Predicting the Quality of Petroleums Generated by Lower Paleozoic Source Rocks, MENA Region*

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Abstract

The composition of reservoired petroleum is controlled by the physical, chemical and biological processes that have acted on the source-carrier-reservoir system over geological time. Because phase behaviour in carrier systems has been identified as the major control of gas-oil ratio in many of the World's petroleum provinces, we established the PhaseKinetics modelling protocol that can be applied in advance of drilling as part of a risk reduction strategy. It begins with the organofacies concept, which states that kerogen abundance and composition are relatable to depositional settings. Our facies, five in all, are based on potential petroleum type and are determined by open system pyrolysis of kerogens or asphaltenes. Having used this as a secondary screening tool, coming after the usual Rock-Eval primary screening procedure, bulk kinetic parameters are then calculated to determine generation characteristics. Petroleum compositions are then assigned to the activation energy distributions using MSSV pyrolysis, a method whose utility has been proven by regional calibrations, including mass balance modelling studies in Canada and Mexico. The pyrolysis data is essentially ready as it is for direct import into PVT models, except for gas composition, which has to be tuned in order to take account of the different radical reactions occurring within gas-forming intermediates in nature versus in the laboratory.

Here we contrast the lateral variability in PhaseKinetics behaviour (GOR, Psat) of Silurian source rocks in Jordan and Libya, with reference to the occurrence of photic zone euxinia during source-rock deposition, and its manifestation in GOR values. A contrast is drawn with the Devonian, and illustrated using a 2-D petroleum system model for the Ghadames Basin., as well as the predicted carbon isotopic composition of gases from primary and secondary cracking reactions. The late gas potential of the Silurian is high, because of a high contribution of dry gas precursors inherited from the unusual biota associated with photic zone euxinia, as well as the presence of neoformed entities that are the last vestiges of live carbon at high thermal maturity (Rm > 2%). The formation of dead carbon from live carbon in some Silurian source rocks and its ramifications for petroleum yield calculations are also discussed.

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- eni for sponsoring "Gas-Oil Correlation in Complex Areas" (Roberto Galimberti)
- Sebastian Lüning for donating his Silurian and Cretaceous samples from North Africa and the Middle East to us
- GEOS 4 for providing the PhaseKinetics parameters from ShalePayFinder MENA-Silurian

Kinetic Modelling

Goal:

Determine timing of petroleum generation in sedimentary basins

Kinetics:

Rates and mechanisms of chemical reactions

Assumptions:

Petroleum generation results from large number of reactions in which

K → K' + petroleum **FIRST ORDER**

Primary and secondary reactions

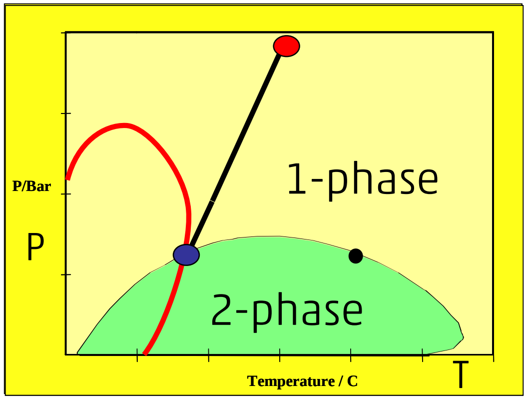
Originally developed for well defined/simple reactions

Engineered for geological systems (Jüntgen & van Heek; Tissot)

Oil versus Gas Occurrence

- Kerogen composition
- Rates of degradation
- Petroleum components in time and space
- GOR

- Expelled and retained petroleum
- Response to P-T change
- Number of phases
- Volumes and properties



Today's Talk

- North African source rocks – conventionals
  * PhaseKinetics
  * Isotopes
- Outlook for unconventionals
  * retained petroleum in shales
  * compositions

Today's Talk

- North African source rocks – conventionals

  * PhaseKinetics

  * Isotopes

- Outlook for unconventionals

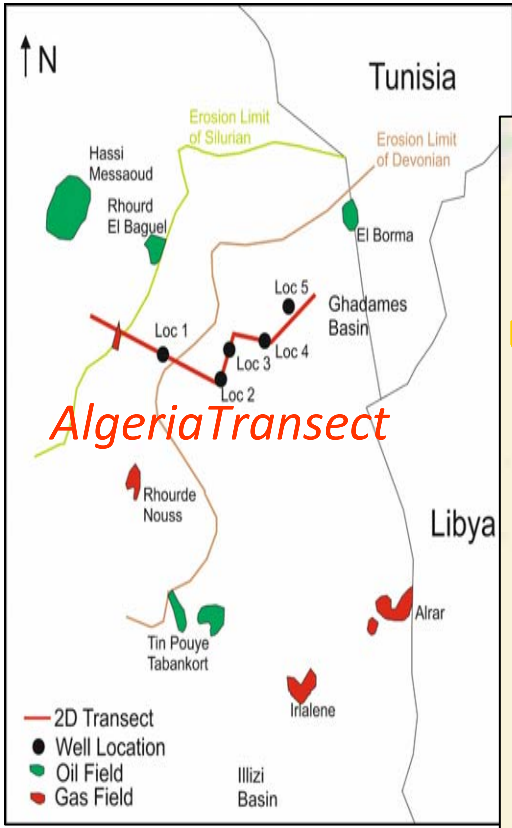
  * retained petroleum in shales

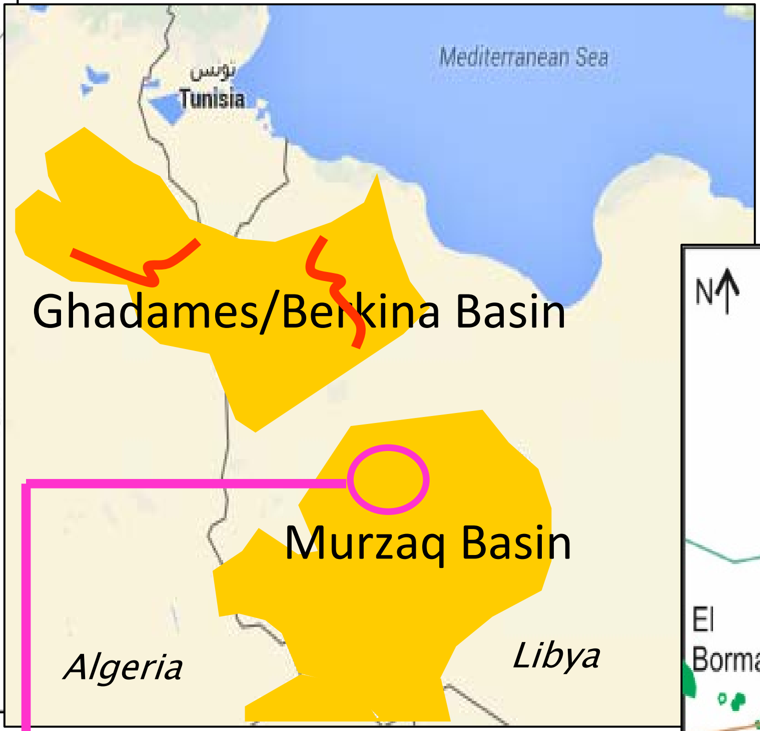
  * compositions

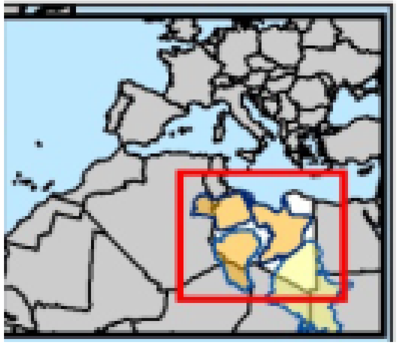
Regional Shale Gas Potential in North Africa and Middle East Region (MENA) EIA Study 2011

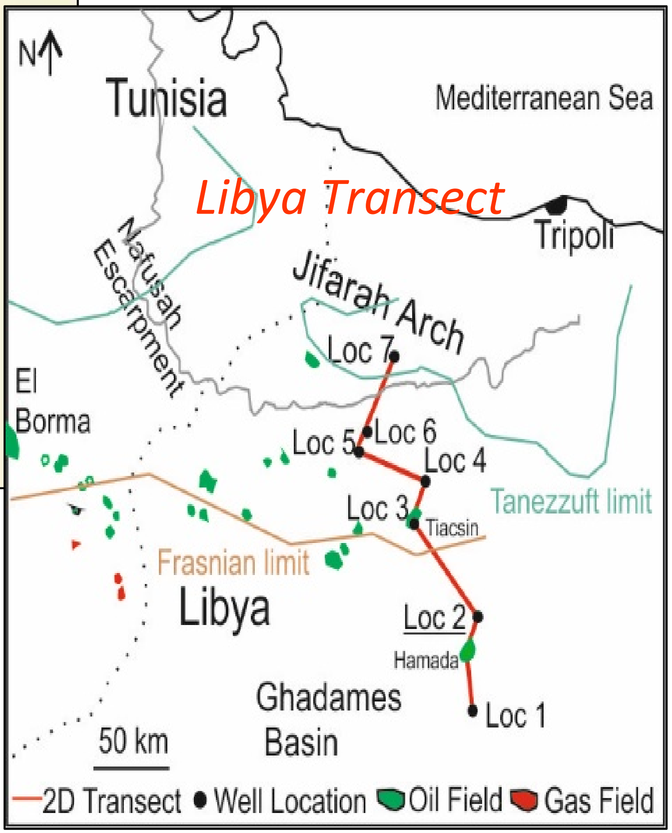
Age		Location	Shale Gas Potential	Comment
Cenozoic	Paleogene	Libya, Tunisia	No	Offshore and immature
Mesozoic	Cretaceous	Libya, Egypt, Morocco	Unlikely	Likely to be oil prone
	Jurassic	Egypt, Morocco	Unlikely	Likely to be oil prone
Palaeozoic	Permo-Triassic	Libya	Negligible	
	Carboniferous	Morocco	Possibly	
	Devonian	Algeria, Libya	Yes (local)	
	Silurian	**Morocco, Algeria, Tunisia, Libya, Jordan, Syria, Iraq, Saudi Arabia,**	**Yes (Regional)**	**Widespread, organic rich, and with suitable burial history**
	Ordovician	Jordan, Algeria	Yes (local)	

