North Atlantic margin petroleum systems: what does the Faeroe-Shetland Basin tell us about prospectivity further south?

Patrick Barnard, Azzurra Cillari, Ian Cutler, Steve Thompson and Helen Kerr.
Applied Petroleum Technology (UK) Limited.

Dublin;
November 2012.

Objectives of presentation

- Overview of the geochemists approach to understanding petroleum systems;
- What makes the North Sea, West of Shetland (WOSI) & Porcupine Basin petroleum systems tick;
- Petroleum fluid character and charge system in the WOSI & Porcupine areas;
- Comparison of WOSI (and N Sea) fluids to Porcupine Basin fluids.

The petroleum system:

- How can geochemistry assist with understanding the petroleum potential of an underexplored area?
- Well known that analogues provide a valuable way to evaluate underexplored areas.
- A range of different pieces of knowledge are presented:
  - Geology;
  - Fluid physical properties;
  - Geochemistry;

for the West of Shetland region (WOSI), North Sea and Porcupine Basin from which we can hopefully learn something about the deep petroleum system.

Hydrocarbon fluids:

- Hydrocarbons contain chemical markers (biomarkers) that contain within them intimate knowledge of:
  - The type of their source organic matter;
  - Their depositional environment conditions;
  - Their thermal exposure – temperature of generation;
  - Post generation alteration both during migration & entrapment/dissipation.
- Hydrocarbons are highly mobile fluids;
- Their migration is driven fundamentally by buoyancy – density of hydrocarbons is less than 1.0 while encasing rocks have densities of greater than 2.7;
- Their source lies in the deep basin while exploration looks for regional highs.

Parameters:

A number of different parameters are used to learn much about the deep petroleum system:

- **Bulk physical properties – API gravity, GOR, wax, pour point.**
- **Hydrocarbon biomarkers – many different forms:**
  - **Whole oil or extract gas chromatograms;**
  - **GCMS chromatograms:**
    - **Hopanes, steranes, aromatics, sulphur aromatics;**
    - **Isoprenoids – pristane & phytane – anoxicity & maturity;**
    - **Gammacerane – enhanced salinity marker;**
    - **Bisnorhopane – intense bacterial activity in near surface sediments;**
    - **Thermal exposure – Ts/Tm, steranes & aromatics;**
    - **Degradation – demethylated hopanes etc..**
- **Bulk chemical composition – carbon isotopes reflect source organic matter input.**

What do we know?

Have carried out two major studies in recent times:

- **West of Shetlands – oils, proxy oils, source rocks & maturity. New sequential analyses of:**
  - **30 flowed oils, gases, 275 core and cuttings extracts;**
  - **Data synthesised with geology & stratigraphy;**
- **Porcupine Basin – 9 flowed oils – 4 fields; 76 core & cuttings extracts; source rocks.**
- **Results integrated with prior legacy data into the geological framework.**

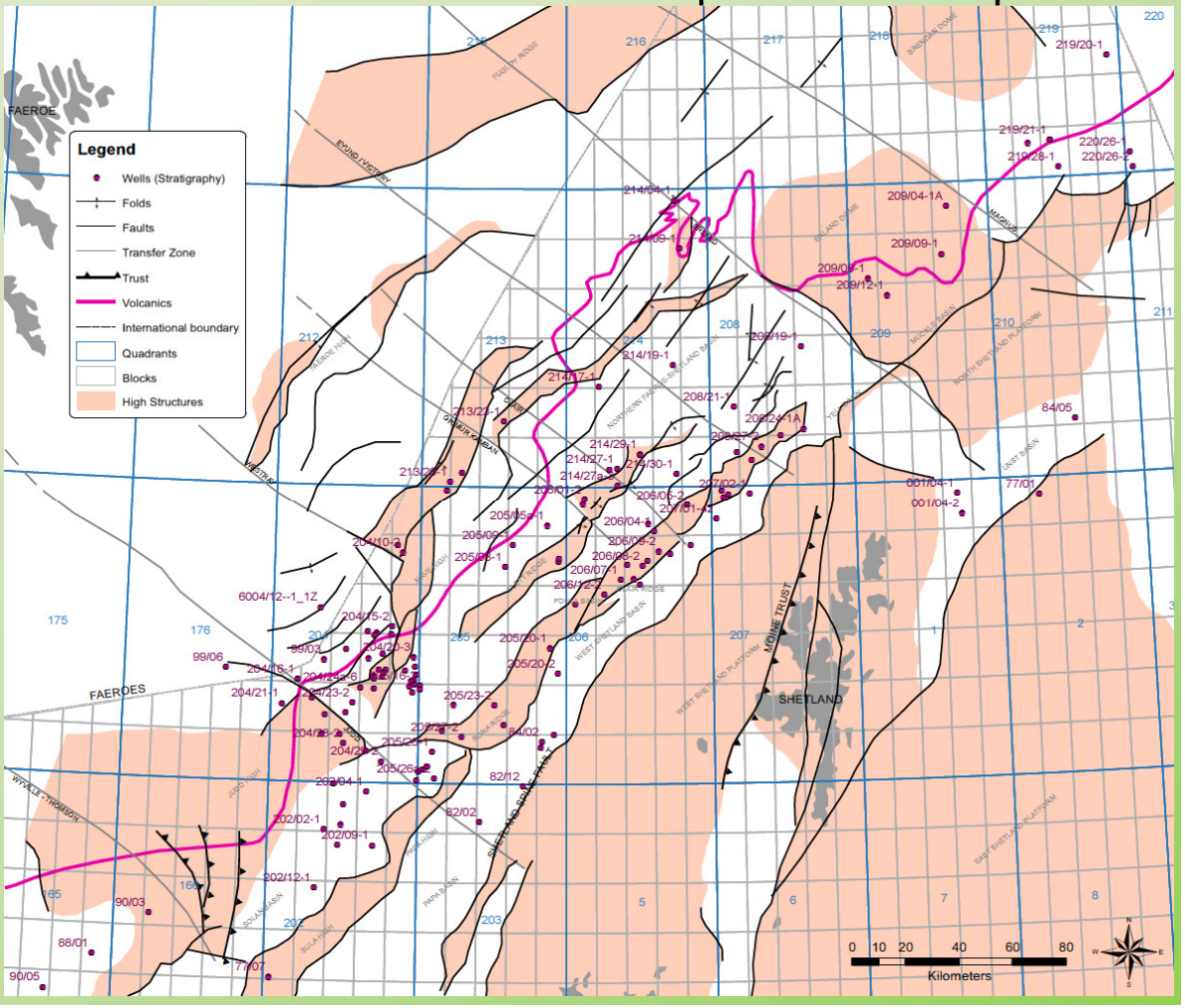
GEOLOGICAL SETTING

WOSI & PORCUPINE BASINS

APT UK – North Atlantic petroleum systems – what do the fluids tell us?

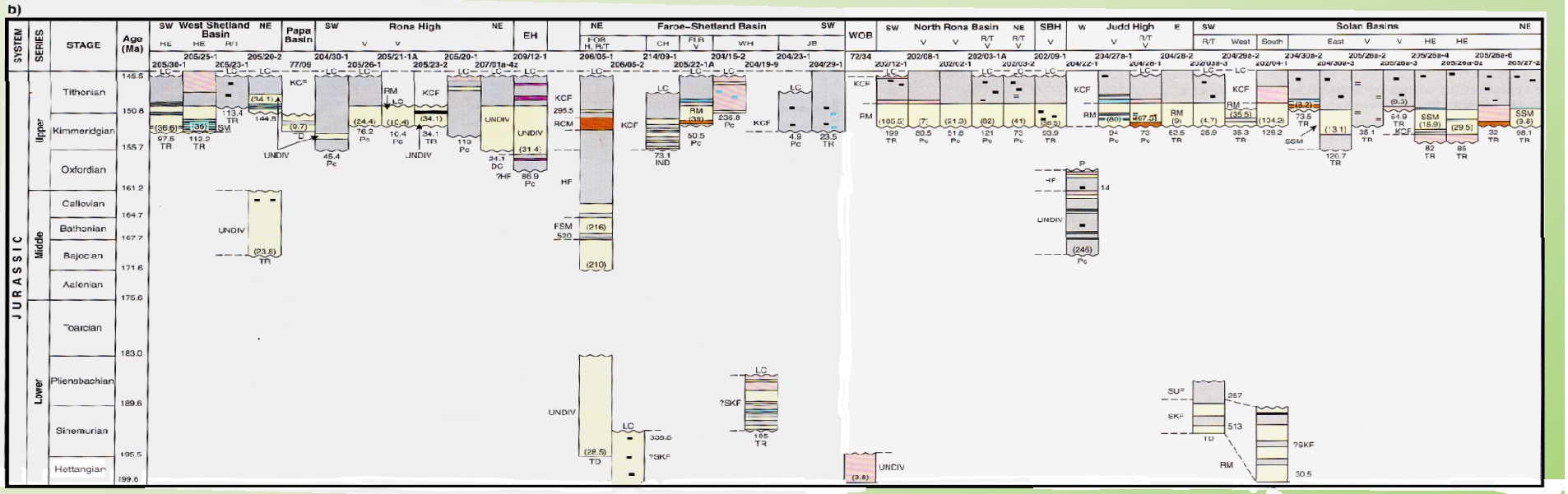
Geological structures and studied wells.

- A complex area of grabens & half grabens, notionally a passive margin (?);
- Basement – igneous & metamorphic rocks overlain by Palaeozoic;
- Triassic through Jurassic rifting interrupted by uplifts – early & Middle Jurassic;
- Main rifting Oxfordian-lower Berriasian resulted in a large anoxic basin & truncated pre-existing Jurassic rift system. Anticlockwise rotation resulted in present V-shape.
- Important Early Cretaceous episodic rifting with inversions - due to the closure of Tethys towards the south?;
- Palaeogene N Atlantic opening & proto Icelandic plume resulted in two inversion events associated with intrusive & extrusive volcanism, especially in north – Erlend & Faeroes etc.;
- Subsequent rapid subsidence with deposition of large clastic input as basin floor fans;
- Mid Miocene – major inversion events?



The sediments.

- Upper Jurassic rocks often appear to be rather proximal, silty with frequent carbonaceous debris and coals;
- Kerogen analyses reveal frequent and strong terrestrial component. Organic richness is often good & HI moderate to high.

