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Study Area and Data Base

Introduction

Stratigraphy in Study Area

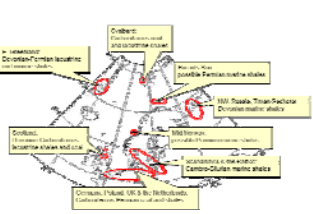


Fig. 1. Some occurrences of Palaeozoic source rocks in the North West Europe.

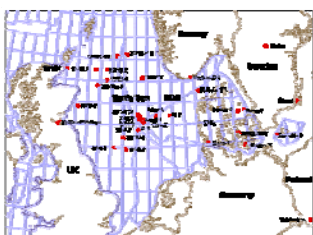


Fig. 2. The study area and well data base.

The dominating oil and gas source rocks in the northern North Sea are of Mesozoic age. Especially important are the Upper Jurassic marine clays of the Kimmeridge Clay Formation, deposited in the Mesozoic Moray Firth Basin and Central and Viking Graben rift structures.

The Palaeozoic successions in the northern North Sea are not as well mapped and understood as younger strata in the North Sea sedimentary basins. This is due to great burial depths, but also because the Palaeozoic was being regarded as of low economic interest in this area.

There are however Palaeozoic sediments with possible petroleum potential in both Norwegian and Danish wells in the northern North Sea. We also know that source rocks of Cambro-Silurian, Devonian, Carboniferous and Permian age are widespread areas, fringing the North Sea, i.e. in Norway, Denmark, Sweden, Poland, Germany, the Netherlands, in the UK and on East Greenland.

In the Skagerrak Sea and northern North Sea, thick sequences of marine sediments most likely accumulated in Cambro-Silurian times. Additionally, shales, coals and mudstones of Devonian to Permian age may have been deposited in Palaeozoic half-grabens and N-S trending rift basins underlying the Upper Permian Zechstein evaporites.

In this study, we investigate Palaeozoic sediments collected from wells and outcrops in the North Sea and adjacent areas. In specific, we focus on Cambro-Silurian, Carboniferous and Permian sediments, which may have petroleum source rock properties. In the northeastern North Sea and Norwegian-Danish Basin (NDB), Palaeozoic source rocks may be a crucial part of plays capped by thick Upper Permian evaporite layers.

Methodology

The sample set contains outcrop samples, core chips and cuttings from selected locations and wells in the North Sea and adjacent areas. The samples represent Cambrian, Ordovician, Carboniferous and Permian sediments of both marine and continental origin.

The samples underwent the following analytical procedures:

- Soxhlet extraction of sediments with DCM/MeOH (97:3)
- GC-FID and GC-MS analysis of solvent extracts
- Kerogen up-concentration from sediment samples using HF and HCl acid
- PY-GC of kerogen concentrates (open pyrolysis)
- Rock-Eval analysis of core chips and cuttings

Era	Period	Age	Group	Rock Group	Basin	Assessed	Used
Cenozoic	Quaternary	Holocene	Njordland	Sandy	Njordland		
	Oligocene	Rogaland	Lark				
						Miocene	Shetland
	Cretaceous	Cenoman	Knokk	Lark			
						Jurassic	Bakkefjord
Triassic	Heron	Lark					
					Permian	Zechstein	Lark
Carboniferous	Rottliegendes	Lark					
					Devonian	Lark	
Silurian	Lark						
					Ordovician	Lark	
Cambrian	Lark						

Fig. 3. Conceptual stratigraphy in the northern North Sea and the Norwegian-Danish Basin, with possible source, reservoir and cap rock indicated.

Petroleum Potential of Source Rocks

Organic Facies of Oils and Source Rocks

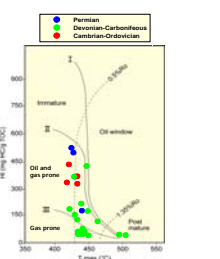


Fig. 4. T_{max} - Hydrogen Index (HI) plot for Palaeozoic samples with TOC over 1 wt%. Cambrian-Ordovician and Permian samples are both oil and gas prone, while Devonian-Carboniferous samples are in general gas prone.

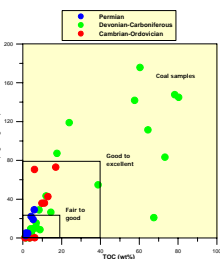


Fig. 5. Total Organic Carbon (TOC) plotted against remaining petroleum potential (S2) of Palaeozoic sediment samples. Carboniferous coals and low-mature onshore samples have the highest S2 values. Devonian and Permian samples have low S2 values, while low-mature Cambrian-Ordovician shales have high S2 values.