Study Areas



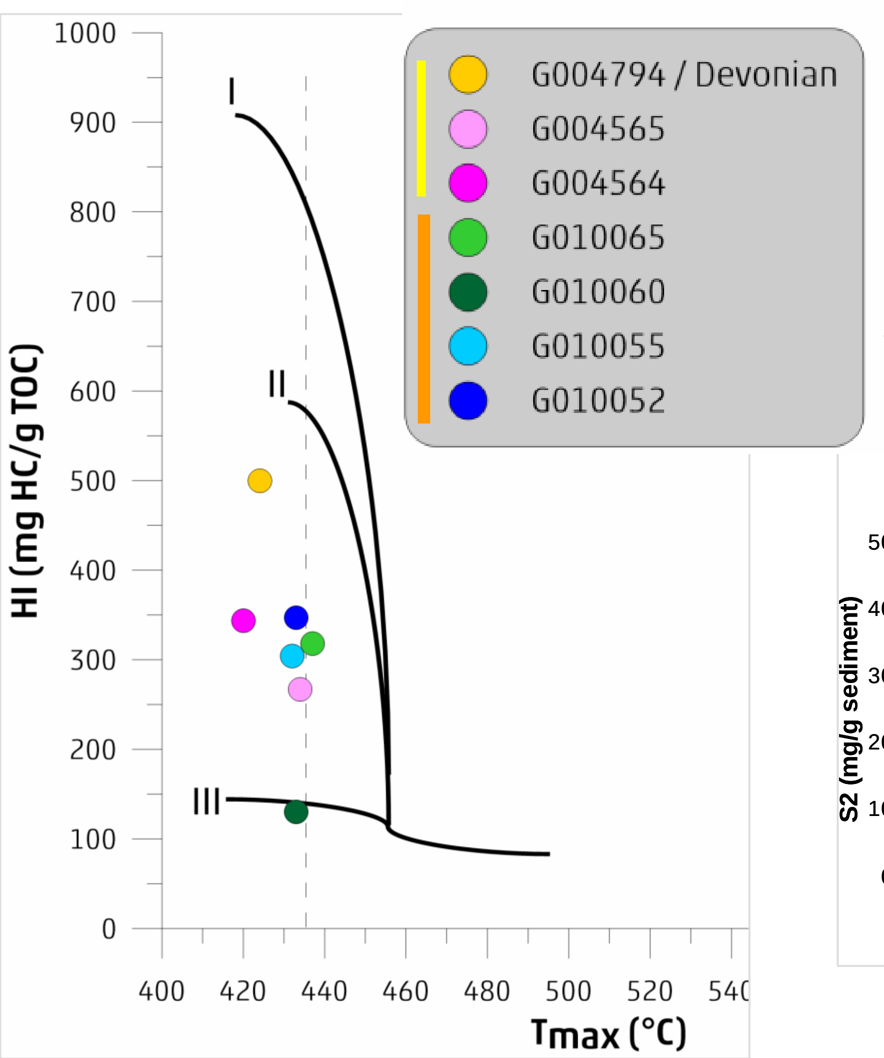


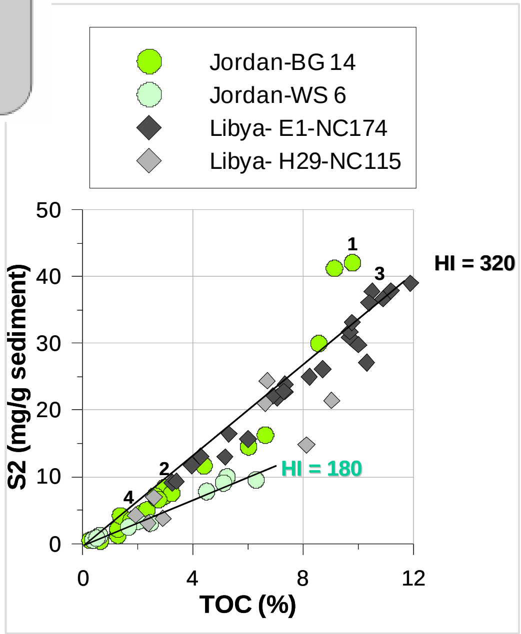




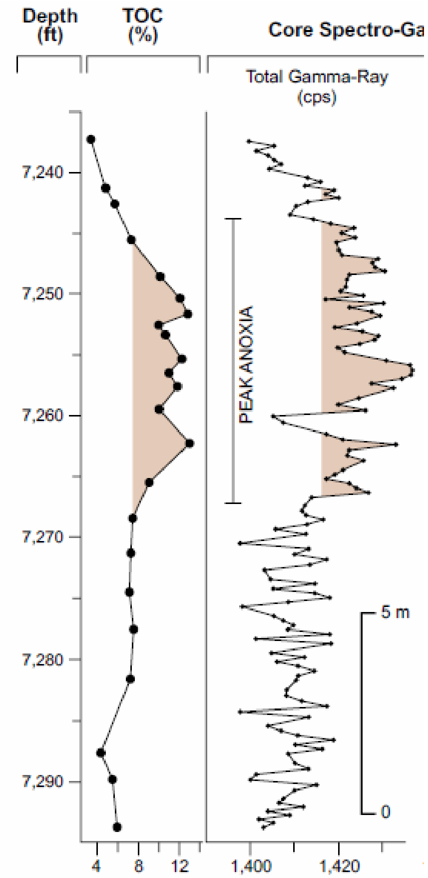
Sample ID	Country	Well	Basin	Age	Type	Depth (m)
G004794			Ghadames	Devonian		
G004564	Libya		Murzuq	Silurian		
G004565	Libya		Murzuq	Silurian		
G010052	Libya	E1-NC174	Murzuq	Silurian	COCH	2210.5
G010055	Libya	E1-NC174	Murzuq	Silurian	COCH	2208.4
G010060	Libya	H29-NC115	Murzuq	Silurian	COCH	1472
G010065	Libya	H29-NC115	Murzuq	Silurian	COCH	1485

Selected Screening Data





Well E1-NC174
(Lüning et al., 2003)



Fluid Property Prediction

Source rock

Kerogen → NSOs + HCs →

Carrier - Reservoir System

Variable GOR, Psat

NSOs + HCs

Forward modelling: PVT prediction using **PhaseKinetics:** di Primio and Horsfield (2006) AAPG Bulletin

Petroleum Type

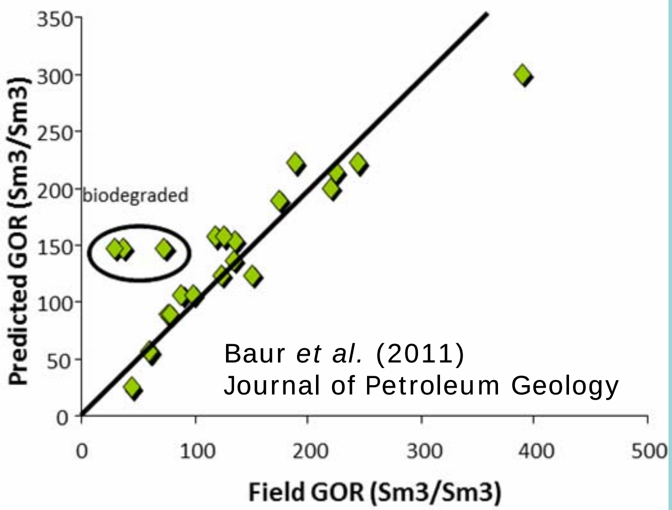
Thermal Response

Evolving Composition

Tuning

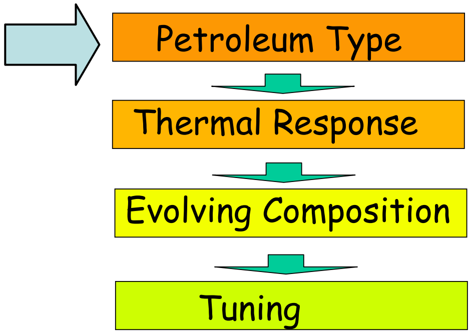
Published examples:

- Sonda de Campeche, Mexico
- Jeanne d'Arc Basin, Canada
- Viking Graben, Norway
- Bakken Shale, Williston Basin
- Reconcavo Basin, Brazil
- Central Graben, U.K.
- Songliao Basin, China
- Georgina Basin, Australia

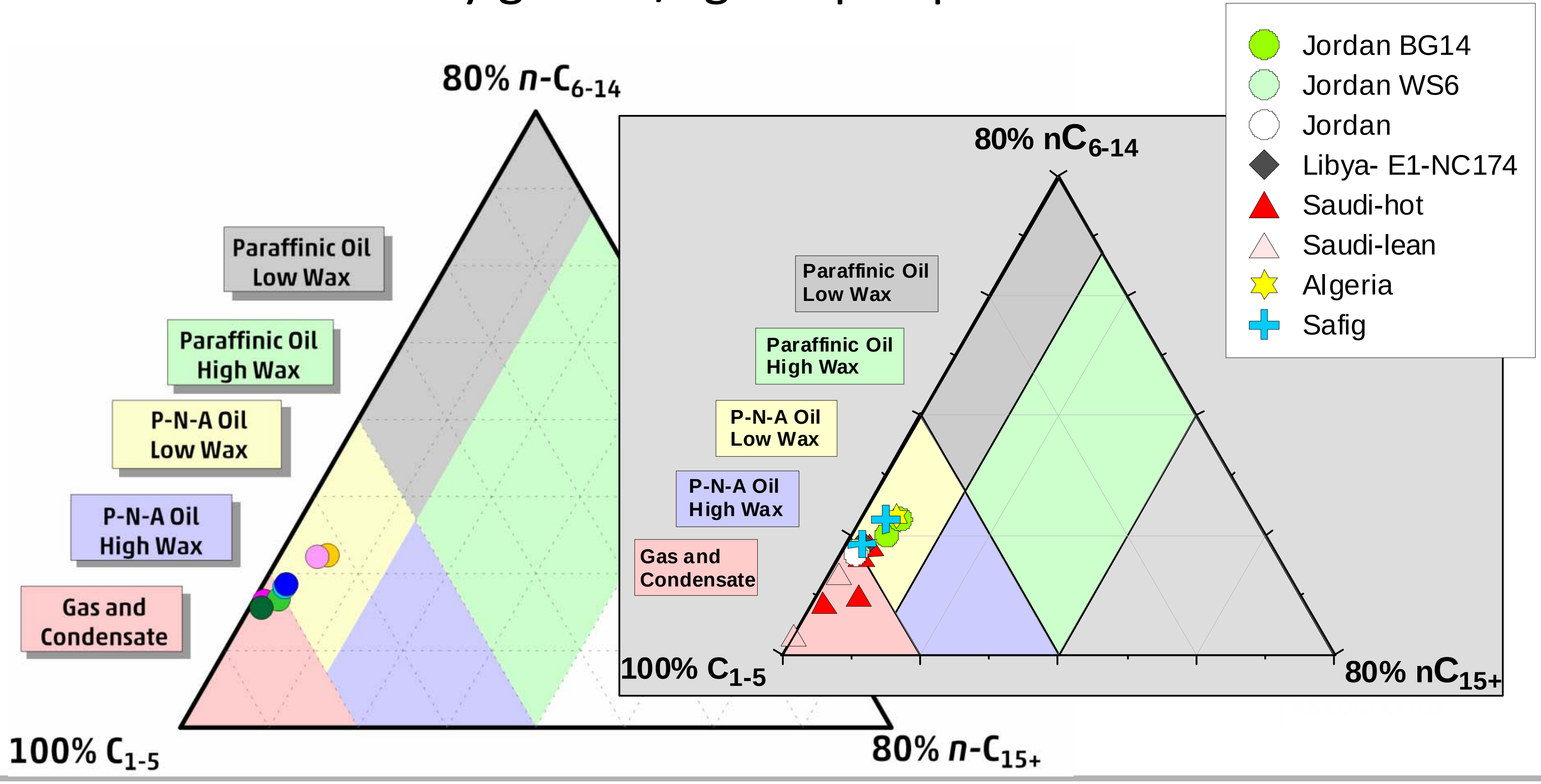


Petroleum Type

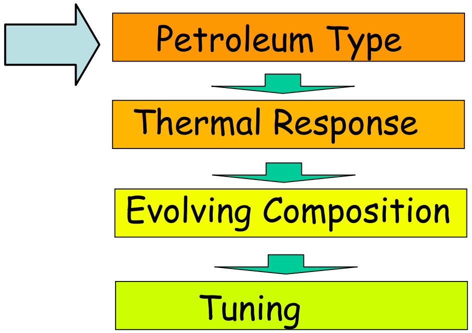
Immature to early mature samples



- Devonian has "normal" CLD for marine SR
- Silurian has mainly gassier/light liquid potential



Petroleum Type
Immature to early mature samples



Cole (1994):

Flooding with intra-shelf ‘sag’ basins

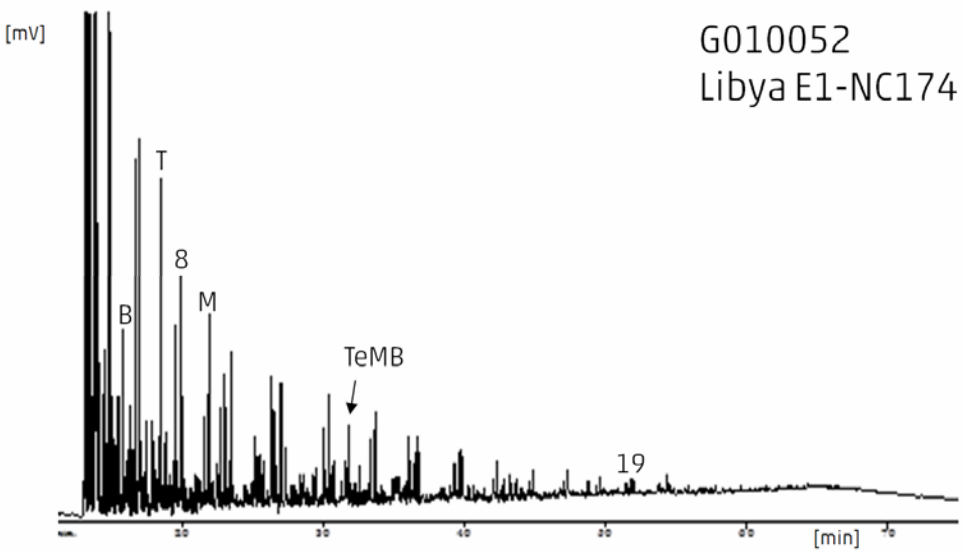
Anoxic condition in sediment starved basins

