

PS Origin of the Mid-Cretaceous Heavy Oils from the Safaniya Sandstone Reservoir, (Wasia Formation), Saudi Arabia*

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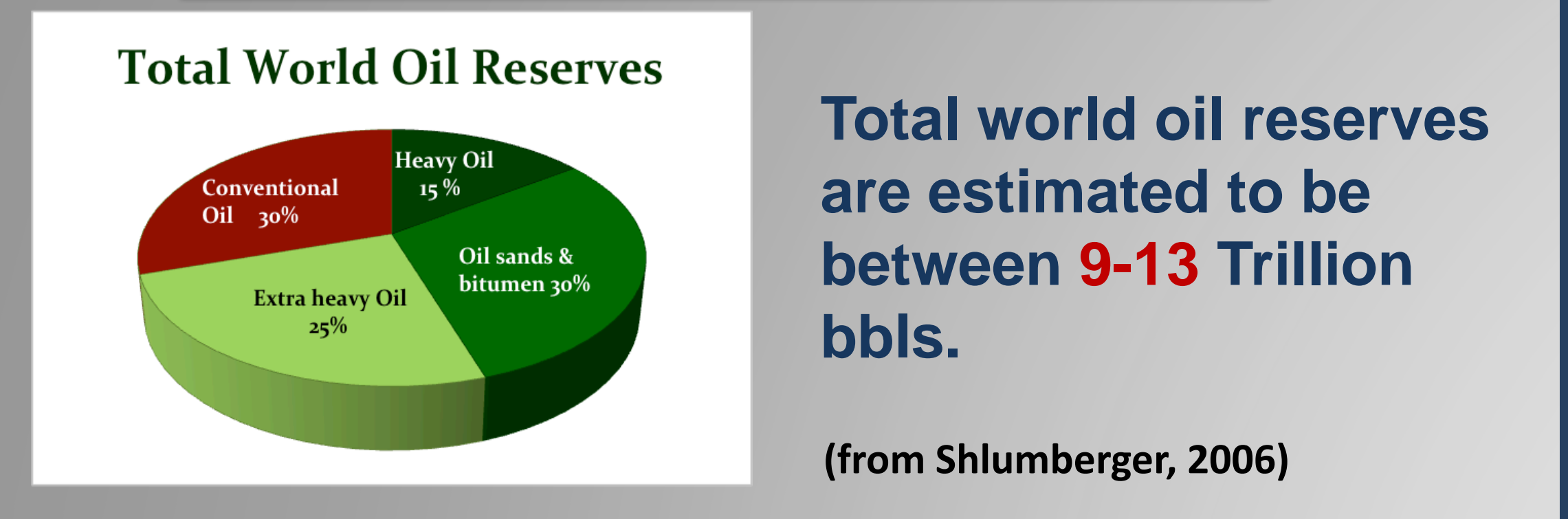
Abstract

Heavy oil and natural bitumen deposits dominate the world oil inventory. There are several mechanisms by which heavy oil and natural bitumen form. They could originate by an early expulsion of oil from low - maturity - organic rich carbonate source rocks (Type II - S), or by in-situ natural alteration processes of conventional oils during migration or in the reservoir. Understanding heavy oil and natural bitumen formation mechanisms, and the geological factors controlling their occurrences, is of importance for petroleum exploration and production. While biodegradation has been found to be the main mechanism producing most Albertan Oil Sands, Venezuelan Orinoco belt heavy oils and other biodegraded oil fields, the origin of the Saudi heavy oils is much less clear.

