# PS Alternative Source Rocks on the Norwegian Continental Shelf: Potential Cretaceous Sourcing in Deepwater Basins*

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## Abstract

Jurassic sequences have long been considered the key source rocks in the Norwegian Sea. However, in the Møre and Vøring Basins, these intervals are likely to be exhausted of any hydrocarbon generation potential due to deep burial and corresponding high maturity. An integrated geochemical and basin modelling investigation was therefore carried out to understand the potential for younger deepwater plays on this part of the Norwegian Continental Shelf. Evaluation of key source rock characteristics including richness, kerogen type and maturity, provided an initial appraisal of Cretaceous sources, which indicate the potential for both oil and gas generation, whilst optical maturity data indicate immature-early oil window maturity throughout most of the drilled locations. Many hydrocarbon samples from the deepwater wells exhibit very different geochemical compositions compared to hydrocarbons associated with Jurassic sources. For example, stable carbon isotope compositions of fluids and stains from the Ellida discovery and Ormen Lange field are heavy (-28.5‰ to -26.5‰) when compared to the Tyrihans field (which has a strong correlation to the Spekk Formation) at -29.5‰. This significant isotopic variation is attributed to alternative sourcing rather than facies heterogeneity or maturity differences within the Spekk Formation. Further evidence for Cretaceous sourcing comes from the biomarker compounds. Greater $C_{29}$ hopane contents in the hydrocarbons of the deeper basins correlate strongly with the more terrestrial signature of potential Cretaceous source intervals. Close proximity of these drilled locations to the palaeo-coastline is likely to have increased terrestrial contribution in comparison with the typical open-marine signature of Jurassic sources. In addition, the high 24-nordiacholestanes, a class of age-diagnostic biomarkers, demonstrate the likelihood of a Cretaceous interval having sourced these hydrocarbons. 1-D basin modelling was conducted for selected drilled wells in the study area, calibrated to measured vitrinite reflectance and temperature data. The models predict main oil window maturity (0.7-1.0% Ro) for the Jurassic sources in the deepwater wells. However, it is likely that the more deeply buried kitchen areas will hold highly mature and post-mature Jurassic source rocks, with Cretaceous intervals potentially lying in the oil window.

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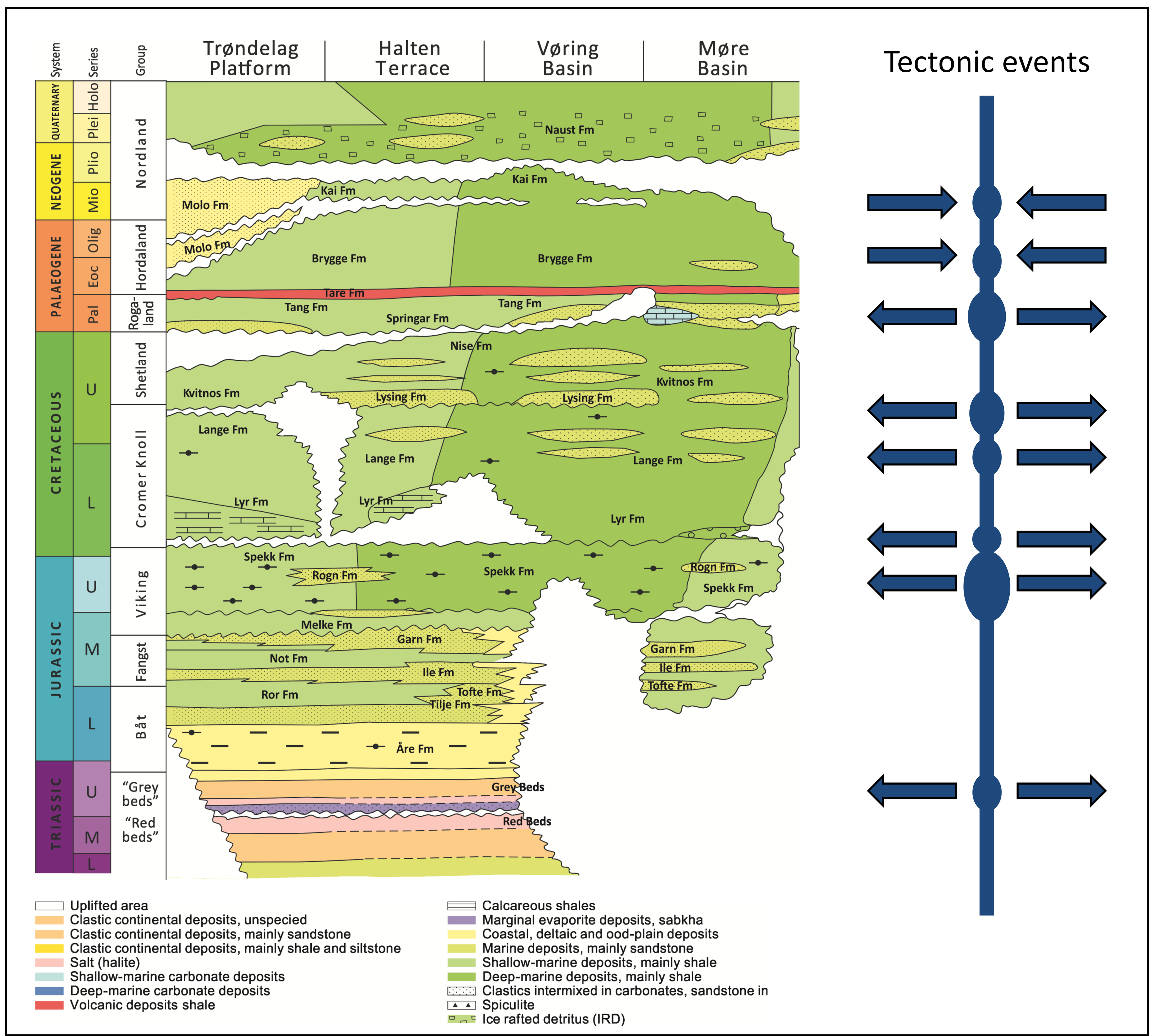
# Introduction

Jurassic sequences have long been considered the key source rocks in the Norwegian Sea. However, in the Møre and Vøring Basins, these intervals are likely to be largely exhausted of any hydrocarbon generation due to deep burial and high maturity. An integrated geochemical and basin modelling investigation was therefore carried out to understand the potential for younger deepwater plays on the Norwegian Continental Shelf, the key findings of which are summarised as follows:

- Cretaceous intervals indicate both the potential for oil and gas generation, and are immature to early oil window mature throughout most of the deepwater basins (based upon geochemical data)
- Hydrocarbon samples from deepwater wells exhibit different geochemical compositions to those from purely Jurassic sources
- The presence of high 24-nordiacholestane biomarkers in Ellida fluids, classic age-diagnostic biomarkers, suggests the possibility of a younger source interval
- Zetaware's Genesis software predicts main to late-oil window maturity (0.7-1.3% Ro) for Jurassic sources close to the deepwater areas. However it is important to note that true maturity is likely much higher in the deeper source kitchens, rather than the drilled highs.

# Geological Setting and Regional Stratigraphy

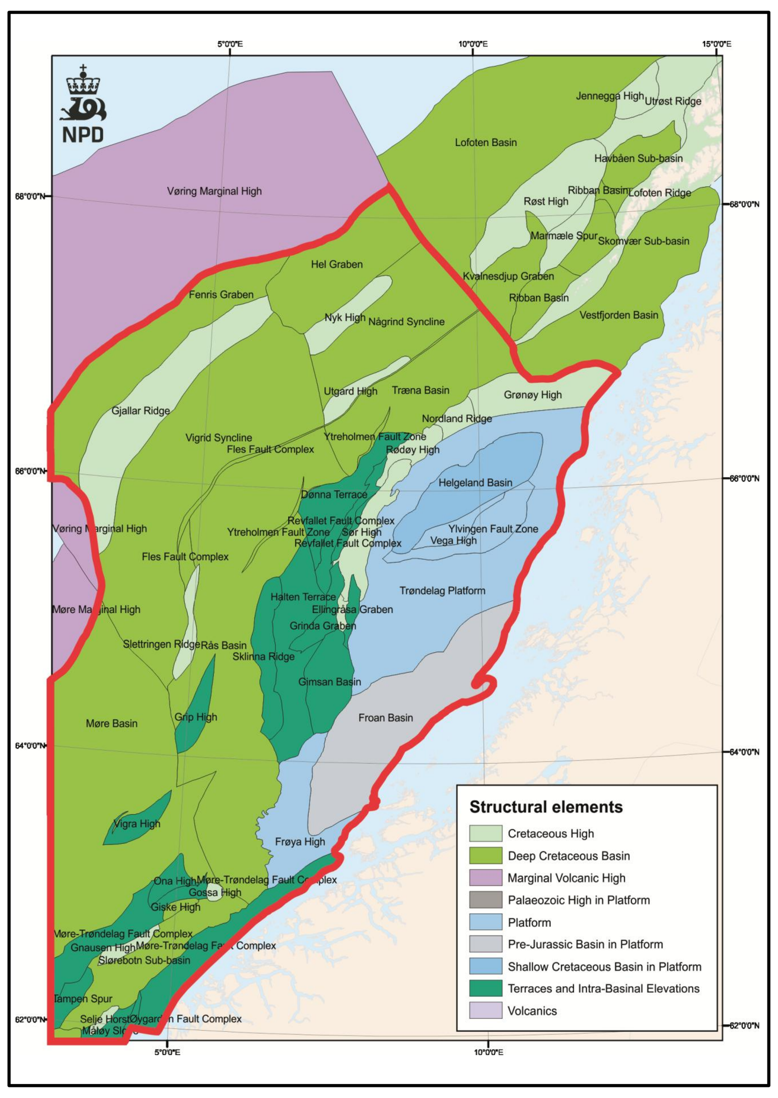



*Regional Norwegian Sea lithostratigraphy and associated tectonic events (based on the NPD lithostratigraphic chart of the Norwegian Sea, Norwegian Petroleum Directorate online). Extensive deposition of Cretaceous sequences is evident within the Vøring and Møre basins.*