Richest source rocks in mini-basins

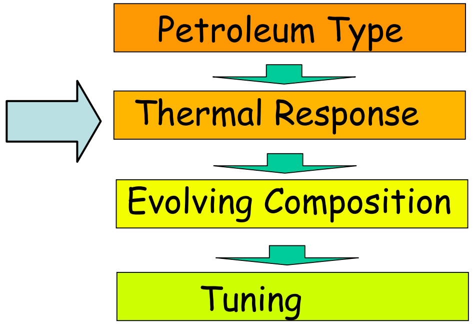
Jones and Stump (1999):

Hot shale best developed on the slope/shelf rather than in the basin centre

Green sulphur bacteria

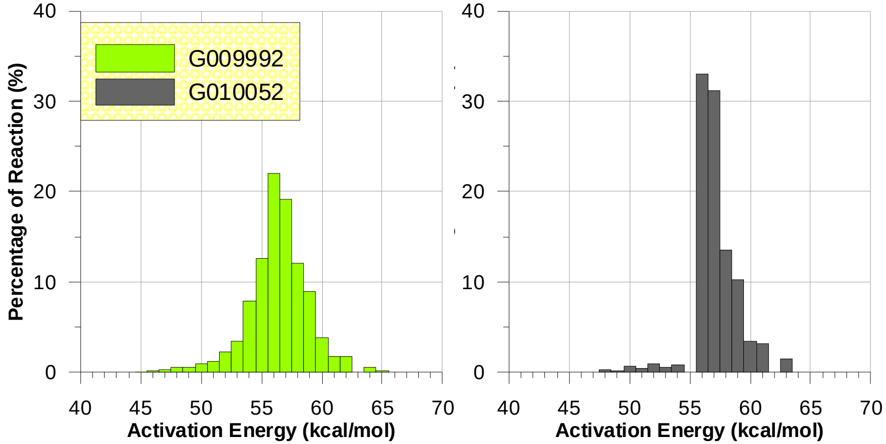


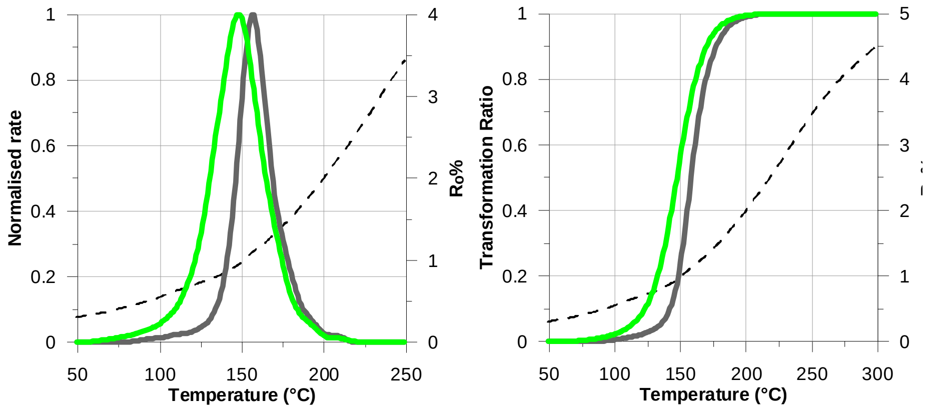
Thermal Response
Immature to early mature samples