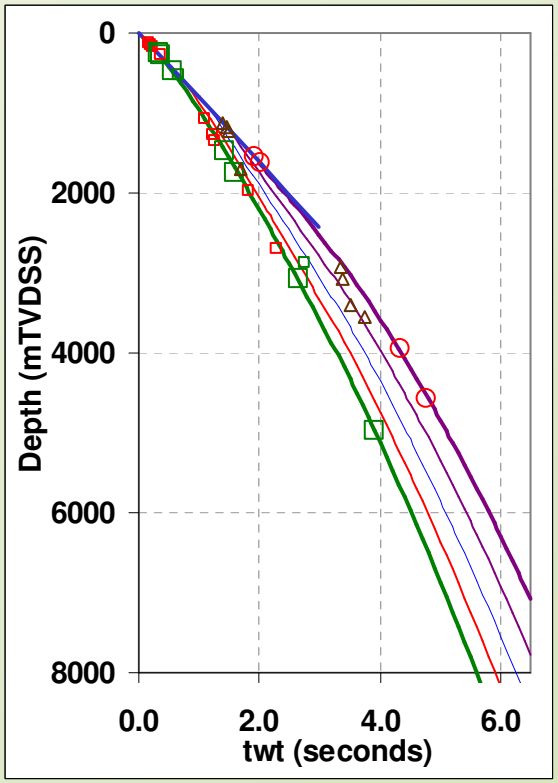


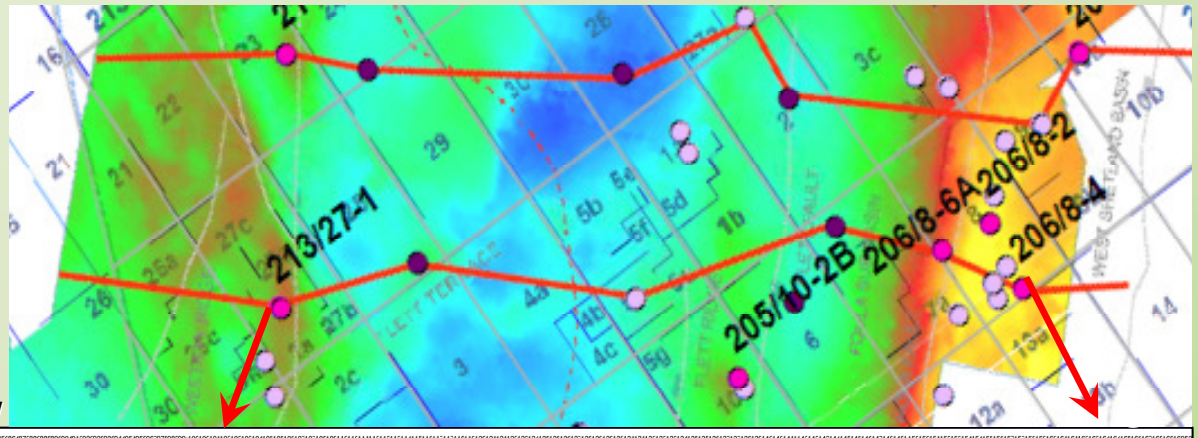
Lower Cretaceous

- L Cretaceous period of renewed rifting with marked thickening in the basinal areas. Sections on highs often coarser clastics. Basinal sections not drilled.
- Albian-Aptian age Carrack Fm. - darker marine sediments deposited in anoxic/dysaerobic conditions. Source quality not known.

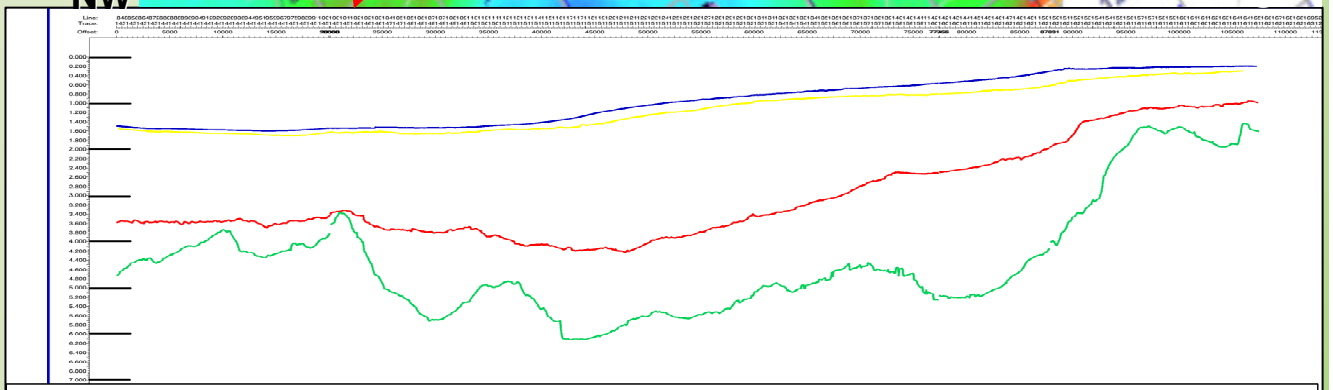
APT UK – North Atlantic petroleum systems – what do the fluids tell us?

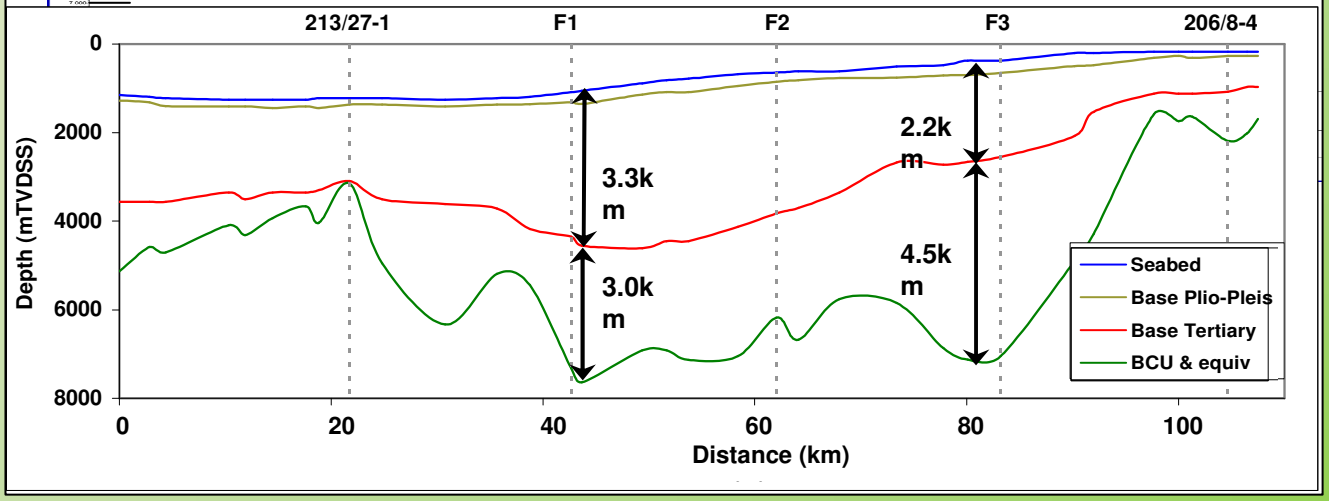
Big deep, mainly undrilled areas; discoveries on (big) highs - flanks





NW

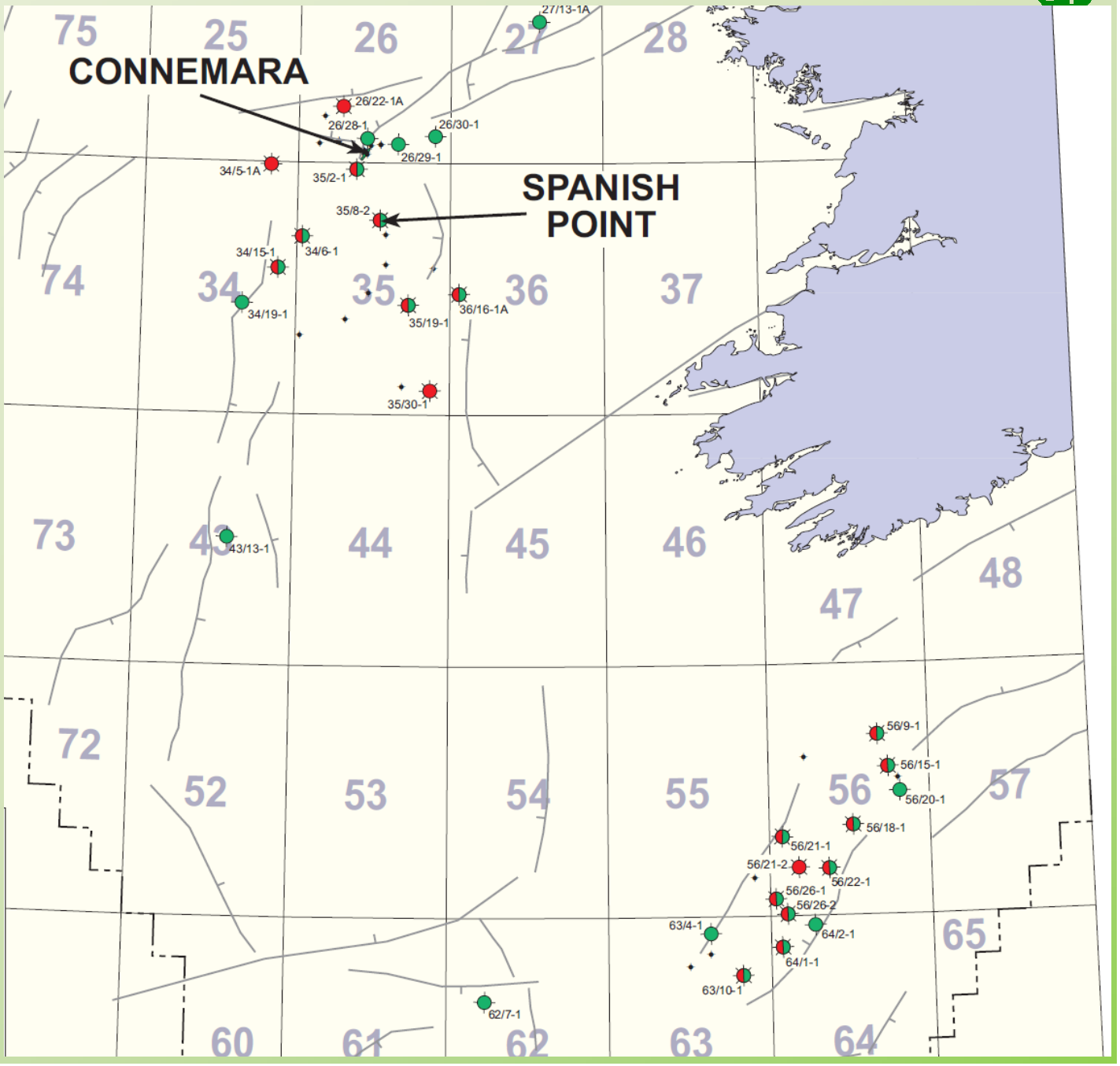




Note: depth structure map & section courtesy of PGS

APT UK – North Atlantic petroleum systems – what do the fluids tell us?