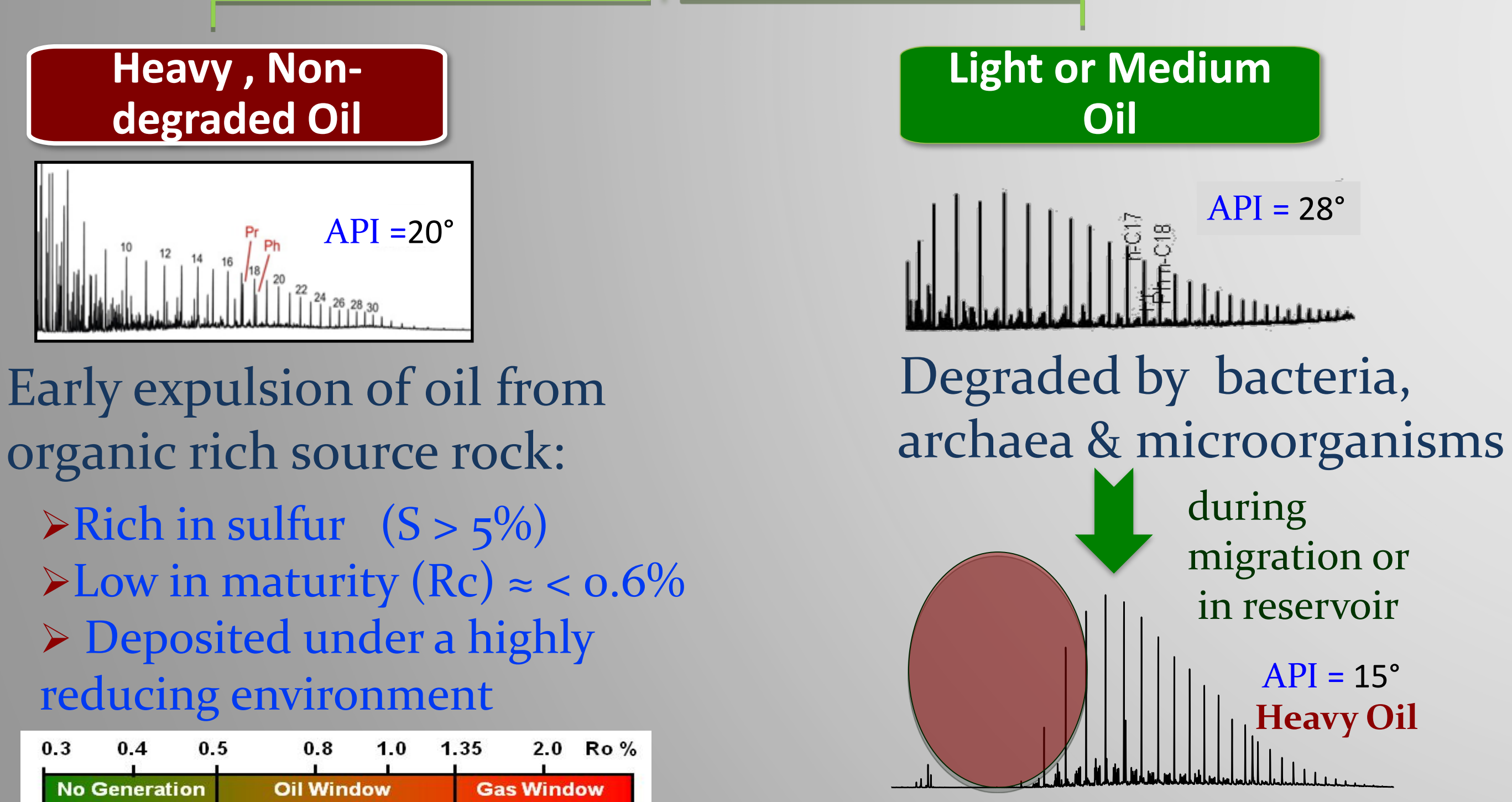
Geochemical characterization of heavy oils across the mid - Cretaceous Safaniya (SFNY) reservoir in Saudi Arabia was conducted using bulk and molecular composition analysis of these oils to gain insight into their origin. They were mostly generated at an early stage of maturation ($RC \approx < 0.6\%$) from a high sulfur (7.8% S), carbonate source rock (Type II - S) deposited under a highly reducing environment. Also, the data reveals a significant depletion in the low molecular weight (LMW) polycyclic aromatic hydrocarbons (PAH) concentrations in the petroleum near the oil water contact zone, possibly caused by water washing. However, the unrealistic volumes of water required to cause such a gradient in the LMW PAH concentrations in the SFNY reservoir necessitates a broader study on the hydrology of the Arabian basin. Measuring hydrogen and oxygen isotopes, and oil/water partition coefficients might help in understanding the interactions between static water and petroleum compound classes and allow a firm conclusion on whether water washing was the main cause for the compositional gradients observed in the LMW PAH of the studied oils.

1. Introduction

How much Heavy Oil?



Origin of Heavy Oils



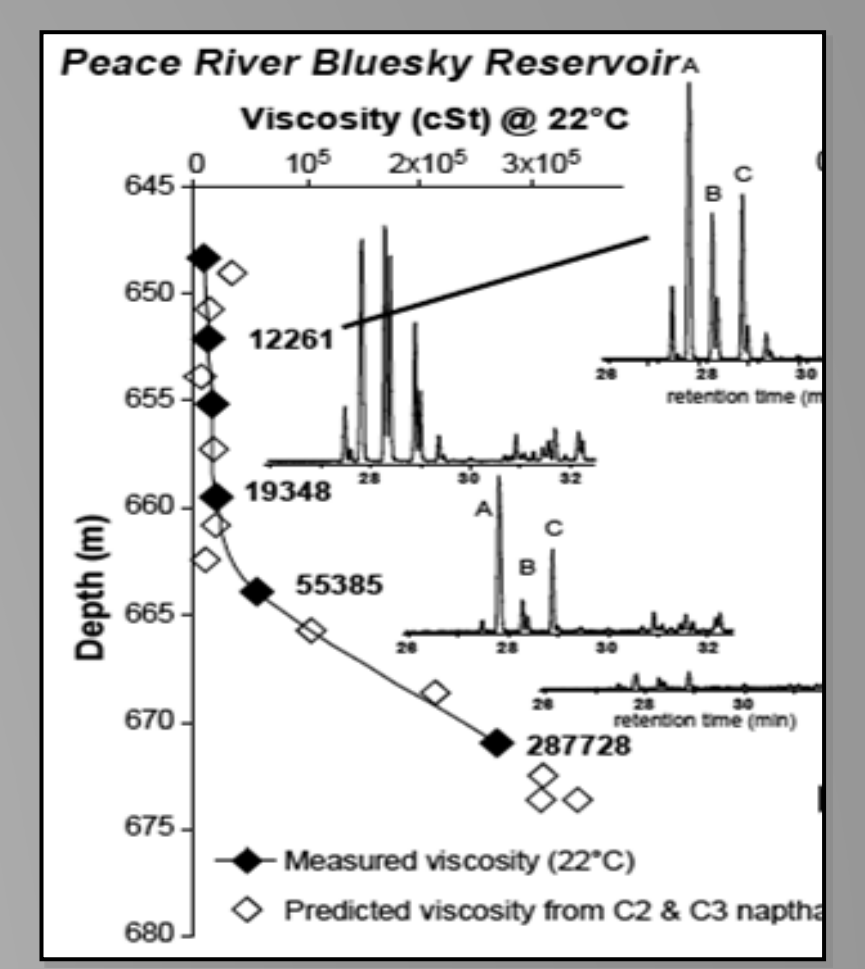
Why to know origin of Heavy Oils?