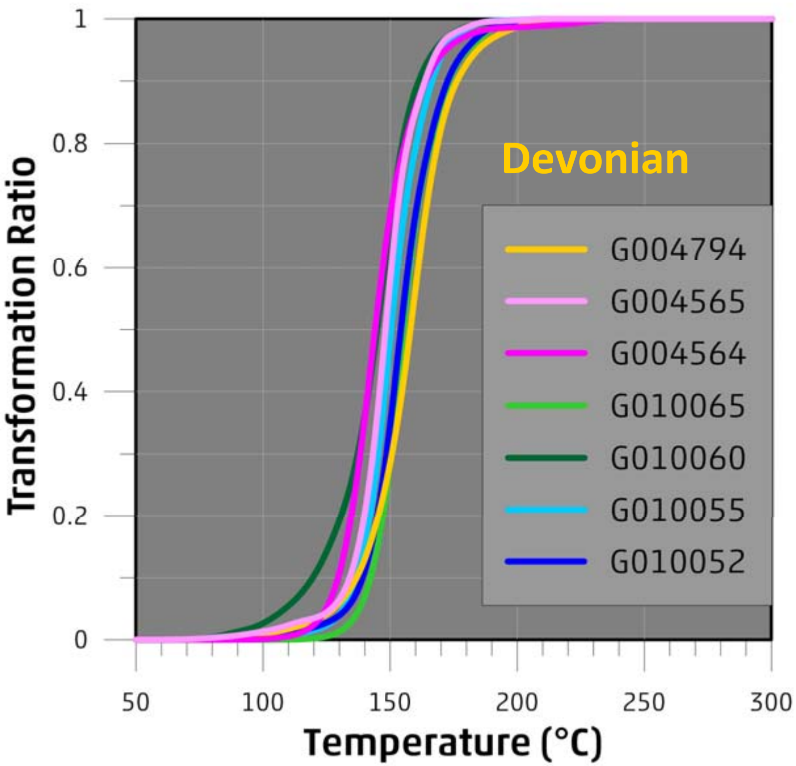


G009992 (#1)
Jordan OS1

G010052 (#3)
Libya E1-NC174

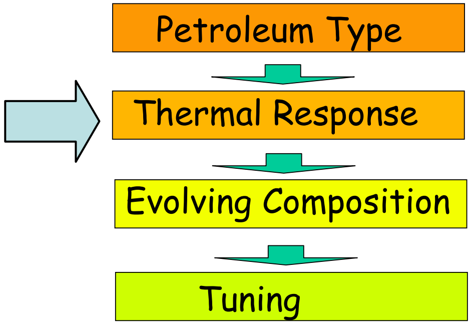


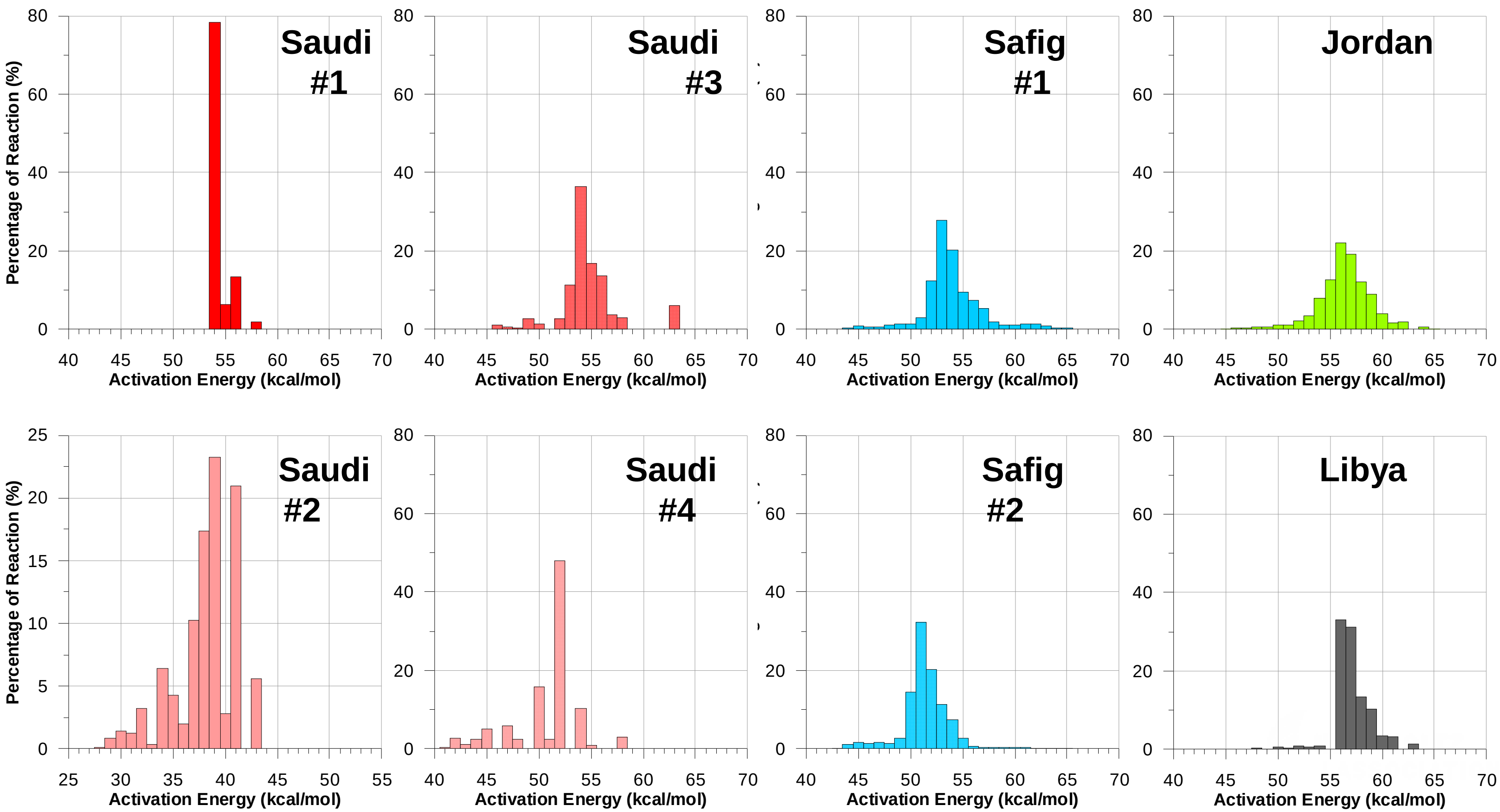




Thermal Response

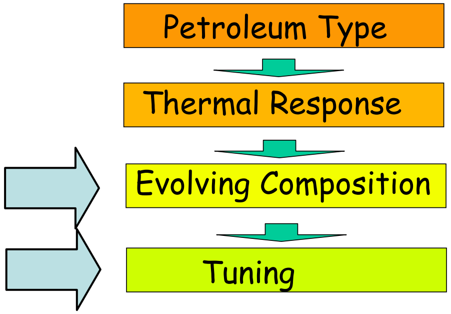
Immature to early mature samples

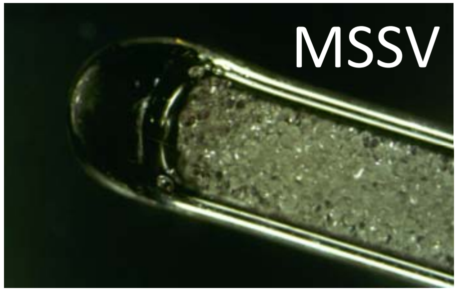


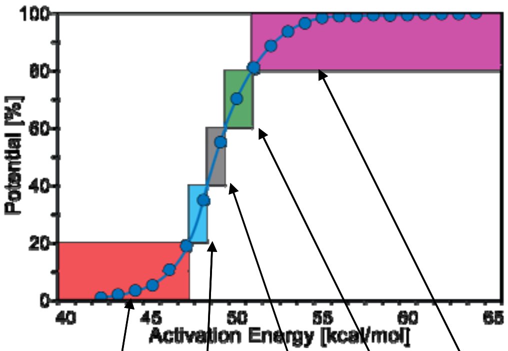


Evolving Composition

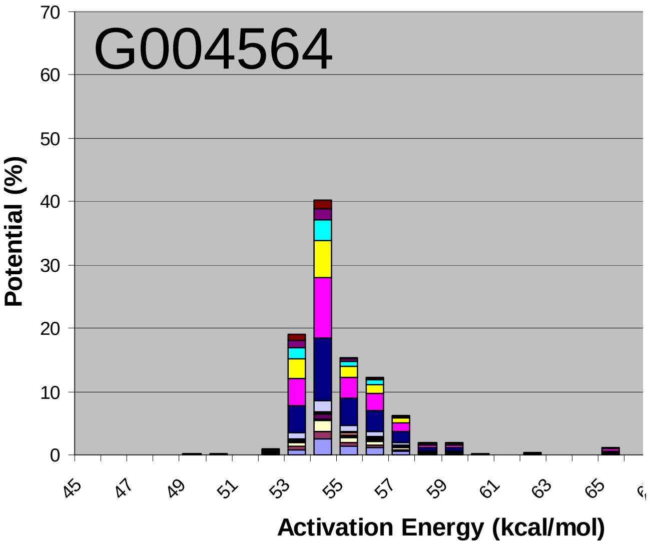
Cumulative or instantaneous

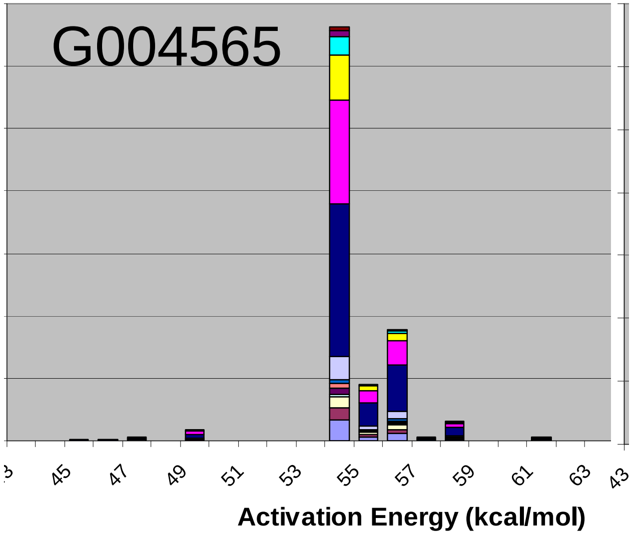






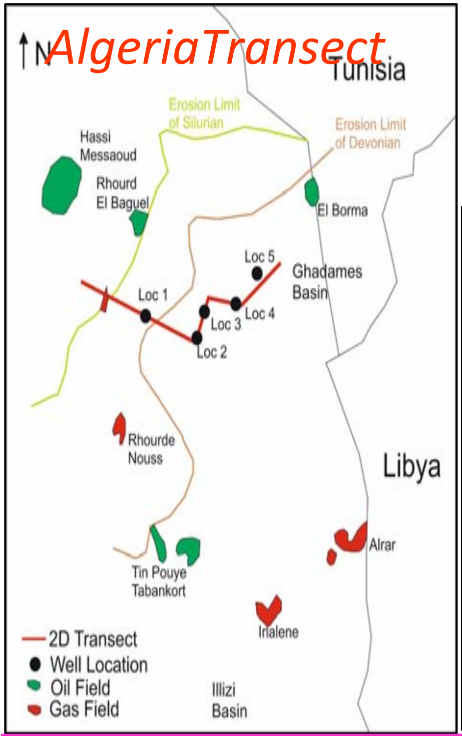
TR	10	30	50	70	90
n-C1	23.05	25.04	25.53	26.82	34.48
n-C2	11.21	11.42	11.66	11.81	10.39
n-C3	10.46	11.43	11.61	11.59	10.16
i-C4	0.84	0.70	0.70	0.65	0.66
n-C4	5.24	4.74	4.40	4.30	3.67
i-C5	2.34	1.54	1.25	1.17	0.90
n-C5	3.09	3.07	3.08	2.91	2.42
n-C6	9.89	11.69	11.58	11.42	11.20
C7 -15	17.00	15.82	16.07	16.22	15.37
C16 -25	9.13	8.15	8.07	7.76	6.75
C26 -35	4.23	3.61	3.48	3.18	2.52
C36 -45	1.96	1.60	1.50	1.30	0.94
C46 -55	0.91	0.71	0.65	0.53	0.35
C56 -80	0.67	0.49	0.43	0.33	0.19

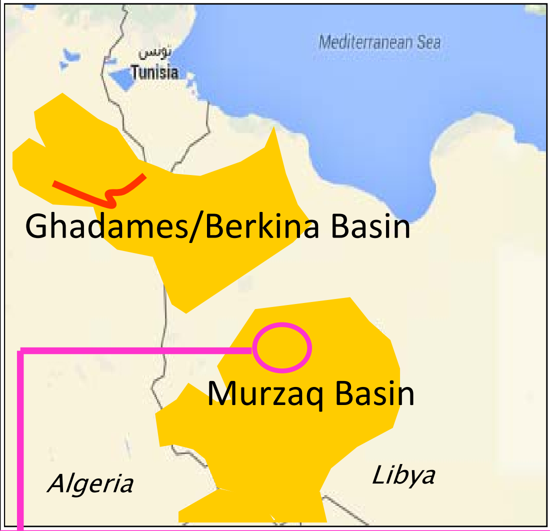




2D Modelling Eastern Algeria

Based on Yahi (1999)





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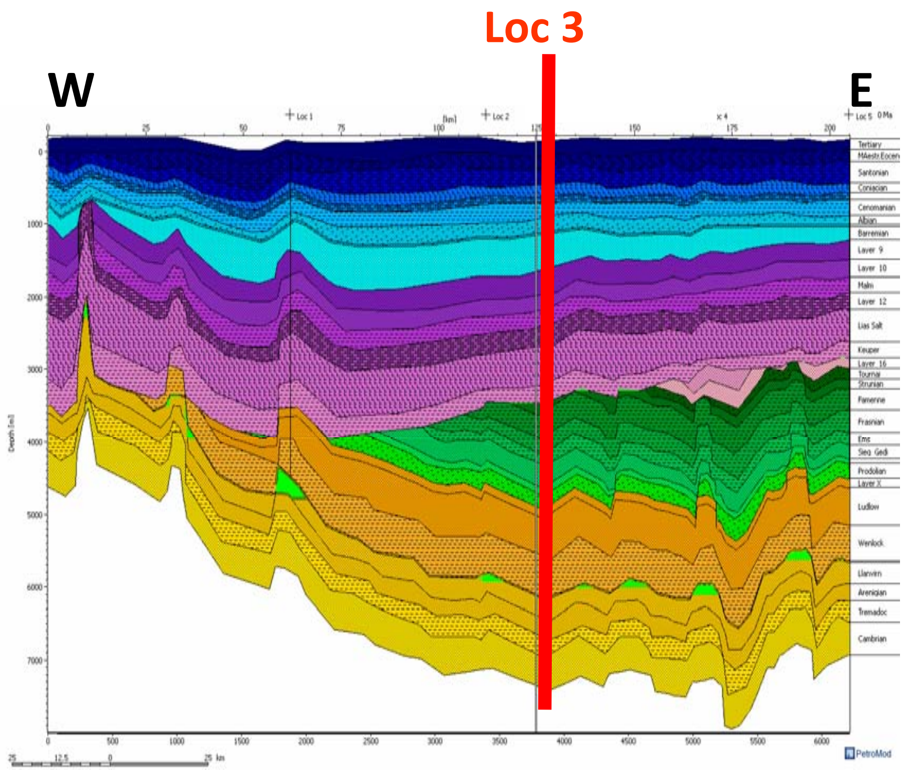
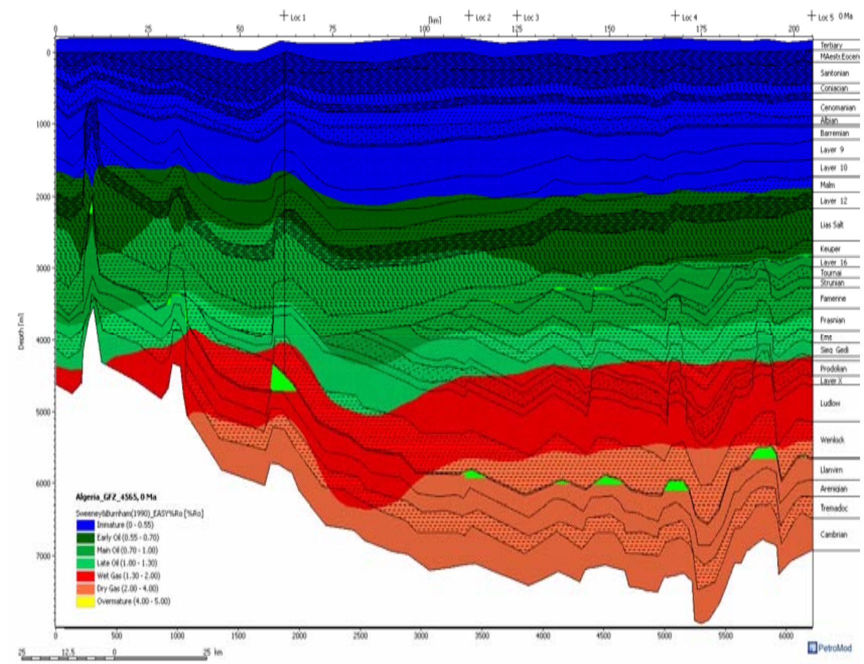
2D Modelling Eastern Algeria