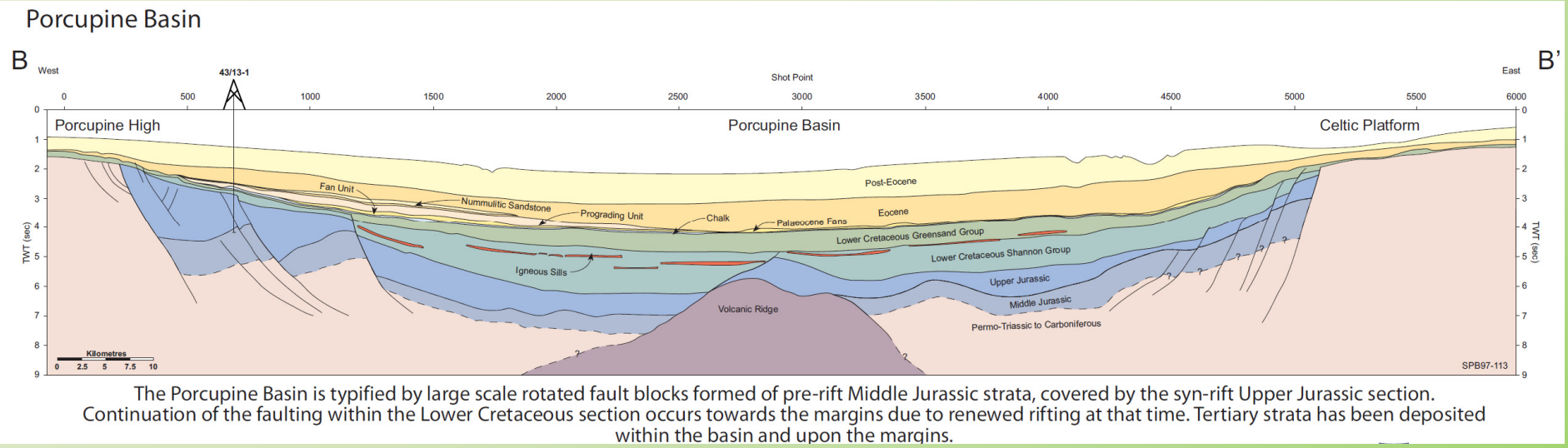
- Porcupine Basin well and discovery map
- Only northern and shallow water part of basin explored to date.
- Shows and tests in most wells.



From Ternan report.

Porcupine Basin structure.

- East-west section shows Jurassic tilt blocks;
- Apparent basin margin to centre fill of Cretaceous and Tertiary sediments.



The Porcupine Basin is typified by large scale rotated fault blocks formed of pre-rift Middle Jurassic strata, covered by the syn-rift Upper Jurassic section. Continuation of the faulting within the Lower Cretaceous section occurs towards the margins due to renewed rifting at that time. Tertiary strata has been deposited within the basin and upon the margins.

From Ternan report.

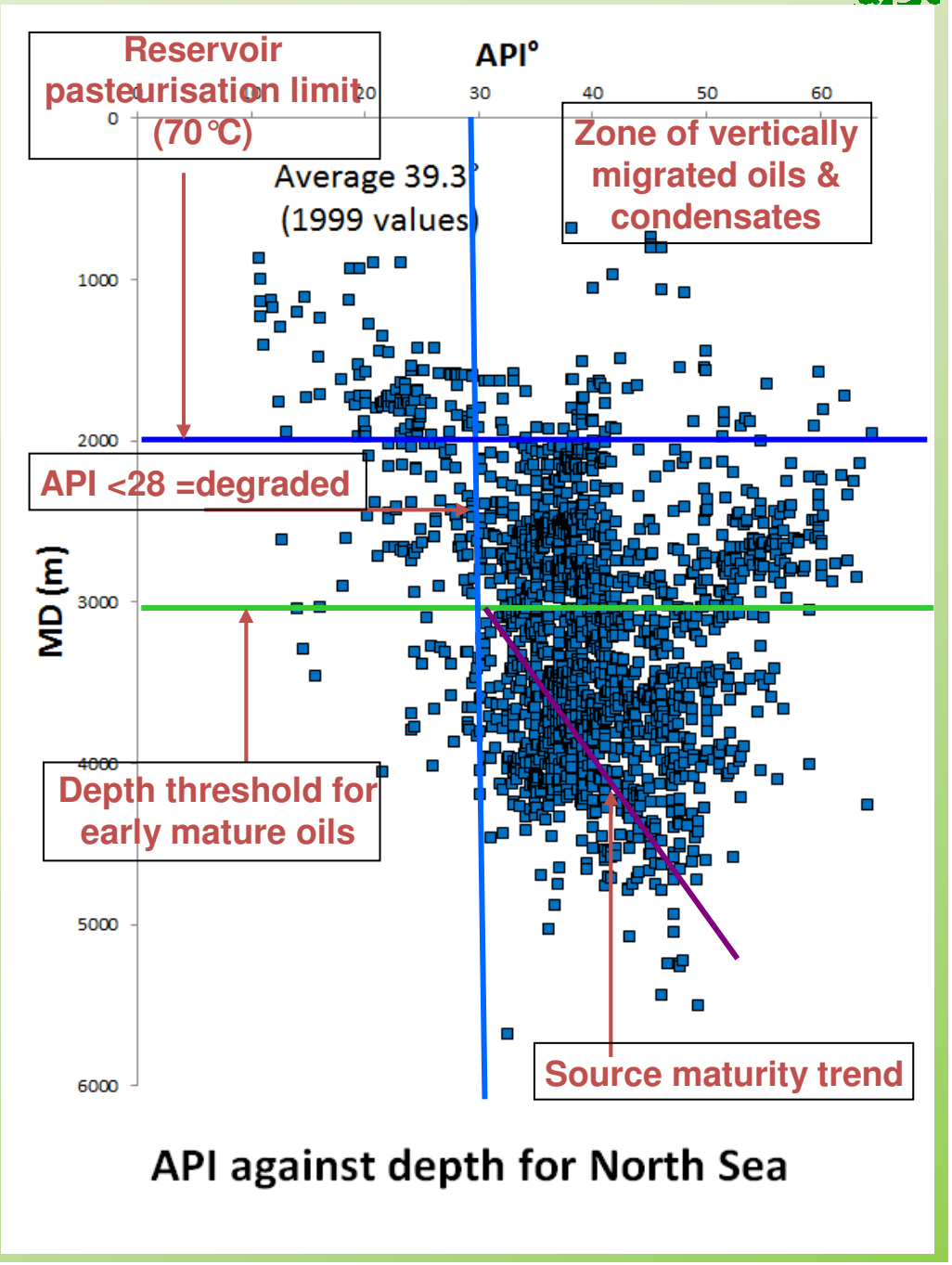
HYDROCARBONS

Bulk properties

North Sea oil depth trends.

The gravity trend for API gravity against depth reveals a number of things:

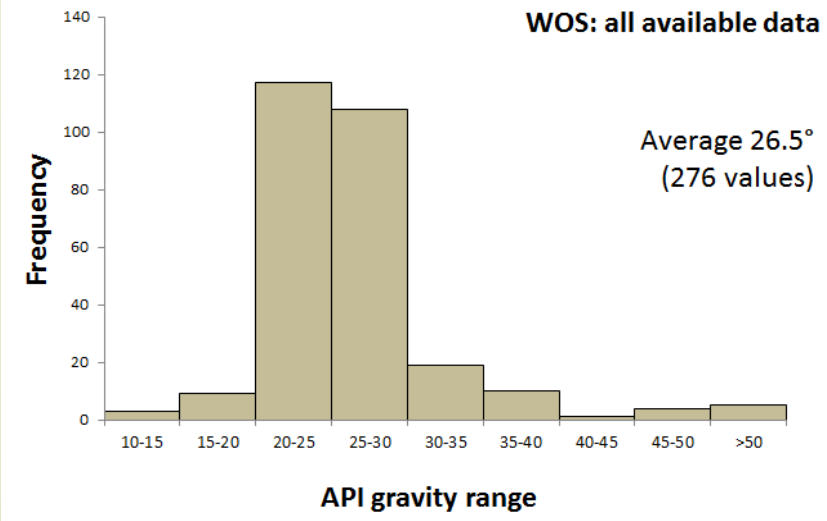
- There is a wide range of oil gravity;
- The presumed depth of source implies very significant vertical migration (1-2+ kms.);
- There are a number of oils displaying low gravities consistent with biodegradation;
- There are a significant number of oils with high gravities at shallow depths.

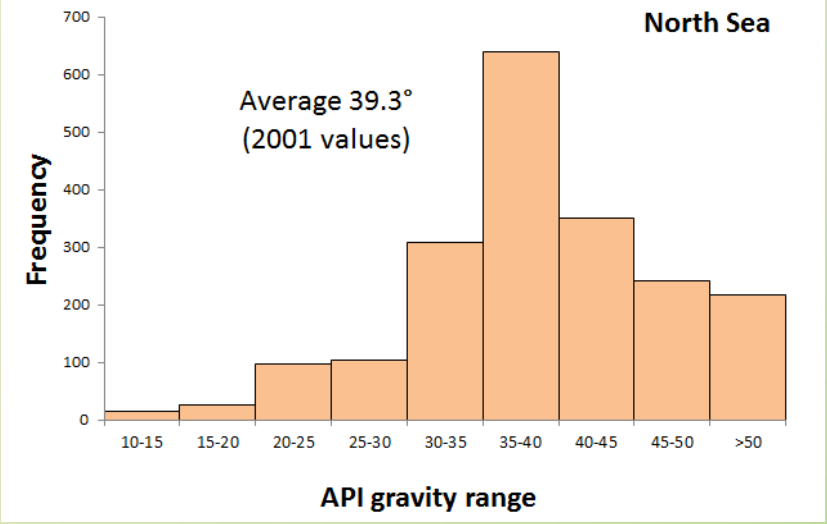


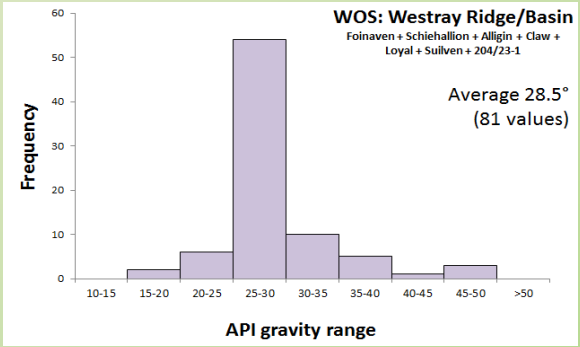
API against depth for North Sea

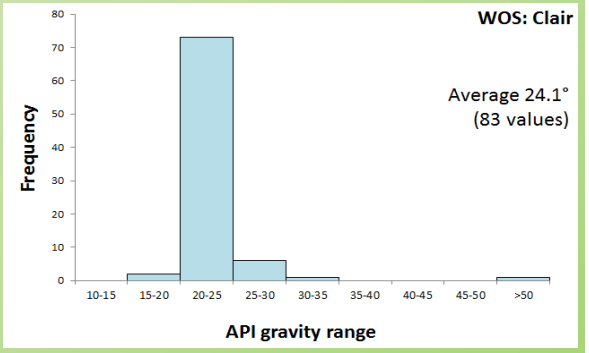
WOSI Oil bulk properties.

