Oil-Source Correlation in the South Viking Graben, Norway

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1. Introduction

Based on molecular and isotopic characteristics of 71 oil samples from nearly all major oil fields in the Norwegian South Viking Graben, six hydrocarbon families have been identified. Using results from detailed source rock analysis, it was possible to relate these families to three active source horizons, the Upper Jurassic Draupne and Heather Formations and the Middle Jurassic Vestland Group. The distribution of the various families in the area is complex and this study aims to establish genetic relationships and investigate possible mixing as well as the geographic and stratigraphic distribution of the families in order to understand the factors that control this distribution. In addition to the source rock typing, the secondary alteration of hydrocarbons in the area has been evaluated.

3. Hydrocarbon Families and Source-Oil Correlation

GC and GCMS data as well as the carbon isotopic composition of source rock extracts and oils have been used to determine oil populations and genetic relationships. The best differentiation among hydrocarbon families is achieved with cross plots of Pr/Ph ratio and the ratio of C_{27} over C_{29} regular steranes (Figure 2a) and stable carbon isotope ratios (Figure 2b) as well as the ratio of C_{29}/C_{30} hopanes and the ratio of dia- vs regular steranes (not shown). Six families and three subfamilies have been identified (Figures 3a,b and Table 2).

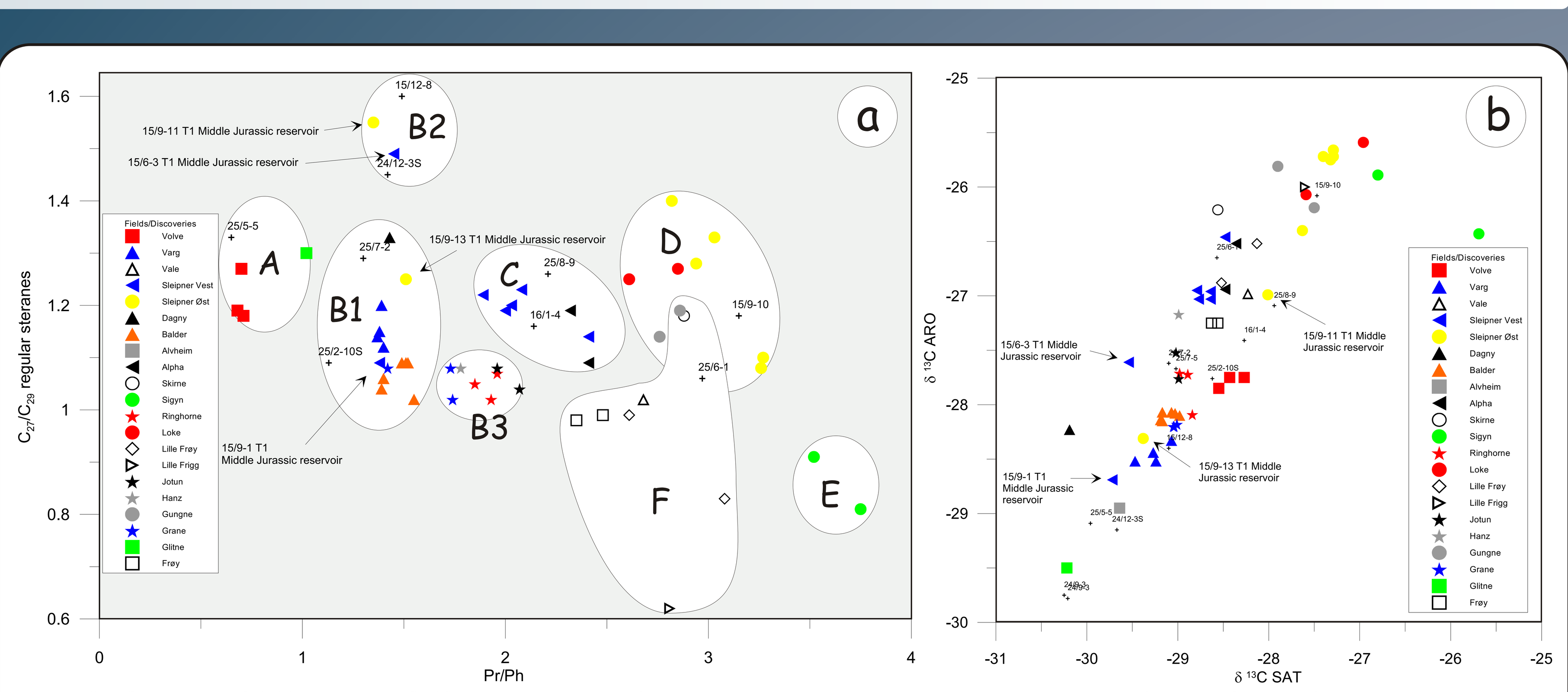

Figure 2a. Cross plot of Pr/Ph ratio and C_{27}/C_{29} regular steranes for analysed oil samples. This plot enables the identification of the six families and three subfamilies in the area. Samples from 25/6-1 and Skirne were assigned to family F based on their isotopic composition. Figure 2b. Carbon isotopic composition of the analysed oil samples. All samples except 24/12-3S, 25/8-9, 16/1-4, 25/11-18 (Grane) and 25/2-12 (Lille Frigg) were analysed in this study.

2. Source Rock Properties and Correlation Parameters

Extracts from the Middle and Upper Jurassic source rocks in the South Viking Graben have been geochemically characterized in order to establish a viable correlation model.

Principal hydrocarbon source rock in the area is the Upper Jurassic Draupne Formation, but also the Heather Formation is source for gas and to minor extent oil (Justwan & Dahl, 2005). The coaly shales and coals of the Middle Jurassic Hugin and Sleipner Formations in the southern half of the study area have potential to generate gas and minor amounts of liquid hydrocarbons (Isaksen et al., 2002).

Source facies and potential of the Jurassic source rocks in the area varies greatly in a regional and stratigraphic perspective (Figure1) as well as the molecular and isotopic characteristics (Table 1). Significant overlap in ranges of geochemical parameters occurs.