Present Day 2D Model

Stratigraphy

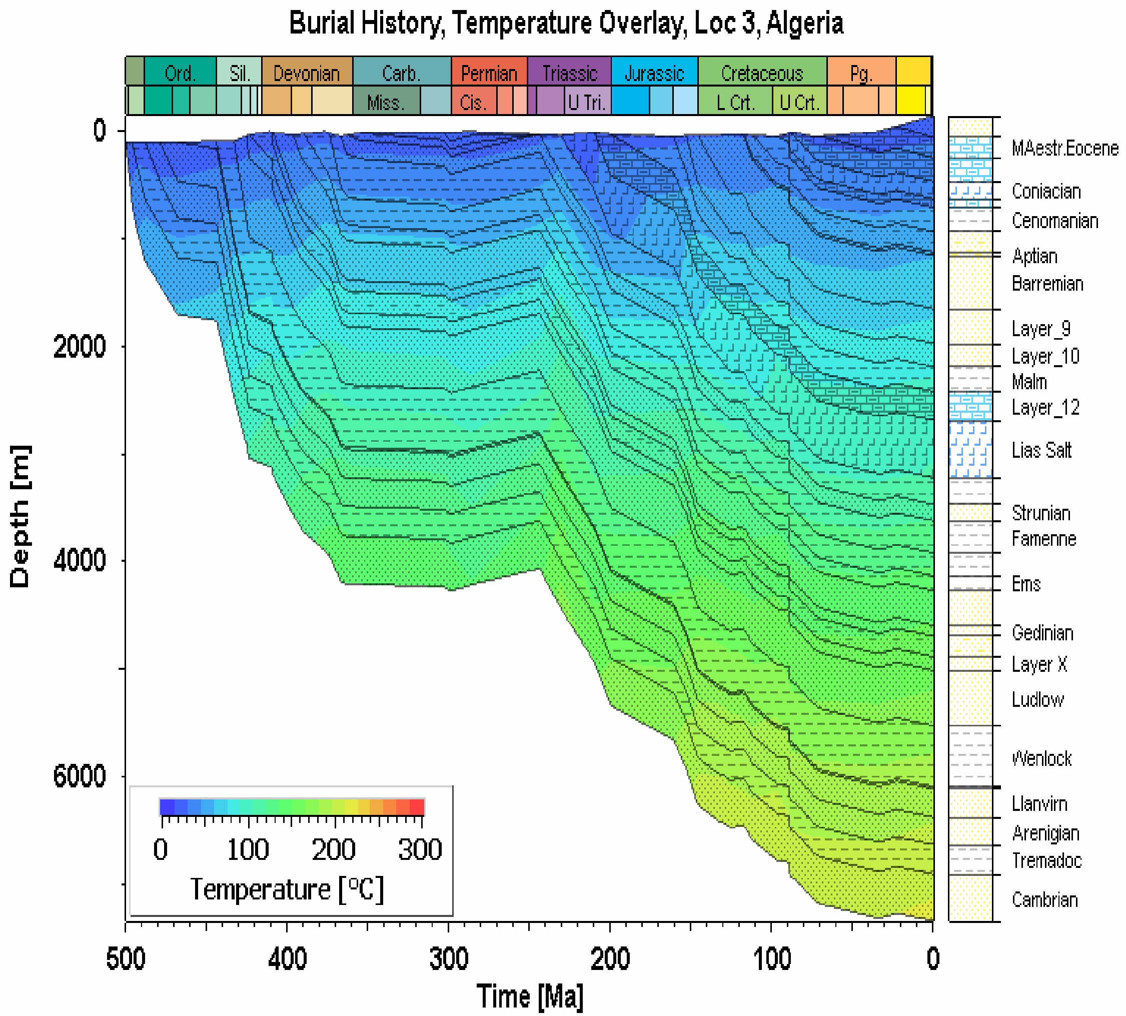
VR Maturity

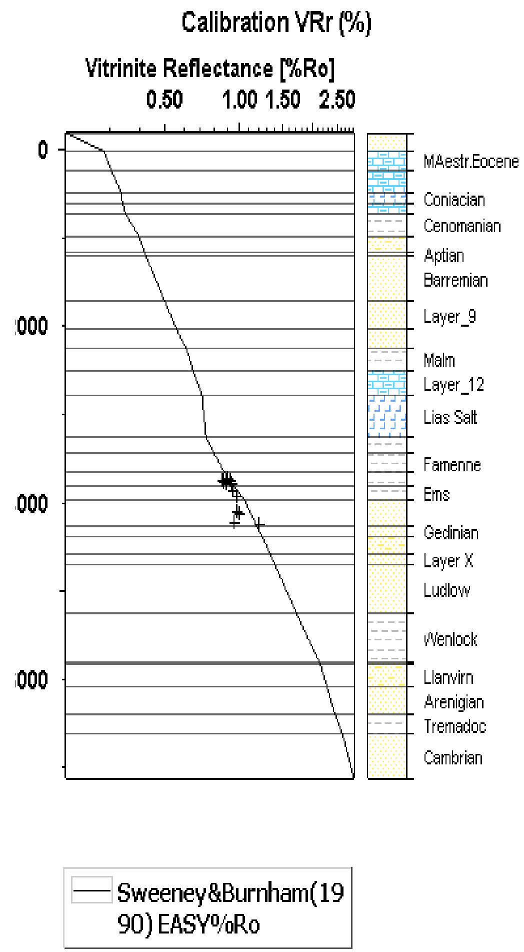




2D Modelling Eastern Algeria

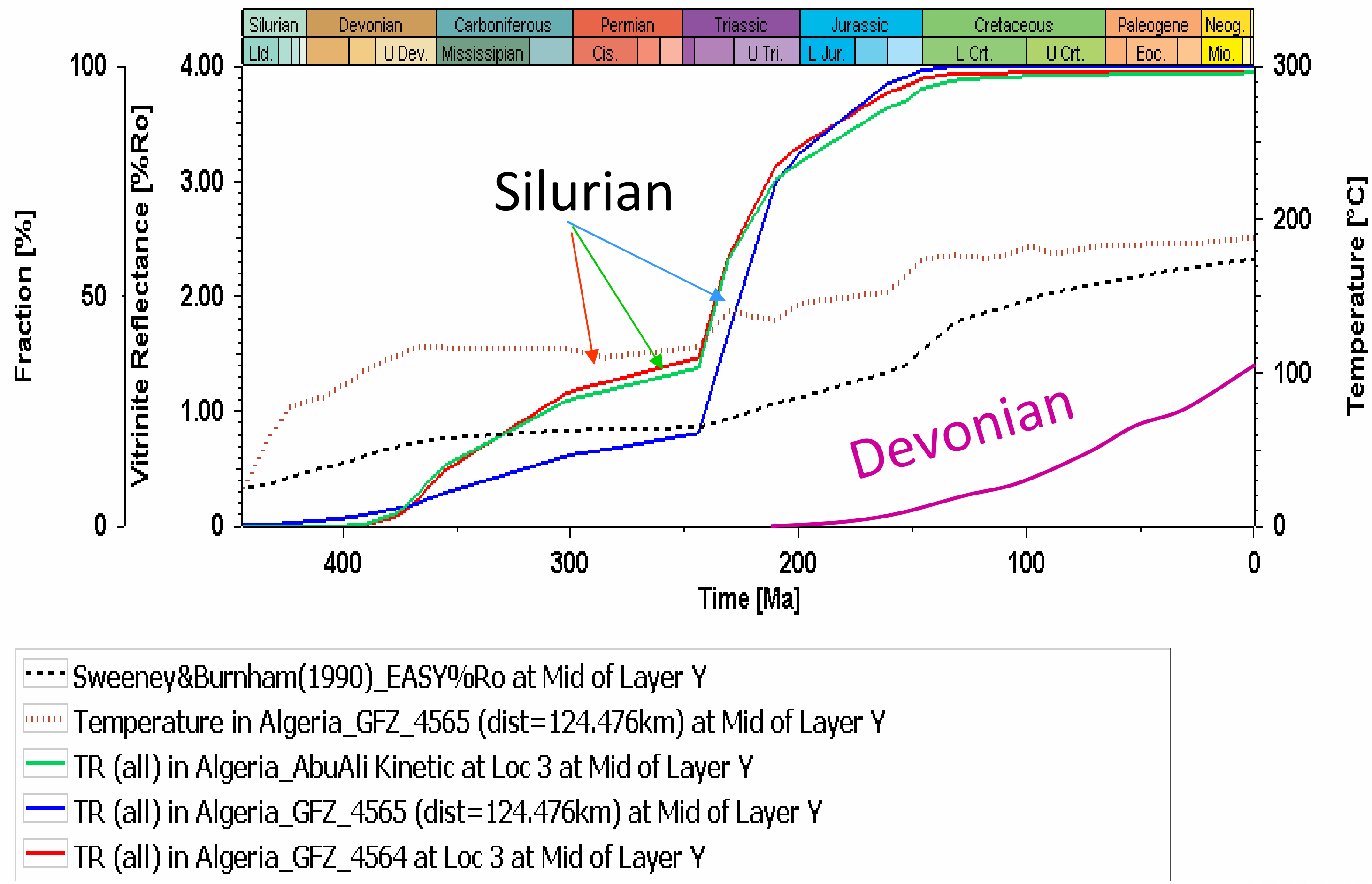
1D Extraction Location 3





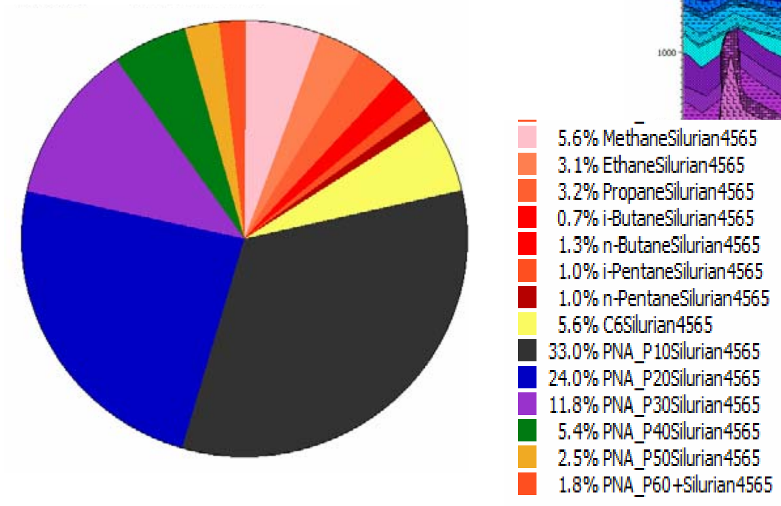
2D Modelling Eastern Algeria

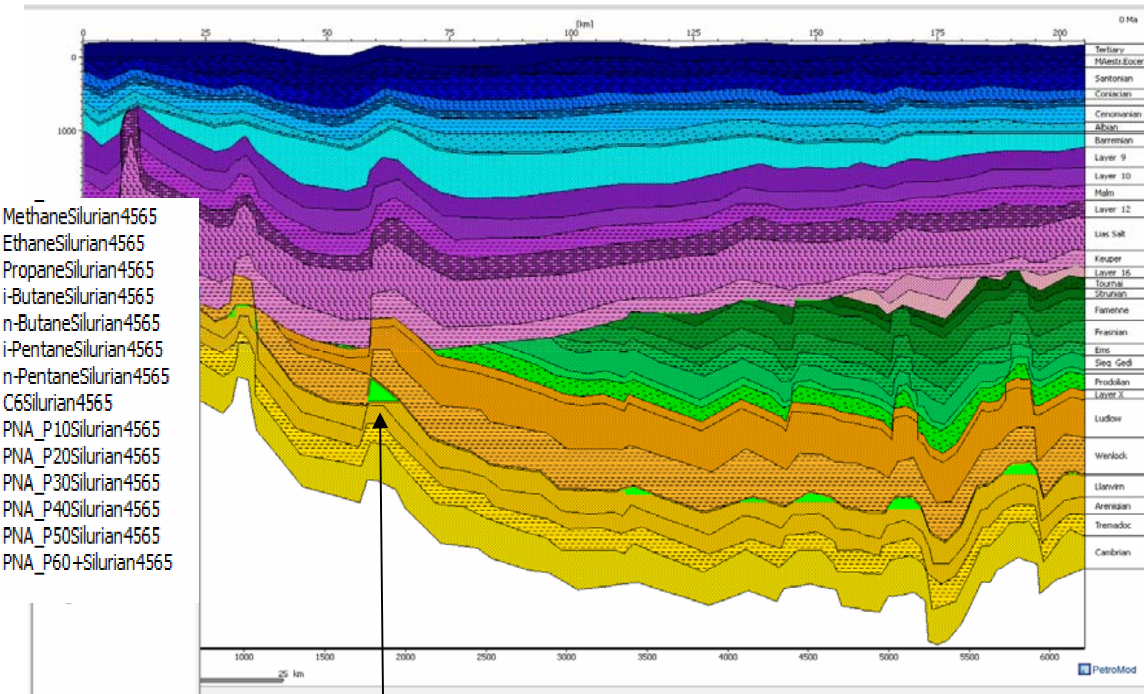
1D Extraction Location 3



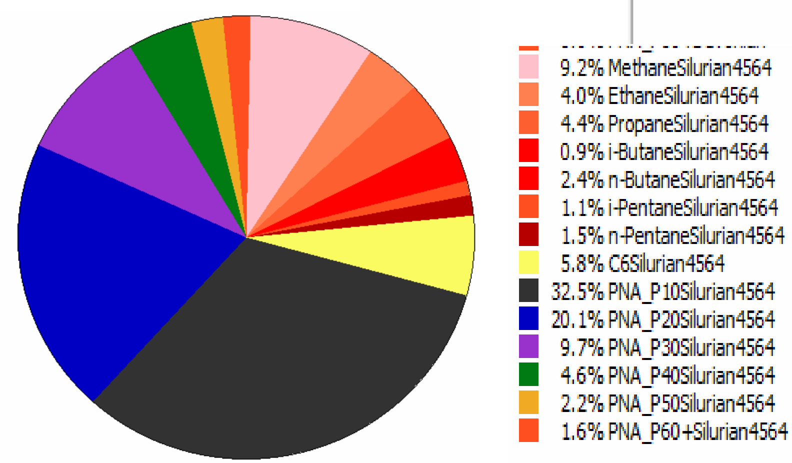
Molar Mass Fractions

Silurian 4565





Silurian 4564

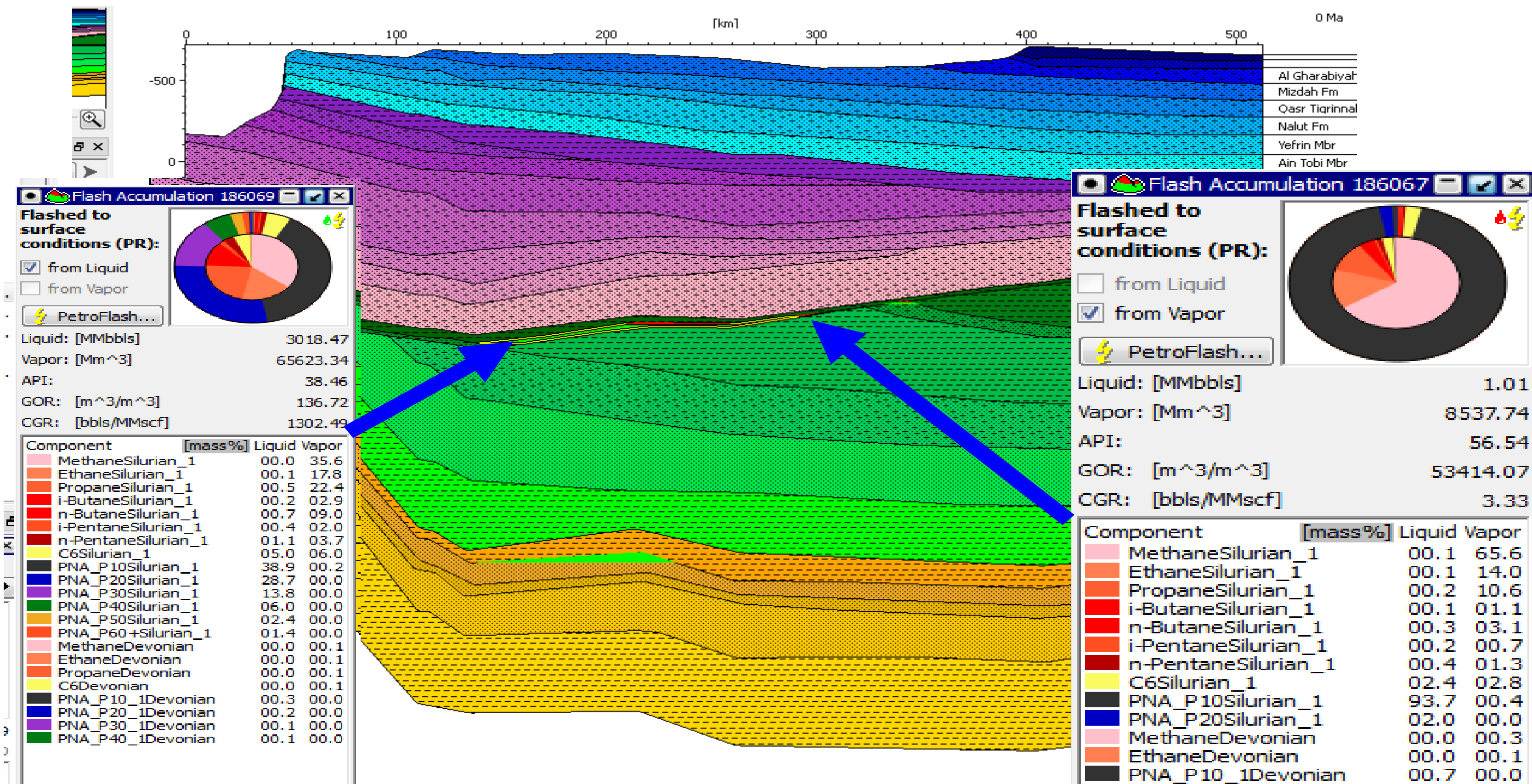