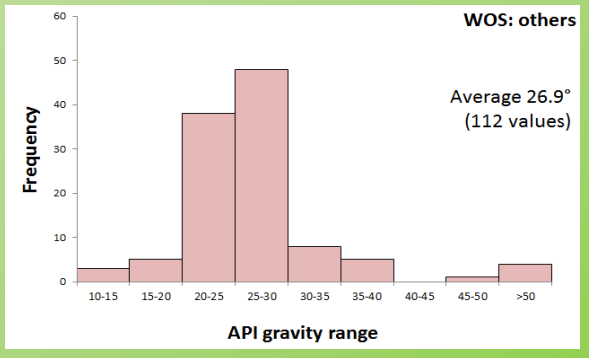
- All available bulk properties of flowed oils from tests have been accessed and compared to similar data for the North Sea;
- API gravity is the most fundamental parameter.





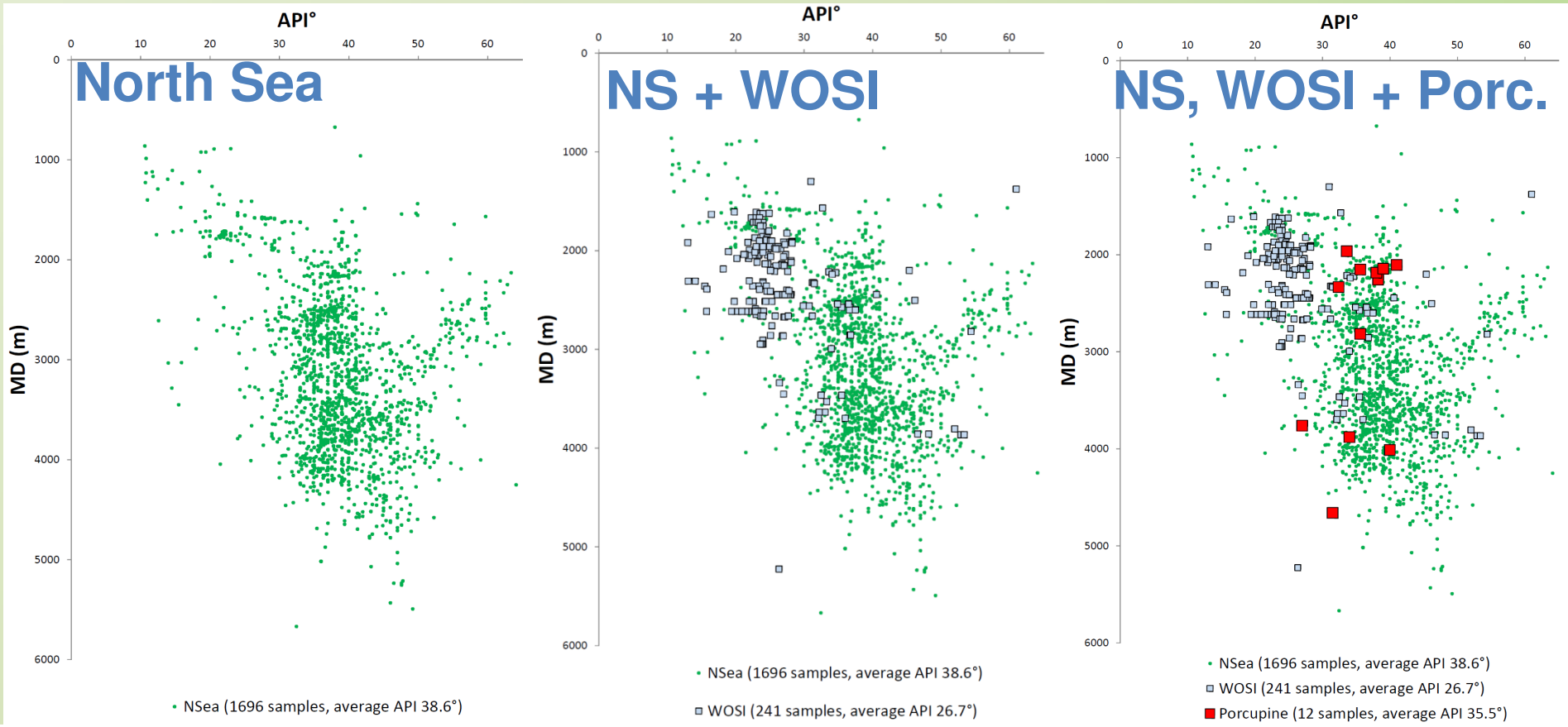






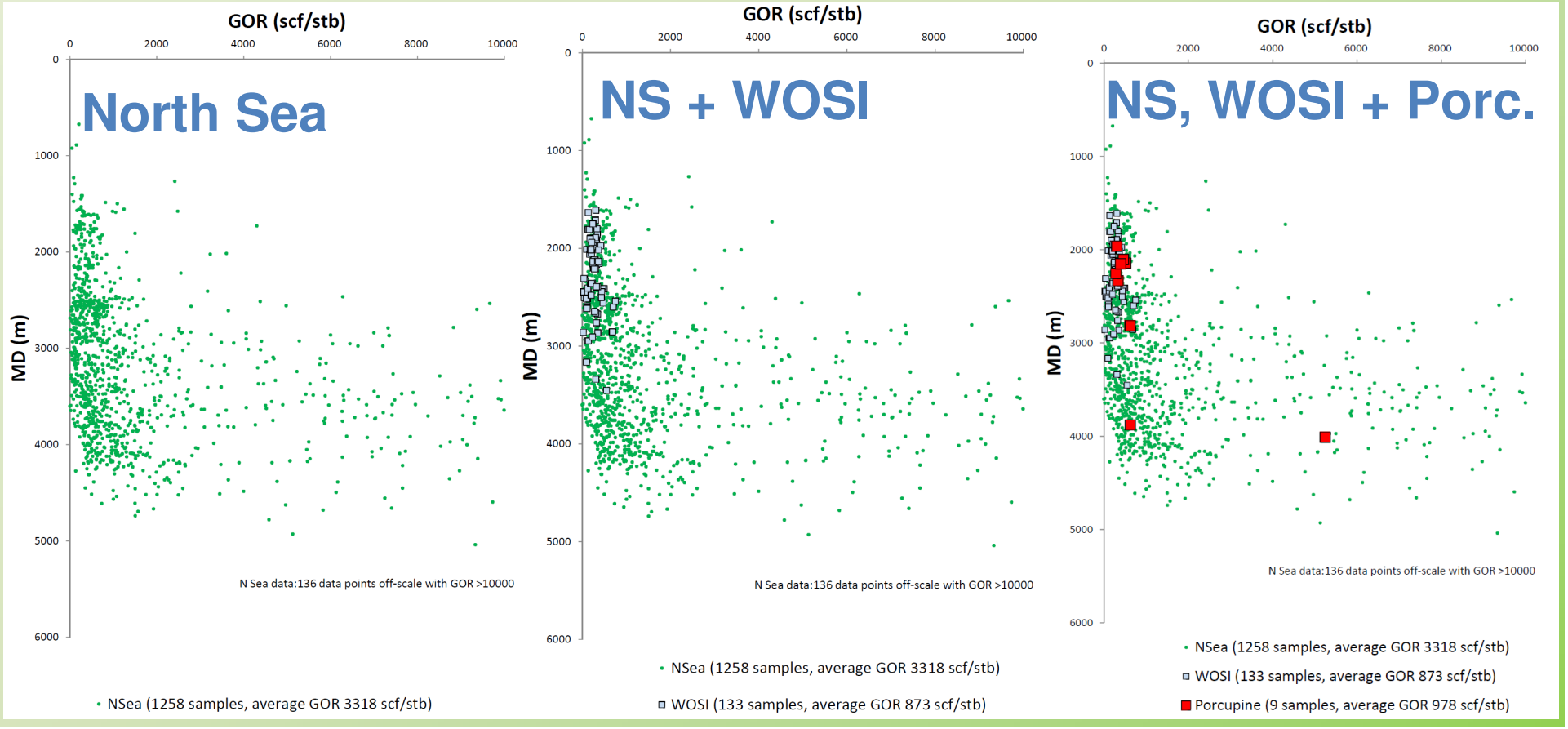
Porcupine Basin physical properties.

- API gravities of the few Porcupine oils are reasonably comparable to North Sea.



Porcupine Basin physical properties.

- **GORs - comparable to North Sea.**



HYDROCARBONS

Geochemistry

Biomarkers

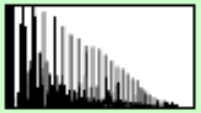
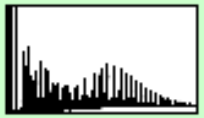
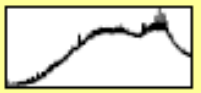
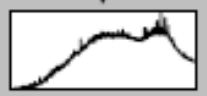
Bacterial degradation effects on oils.

Progressive removal of:

Light alkanes;
Heavier alkanes;
Branched alkanes;
Isoprenoids;
Polycylic alkanes;
Aromatics.

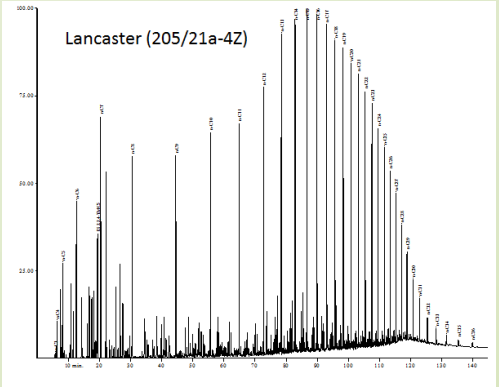
Results in steady decrease in:

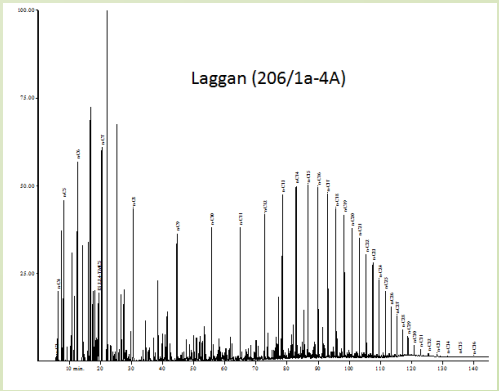
Gravity;
GOR;
Viscosity

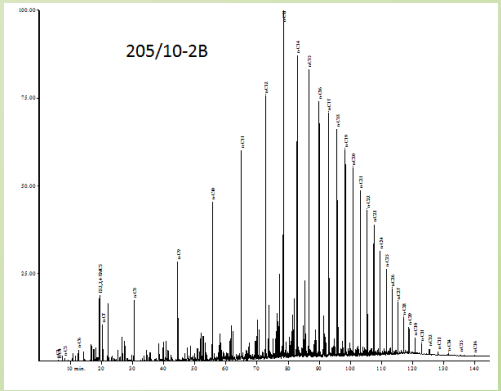
Severity	Hydrocarbon fingerprint		Biomarker	Limit (°C)	API Gravity	Mass
0	Normal		Normal	~70	~40	1
1	Less C4 to C12 n-alkanes		Normal			
2-4	UCM and isoprenoids		Normal			
5	UCM only		Normal	~50		
6-7	UCM only		Biomarker degradation			
8-9	UCM only		Demethylated hopanes			
10	UCM only		No biomarkers	~20	~10	~75%

Whole oil gas chromatography – selected WOSI oils.