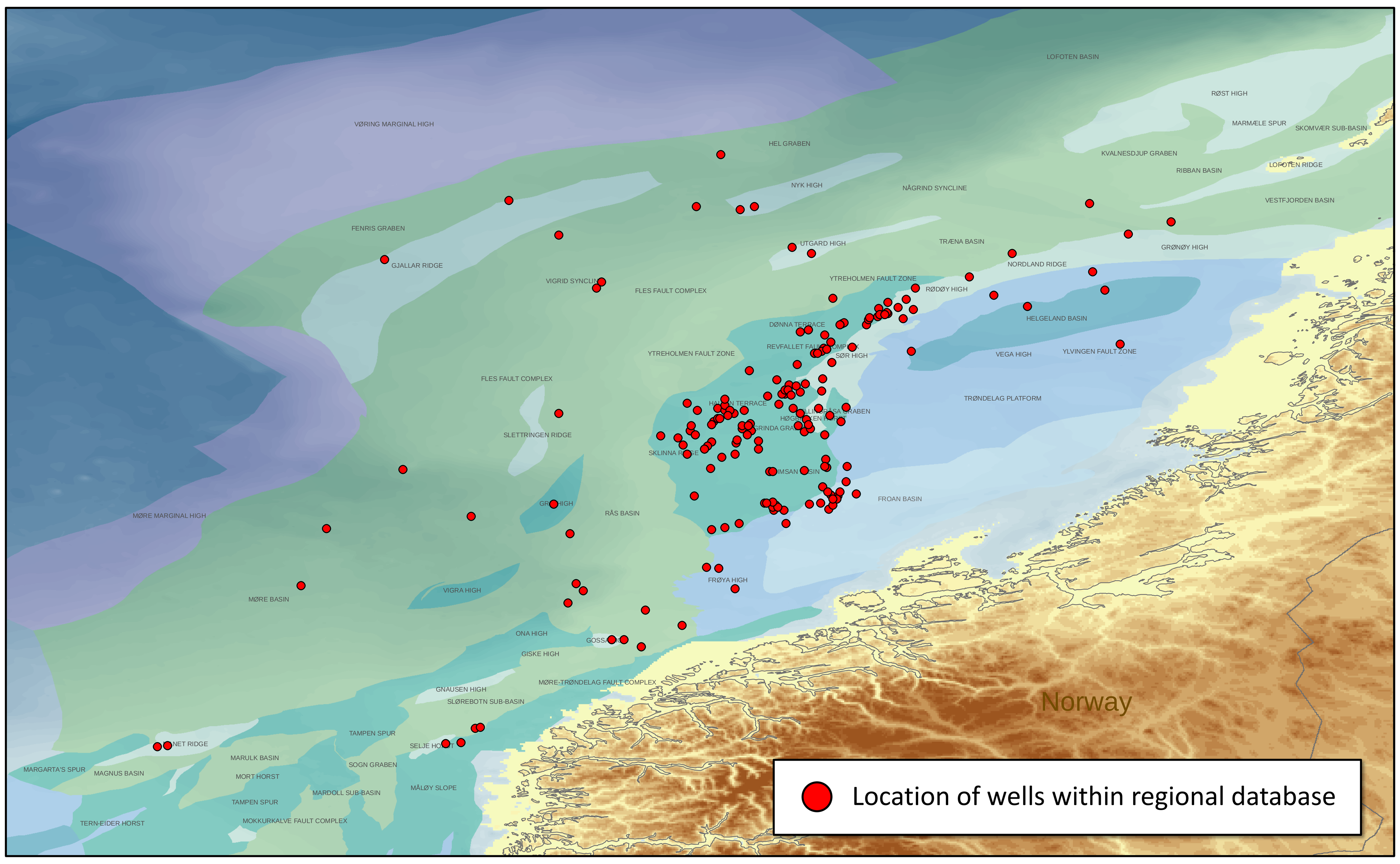
Covering the continental margin between 62° and 69°N, the Norwegian Sea contains a NE-SW trend of deep Cretaceous basins, namely the Vøring and Møre Basins, which are flanked by palaeo-highs and platforms, as well as the elevated mainland to the east (Brekke *et al.,* 1999). The structural configuration of the region was controlled by three main rifting episodes within the Carboniferous to Permian, Middle Jurassic to Early Cretaceous (both extensional tectonics related to continental rifting), and a final major rifting episode in the Late Cretaceous to Paleocene, as a result of the onset of seafloor spreading within the North Atlantic (Faerseth & Lien, 2002). The Jan Mayen Lineament has acted as a tectonic barrier between the Vøring Basin, which has undergone extensive tectonic activity from the Middle Jurassic to the present day, and the Møre Basin experiencing only passive subsidence since the late Middle Jurassic-Early Cretaceous (Blystad *et al.,* 1995).

Norwegian Sea exploration has typically focussed on the Haltenbanken area, which provides a reliable petroleum system encompassing the prolific Jurassic source rocks of the Spekk, Melke and Åre Formations, as well as extensive mid-Cretaceous to Lower Tertiary reservoir intervals. Drilling in the frontier deepwater basins began in 1997, so far resulting in only six discoveries (including Ellida and the Ormen Lange gas field).

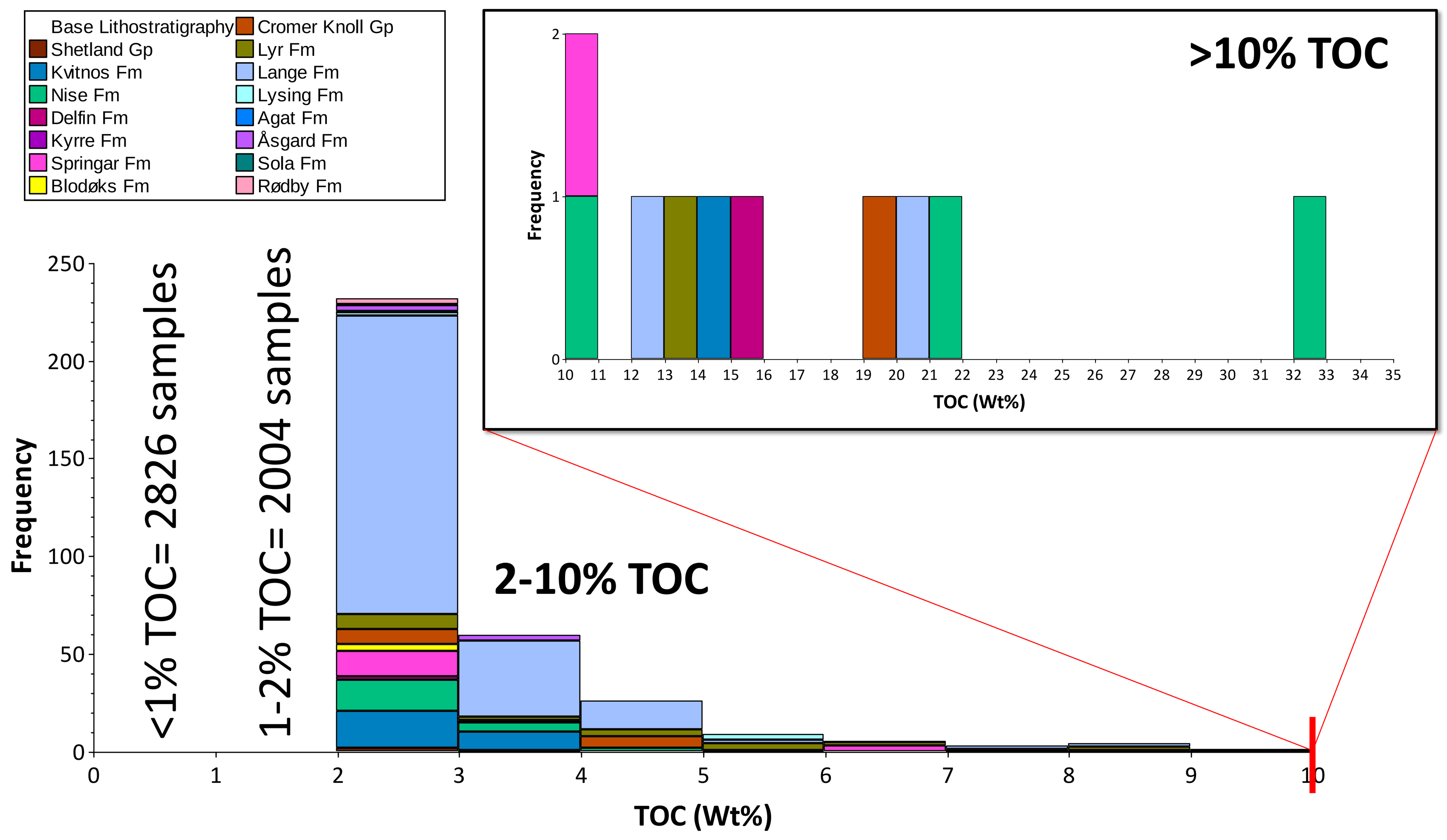
# Study Area



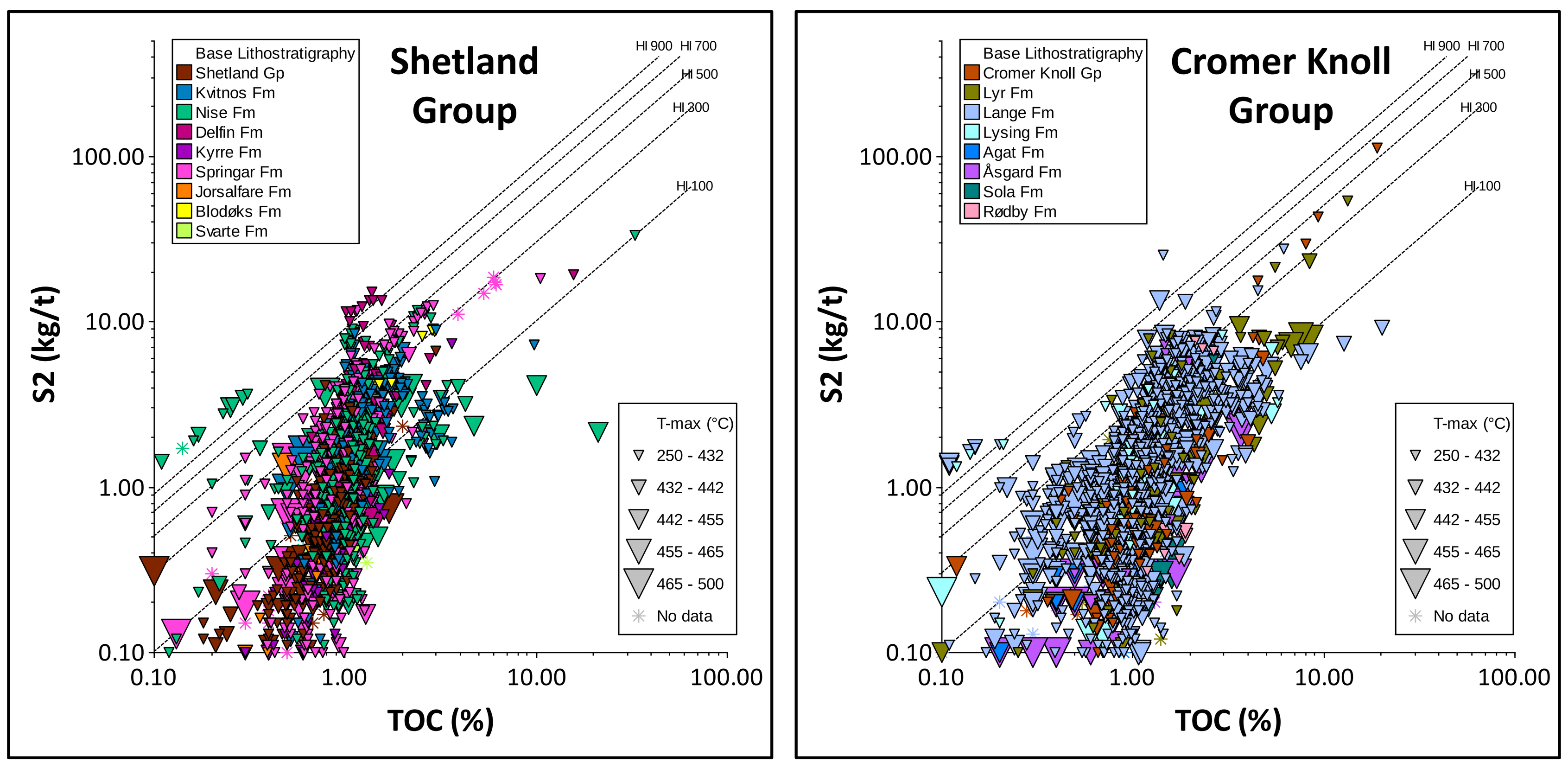

*The study area and coverage of the database outlined (based upon structural elements in the Norwegian Sea, NPD online), with location of wells with geochemical data from within the regional database (right)*