Llanvirn trap

- One-phase accumulation
- Saturation pressure is source-dependent

Libya: Keuper Unconformity

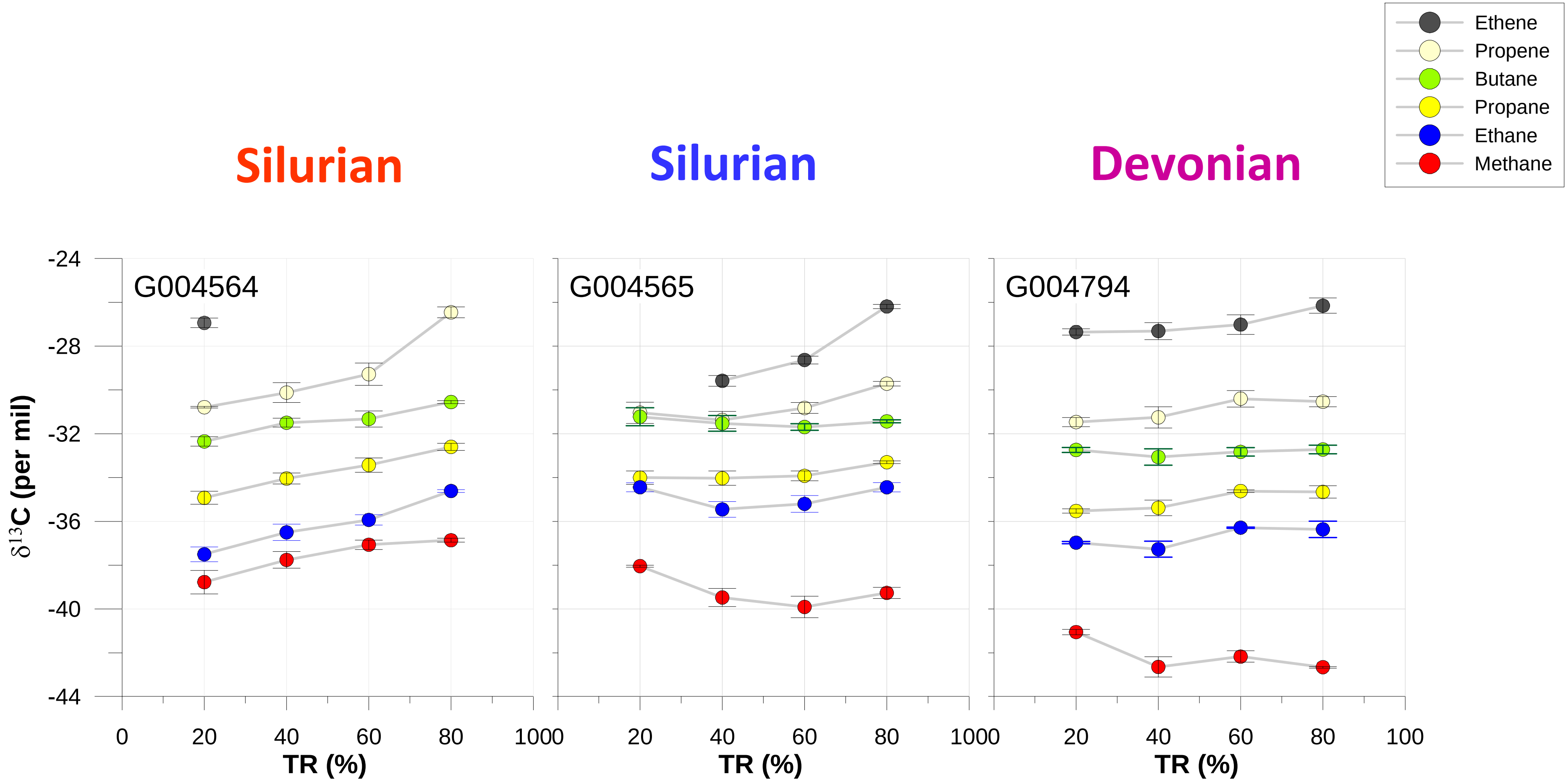
Two-phase accumulation



Inner vapour, outer liquid

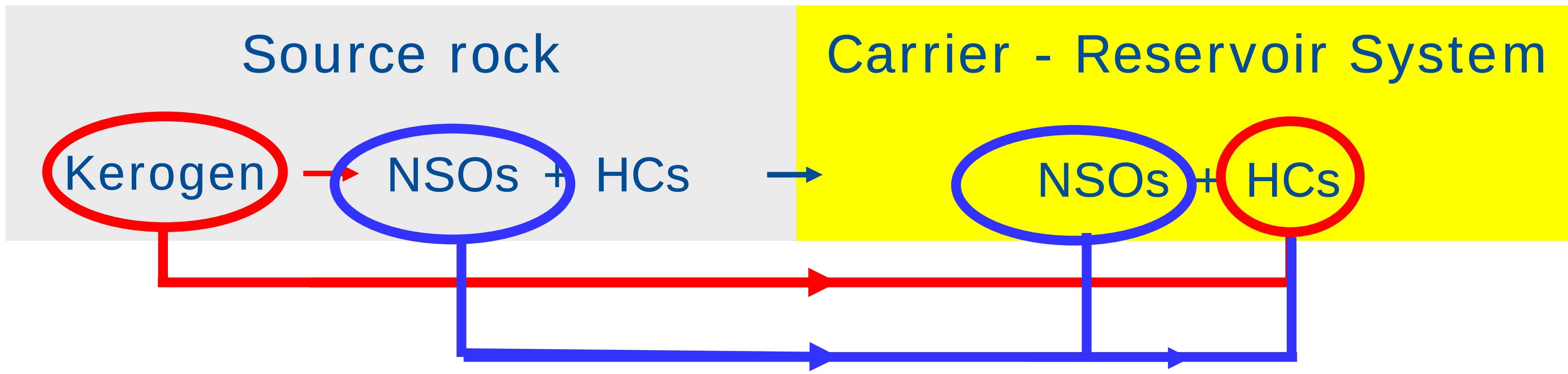
Inner vapour, outer liquid

Stable Isotopes of MSSV Pyrolysis Gases



Isotopically lighter methane

Fluid Property Prediction



Petroleum Type

↓

Thermal Response

↓

Evolving Composition

↓

Tuning

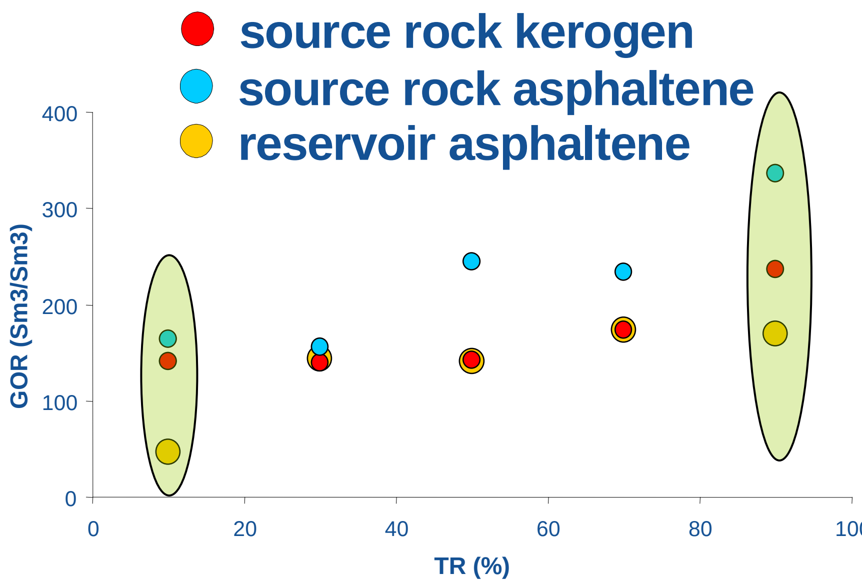
Proxies?