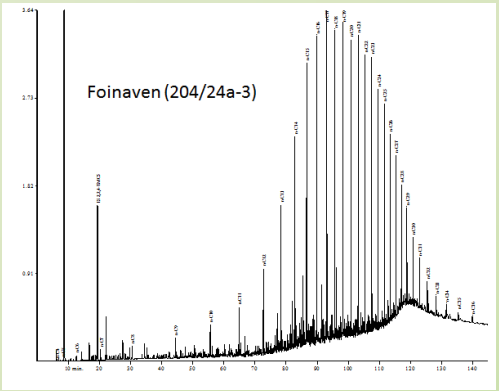
Fresh oils

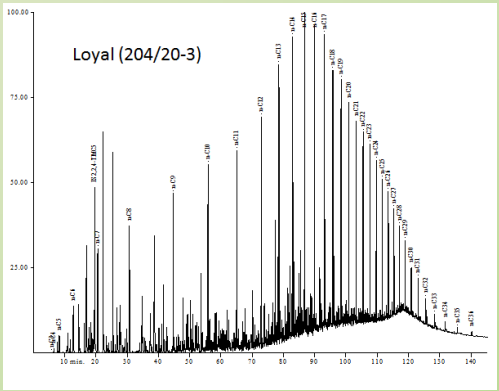


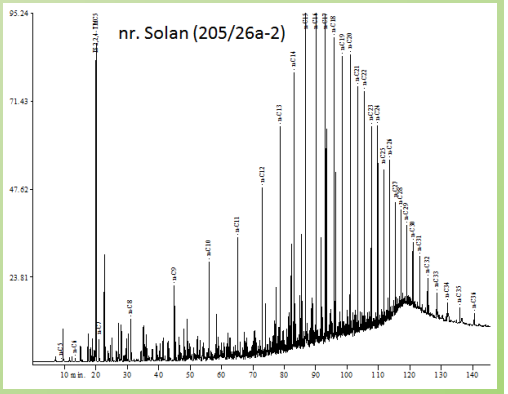




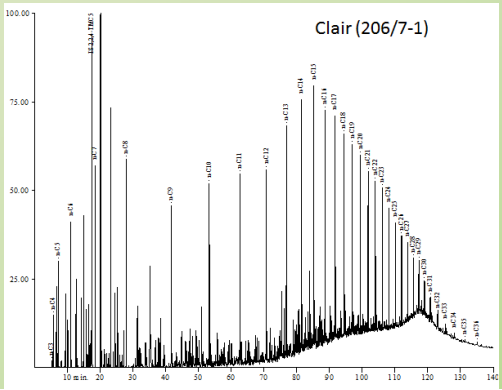
Partially degraded oils







Extensively degraded oils

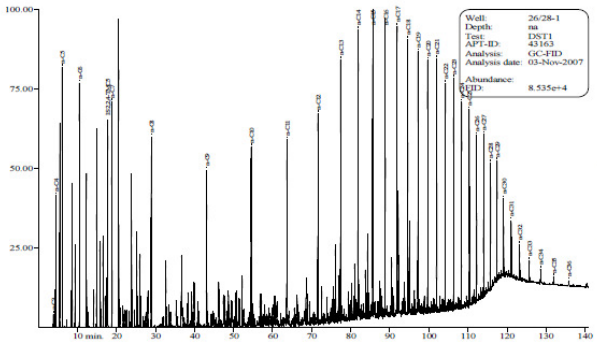


Mixtures of extensively degraded with varying but generally small amounts of fresh oils are the norm in the WOSI area.

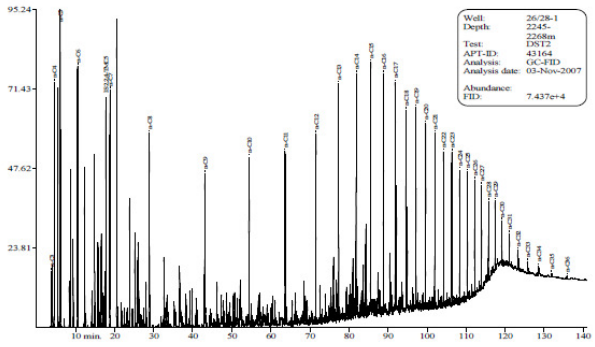
APT UK – North Atlantic petroleum systems – what do the fluids tell us?

Whole oil gas chromatography – Porcupine oils.

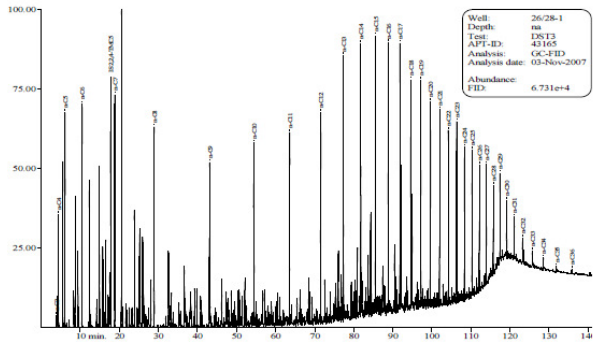
Connemara – single phase fresh oils;
35/6-1 & 35/8-2 – depleted light HC's.



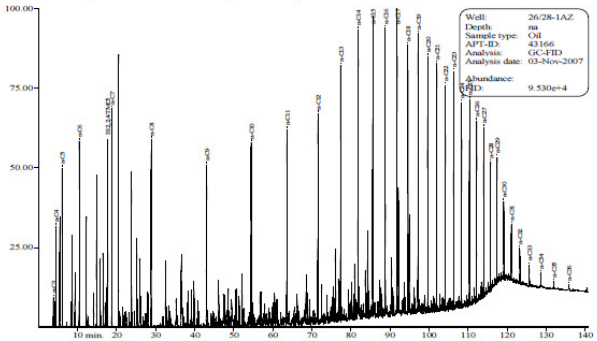
26/28-1, 1960-1970m, DST-1, Callovian



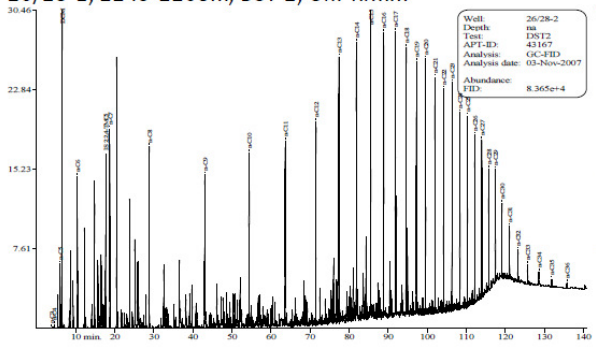
26/28-1, 2245-2268m, DST-2, Oxf-Kimm



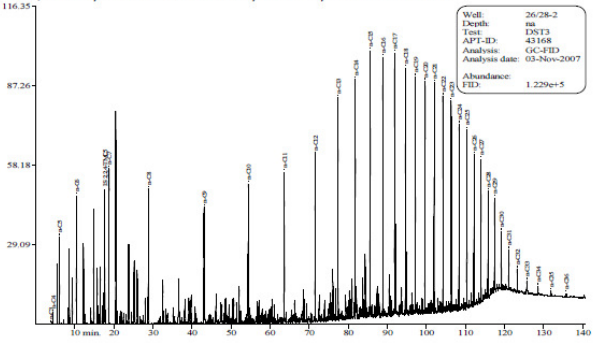
26/28-1, 2328-2339.5m, DST-3, Portlandian



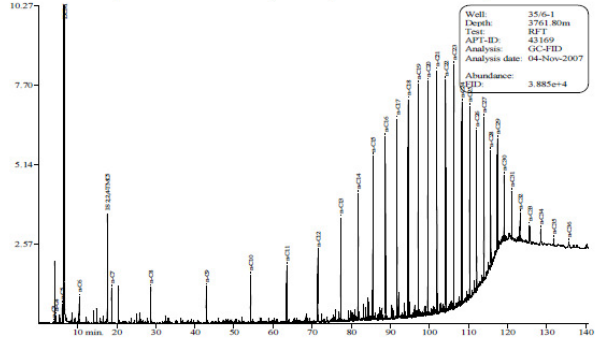
26/28-A1Z, 2089-2122.1m, EWT, Oxf-Kimm to Apt-Alb