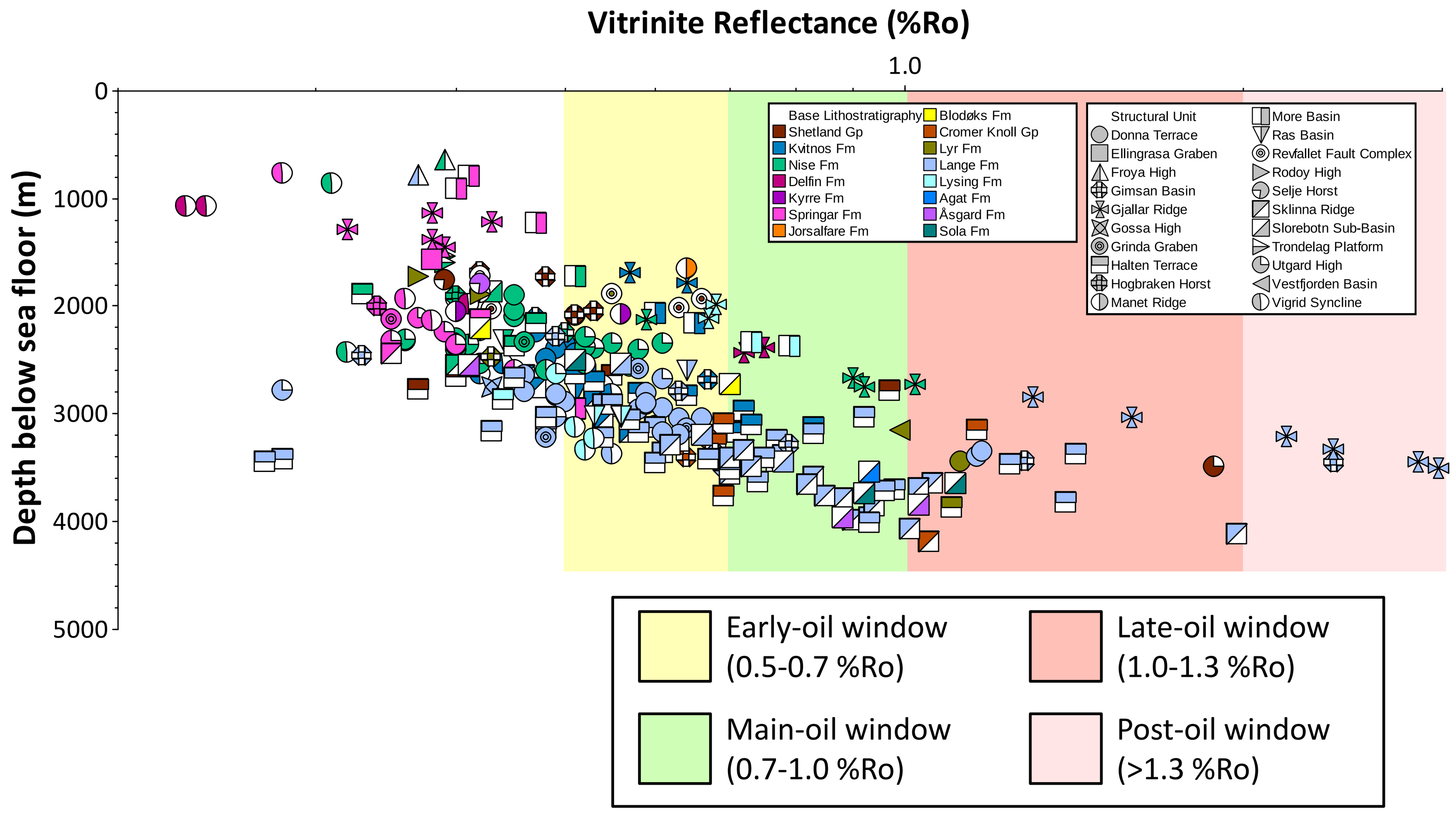
# Cretaceous Source Rock Potential and Maturity



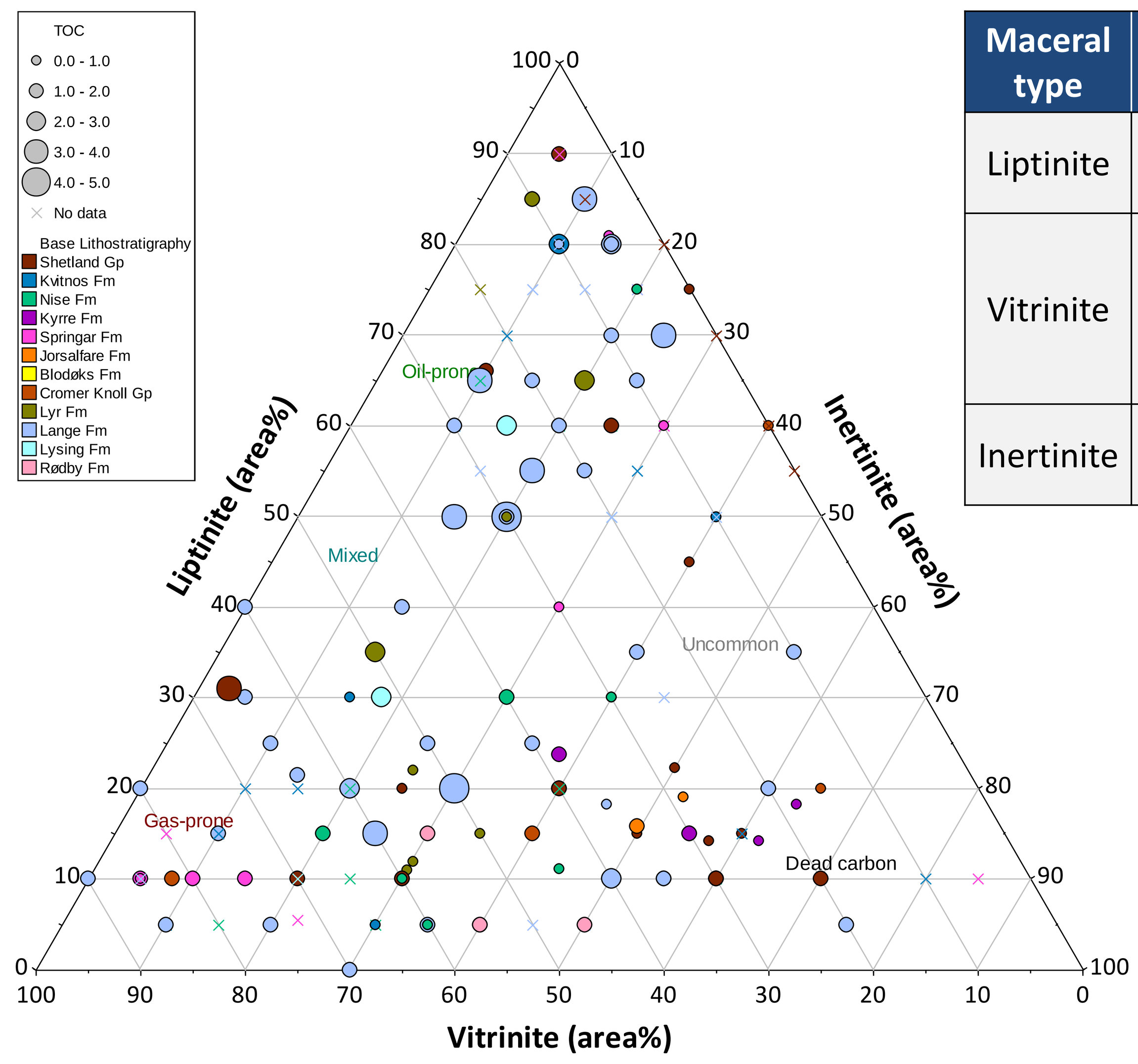

*Total Organic Carbon (TOC wt.%) for all Cretaceous rocks (excluding samples with non-source-rock lithology such as sandstones)*




*Rock-Eval Pyrolysis S2 parameter (generative potential) vs. TOC, with Hydrogen Index trendlines as underlay, indicating kerogen type and likely hydrocarbon product*



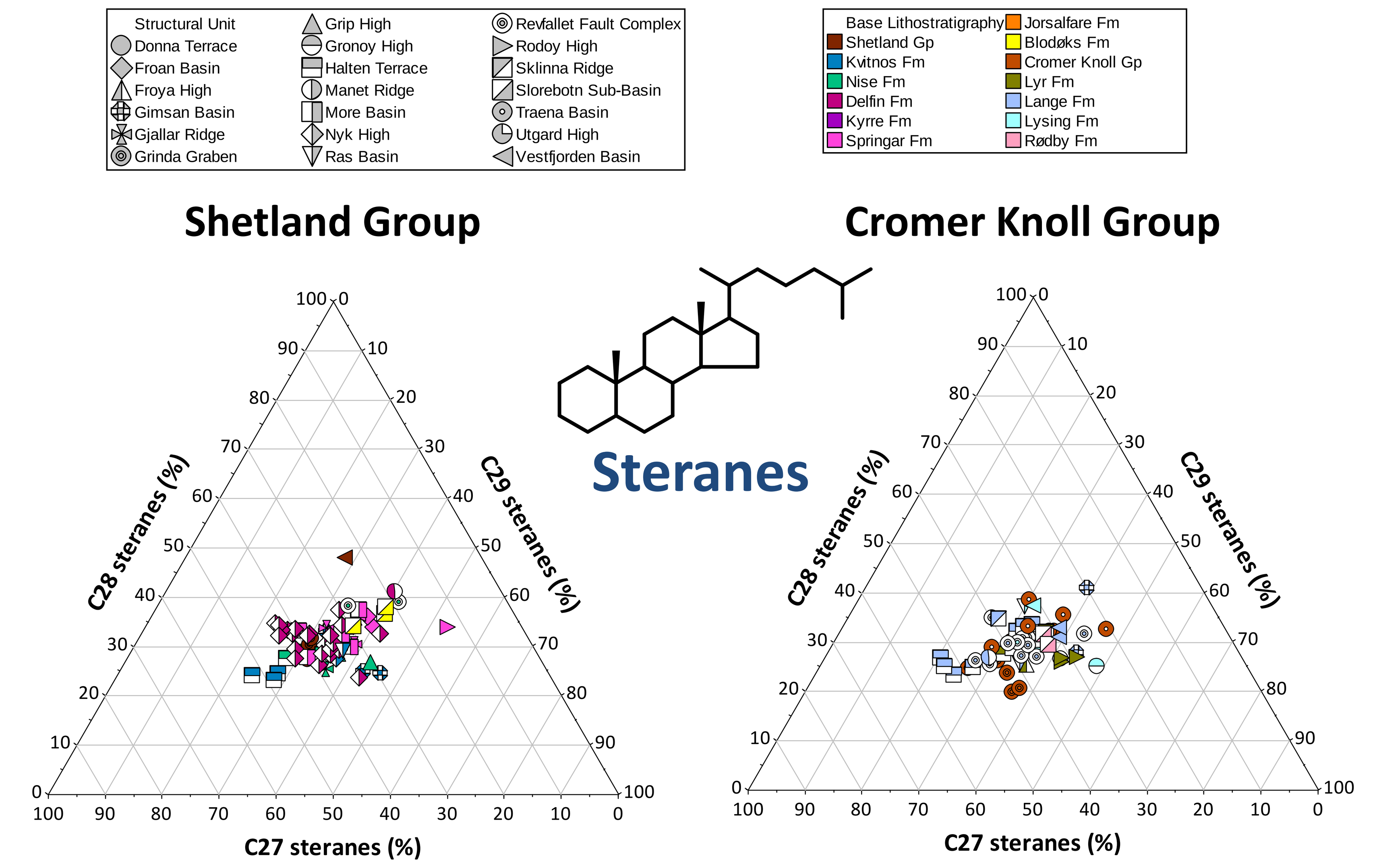

*Vitrinite Reflectance (VR) vs. depth below sea floor (m), with underlay of maturity window equivalences*



