Petroleum potential and thermal maturity of Palaeozoic sediments from the North Sea region

Jon H. Pedersen[1], Dr. Dag A. Karlsen[1], Dr. Jan E. Lie[2] and Harald Brunstad[2]

[1]Department of Geosciences, University of Oslo, P.O. Box 1047 Blindern, N-0316 Oslo, Norway
[2]RWE Dea Norge AS, P.O. Box 243 Skøyen, N-0213 Oslo, Norway

Introduction

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 Jurassic Moray Firth Basin and Central and Viking Graben rift structures.

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 found in 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 half-grabens and N-S trending rift basins underlying the Upper Permian Zechstein evaporites.

In this study, we investigate the kerogen types, petroleum potential and thermal maturity of some of these Palaeozoic sediments, and look for traces of Palaeozoic petroleum in reservoir rocks in the North Sea. 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.

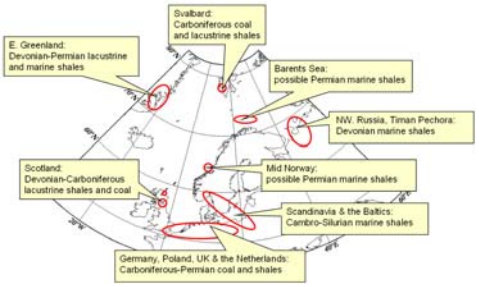

Fig. 1. Some occurrences of Palaeozoic source rocks in the North West Europe.

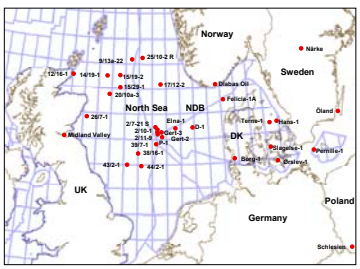

Fig. 2. The study area and well data base.

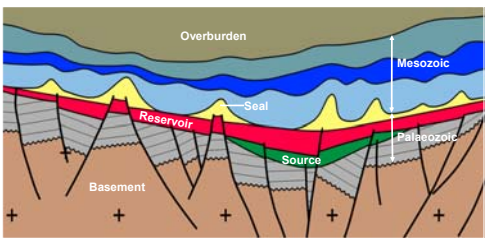

Fig. 3. The concepts of a possible Palaeozoic petroleum system in the Norwegian -Danish Basin. Possible source rocks are Lower Palaeozoic marine shales, Carboniferous coals and mudstones and Permian marine shales and mudstones.

Conceptual stratigraphy

Era	Period		Age	Group	Rock unit	Source	Reservoir	Cap
Cenozoic	Quarternary		1.8 Ma					
	Tertiary	Neogene	23.8 Ma	Nordland	Bergen			
					Stavanger			
					Lark			
		Paleogene		Hordaland	Horda			
					Balder			
				Rogaland	Sele/Flekkefjord			
			65.0 Ma		Lista			
Mesozoic	Cretaceous	Upper	99.6 Ma	Shetland	Våle			✓
					Ekofisk		✓	
					Tor			
					Hod			
					Blodøks/Plenus Marl			
		Lower	142.8 Ma	Cromer Knoll	Hidra			
					Rødby			
					Sola			✓
					Åsgard			
	Jurassic	Upper	155.4 Ma	Boknfjord	Fiskebæ/Lord			✓
					Sauda	●		✓
					Tau			
					Egersund		✓	
		Middle	180.1 Ma	Vestland	Sandnes	○		
					Brynehildeger			
		Lower	200.7 Ma		Fjerritslev			
					Gassum			
	Triassic	Upper	227.0 Ma	Heron	Skagerrak			
		Middle	241.7 Ma		Smiths Bank			
		Lower	249.2 Ma		Bunter Sst.			
Paleozoic	Permian	Upper	256.0 Ma	Zechstein	Kupferschiefer	●	✓	✓
		Lower	290.0 Ma	Rotliegende	Ask			
					Kart			
	Carboniferous	Upper	323.0 Ma					
		Lower	354.0Ma		Scremerston/ Firth Coal	○		
	Devonian	Upper	370.0 Ma		Buchan		✓	
		Middle	393.0 Ma					
		Lower	417.0 Ma		Old Red Sst.		✓	
	Silurian	Upper	423.0 Ma		Ringerike/ Old Red Sst.		✓	
		Lower	443.0 Ma		Rastrites Sh.			✓
	Ordovician	Upper	458.0 Ma		Tretaspis Sh.	●		
		Middle	470.0 Ma					
		Lower	489.0 Ma		Dictyonema Sh.			✓
	Cambrian	Upper	500.0 Ma		Alum Sh.	○		✓
		Middle	510.0 Ma					
		Lower	540.0 Ma		Hardeberga Sst.		✓	

Fig. 4. Conceptual stratigraphy in the northern North Sea and the Norwegian-Danish Basin, with possible source, reservoir and cap rocks indicated.