Production

1- Oil quality prediction (API, Viscosity) which is crucial for reservoir characterization, modeling, simulation, reserves calculation & well placement).

Exploration

- 1- Oil-oil & oil-source correlation studies.
- 2- Pre-drill prediction of oil-degraded prospects.



(Larter et al., 2008)

2. Motivation & Objective

Biodegradation Main mechanism producing most heavy oil fields (i.e., Alberta Oil Sands, Venezuelan Orinoco belt heavy oils)
Origin of the Saudi heavy oils is much less clear.

The objective of this study is to investigate the bulk and molecular composition of heavy oils from the mid-Cretaceous Safaniya (SFNY) sandstone reservoir from well-X in Saudi Arabia to help gain insight into the origin of these heavy oils.

3. Origin of the Saudi Heavy Oils (Case Study from Safaniya Reservoir)

IatroScan: Bulk Composition Screening

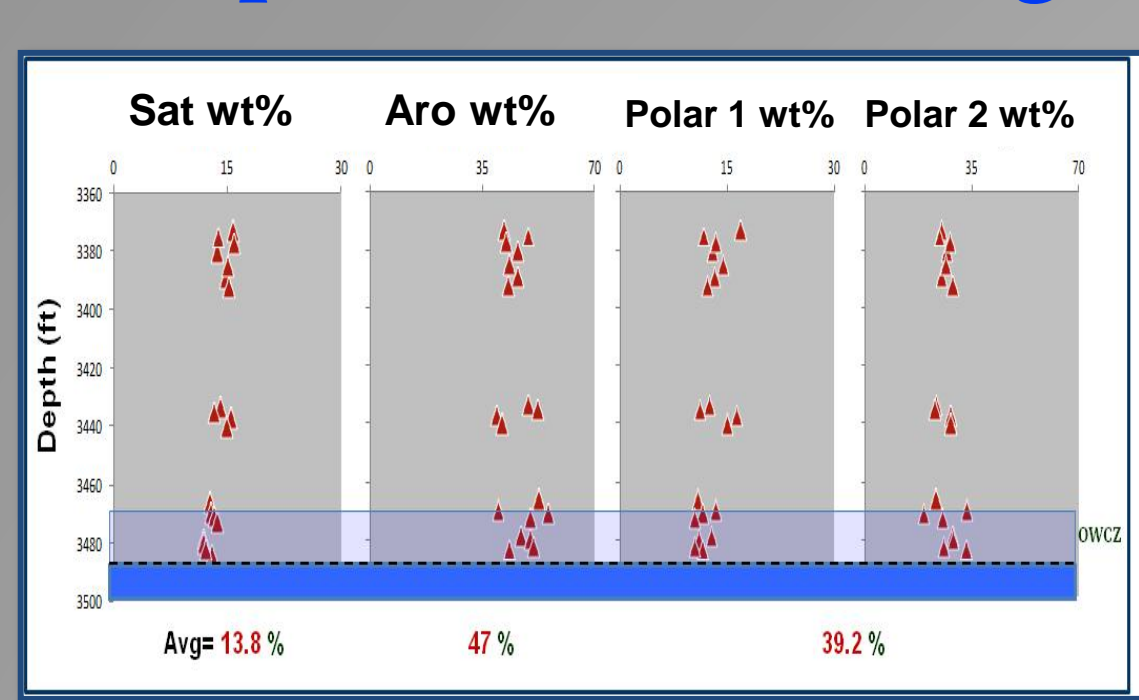


Figure 2. Bulk composition of the samples is homogeneous indicating common source rock

Physical Properties: Sulfur Content

Studied samples are rich in sulphur
%S = 7.7 Avg.