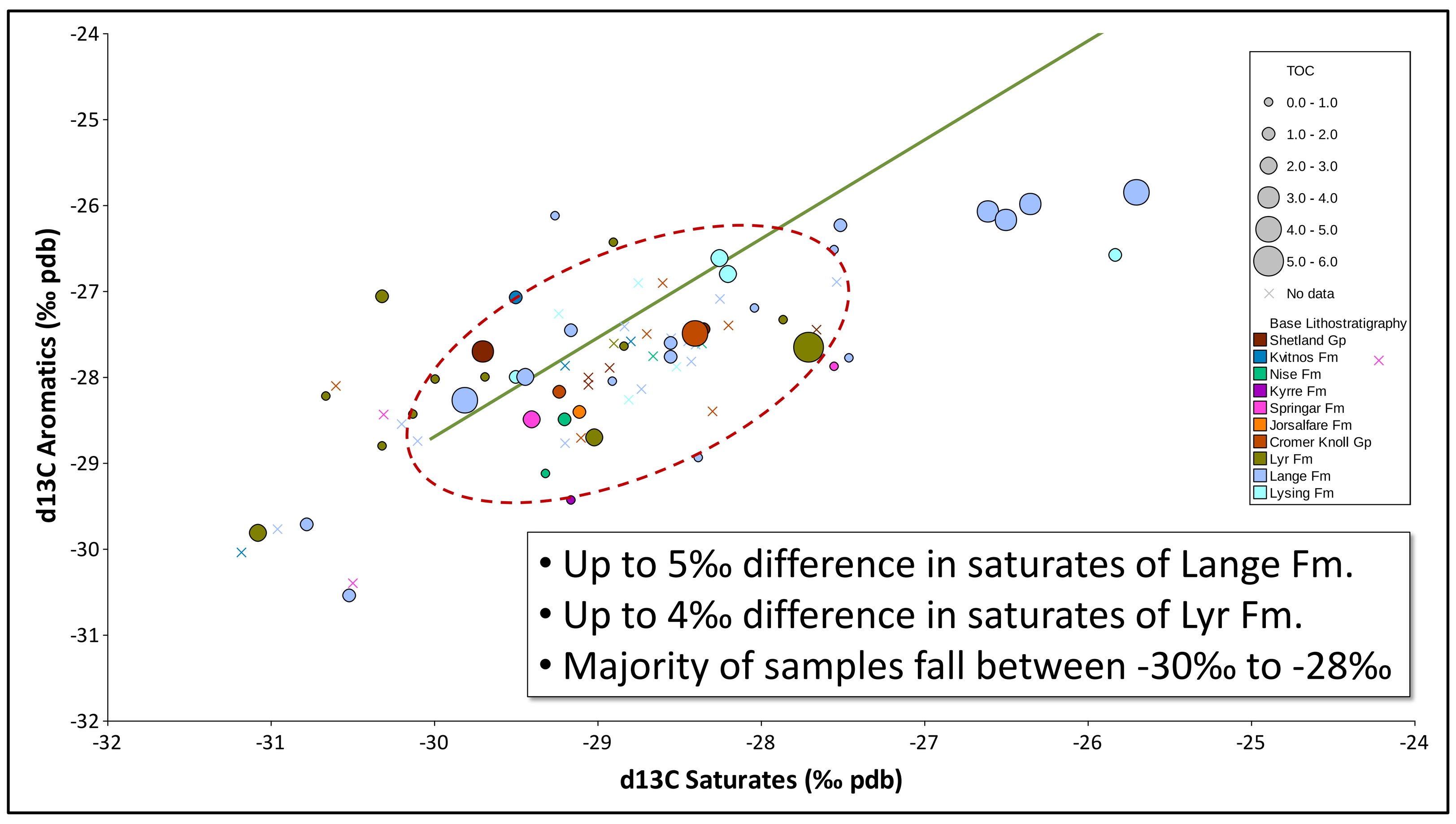

| Maceral type | Kerogen type | Hydrocarbon type |
|---|---|---|
| Liptinite | Type I/II | Oil-prone, intense fluorescence |
| Vitrinite | Type III | Gas-prone, not fluorescent (unless impregnated by liptinitic material) |
| Inertinite | Type IV | Negligible source rock potential |

*Maceral composition (% of liptinite, vitrinite and inertinite content) of all Cretaceous rocks)*

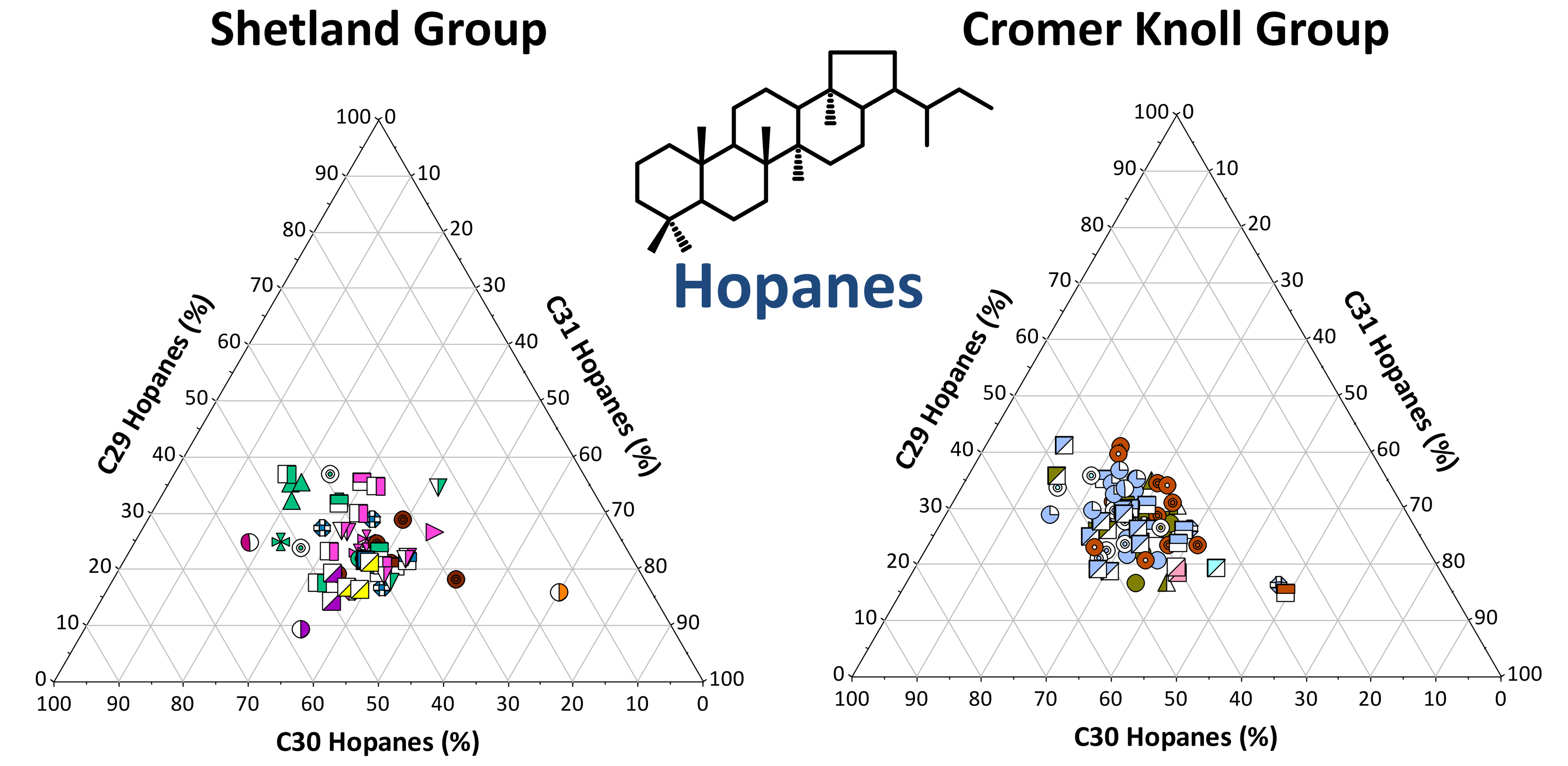
# Cretaceous Source Rock Geochemical Characteristics



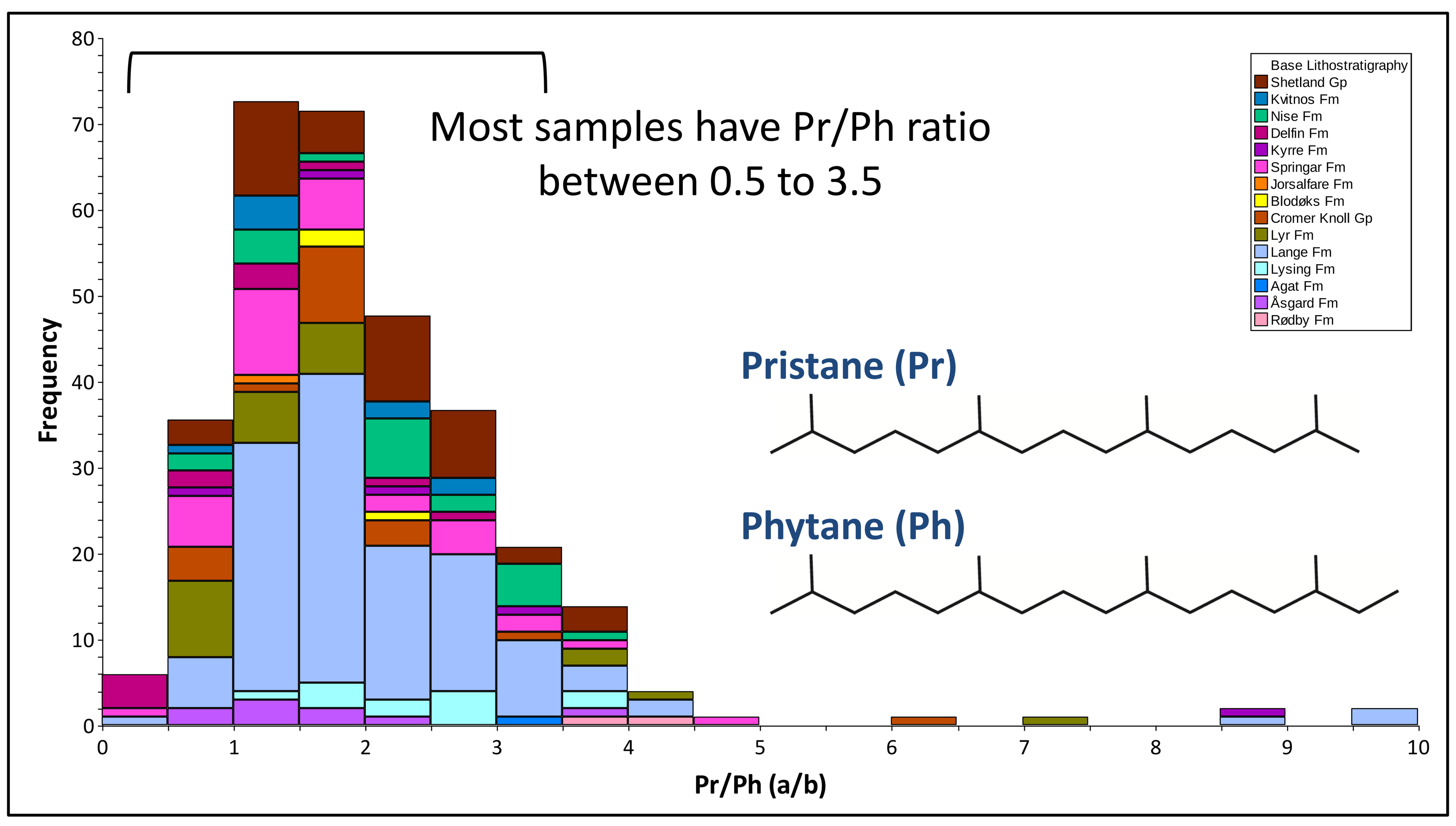

*Sterane carbon number distributions. In general, $C_{27}$ and $C_{28}$ steroids represent algal (i.e. "marine") inputs, and $C_{29}$ steroids characterise higher plants (terrigeneous inputs)*




*Stable carbon isotopes ($\delta^{13}C$) of the saturate and aromatic fractions of the Cretaceous rocks infer the likely depositional origin of the organic matter input*