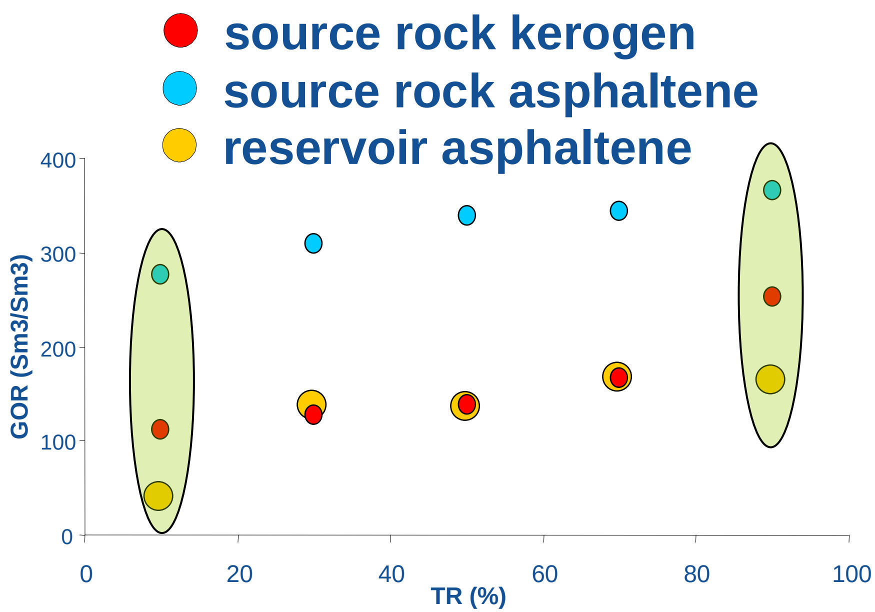
Source rock asphaltenes

Reservoir core asphaltenes

Duvernay Formation, Canada

- Petroleum type
- Thermal response
- Evolving composition
- PVT compatibility

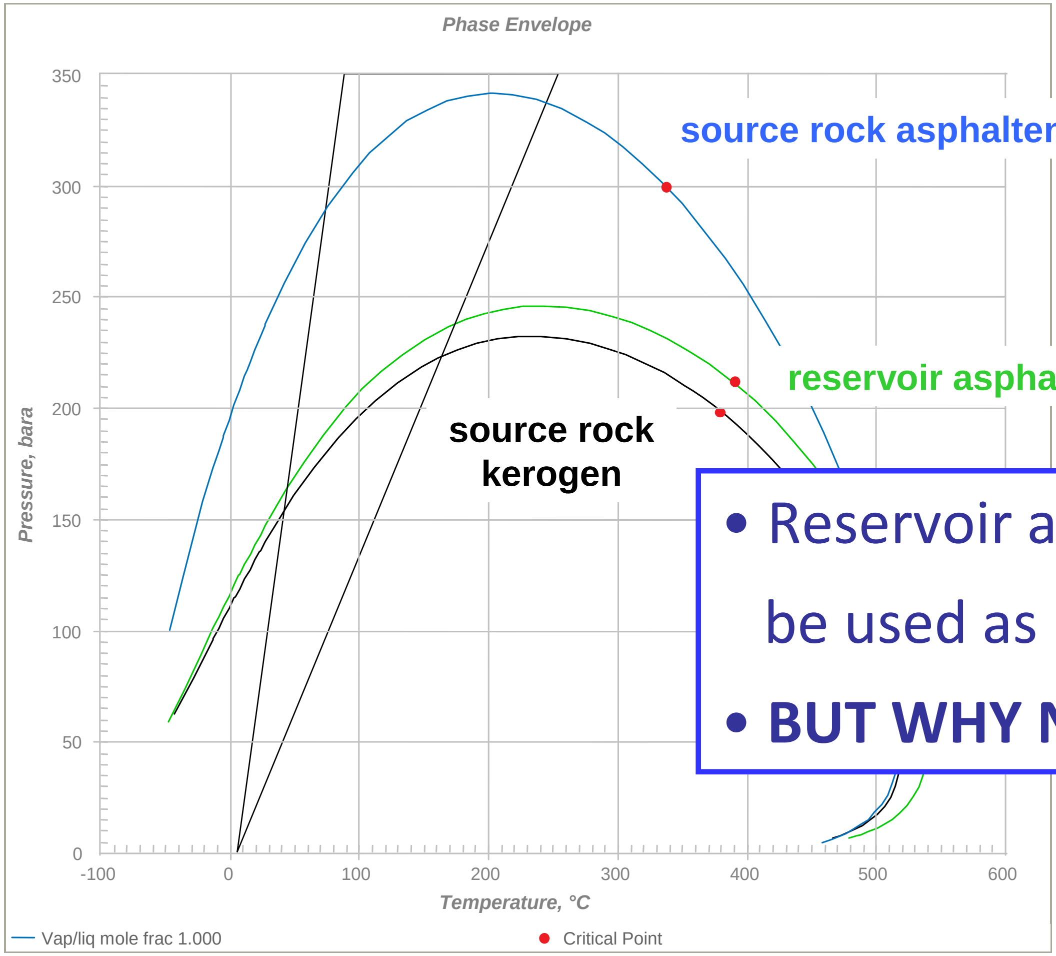




- SR and RA similar GOR between 30-70% TR
- SRA different
- differences at lowest and highest maturity range (10% and 90% TR)

Duvernay Formation, Canada

Phase Envelopes (50% TR)



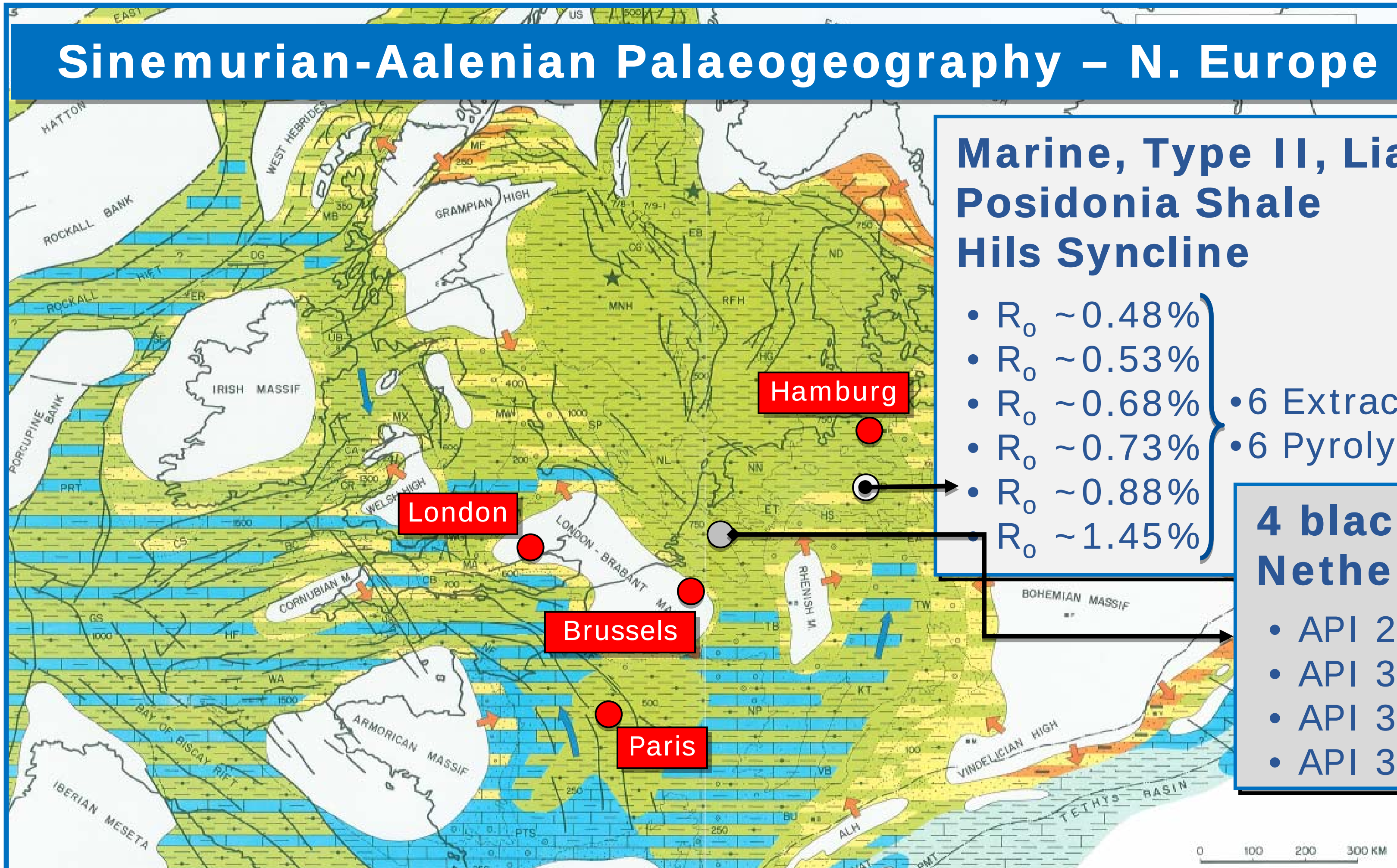
- Reservoir asphaltenes can be used as kerogen proxy
- **BUT WHY NOT SR ASPHALTENES?**

Theuerkorn, 2012)

Today's Talk

- North African source rocks – conventionals
  * PhaseKinetics
  * Isotopes
- **Outlook for unconventionals**
  *** retained petroleum in shales**
  *** compositions**

Posidonia Shale Natural Laboratory



Marine, Type II, Lias ε
Posidonia Shale
Hils Syncline

- R_o ~0.48%
- R_o ~0.53%
- R_o ~0.68%
- R_o ~0.73%
- R_o ~0.88%
- R_o ~1.45%

•6 Extracts
•6 Pyrolysates

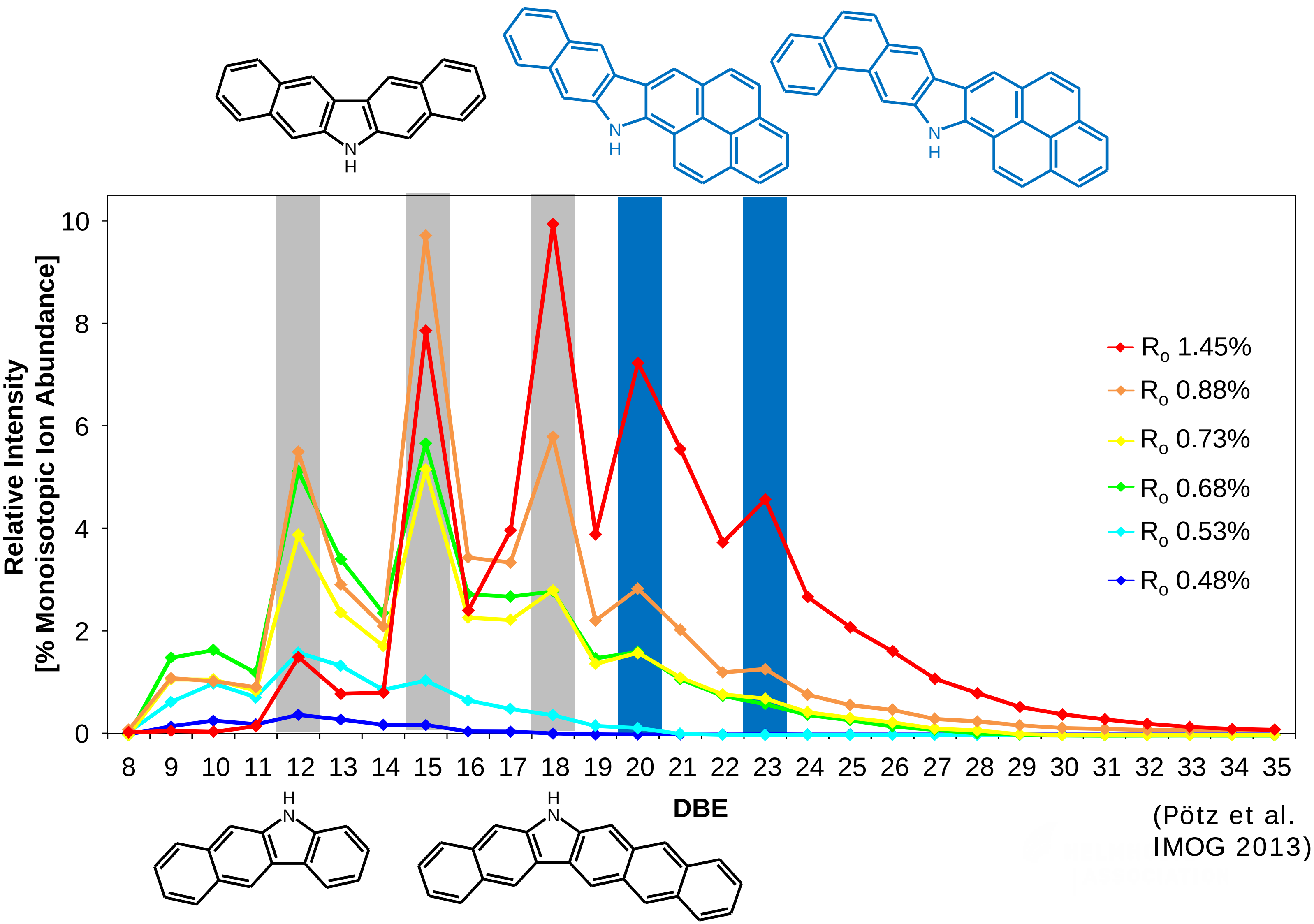
4 black oils: Netherlands

- API 28
- API 31
- API 33
- API 35

Backgroundmap: Ziegler (1982)