Biomarkers: Maturity Assessment of Oils

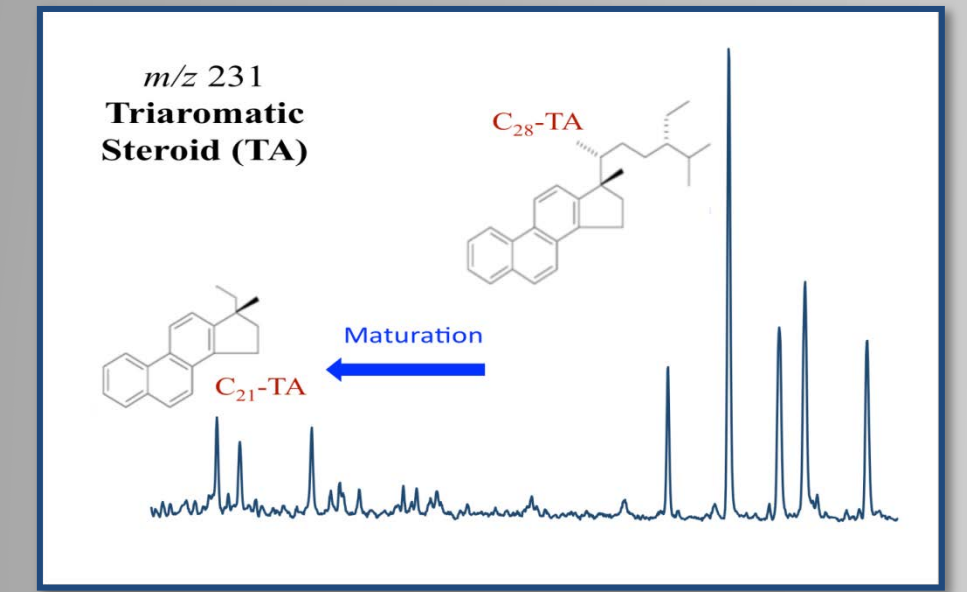


Figure 3. Studied samples are low in thermal maturity as reflected by the high concentrations of C_{28} triaromatic steroids compared to the C_{21} triaromatic steroids

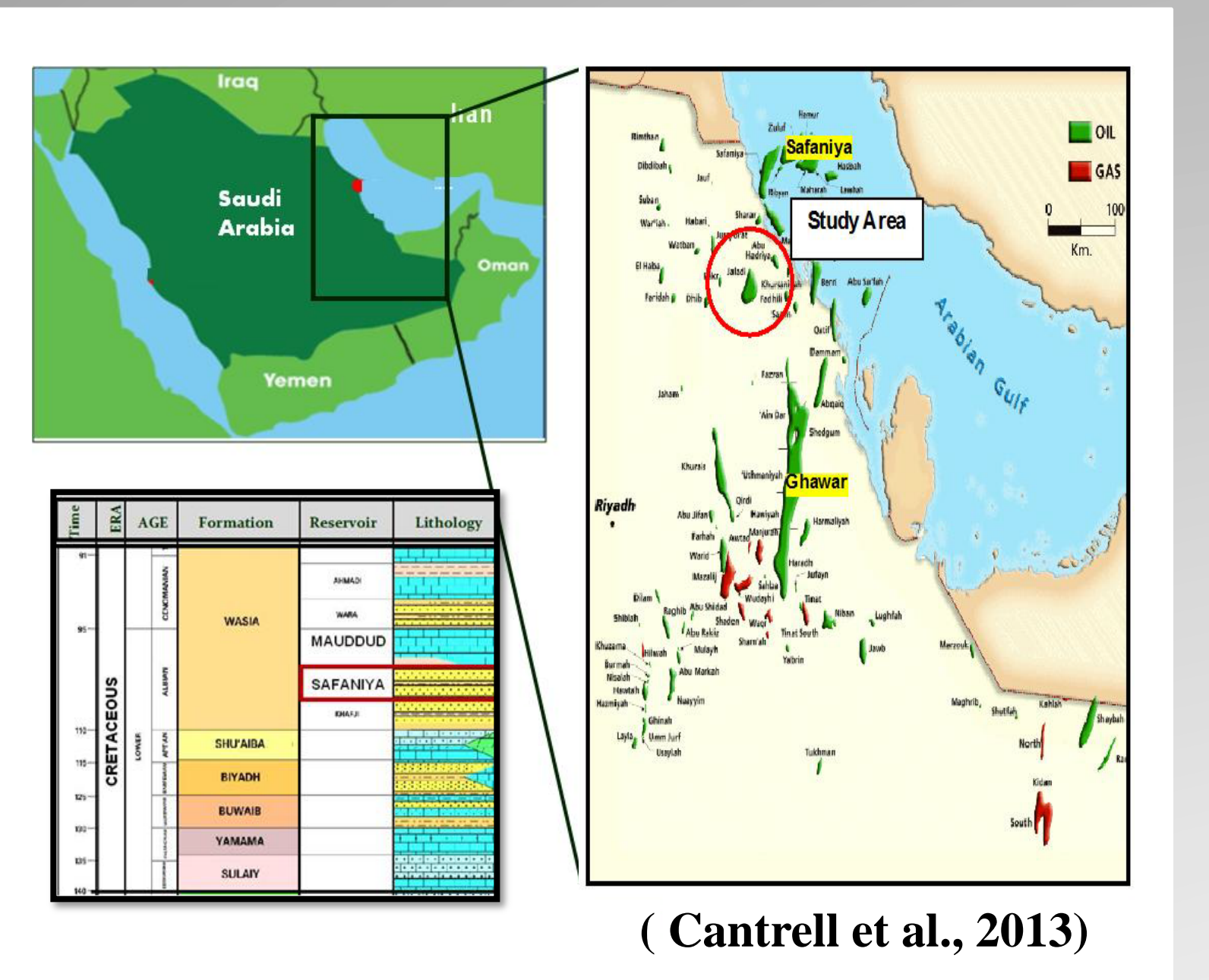


Figure 1. Map of the Middle East (top left) showing location of Saudi Arabia and a map on the right showing the well-X within the onshore oil and gas producing area along the west coast of the Arabian Gulf.