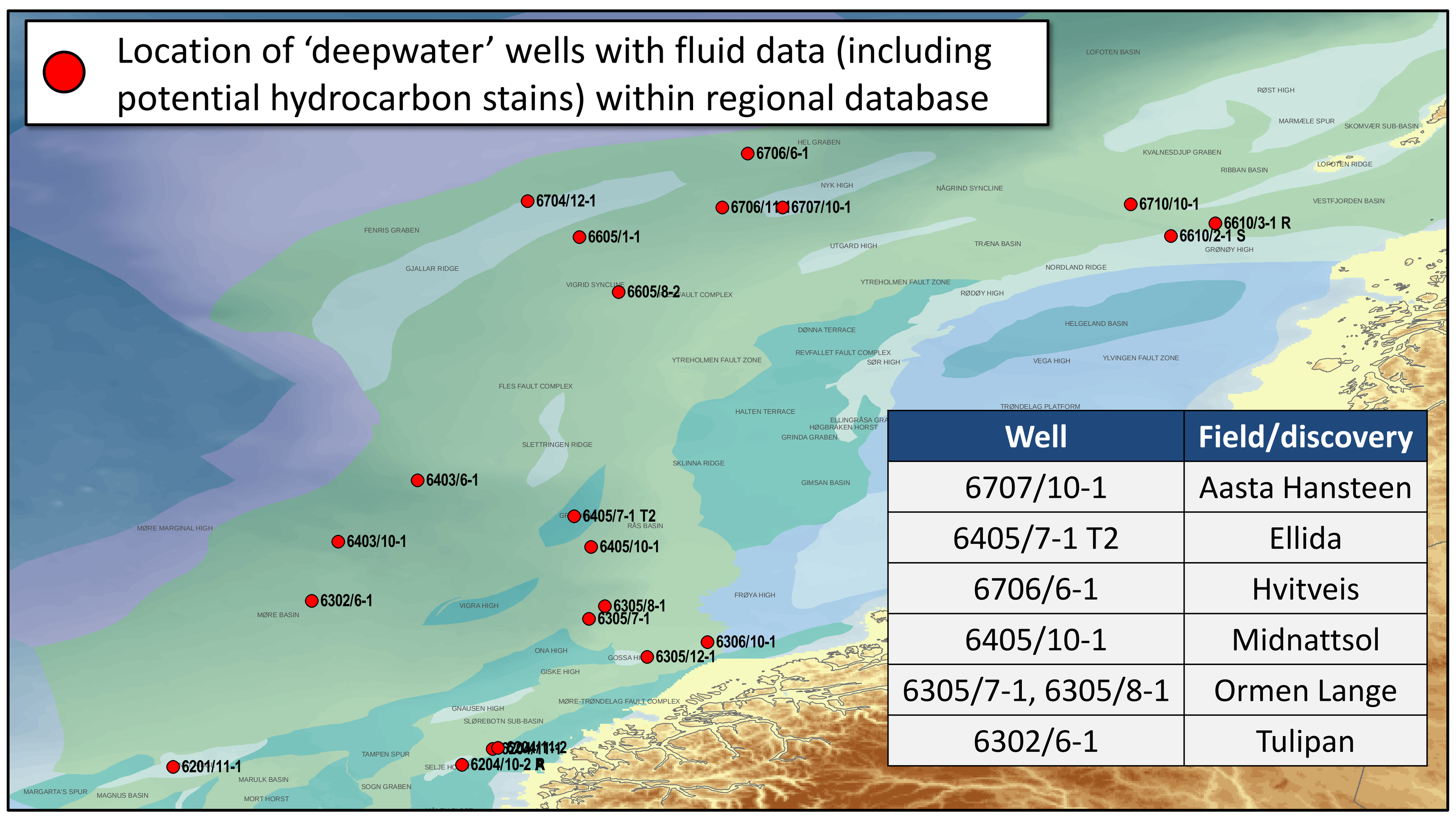



*Hopane carbon number distributions. Coals and terrestrially dominated source rocks are often characterised by elevated $C_{29}$ hopanes*




*Coals and terrestrially influenced shales typically display high values for Pr/Ph (typically greater than 3.0)*

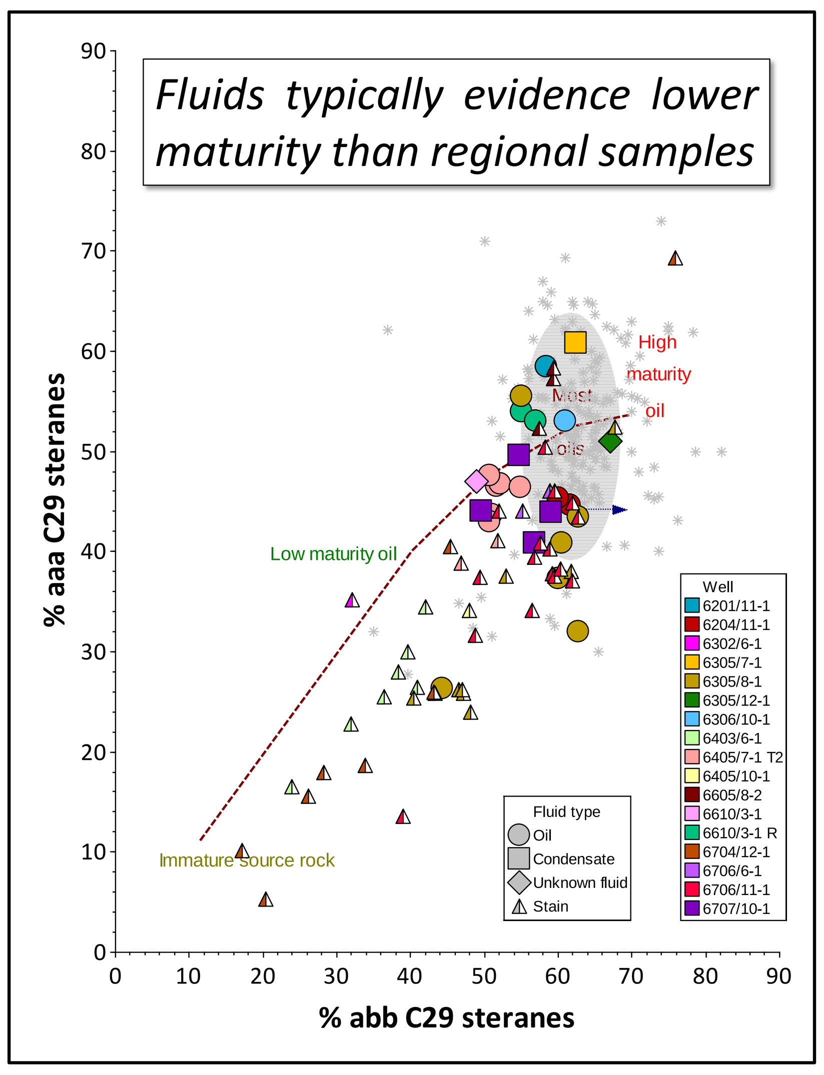
# Fluid Geochemistry

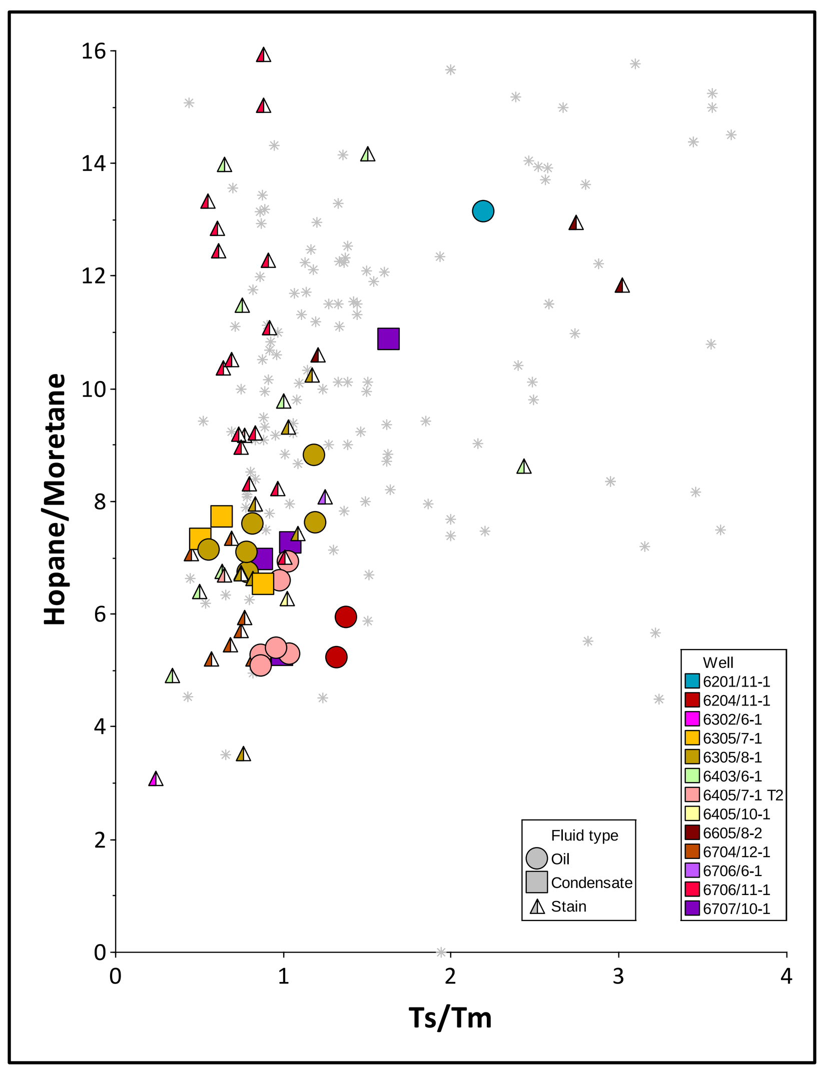



| Well | Field/discovery |
|---|---|
| 6707/10-1 | Aasta Hansteen |
| 6405/7-1 T2 | Ellida |
| 6706/6-1 | Hvitveis |
| 6405/10-1 | Midnattsol |
| 6305/7-1, 6305/8-1 | Ormen Lange |
| 6302/6-1 | Tulipan |

## Hydrocarbon maturity

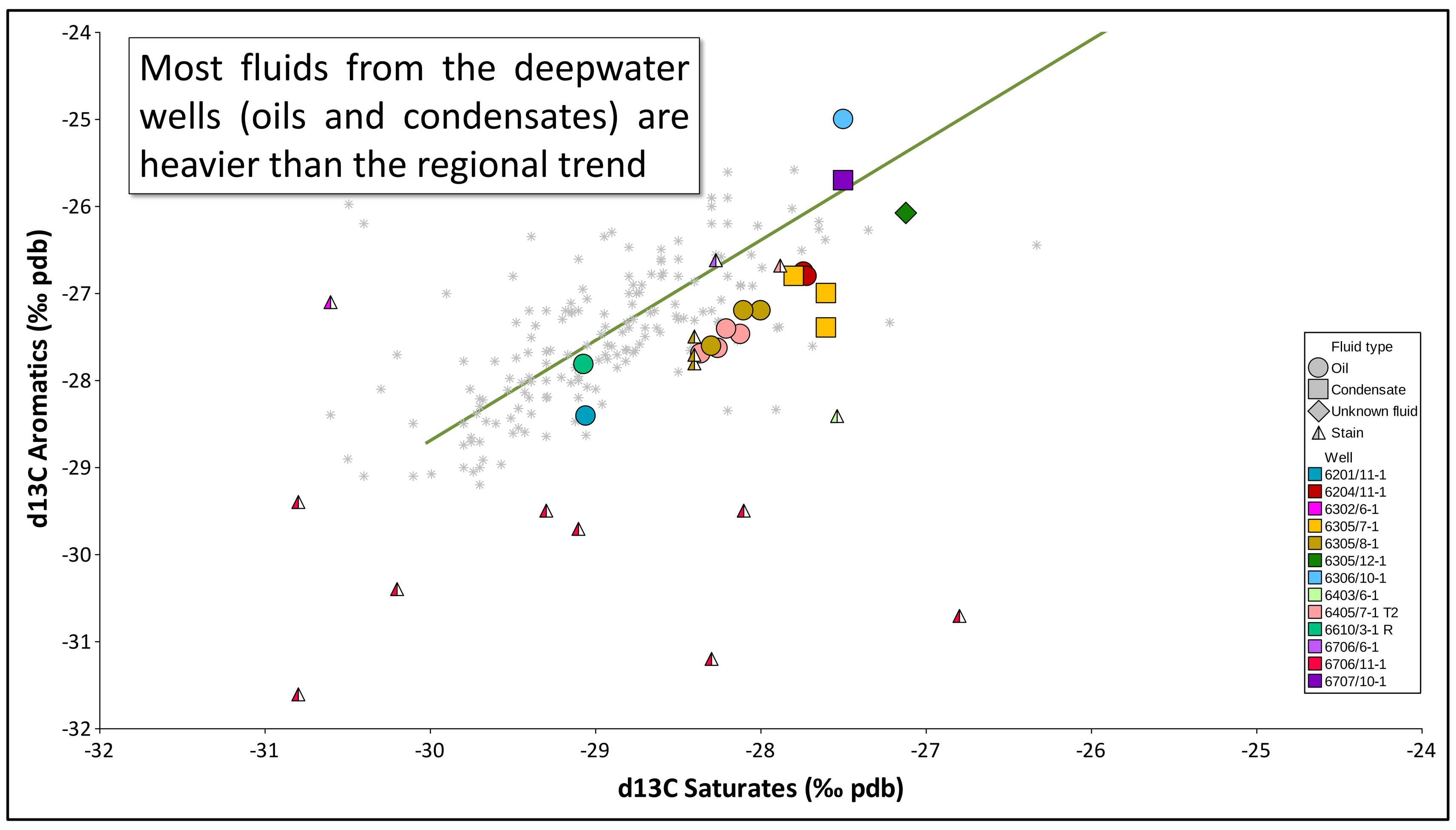
Grey stars represent all regional fluid samples



