terrestrial input and oxygen: Eldfisk (oil 27) < Eldfisk (oil 26) < Ekofisk, Tor, Northwest Tor < Eldfisk, West Ekofisk, Hod, Edda (oil 17) < Albuskjell, Valhall, Ekofisk (oil 12), Edda (oil 18).

These variations are the result of locally different source rock subfacies within the Upper Jurassic. Within the Ekofisk, Valhall, Edda, West Ekofisk and Eldfisk structures the Danian and/or Cretaceous reservoirs appear to be differentially filled from these source subfacies.

INTRODUCTION

The discovery of the Ekofisk Field in the Norwegian sector of the North Sea has been cited as one of the major finds of the decade 1968–1978, and the first of the giant oil fields in Western Europe (Van den Bark and Thomas, 1980). Since Ekofisk, many additional fields, including a number of giants, have been discovered in the North Sea, with present estimated recoverable reserves of greater than 40 billion barrels of oil and 130 trillion ft³ of gas (Dolan, 1983).

Organic geochemistry has clarified the source of Ekofisk oils (Van den Bark and Thomas, 1980), the source in broad terms of central and northern North Sea oils (Oudin, 1976; Barnard and Cooper, 1981, 1984), and the source/maturity relationships among oils from the major grabens (Grantham et al., 1980; Mackenzie et al., 1983). The economic and historical significance of the Ekofisk area merits a comprehensive geochemical study of greater Ekofisk crude oils. The objective of this study was to infer the source (organic input and depositional environment) and thermal maturity relationships of the oils. This was accomplished by obtaining detailed geochemical analyses, including bulk properties, saturated and aromatic molecular fossils and carbon isotopes, of 30 greater Ekofisk crude oils.

SAMPLES AND METHODS OF ANALYSIS

The 30 greater Ekofisk crude oils included in the study are listed in Table 1 and located by well and field of origin on the index map in Fig. 1.

After precipitation of asphaltenes with 20 x volumes of n-pentane, and filtration, the oils were separated by medium-pressure liquid chromatography on the combination of a cyanophase pre-column and an activated silica main column. The saturate and aromatic fractions were eluted with n-hexane from the main column, and the polar fraction was backflushed with dichloromethane from the pre-column. The aromatic fraction was analyzed directly by gas chromatography using a flame photometric detector (GC–FPD) and by gas chromatography–mass spectrometry (GC–MS). The total saturate fraction was analyzed by gas chromatography using a flame ionization detector (GC–FID) and by gas chromatography–mass spectrometry (GC–MS). The total saturate fraction was analyzed by gas chromatography using a flame ionization detector (GC–FID) and, following removal of n-alkanes by molecular sieve addition, by GC–MS. The n-alkanes liberated by dissolution of the molecular sieves with hydrofluoric acid were analyzed by GC–FID.

GC–FID analysis of the total saturate fraction was made on a 30 m SE-54 fused silica capillary column heated from 120°C to 320°C at 4°C/min. The n-alkane fraction GC–FID analysis was made on the same column heated from 150°C to 320°C at 8°C/min.
The oils are very low in asphaltenes, with the notable exception of the Eldfisk Jurassic oil. The other chemical class compositional data (saturate, aromatic, and polar fractions) are plotted on the triangular diagram in Fig. 3. A trend with field is evident with the Albuskjell oils highest in saturates and lowest in polars, and the Hod oil next to the lowest in saturates and highest in polars. The Eldfisk Jurassic oil is significantly different from the other Eldfisk oils and similar in its chemical class composition to the Hod oil.

The Northwest Tor oil is very similar to the Tor oils, and is plotted with them in this and all subsequent figures.

The carbon isotopic compositions of the total crude oils were determined using a Craig combustion system and a MM903 isotope ratio mass spectrometer.

Multivariate factor analysis was accomplished with ARTHUR 81, a statistical software package obtained from Infometrix, Inc.

GEOLOGICAL SETTING OF THE GREATER EKOFISK AREA

The eight fields included in the study lie in a general NW–SE geographic trend within the Central Graben in the southern part of the Norwegian sector of the North Sea (see Fig. 1). Most of the oils are produced from either the Ekofisk Formation of Danian age or the Tor Formation of Maastrichtian age (see Table 1 for reservoir formations and depths). Three oils are from the Hod Formation of Campanian–Turonian age. The remaining oil is from the Jurassic in the Eldfisk field. The Ekofisk, Tor, and Hod reservoirs are fractured chalks located on structural highs, which often overlie salt diapirs. Overpressured Paleocene age shales generally act as seals for the greater Ekofisk reservoirs.

Rapid subsidence, coupled with a eustatic rise in sea level, resulted in the deposition of organic-rich mudstones during the late Jurassic. Reduced circulation within the Central Graben, caused by differential subsidence resulted in anoxic conditions at the sediment–water interface with resulting preservation and burial of the organic matter (Van den Bark and Thomas, 1980; MacKenzie et al., 1983a). These organic-rich Upper Jurassic shales are generally believed to be the source of most crude oils in the northern and central North Sea (Barnard and Cooper, 1981, 1984).

RESULTS

Bulk properties

The geochemical properties we define as bulk properties are listed in Table 2 for the greater Ekofisk oils. The crudes are medium to high API gravity and low in sulfur nitrogen. As observed for many crude oils (Tissot and Welte, 1978), there is an inverse correlation between sulfur and API gravity (see Fig. 2). In addition, this correlation follows a general geographical trend by field with West Ekofisk/Albuskjell having the highest API gravities and lowest sulfur contents and Valhall/Hod having the lowest API gravities and highest sulfur contents (see Fig. 2). The nitrogen content shows a linear correlation with the sulfur content ($R^2 = 0.73$).

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