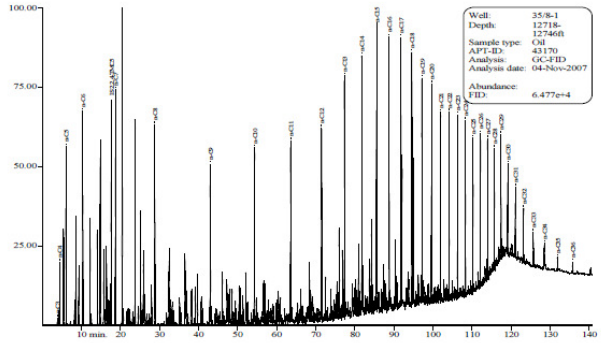
26/28-2, 2134-2154.1m, DST-2, Bathonian



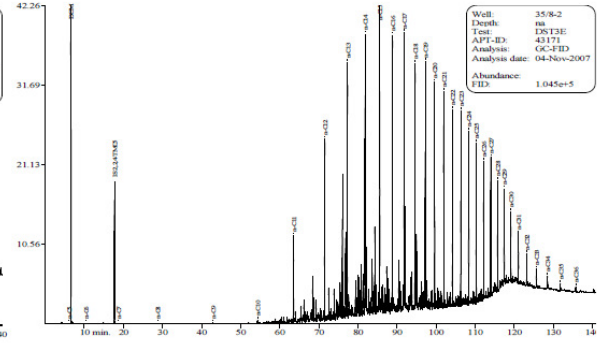
26/28-2, 2320-3313m, DST-3, Bathonian



35/6-1, 3761.8m, RFT-3B, Bajocian-Bathonian



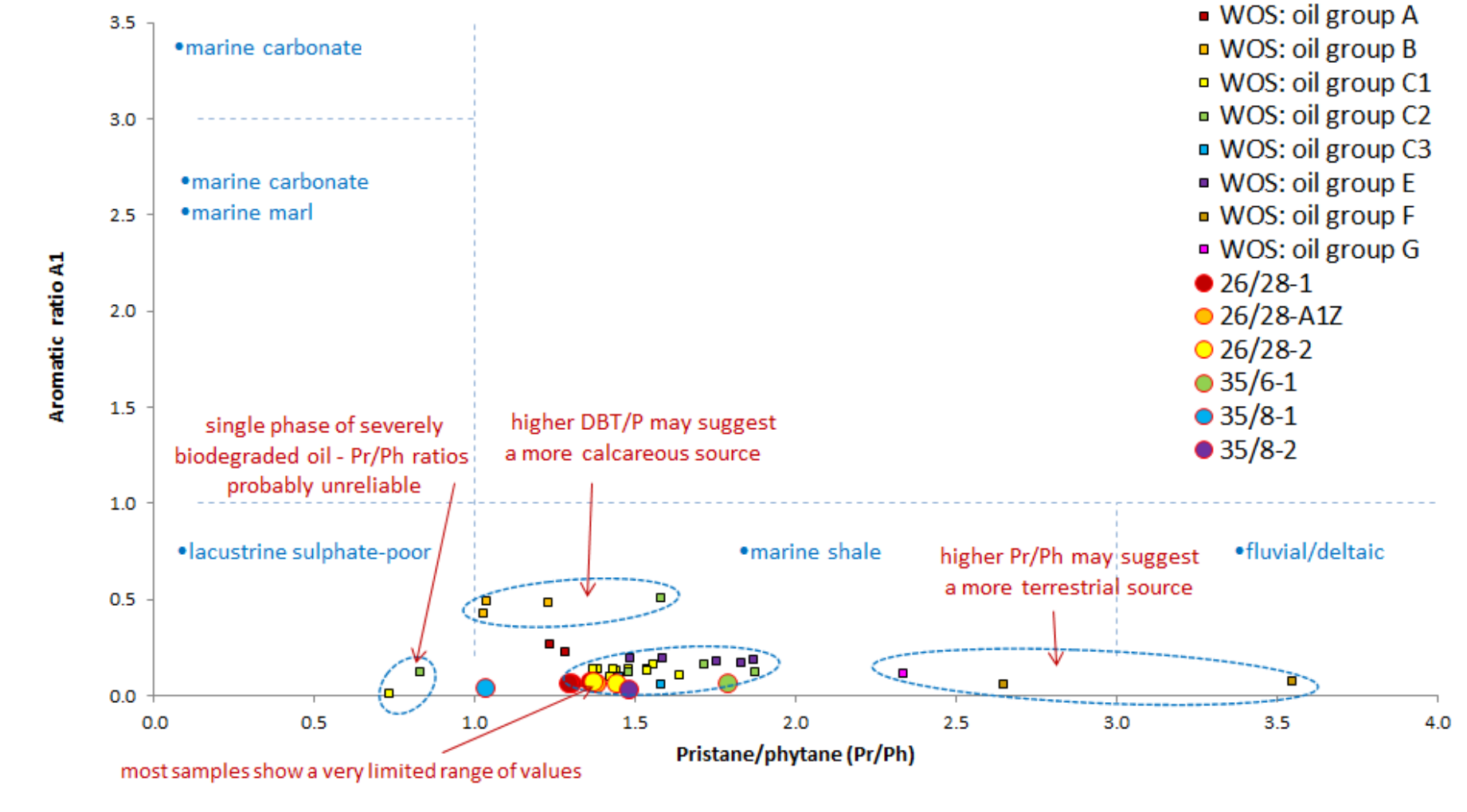
35/8-1, 12718-12746ft, DST-1B, Barremian



35/8-2, 13110-13220ft, DST-3, Oxf-Kimm

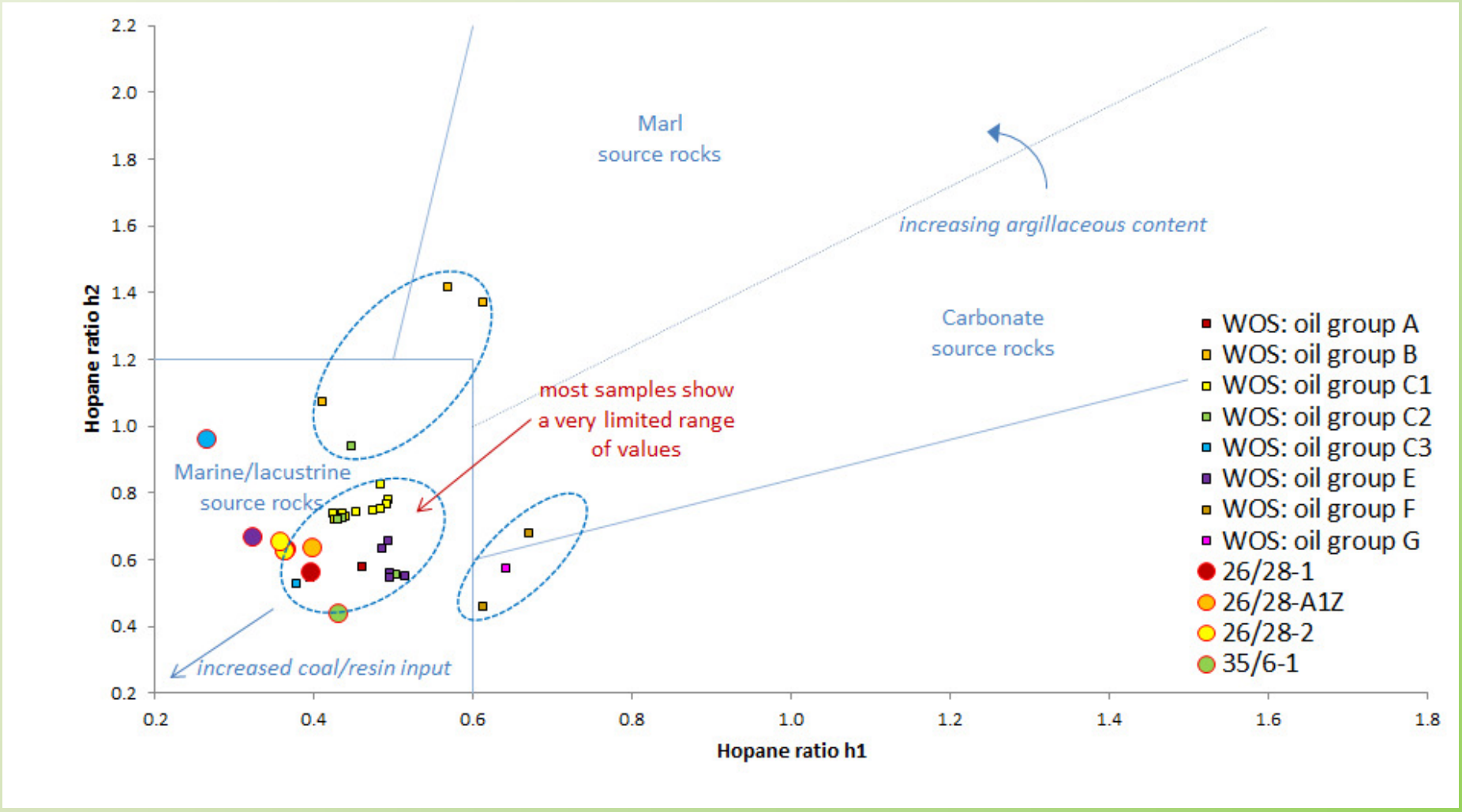
Source environment biomarkers.

- WOSI oils aromatics and isoprenoids similar to bulk of ?KCF sourced oils.
- Porcupine oils shows greater similarity in depositional environment.



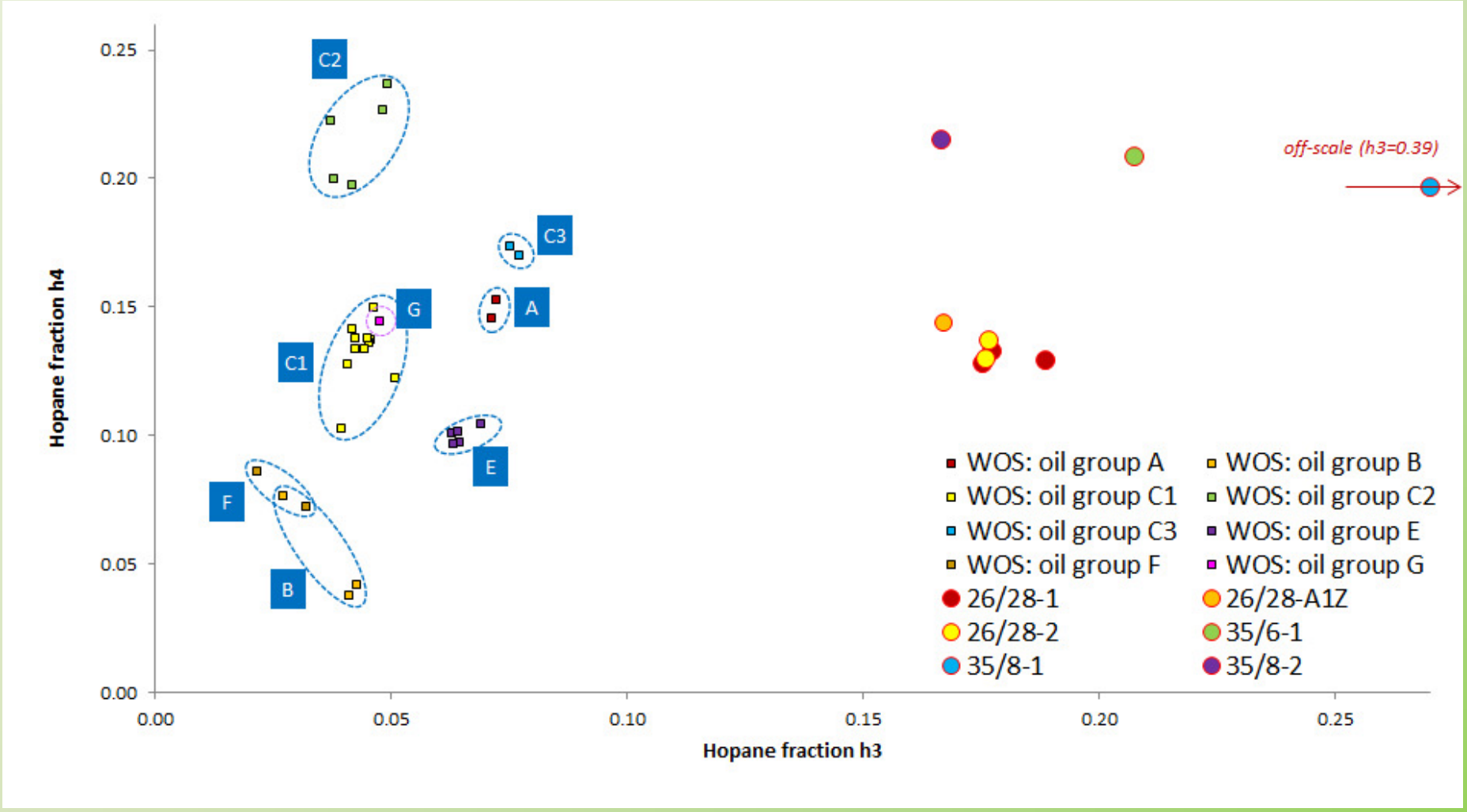
Source environment biomarkers.