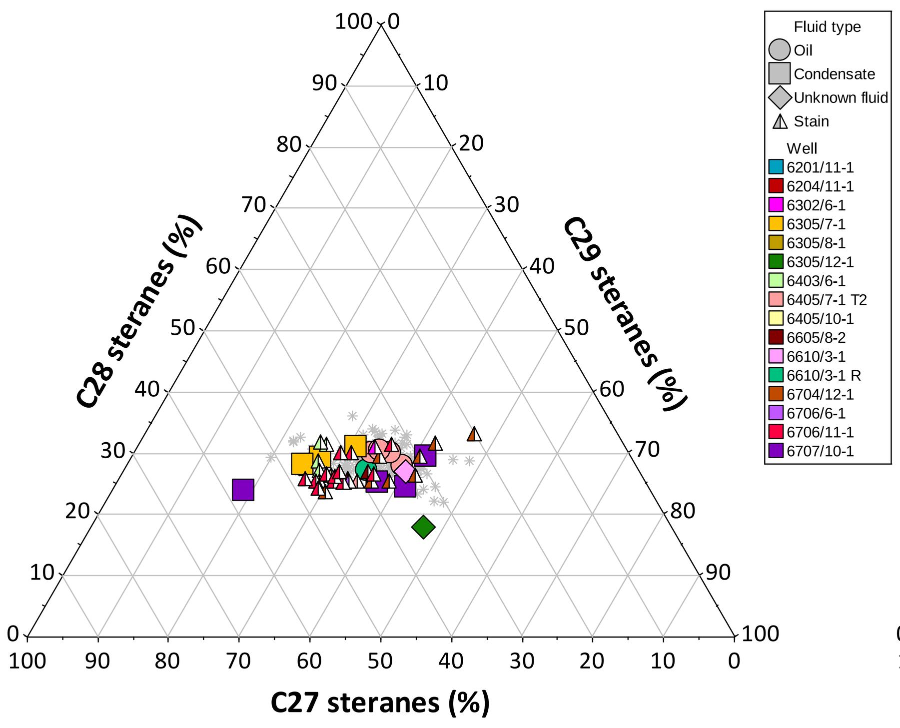

Sterane isomerisation (ratio of more-to-less thermally stable isomers, *ααα* $C_{29}$ *S/R* against $C_{29}$ *Iso/Regular* (*αββ/ααα*) & *H27Ts/H27Tm vs. H30αβ/H30βα maturity plots*

## Hydrocarbon correlations

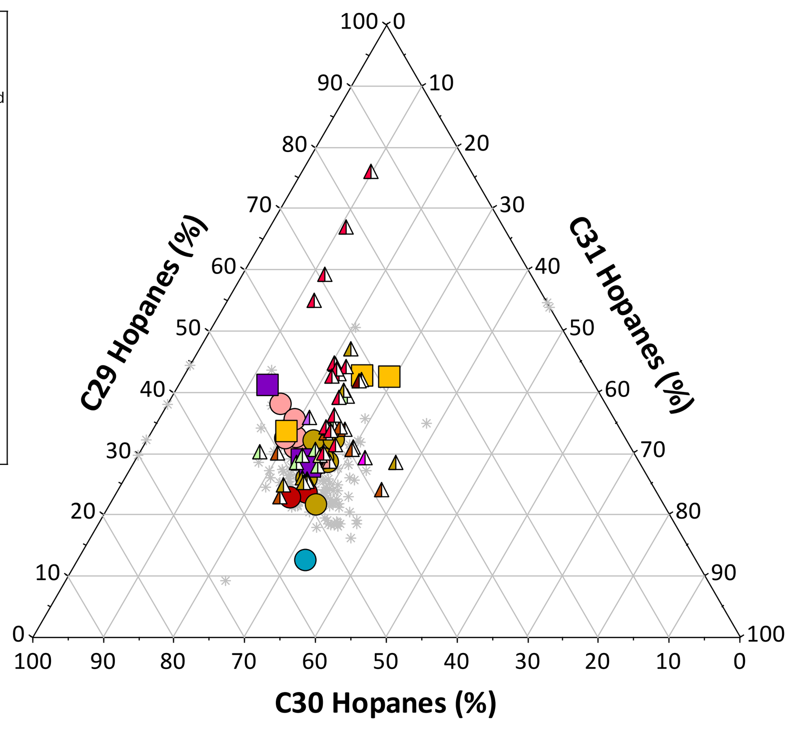



*Stable carbon isotopes ($\delta^{13}C$) of the saturate and aromatic hydrocarbons. Oils are isotopically lighter than the parent kerogen (source rock)*

### Steranes




### Hopanes

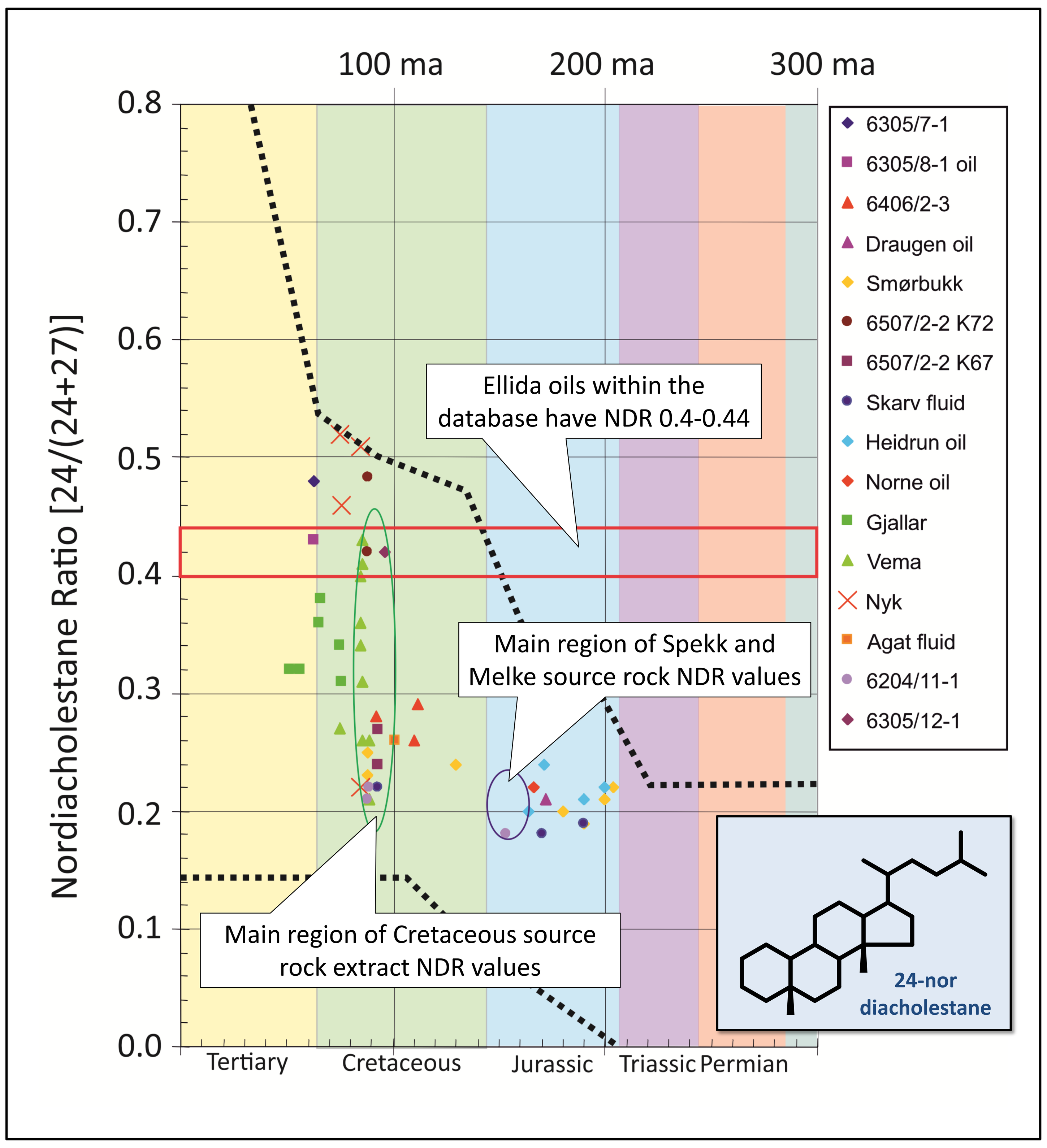



*Sterane and hopane carbon number distributions of the fluids infer the likely source rock facies from which the oils were generated*