Petroleum Potential

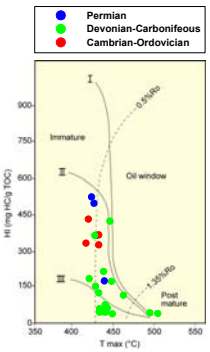

Fig. 5. T_{max} – Hydrogen Index (HI) plot for Palaeozoic samples with TOC over 1 wt%. Cambrian-Ordovician and Permian samples are both oil and gas prone, while Devonian-Carboniferous samples are in general gas prone.

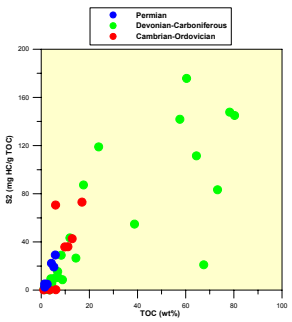

Fig. 6. Total Organic Carbon (TOC) plotted against remaining petroleum potential (S2) of the sediment samples. Carboniferous coals and low-mature onshore samples have the highest S2 values. Devonian and Permian samples have low S2 values, while low-mature Cambrian-Ordovician shales have high S2 values.

Thermal maturity

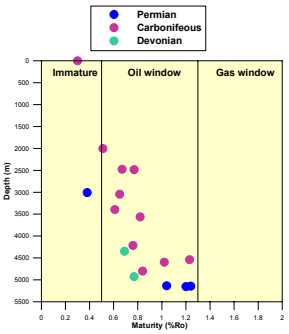

Fig. 7. A vitrinite reflectivity versus depth plot. Burial and maturity of the samples increases from the western parts (UK) to the eastern parts of the North Sea (Norway and Denmark). The majority of samples are in the oil generating zone (the oil window).

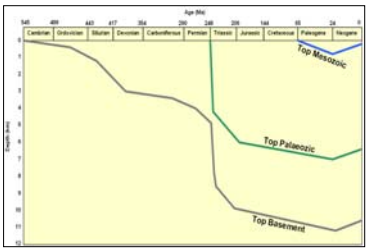

Fig. 8. Tentative burial curves for the Palaeozoic to present in the Norwegian - Danish Basin and the Skagerrak Sea area. Major subsidence episodes occurred during the Silurian-Devonian Caledonian orogenic event, and as post-rift thermal subsidence in the Triassic subsequent of Permian rifting and volcanism. The Skagerrak Sea area was uplifted and eroded in Neogene times.

Conclusions

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 (%Ro = 0.3–1.3).

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

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Evaluation of extracts and pyrolysates from Palaeozoic sediments from the North Sea region

Jon H. Pedersen[1], Dr. Dag A. Karlsen[1], Dr. Rolando di Primio[2], Dr. Jan E. Lie[3] and Harald Brunstad[3]

[1]Department of Geosciences, University of Oslo, P.O. Box 1047 Blindern, N-0316 Oslo, Norway

[2]GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany

[3]RWE Dea Norge AS, P.O. Box 243 Skøyen, N-0213 Oslo, Norway

Introduction

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 has been regarded as of low economic interest in this area.

In this project 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.

We hope that this study will increase our understanding of the distribution, organic facies and thermal maturity of Palaeozoic sediments in the northern North Sea. We also believe that this work may help us to better evaluate the significance of Palaeozoic petroleum systems in the northern North Sea and Norwegian Danish Basin.

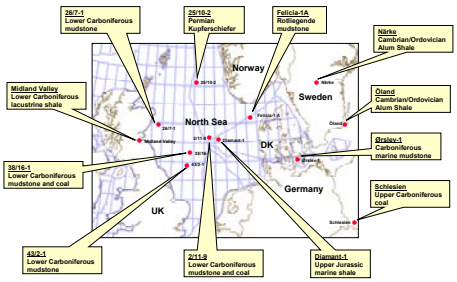

Fig.1. Study area and samples selected for pyrolysis analysis.

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:

- Soxtec 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, 300ºC-600ºC in 10 minutes in a helium atmosphere)