- Hopanes similar to bulk of ?KCF sourced oils.
- 35/6-1 and 35/8-1 oils fall in slightly different areas.



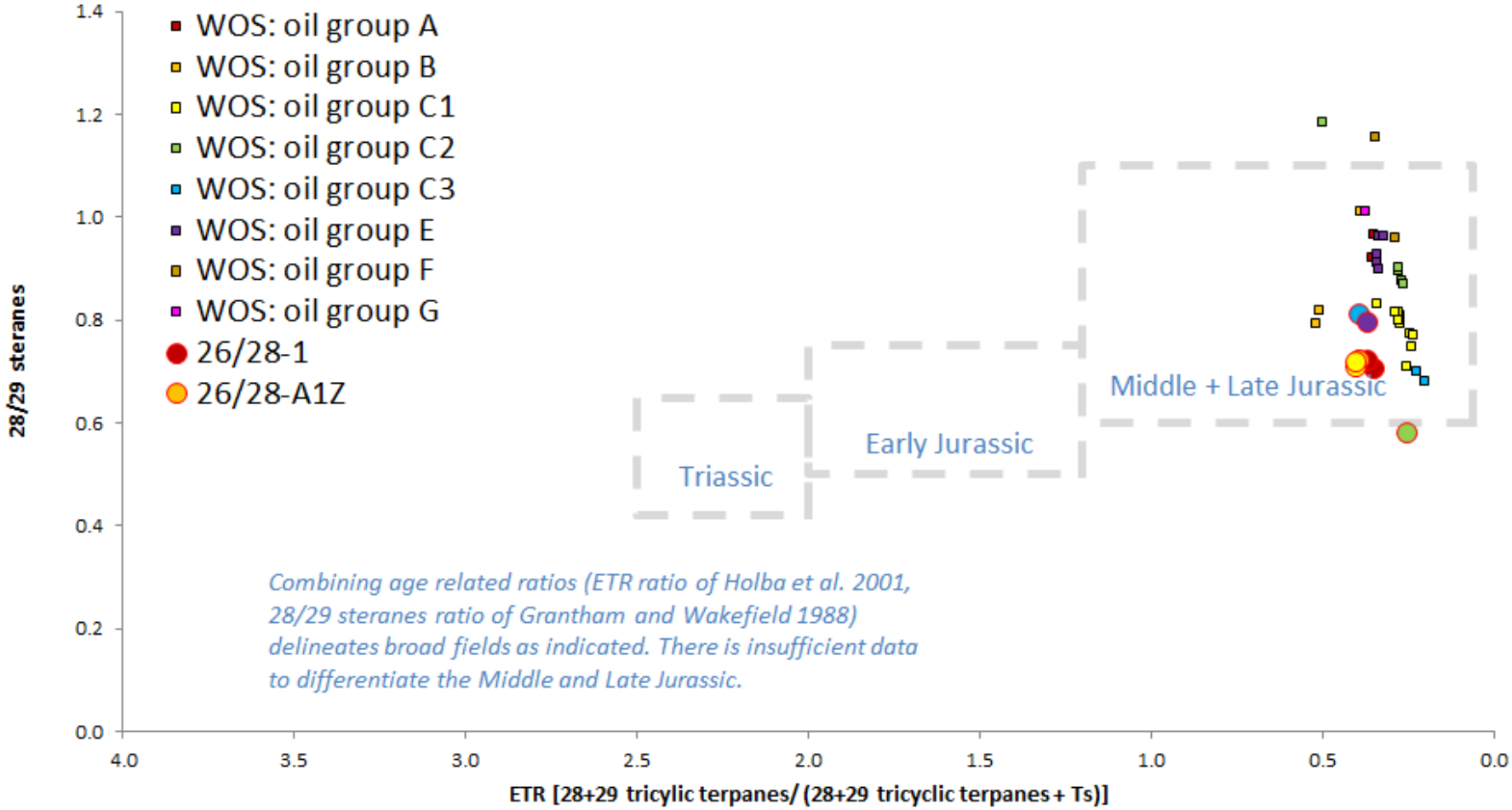
Source salinity biomarkers.

- Porcupine gammacerane contents significantly higher than WOSI oils – greater salinity / anoxia?



Source rock age.

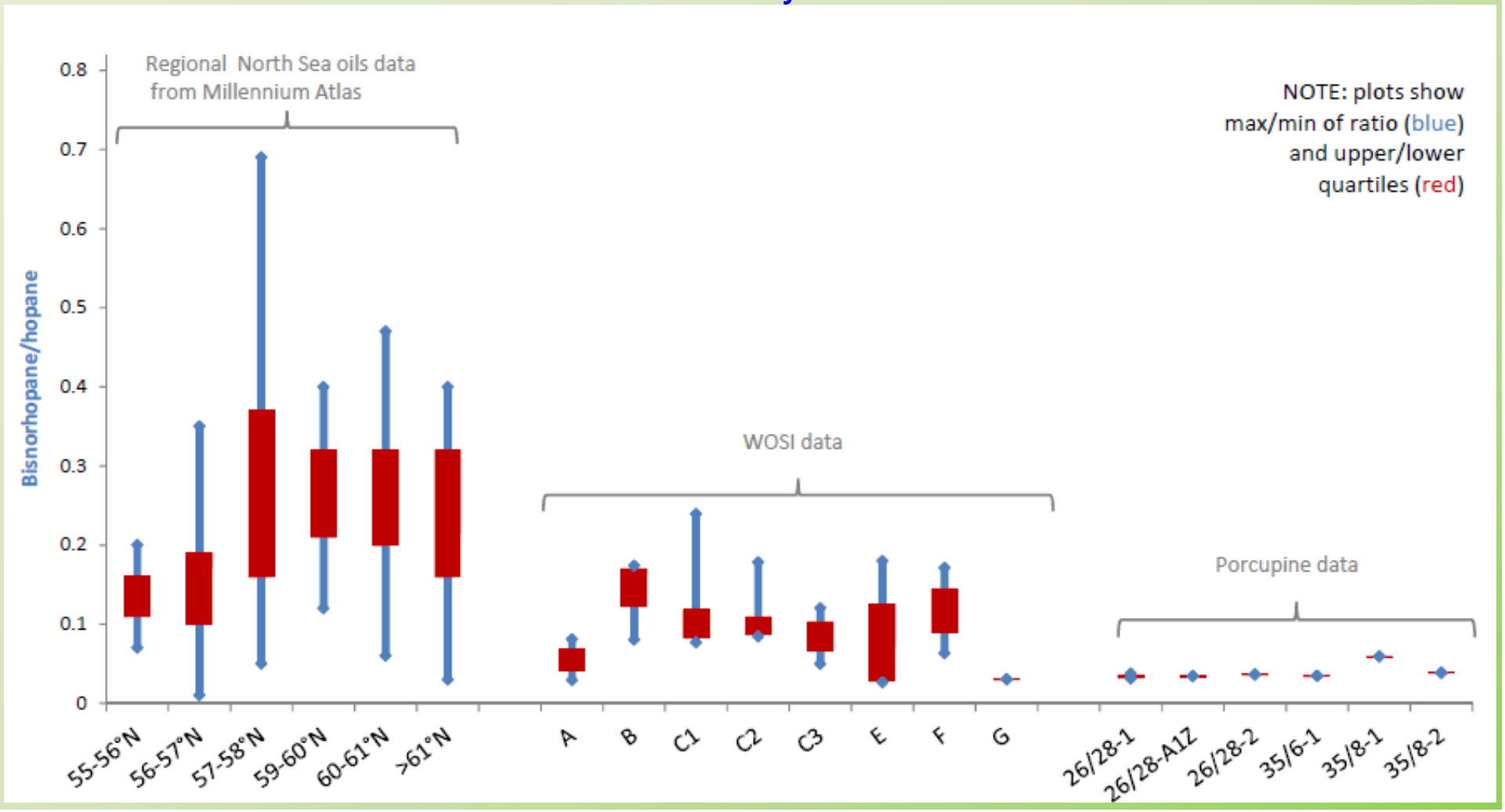
- This plot does not distinguish the age of source for these oils.
- Appears source rocks are certainly within mid to Late Jurassic range.
- Porcupine and WOSI oils similar source age including 35/6-1 waxy oil.



APT UK – North Atlantic petroleum systems – what do the fluids tell us?

Bisnorhopane (bnh).

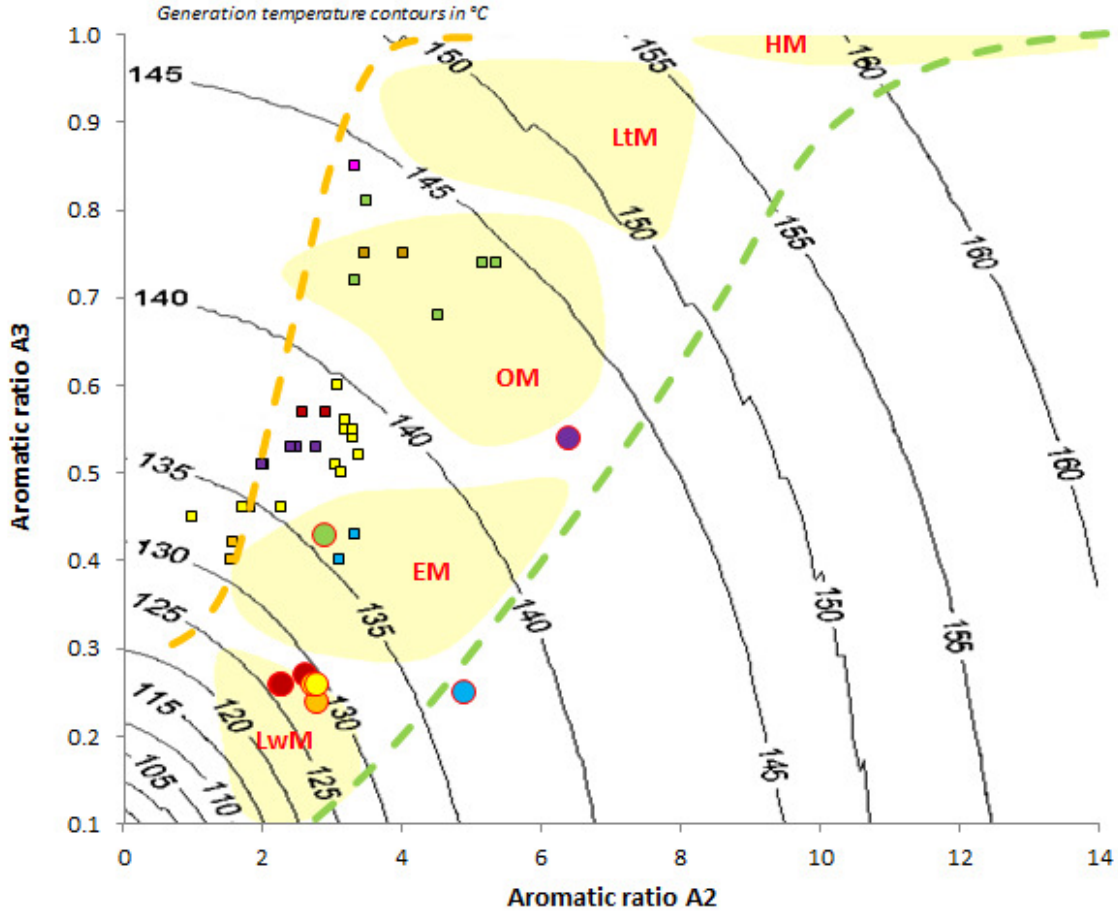
- The Porcupine oils are depleted in bnh relative to both WOSI & NS.
- Typically KCF onshore UK Yorkshire and Dorset etc, and Jean d'Arc oils depleted in it.
- Believed to be a reflection of Tethyan rather than Boreal influence.