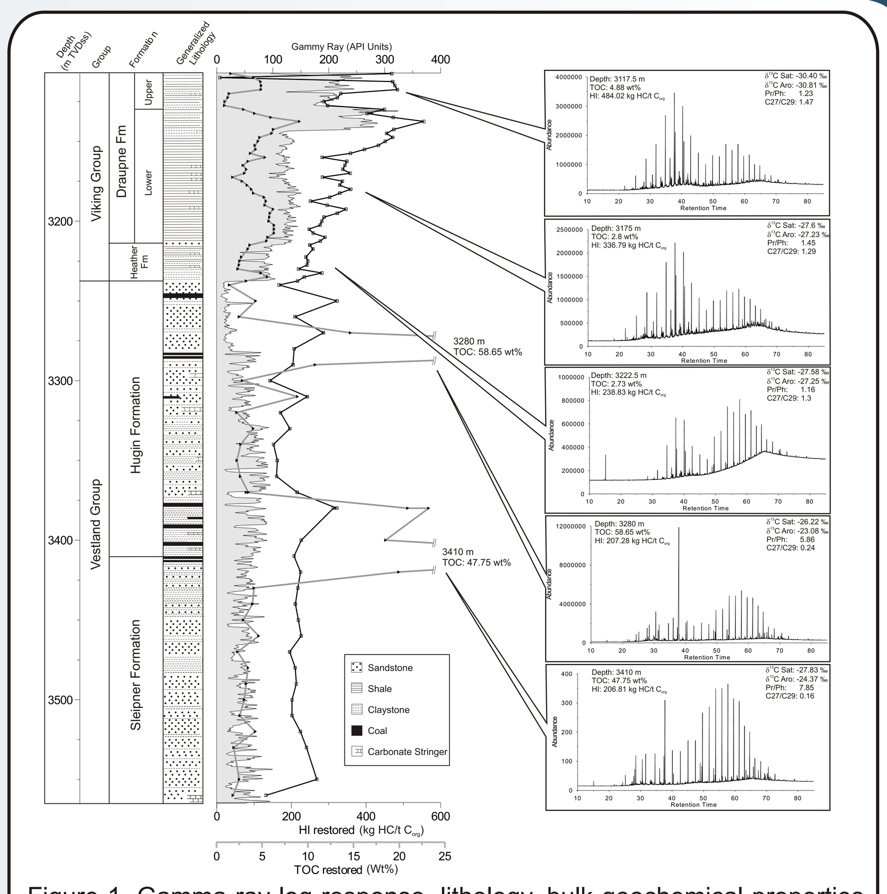

Figure 1. Gamma ray log response, lithology, bulk geochemical properties and exemplary gas chromatograms for source rock extracts for the Upper and Middle Jurassic section of Well 15/9-18. HI and TOC are maturity corrected. The Draupne Fm was subdivided in a synrift (Lower Draupne) and postrift section (Upper Draupne).

Typical for the upper, post-rift section of the Draupne Formation are the dominance of lighter compounds in the range up to n-C_{19}, low Pr/Ph ratios, high ratios of C_{34}/C_{35} homohopanes. The Upper Draupne Formation is isotopically lightest and shows high contents of 17a(H),21ß(H)-28,30-bisnorhopane (BNH). The lower, syn-rift Draupne Formation shows higher Pr/Ph ratios, is isotopically heavier and contains only little BNH. The Heather Formation is generally isotopically heavier than the Draupne Fm and BNH is nearly absent. Elevated Pr/Ph ratios and C_{34}/C_{35} homohopane indices indicate higher degree of oxygenation of the Heather Formation. The samples of the Hugin and Sleipner Formation show the largest variation in molecular properties due to mixed lithologies comprising sands, shales and coal beds. The samples are isotopically heaviest and shows a very strong dominance of C_{27} over C_{29} regular steranes both indicative of strong terrestrial input. Pr/Ph and C_{34}/C_{35} homohopane ratios indicate oxygenation and the gas chromatograms show a predominance of heavier compounds in the range of C_{23} to C_{30}.

	Ranges in ‰ PDB		Average values based on analysis of 183 samples from 8 wells					
Formation	$d^{13}C$ Sat	$d^{13}C$ Aro	Pr/Ph	Waxiness	CPI	C_{27}/C_{29}	BNH%	C_{34}/C_{35}
Upper Draupne Fm	-29.5 to -32.4	-28.5 to 32	1.38	0.79	1.01	1.19	0.24	1.06
Lower Draupne Fm	-27.5 to -30.5	-26 to -31	1.61	0.8	1.11	1.1	0.17	1.19
Heather Fm	-26 to -29	-25 to 28.5	1.98	0.75	1.49	1.12	0.13	1.7
Hugin Fm	-24.5 to -29	-24 to -28.5	3.09	0.68	1.29	0.75	0.3	2.37
Sleipner Fm			2.15	0.63	1.03	0.88	0.12	1.71

Table 1. Ranges and averages for selected geochemical parameters for the analysed source rock horizons