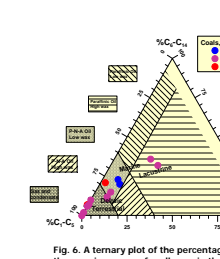


Fig. 6. A ternary plot of the percentages of the three main groups of n-alkanes in thermal extracts generated by pyrolysis of rock samples. Coals and organic lean mudstones generate gas only, while algae rich coals and marine shales produce a low wax oil. Two organic rich Carboniferous lacustrine shales generate a high wax paraffinic oil. Adapted from Horsfield (1989).

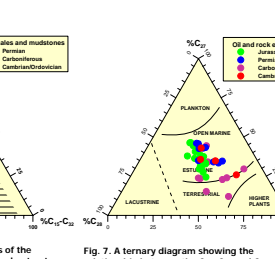


Fig. 7. A ternary diagram showing the relationship between the C_{10} , C_{20} and C_{30} regular steranes in oils and source rock extracts. The regular steranes indicate the organic facies of a source rock. Cambro-Silurian, Permian and Jurassic source rocks have a marine origin, while Carboniferous samples are from a terrestrial environment. Modified from Shanmugam (1985).

Thermal Maturity of Source Rocks

Possible Offshore Distribution of Palaeozoic Source Rock Candidates

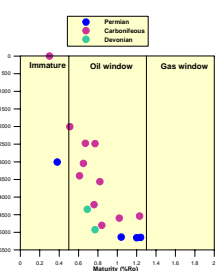


Fig. 8. A vitrinite reflectivity versus depth plot showing thermal maturity of source rocks. Burial and maturity of the samples increase from the western parts (UK) to the eastern parts of the North Sea (Norway and Denmark). The majority of samples are in the oil generating zone (the oil window).

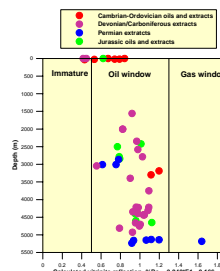


Fig. 9. The maturity of source rock extracts and oils expressed by the aromatic compound methylphenanthrenes (Kvalheim et al., 1987). The samples are in general of oil generating maturity, and correspond well with the maturity indicated by vitrinite reflectivity. Shallow samples are from outcrops or onshore wells.

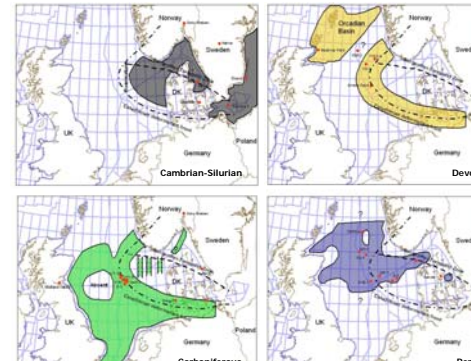


Fig. 10. Possible distribution of Palaeozoic sediments in the North Sea, Norwegian - Danish Basin (NDB) and Skagerrak Sea. Lower Palaeozoic sediments are over-mature close to the Caledonian deformation front, but maturity decreases eastwards. Upper Palaeozoic sediments may be present in reactivated Caledonian thrusts, forming half-grabens along the Caledonian deformation front. Rifting in the Upper Palaeozoic may also have provided accommodation space for continental sediments in the NDB.

Conclusions

Acknowledgements

Palaeozoic sediments of Cambrian-Ordovician, Devonian-Carboniferous and Permian age are found in wells in the northern North Sea and Skagerrak Sea. Palaeozoic mudstones and shales from the northern North Sea have TOC values in the range of 0.1-14.4 wt%.

Upper Palaeozoic coals from the northern North Sea have TOC values in the range of 17-80 wt%.

Cambrian-Ordovician and Permian samples are oil and gas prone. Devonian and Carboniferous samples from the North Sea are gas prone. The Palaeozoic northern North Sea samples in this study have thermal maturities within the oil window ($R_o \approx 0.3-1.3$).

Burial, and hence maturity, of the Palaeozoic samples increases from west to east in the northern North Sea.

Carboniferous samples (coals and mudstones) from the North Sea generates mainly gas under open pyrolysis.

Cambrian-Ordovician and Permian samples (shales) generates both gas and oil products under open pyrolysis.

GC-FID data suggest Cambrian-Ordovician and Permian samples to have a marine origin. GC-FID data suggest Devonian-Carboniferous samples to have a lacustrine or deltaic origin.

Palaeozoic coals, shales and mudstones in the North Sea region have probably generated petroleum.

For supplying samples:
 NPD, Stavanger, Norway
 GFZ, Copenhagen, Denmark
 SCU, Uppsala, Sweden
 DTI, Core Store, Edinburgh, Scotland
 Nils Sjældnes and Sven Dahlgreen

For funding:
 RWE Dea Norge AS

For analytical help:
 UIB, Bergen, Norway

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