Biomarkers: Facies Assessment/ Depositional Environment

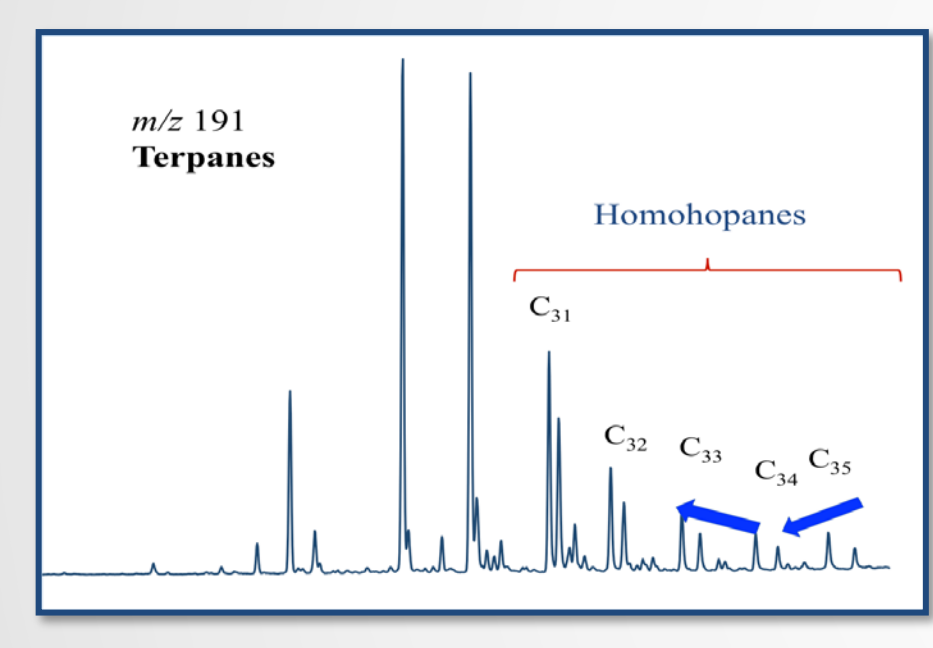


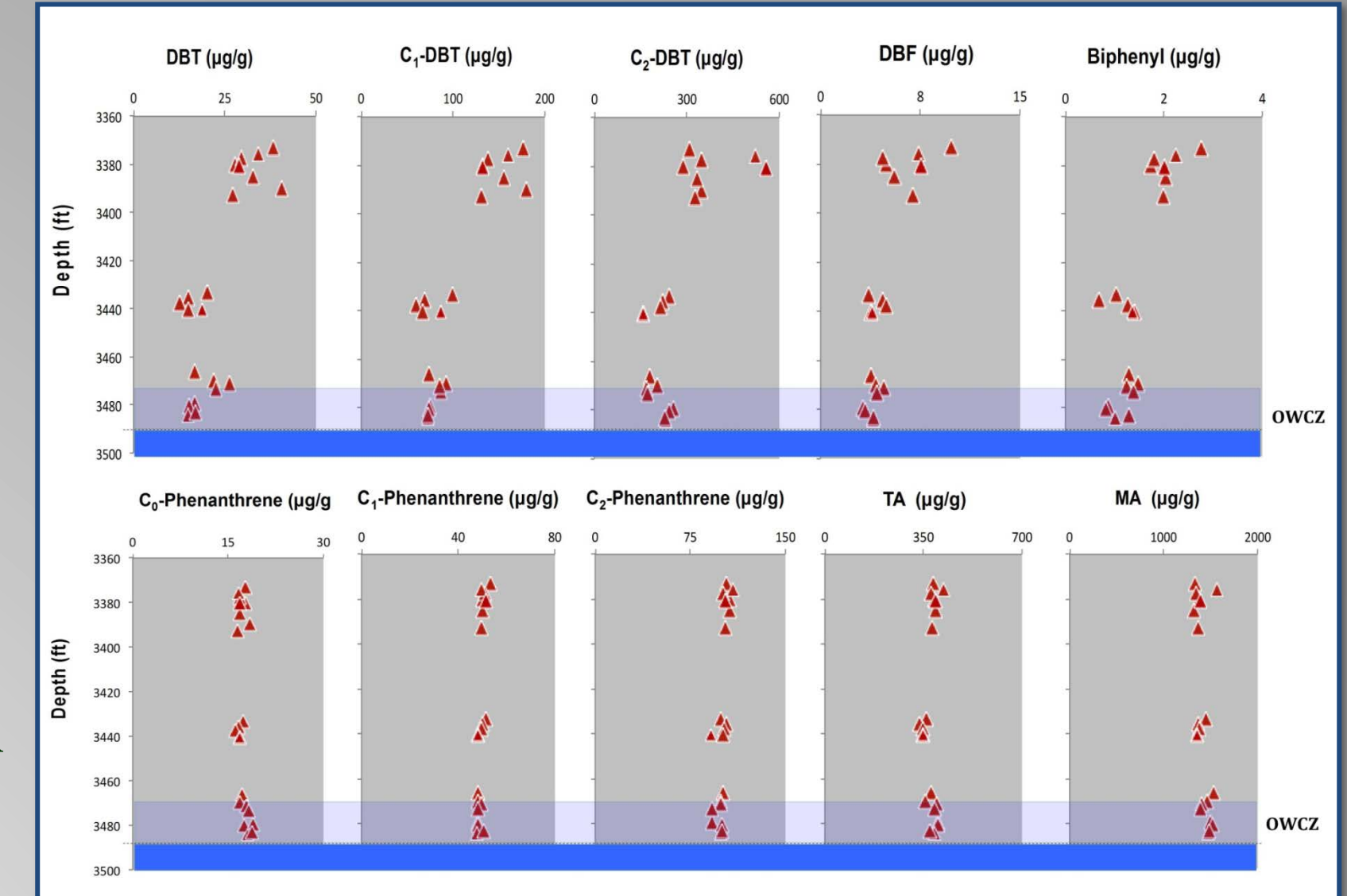
Figure 4. Elevated C_{29} Hopane (H) compared to C_{30} (H), and C_{35} homohopane (HH) compared to C_{34} HH in all samples indicates generation from carbonate source rocks deposited under highly reducing conditions