Results

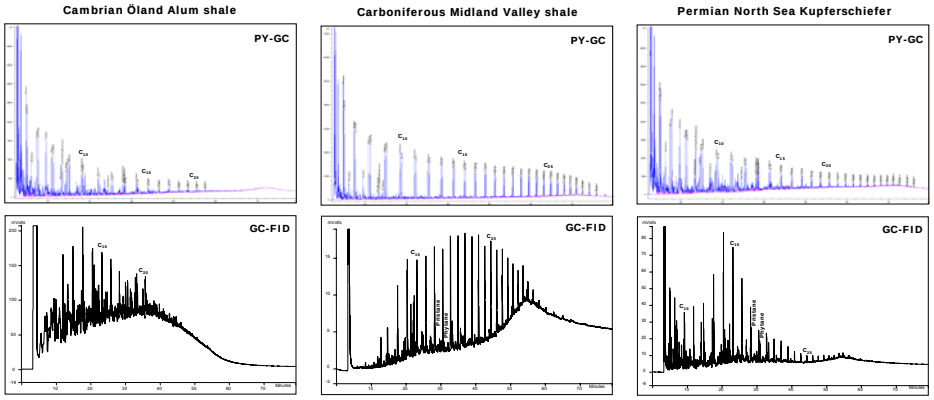

Fig.2. Chromatograms of pyrolysis products (PY-GC) and solvent extracts (GC-FID) of Palaeozoic samples. The samples are of low to moderate maturity. Identifiable compounds on the pyrograms are alkene-alkane pairs and aromatic compounds like benzene, toluene and napthalene. The isoprenoids pristane and phytane are not generated during pyrolysis. The products from the marine Alum shale are dominated by low waxiness and high amounts of aromatic compounds. The organic rich Carboniferous Midland Valley lacustrine shale generates a high-wax product with an odd-even predominated n-alkane distribution, while the marine/hypersaline Permian Kupferschiefer gives a product with a typical marine n-alkane envelope. Note however the enrichments of C_{13}-C_{16} n-alkanes on the Kupferschiefer GC-FID chromatogram.

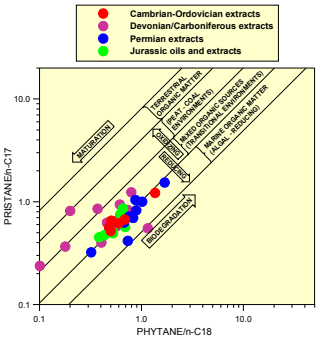

Fig.3. A plot of phytane/n-C_{18} versus pristane/n-C_{17} is used here to evaluate organic facies, thermal maturity and degree of biodegradation of oils and extracts. Cambrian-Ordovician and Permian samples have a marine affinity, resembling Jurassic oils and extracts. Extracts from Devonian/Carboniferous sediments points to a lacustrine or transitional environment (Modified from Shanmugam, 1985).

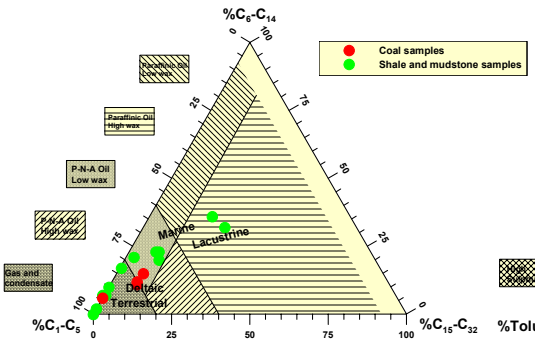

Fig.4. A ternary plot of the percentages of the three main groups of n-alkanes in the pyrolysates. Coals and organic lean mudstones generates gas only, while algae rich coals and marine shales produce a low-wax oil. Two organic rich Carboniferous lacustrine shales generates a high wax paraffinic oil. (Adapted from Horsfield, 1989).

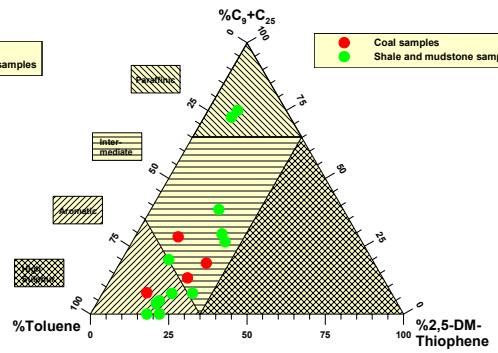

Fig.5. A ternary plot of an aromatic compound (toluene), an n-alkane component (C_9+C_{25}) and a sulphur-compound (2,5-dimethylthiophene) identified in the pyrolysates. Organic lean mudstones have high percentages of aromatic compounds, while the majority of samples, both coals and shales classifies as intermediate, but biased towards the aromatic corner. (Adapted from Horsfield, 1989).

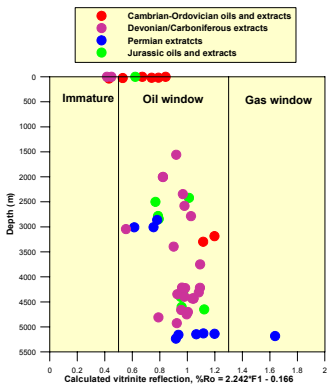

Fig.6. The maturity of extracts and oils expressed by the aromatic compound methylphenanthrene (Kvalheim et al., 1987). The samples are in general of oil generating maturity. Shallow samples are from outcrops or onshore wells.

Conclusions

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

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

The samples are within the oil window in terms of thermal maturity.

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.

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GEUS, Copenhagen, Denmark
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DTI Core Store, Edinburgh, Scotland

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