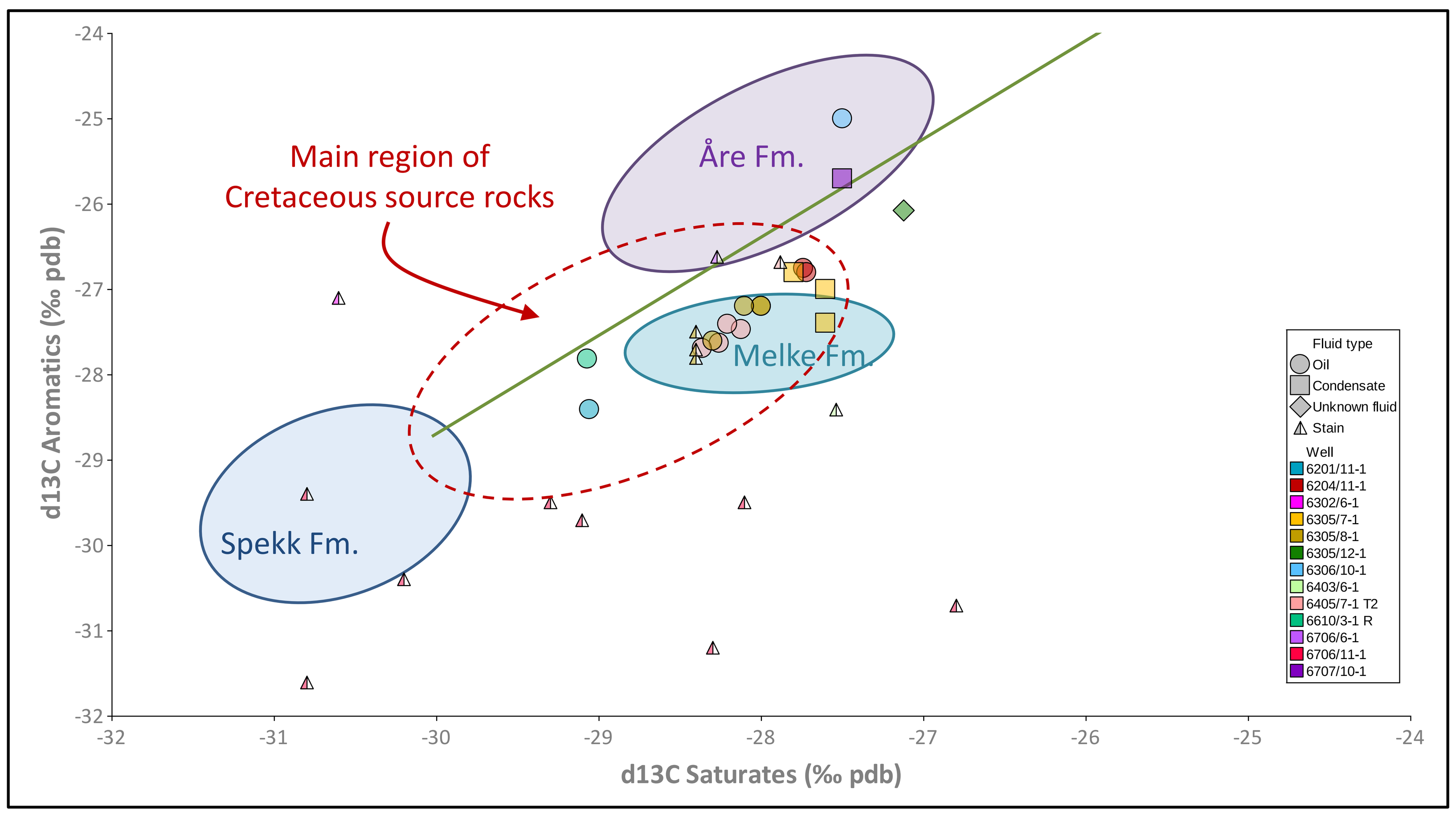
# Fluid and Source Rock Correlation

## 24-norcholestanes: age-diagnostic biomarkers

Compounds typically found in low concentrations (<1% of regular $C_{27}$-$C_{29}$ steranes), that show stepwise increase in concentration relative to 27-norcholestanes in sediments and petroleum from the Jurassic, Cretaceous and Oligocene-Miocene respectively (Rampen *et al.*, 2007). Their specific sources remain unknown but they are hypothesised to have derived from dinoflagellates or other algae.

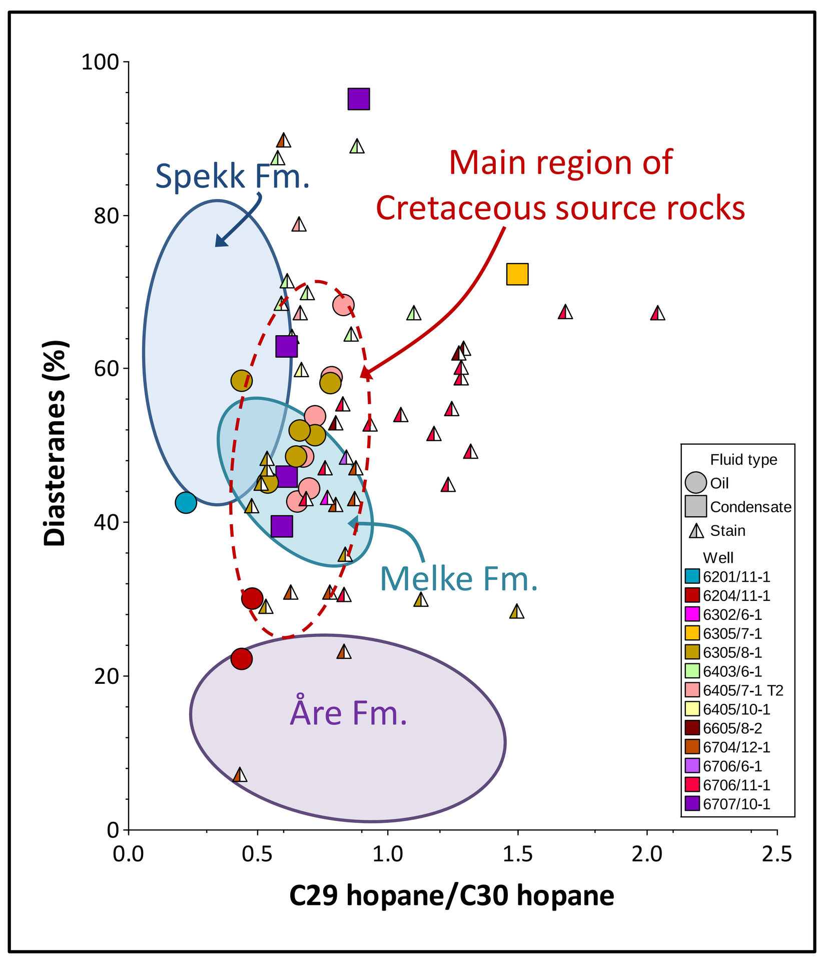



*Plot of Nordiacholestane ratio against geological time for reservoir fluid and extracts data, with areas of source-rock data highlighted. A region for Ellida oil samples from the database has been added (adapted from Øygard & Olsen, 2002).*

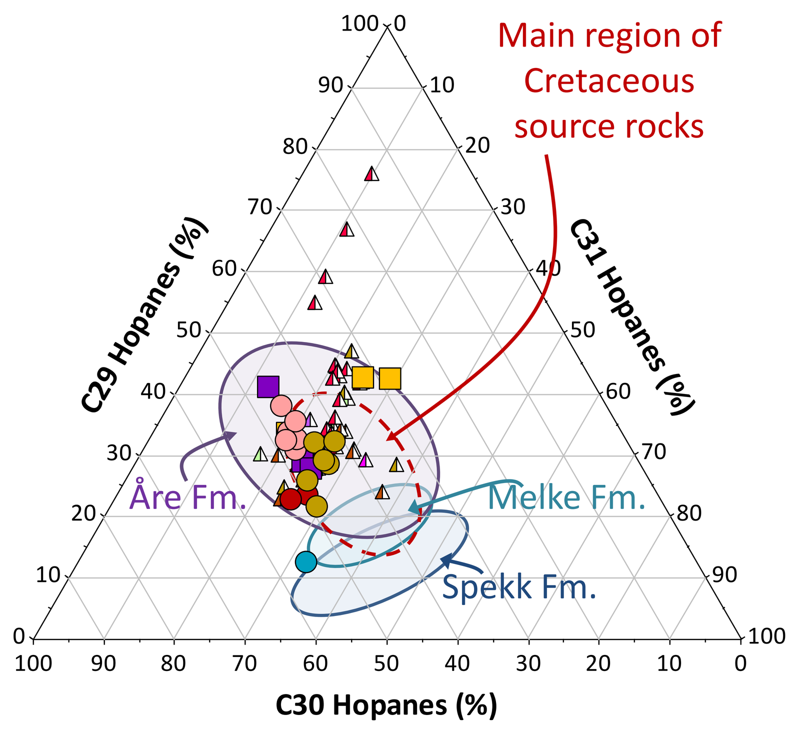



*Stable carbon isotopes ($\delta^{13}C$) of the hydrocarbons, with source rock underlays presenting the regions of highest sample density for each respective source interval*

The fluids in the deepwater wells generally correlate well with the main region of Cretaceous source rocks