Conclusion: The origin of the mid-Cretaceous heavy oils from the SFNY reservoir are believed to be generated from source rock (SR) at an early stage of maturation ($RC \approx < 0.6\%$)

- Sulfur Rich SR
- Low Maturity SR
- Reducing Cond.

Assessment of Petroleum Column Compositional Gradient-Inducing Processes

Figure 5. The component absolute concentration ($\mu\text{g/g}$ or ppm) profiles of the different polycyclic aromatic hydrocarbon families (PAHs) for the studied oils. There is a clear depletion in the low molecular weight (LMW) aromatic hydrocarbons (C_{14} - range) with increasing reservoir depth towards the oil-water contact zone (OWCZ)



1- Petroleum Charging & Compartmentalization

Reservoir fluid heterogeneities may result from the oils at the top of the reservoir mixing with a different petroleum charge, or a later, relatively more mature charge from the same source rock, as reservoirs are normally charged with petroleum downward from the top.

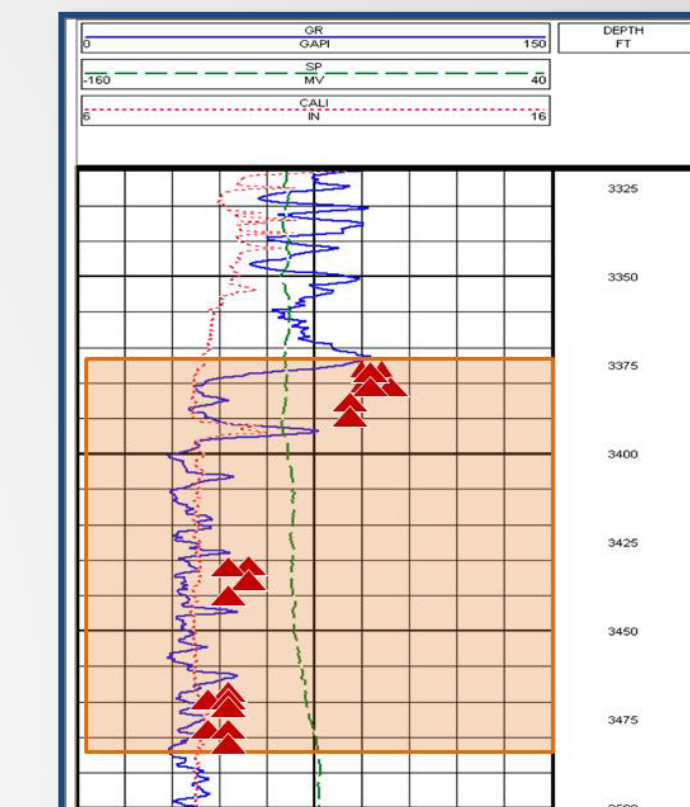


Figure 6. No pronounced compartments on Gamma ray log within the studied Safaniya Reservoir