Table 2. **Oil Families in the South Viking Graben**

Source	Family	Description
Draupne sourced	A	**Characteristics:** predominance of Phytane over Pristane, low ratios of C_{34} to C_{35} homohopanes, regular steranes dominate over diasteranes, high contents of BNH, low CPI values **Interpretation:** highly anoxic, algal source with varying degree of evaporitic character, most likely a locally developed Upper Draupne Formation facies.
Draupne sourced		**Characteristics:** predominance of C_{27} over C_{29} regular steranes, Pr/Ph ratios below 2, isotopic values between -28.5 and -30.5 ‰ for the saturate fraction and -27 and -30 ‰ for the aromatic fraction. CPI between 1 and 1.1, n-C_{17}/(n-C_{17}+n-C_{27}) below 0.8. **Interpretation:** origin from marine dominated, anoxic to dysoxic Draupne Formation. Three subfamilies have been identified, originating from different Draupne source facies.
	B1	Subfamily B1 Draupne, dysoxic, algal dominated
	B2	Subfamily B2 Draupne, dysoxic, strongly algal dominated
	B3	Subfamily B3 most oxic Draupne source, higher terrestrial input.
Mixture of marine and terrestrial sourced HC	C	**Characteristics:** high C_{27}/C_{29} values, lower Pr/Ph ratios, CPI values around 1.1 **Interpretation**: mixture of Type II and Type III sourced hydrocarbons, probably from Middle and Upper Jurassic or Heather and Draupne sources. Distribution of regular steranes and dominance of rearranged over regular steranes suggests Upper Jurassic, algal dominated source, while Pr/Ph ratio and isotopic values are between typical values for Draupne and Middle Jurassic/Heather sources.
Mixture of marine and terrestrial sourced HC	D	**Characteristics:** very high Pr/Ph ratios (between 2.61 and 3.27), dominance of C_{27} over C_{29} regular steranes, front biased n-alkane distribution with n-C_{17}/(n-C_{17}+n-C_{27}) ratios close to unity; saturate and aromatic fractions are isotopically very heavy; dominance of rearranged over regular steranes **Interpretation:** mixture of hydrocarbons derived from Upper and Middle Jurassic sources with stronger Middle Jurassic character. Pr/Ph values well above 2.5 and isotopic values are indicative for a Middle Jurassic source, while dominance of C_{27} over C_{29} regular steranes and the ratio of dia- vs regular steranes in the range of 1.26 to 1.82 support Upper Jurassic source.
Middle Jurassic sourced	E	**Characteristics:** high amounts of saturates relative to aromatics and NSO compounds, highest Pr/Ph ratios of the data set, strong predominance of C_{29} regular steranes over C_{27} regular steranes; isotopically very heavy. predominace of C_{34} over C_{35} homohopanes; very high Bisnorhopane contents **Interpretation:** oxic, very strongly terrestrial dominated source rock. Pr/Ph ratio, distribution of regular steranes and especially isotopic characteristics are consistent with a Middle Jurassic source
Heather sourced	F	**Characteristics:** isotopically heavy, however slightly lighter than family E; very low C_{27}/C_{29} regular sterane ratios and high Pr/Ph ratios **Interpretation:** origin from an oxic, terrestrial Type III source. Pr/Ph ratios and C_{27}/C_{29} regular sterane ratios exclude origin from the Draupne Formation; carbon isotopic compositions suggest Heather origin. This supports the findings of di Primio (2002). (Middle or even Lower Jurassic origin cannot be ruled out entirely).