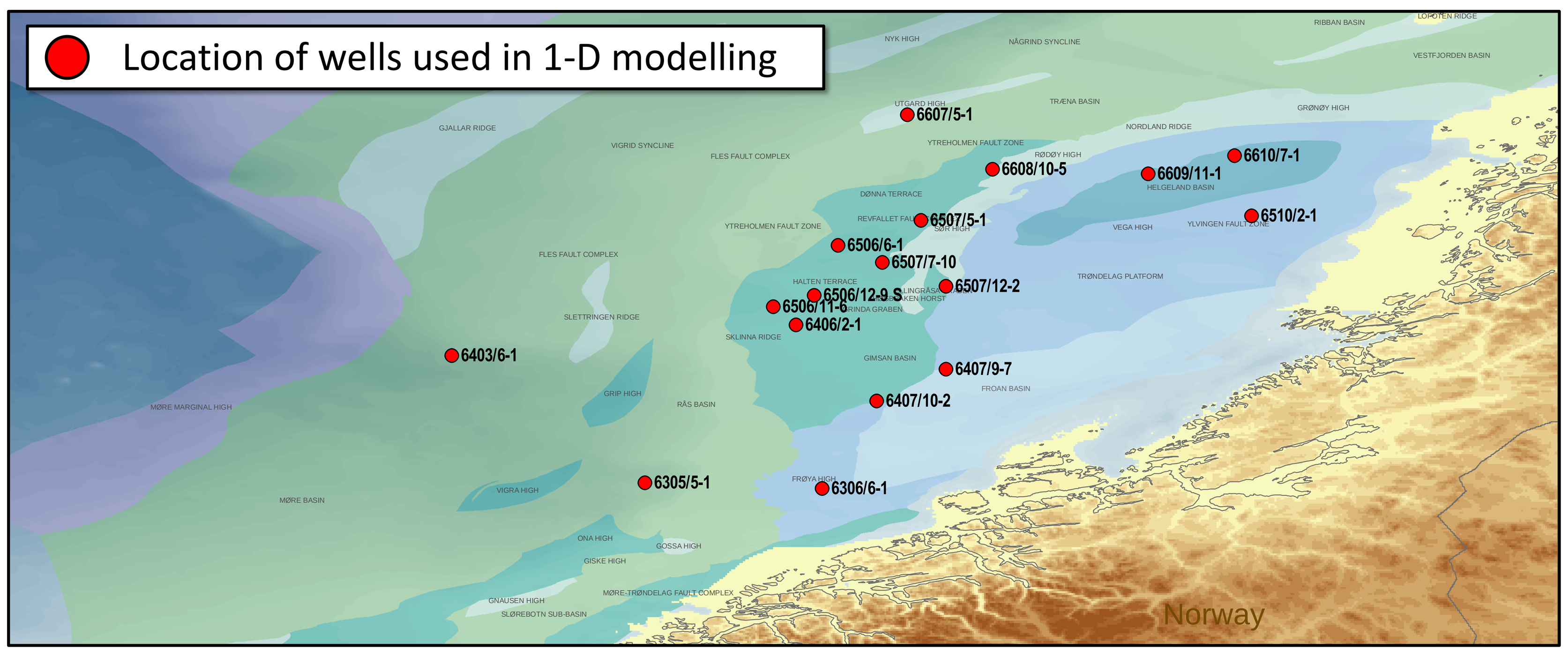


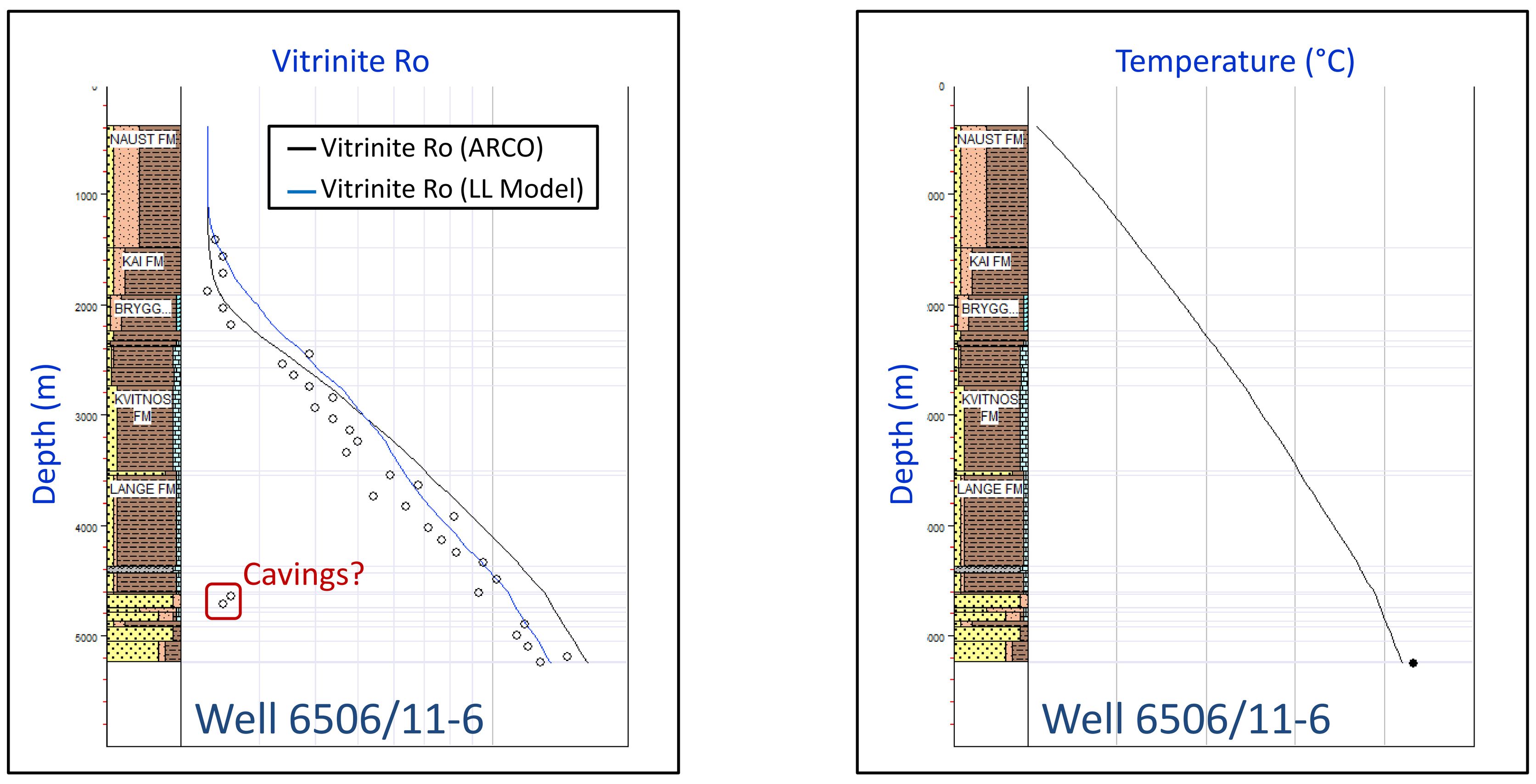

*Diasteranes vs. $C_{29}/C_{30}$ hopanes with source rock underlay regions*



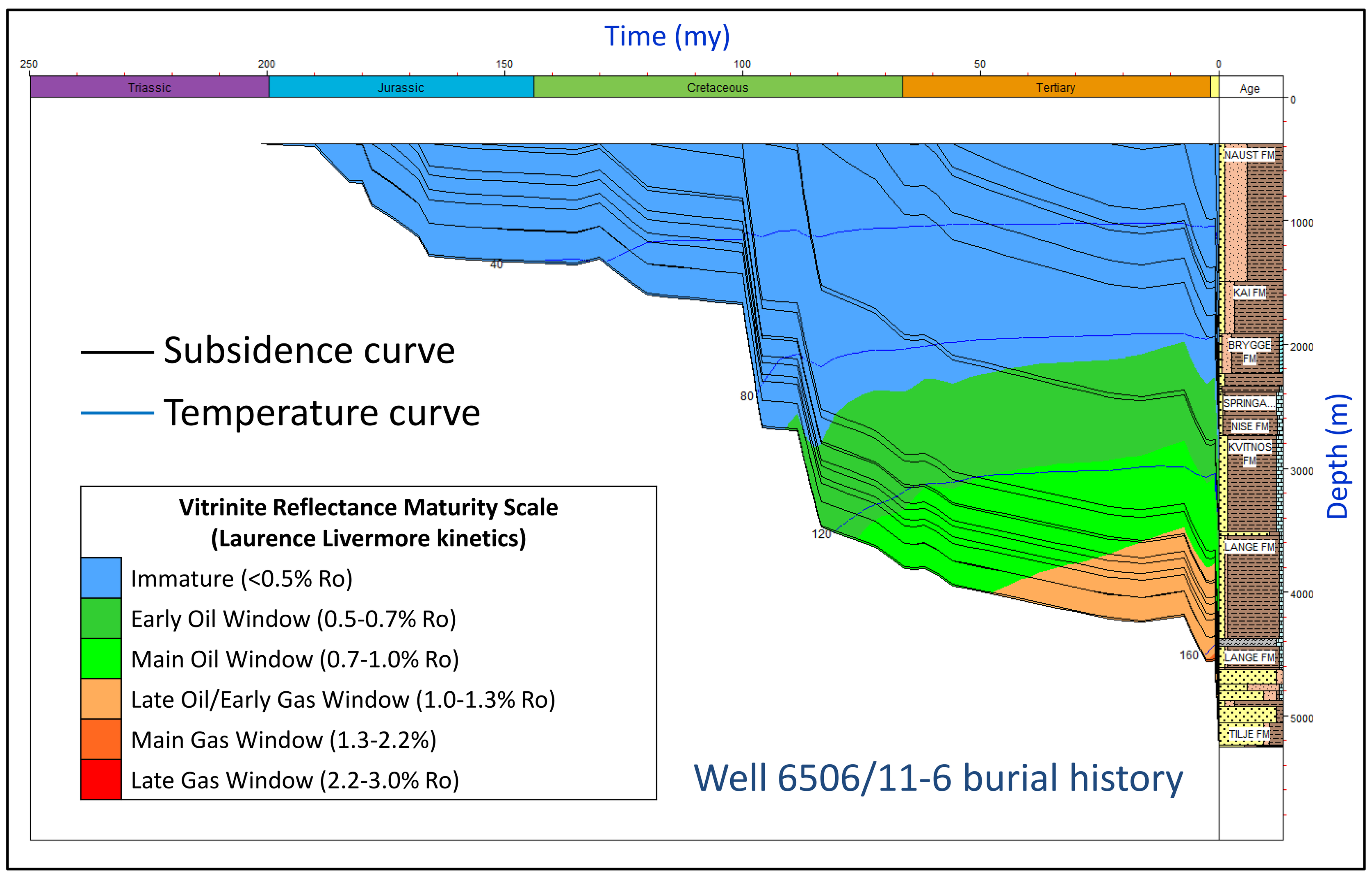

*Hopane ternary plot comparing fluids with source-rock compositions*

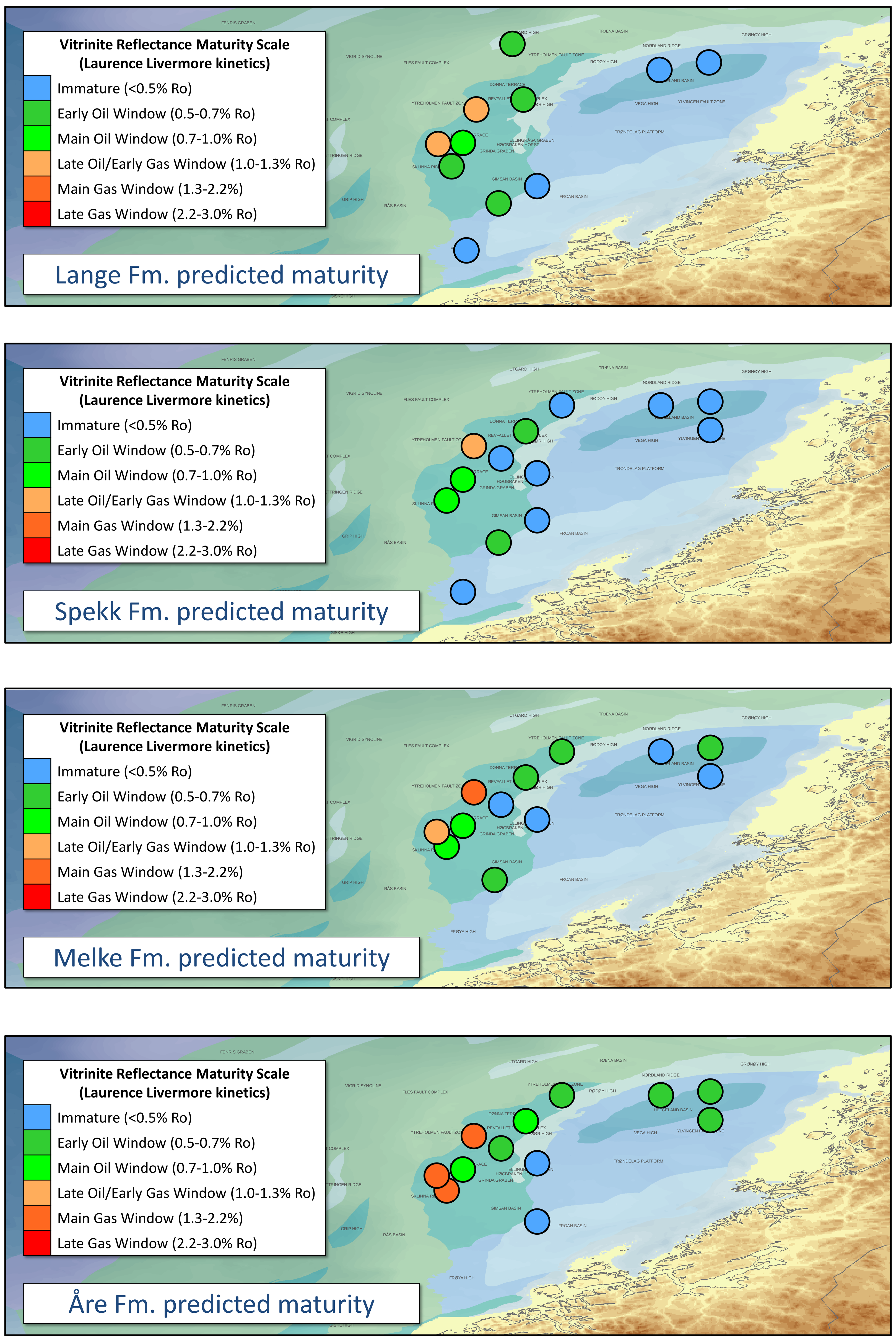
# 1-D Basin Modelling




*1-D model calibration for well 6506/11-6 to bottom hole temperature and vitrinite reflectance data*




*Predicted present-day source-rock maturity for the Lange, Melke, Spekk and Åre formations. It is important to note that wells are typically drilled on structural highs, and therefore the maturity of the source rocks is likely to be higher in the main kitchen areas*

# Conclusions

- The possibility of Cretaceous-sourced hydrocarbons is highlighted, particularly in the deep water areas to the west, where fluids are identified to be geochemically distinct compared with the bulk of regional fluid data
- Here, Jurassic source rocks are likely to be mainly overmature, whilst potential Cretaceous source rocks may lie within the main oil window
- Oils in this area show strong evidence of having a marine source rock other than the Spekk Fm., and limited age-diagnostic biomarker data indicate likely Cretaceous sourcing; in general, many of these deep-water hydrocarbons show a broad correlation with the Cretaceous source rock data presented
- The study shows that there is a strong potential for younger source intervals within this region that should not be discounted, and could prove to be key considerations for further frontier exploration in the deeper water areas.

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Rampen, S. W., *et al.* (2007). On the origin of 24-norcholestanes and their use as age-diagnostic biomarkers. *Geology* **35** (5): 419-422.


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