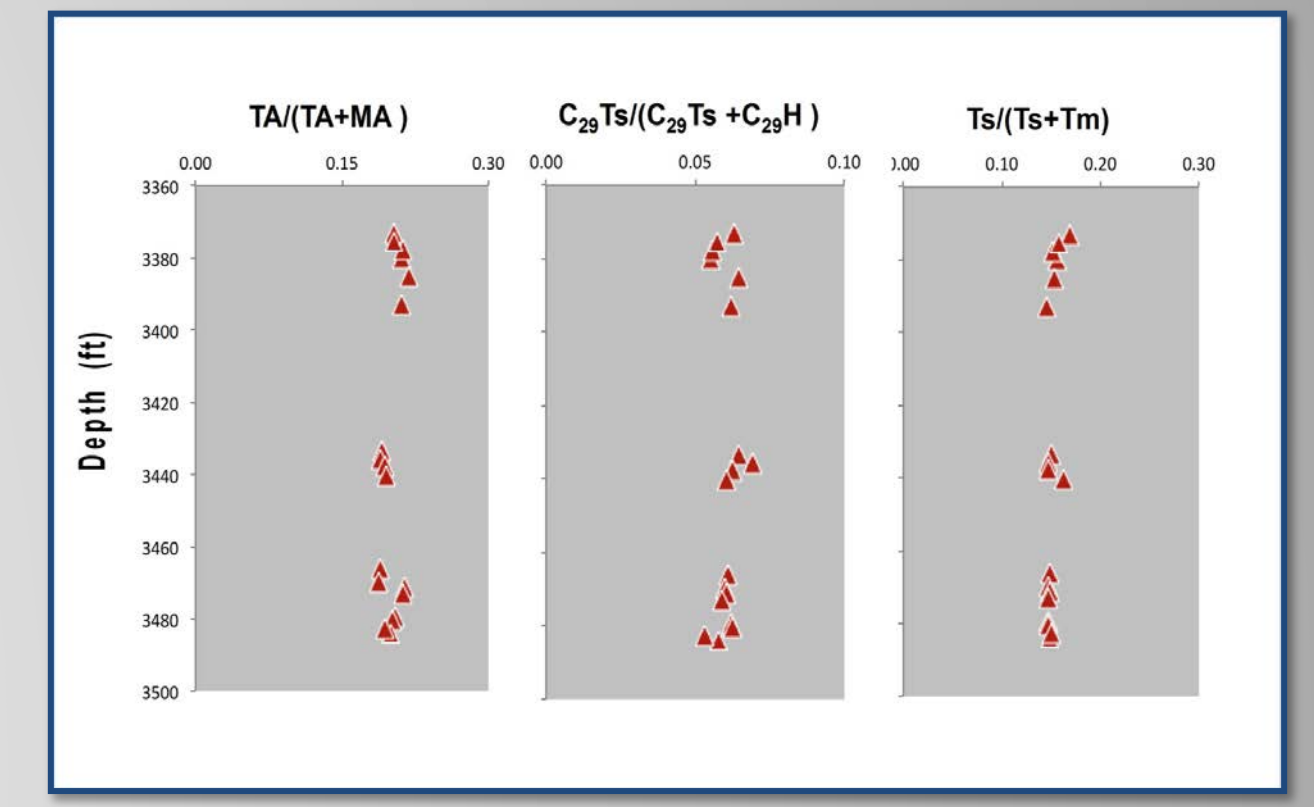


Figure 7. SFNY oils are generally well-mixed throughout the reservoir as reflected by the uniform source and maturity biomarker parameters

2- Biodegradation

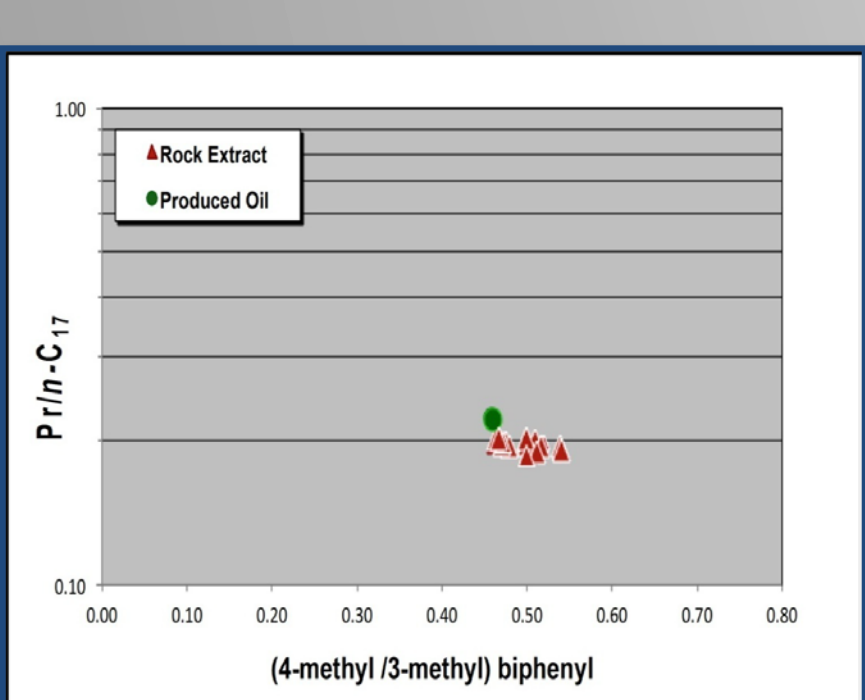


Figure 8. Pristane/n- C_{17} vs. 4-methyl biphenyl/3-methyl biphenyl ratios for the samples are used to infer the degradation pathways under anaerobic conditions (from Jones et al., 2008). No evidence of biodegradation under sulfate reducing conditions