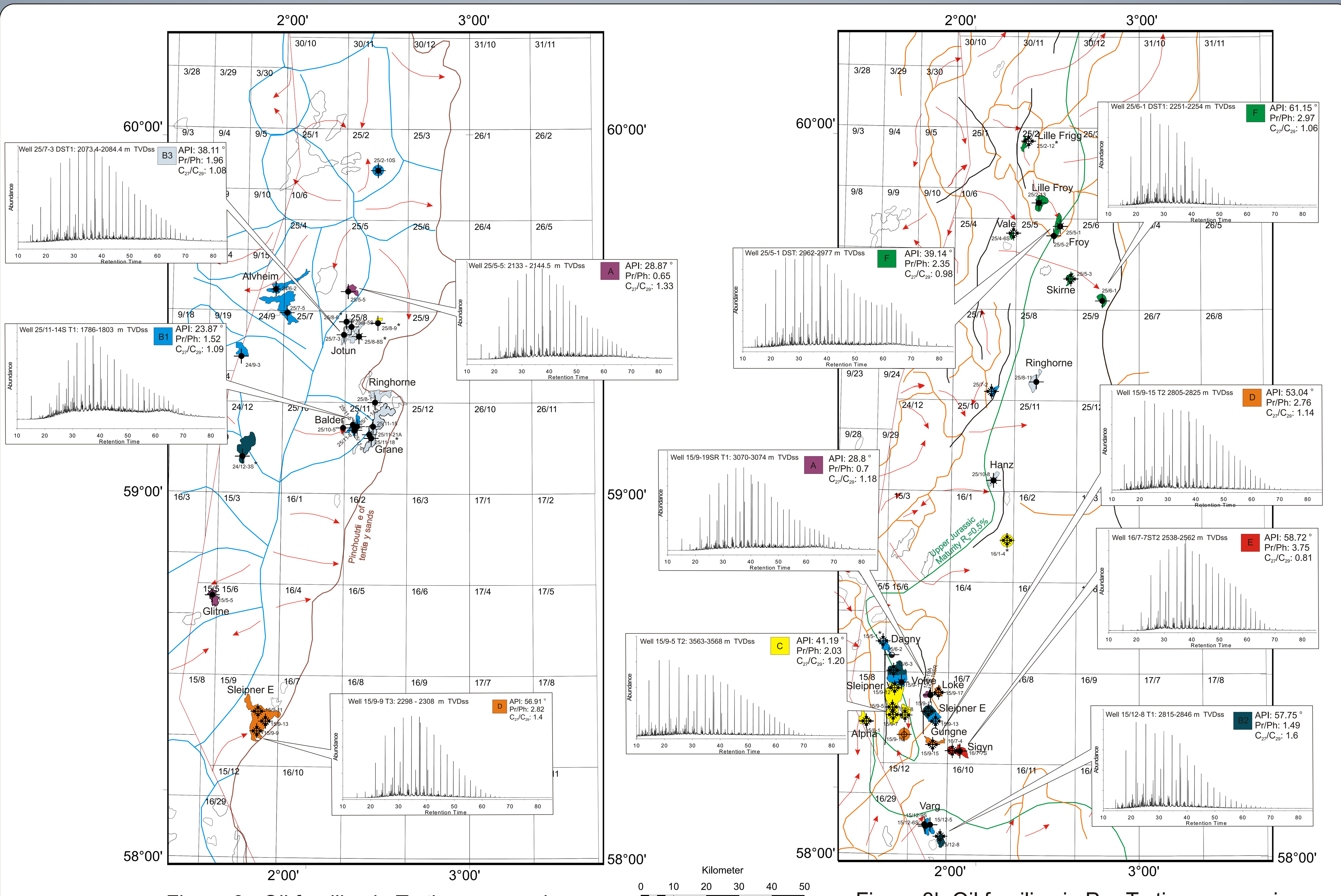

Figure 3a Oil families in Tertiary reservoirs

Figure 3b Oil families in Pre-Tertiary reservoirs

Figure 3a. Regional distribution of oil families in Tertiary reservoirs. Figure 3b. Regional distribution of oil families in Pre-Tertiary reservoirs. Drainage polygons (within the Tertiary system in blue, within the Jurassic in orange), pinch out line of the Tertiary sandstones (in red) and the eastern boundary of the Draupne source kitchen (R_o=0.5%, green line) are taken from Kubala et al.(2003). Description of families see Table 2.

4. Implications for migration pathways

- Tertiary reservoirs (Figure 3a) contain with exception of Well 25/8-9 and Sleipner East exclusively hydrocarbons sourced from the Draupne Formation. The general migration model for the tertiary fields in the area is basin to margin movement with vertical fault leakage. The fields on the Utsira High are fed through migration up fault planes along the westbounding fault system. The hydrocarbons in Sleipner Øst represent a mixture of hydrocarbons sourced from terrestrial and marine dominated rocks which spilled over from Middle Jurassic reservoirs in Loke and Gungne. The hydrocarbons in 25/8-9 show strong signs of terrestrial input, and are distinctively different from the neighboring Jotun field. A source to the North as proposed in Kubala et al. (2003) seems likely. Wells 25/5-5 and 15/5-5 contain oils sourced from a special Draupne facies, probably only occuring in patches.

- The Pre-Tertiary reservoirs (Figure 3b) show a more complex picture. Family F occurs only North of 59°30' and appears to be sourced from the Heather Formation in Blocks 25/1 and 25/4. In the Greater Sleipner Area two active source rock horizons lead to a complex mixing with a Draupne source to the North and a Middle Jurassic source to the Southwest. Sigyn represents the Middle Jurassic endmember, while all other samples from Sleipner Vest, Alpha and 15/9-10 represent mixtures of the two sources.