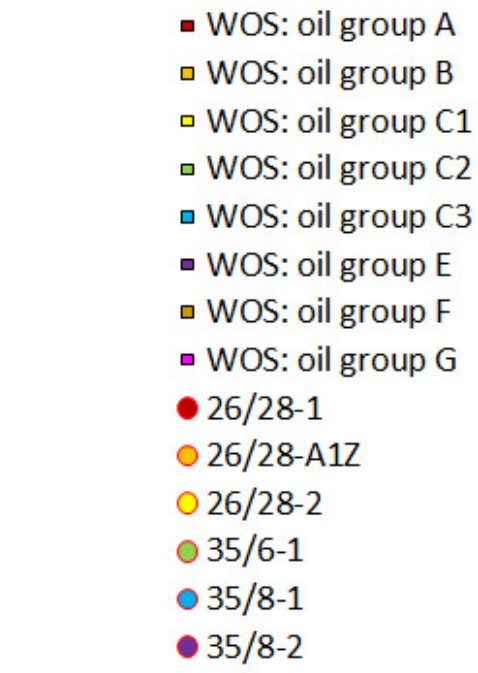


APT UK – North Atlantic petroleum systems – what do the fluids tell us?

Maturity parameters.

- WOSI oils display early to mid range generation temperatures.
- None of the oils are sourced from late mature source rocks.
- Porcupine oils display a range of generation temperatures.





LwM low maturity oils

EM early mature oils

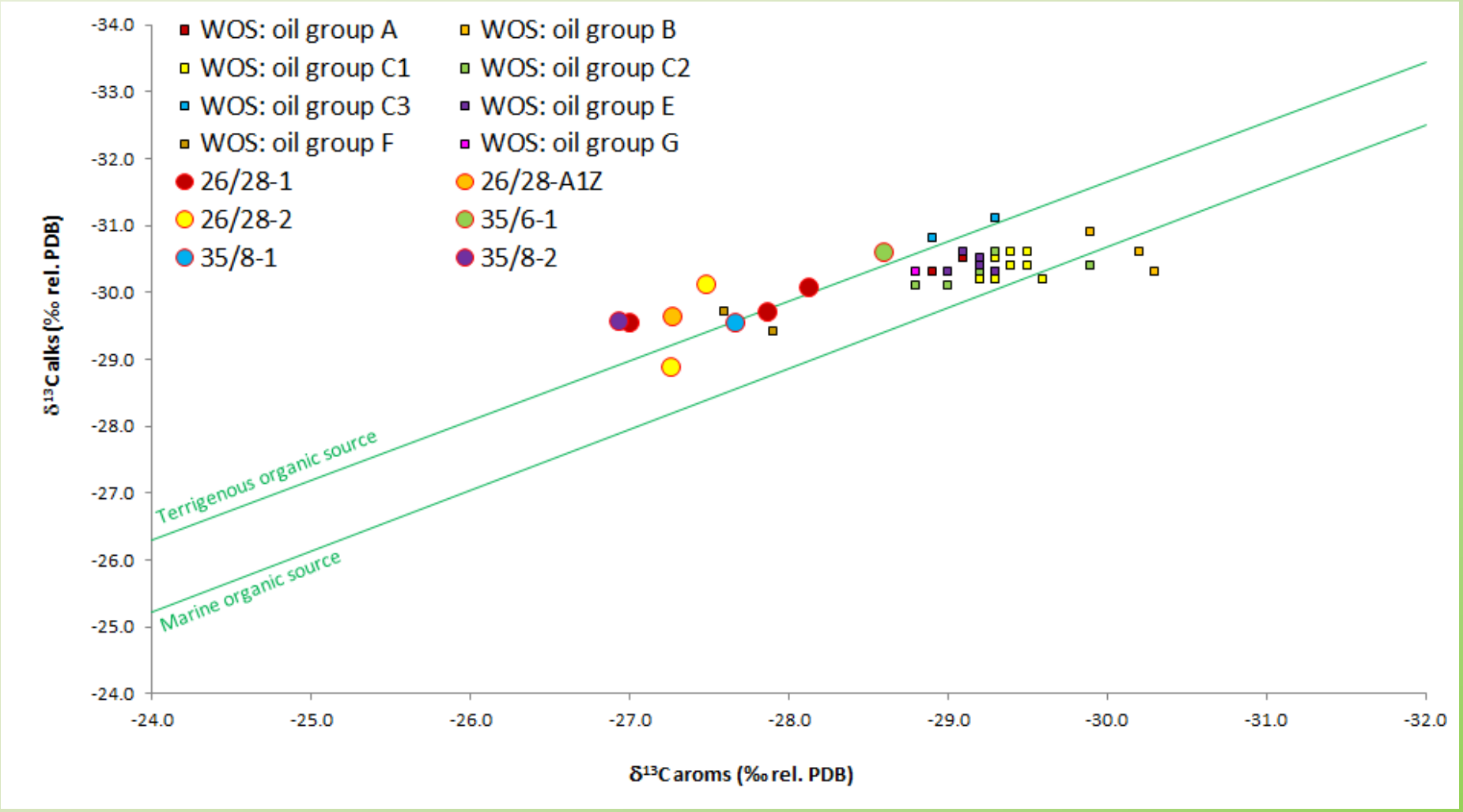
OM optimum mature oils

LtM late mature oils

HM high maturity oils

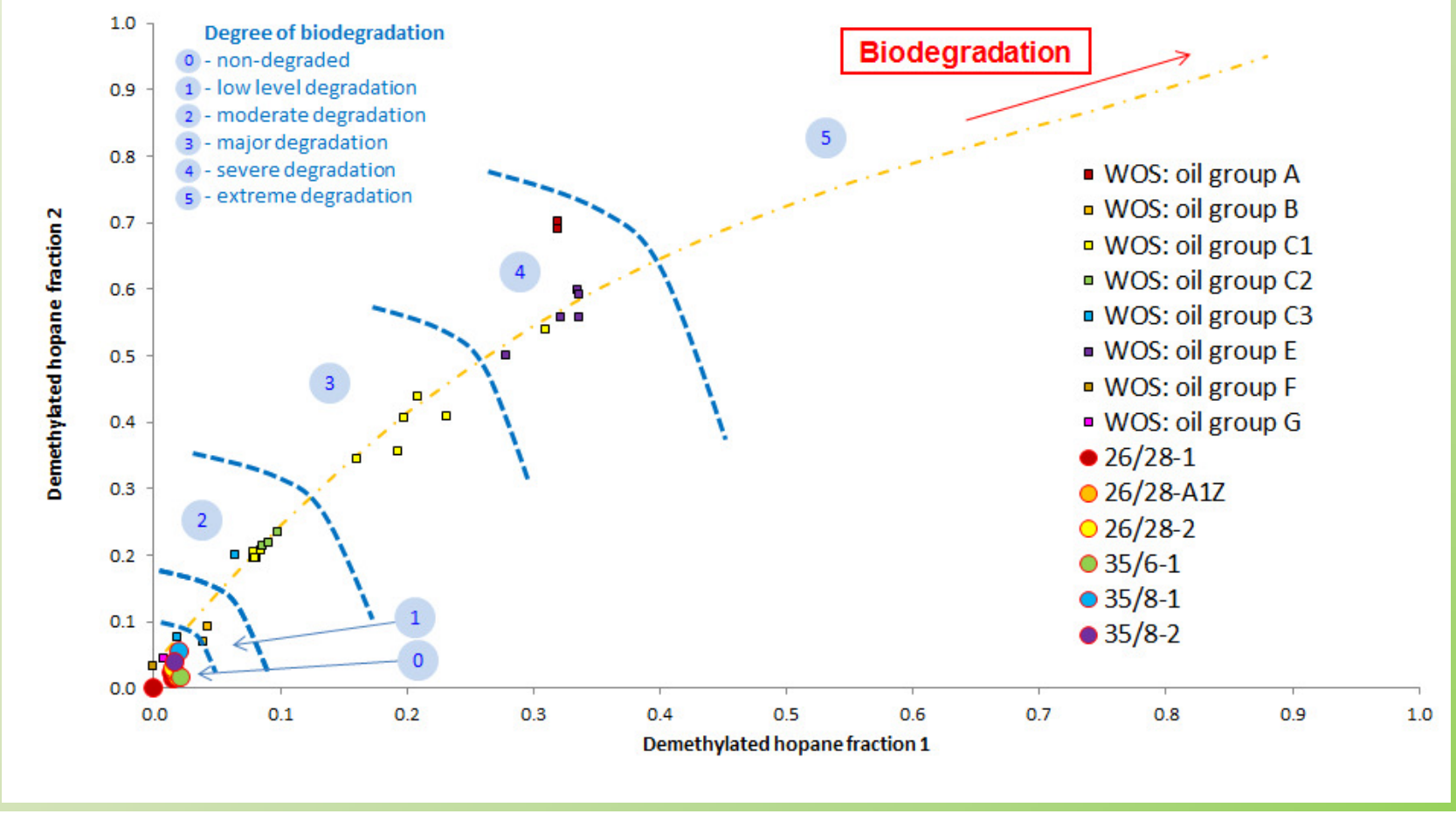
Bulk carbon isotope data.

- Porcupine oil have distinctly heavier carbon isotopes.
- Little bit heavy even for North Sea KCF oils?



Oil characterisation – degradation.

- The appearance of demethylated hopanes in oils is generally recognised as evidence for severe bacterial alteration.
- It is usually assumed this occurs in the reservoirs; maybe degradation during the migration is a more important process?;
- Demethylated hopanes common in WOSI but not in Porcupine oils.



IN SUMMARY:

North Atlantic margin petroleum systems: what does the Faeroe-Shetland Basin tell us about prospectivity further south?

Actually not a lot directly!

However, insights from extensive studies of WOSI fluids allows better recognition of complex source systems in terms of:

- **Fluid types & source rocks;**
- **Degradation, burial and uplift histories;**
- **Thermal history compared to commonly presented thermal model outcomes.**

Porcupine Basin fluids discovered to date bear more similarity to the North Sea petroleum system and probably to the Jean d'Arc Basin than to the Faeroe-Shetland Basin.