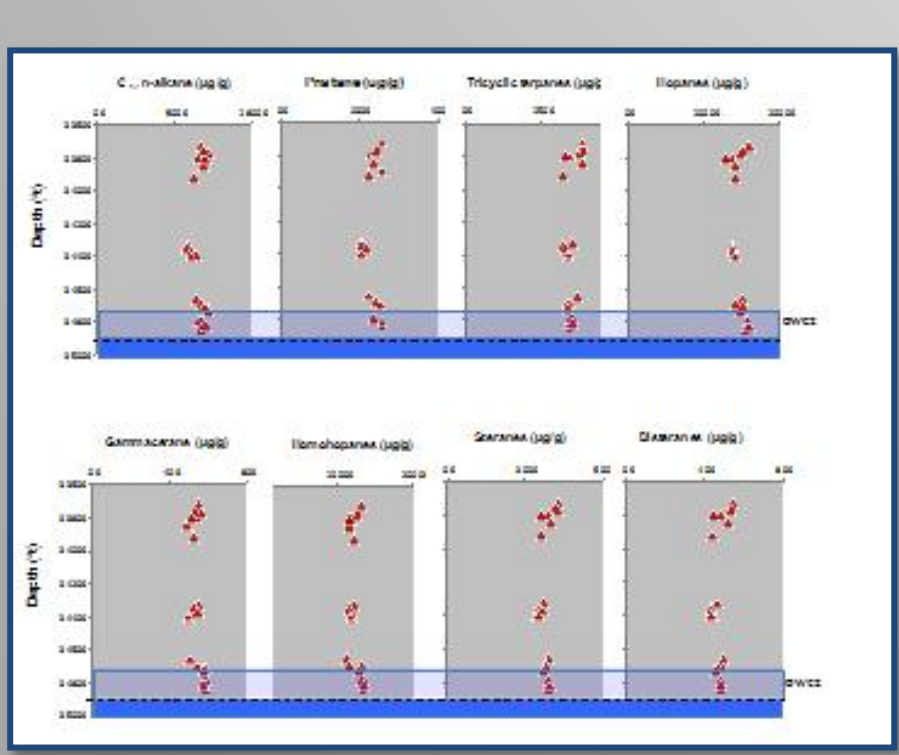
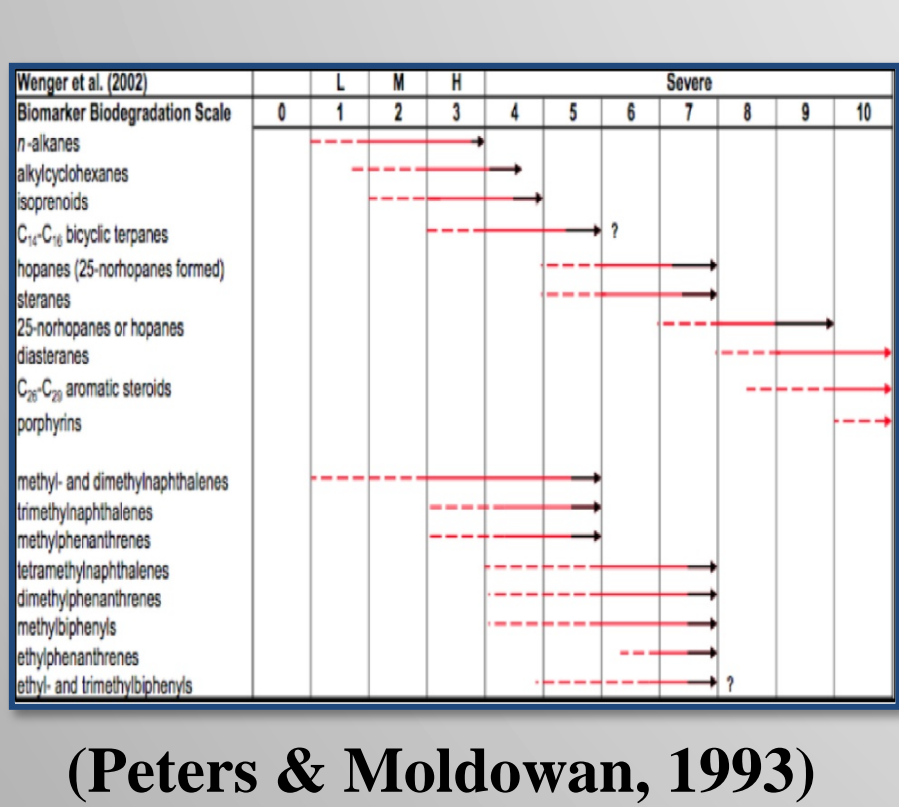


Figure 9. No sign of classical biodegradation as reflected by the constant concentration of the n-alkanes, isoprenoids and the more resistant saturated hydrocarbons

3- Water washing

Waterwashing could possibly be responsible for the observed compositional gradient as it leads to selective depletion of **DBT** followed by removal of **aromatic hydrocarbons** while hopanes and steranes remain unaffected.

- However,**
- > Actual solubility of hydrocarbons in water are generally very low.
 - > Calculation based on octanol-water partition coefficient of compounds indicate that large water volumes are needed to justify this gradient (i.e., 28,000 m^3 of water is needed to reduce DBT concentration from 41 to 13 $\mu\text{g/g}$.
 - > This condition is typically met in shallow reservoirs close to mountain ranges or other elevated terrain where ground water at height can drive water flow in the subsurface, which is not the case with the Arabian intra-shelf basin.

Conclusions:

- The depletion patterns in the LMW aromatic hydrocarbons (C_{15} -) in the studied petroleum towards the OWCZ, along with the absence of isomeric discrimination in the loss profiles of these compounds, suggest that these gradients might be associated with water washing.
- The unrealistic volumes of water lead to the conclusion that the main process resulting in the compositional heterogeneities observed in the LMW polycyclic aromatic hydrocarbons across the SFNY reservoir remains a mystery.

Octanol-water Partition Coefficient

$$C_0 = C_i ((PV_0)/(PV_0 + 1))^{V_w}$$

Measures how hydrophobic (water-hating) or hydrophilic (water-loving) a substance is.

4. Future Direction

A broader study on the hydrology of the Arabian basin involving **hydrogen and oxygen isotopes**, and **oil/water partition coefficient measurement** under subsurface conditions is needed to better understand interactions between static water and different compound classes of petroleum. Hence, to draw a firm conclusion on whether water washing was the main cause for the compositional gradients observed in the LMW aromatic hydrocarbons of the studied SFNY oils.

5. Acknowledgments