The hydrocarbons in Volve (Family A) represent an exception and are likely to be sourced from a subbasin between Sleipner Øst and Vest (Isaksen et al., 2002).

5. Biodegradation

The degree of biodegradation is strongly related to temperature in the reservoir and hence indirectly also to reservoir depth. Only hydrocarbons in the Tertiary reservoirs in the South Viking Graben show signs of biodegradation, while the generally deeper situated and thus warmer Pre-Tertiary reservoirs are sterile.

No biodegradation is evident in the sample set above a reservoir temperature of 68ºC (Figures 4a,b).

Exceptionally deep occurrences of biodegradation in Well 25/2-10S, 25/7-5 and 24/6-2 can be explained by the regional low geothermal gradient shown in Kubala et al. (2003).

Degradation levels after Peters and Moldowan (1993) range from heavy in 24/9-3 and 25/2-10S to moderate in 25/7-5 and Alvheim. The oils in the tertiary reservoirs of the Greater Balder Area are the result of at least two phases of oil charge. The initial oil charge to these oil fields was severely biodegraded and subsequently diluted with fresh oil. A remnant of the severely degraded oils are the high amounts of 17a(H),21b(H)-25-norhopane, while the GC trace only shows light biodegradation. The remaining tertiary samples are undegraded.

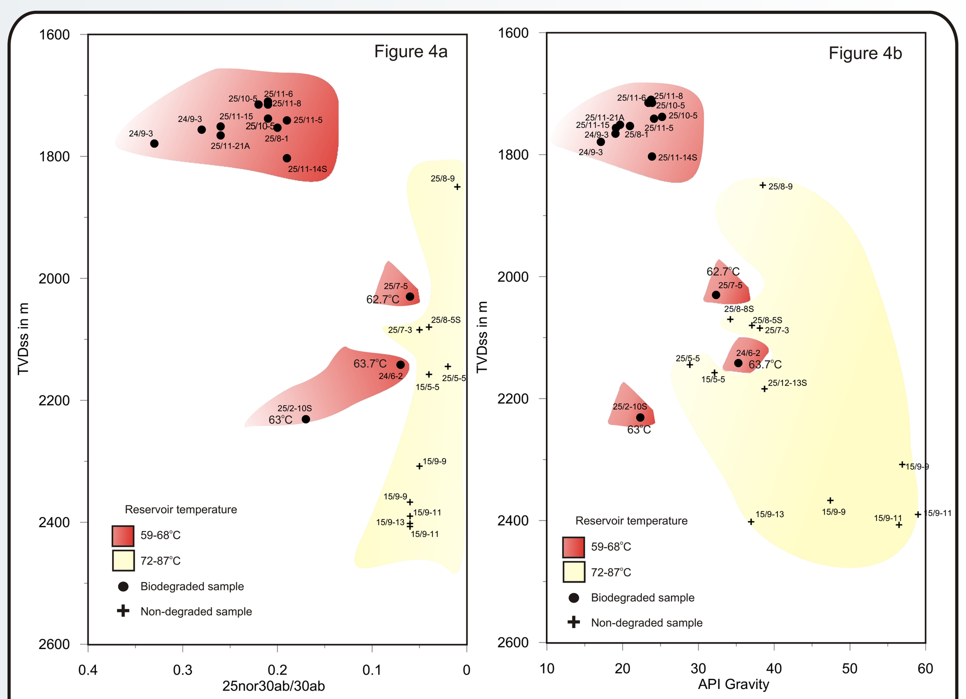

Figure 4. Depth – reservoir temperature – biodegradation relation in the tertiary reservoirs of the South Viking Graben. The occurrence of 17a(H),21b(H)-25-norhopane (4a) and API gravity (4b) were here chosen as indicators of biodegradation. Maximum reservoir temperature for a biodegreaded reservoir is 68ºC. Exceptionally deep occurrences of biodegradation are related to local minima of the geothermal gradient.

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