Source Rock Extracts - FT-ICR MS

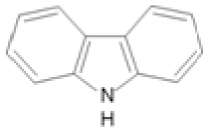
N_1 class:
DBE distributions

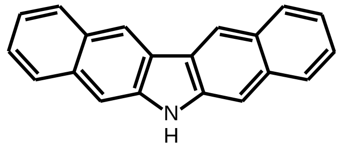


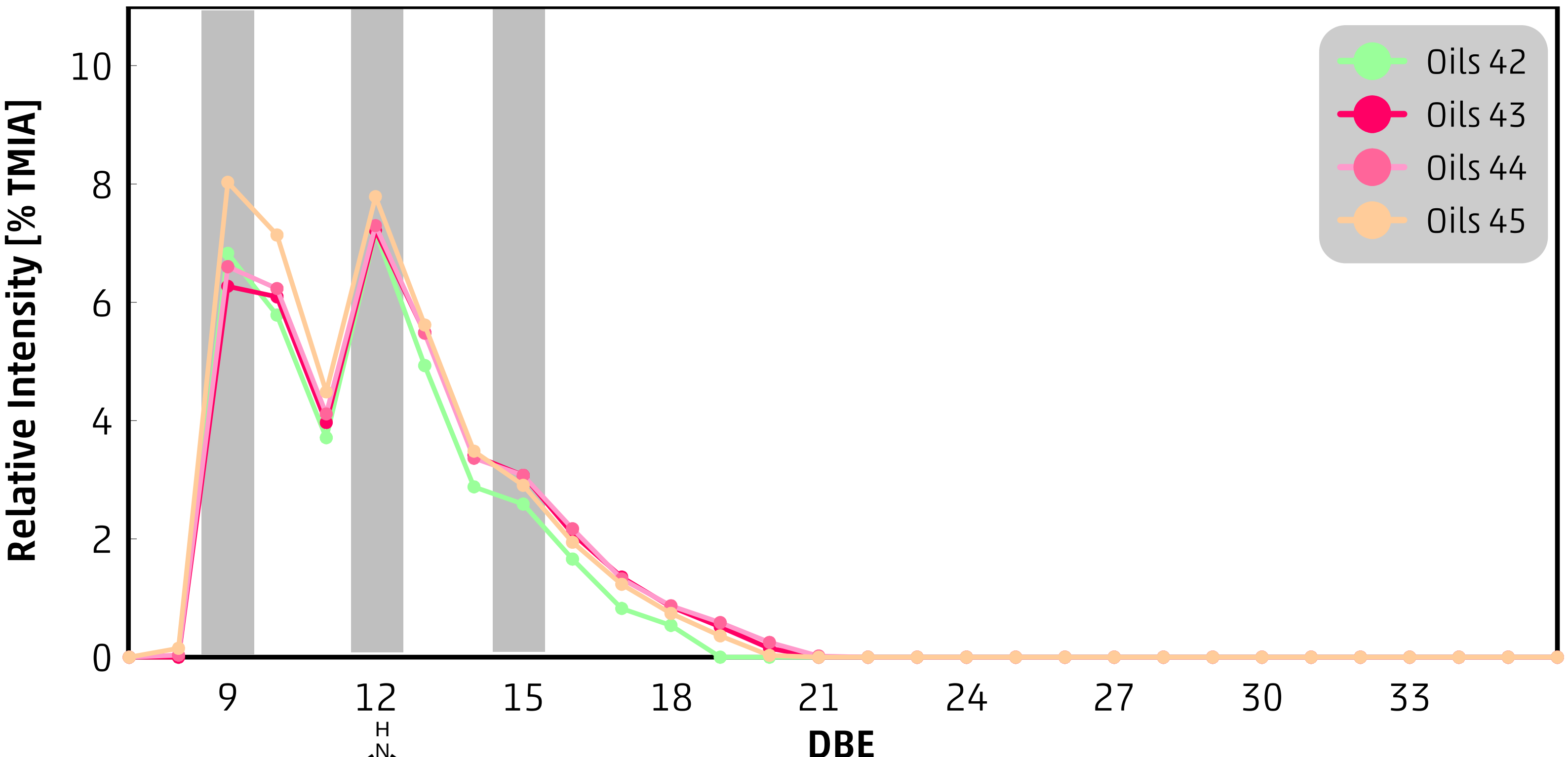
(Pötz et al. IMOG 2013)

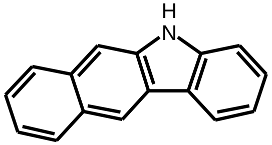
Conventional Oils - FT-ICR MS

N_1 class: DBE distributions



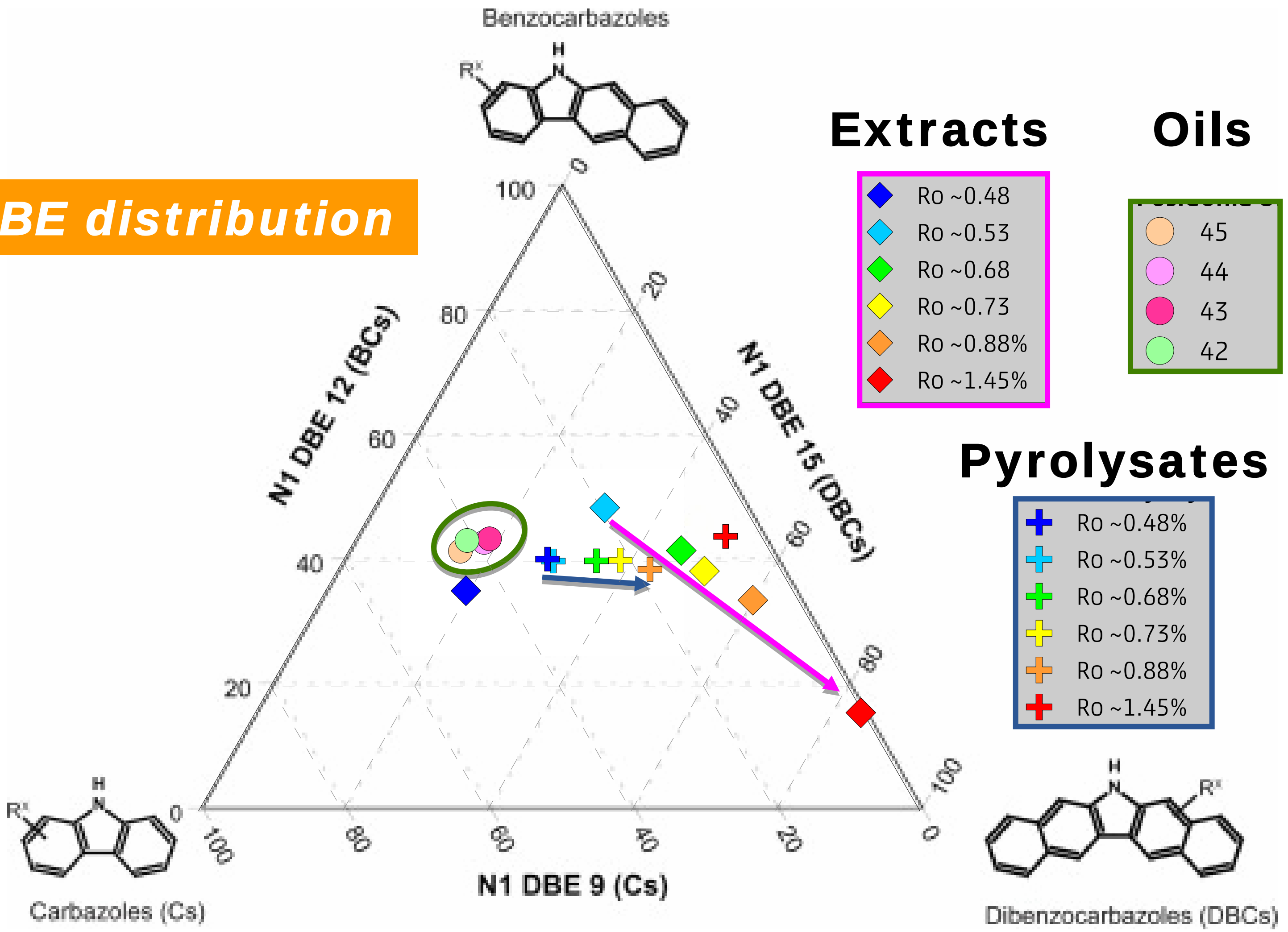






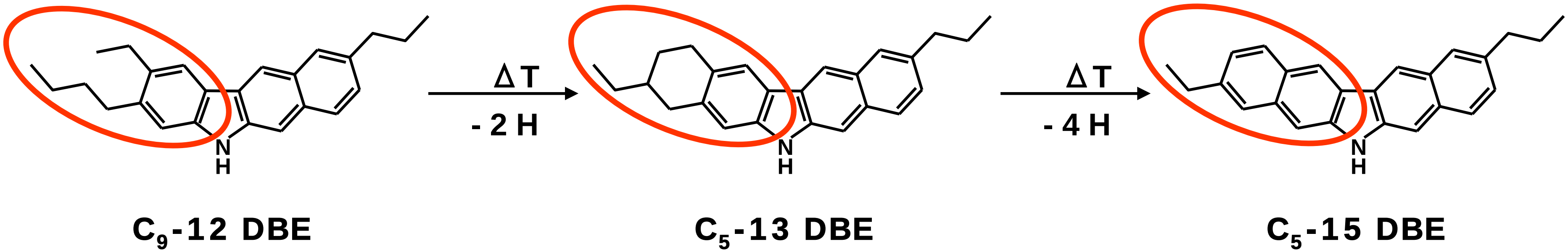
„Aromaticity“ - FT-ICR MS

N_1 class: DBE distribution



Explaining aromaticity and chain-length evolution

Cyclization/Aromatization at the cost of aliphatic carbon

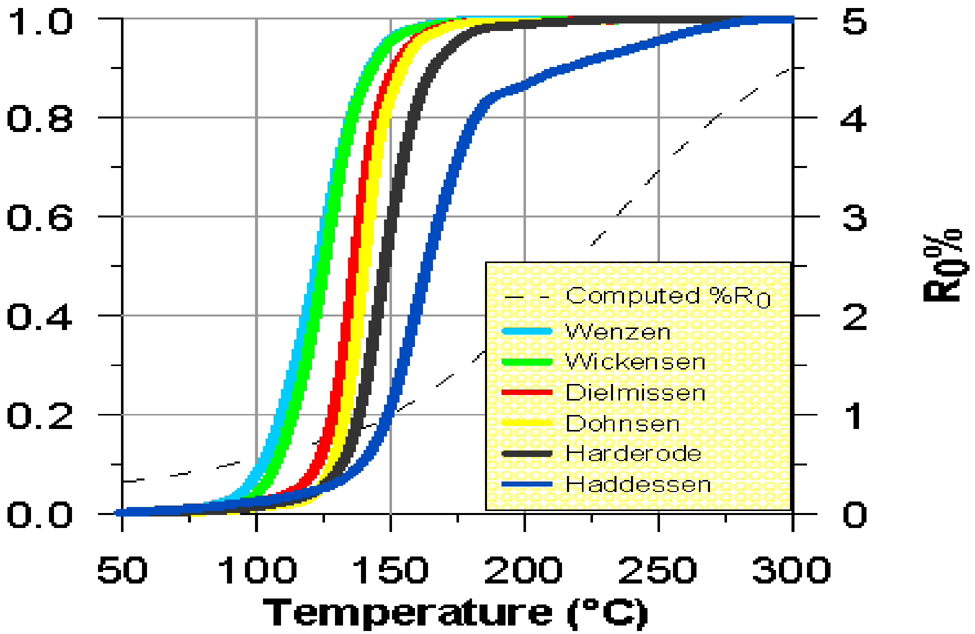


→retained asphaltene has more aromatics and shorter chains

→products are more "gas-rich"

Worlds Apart

Cumulative



Instantaneous

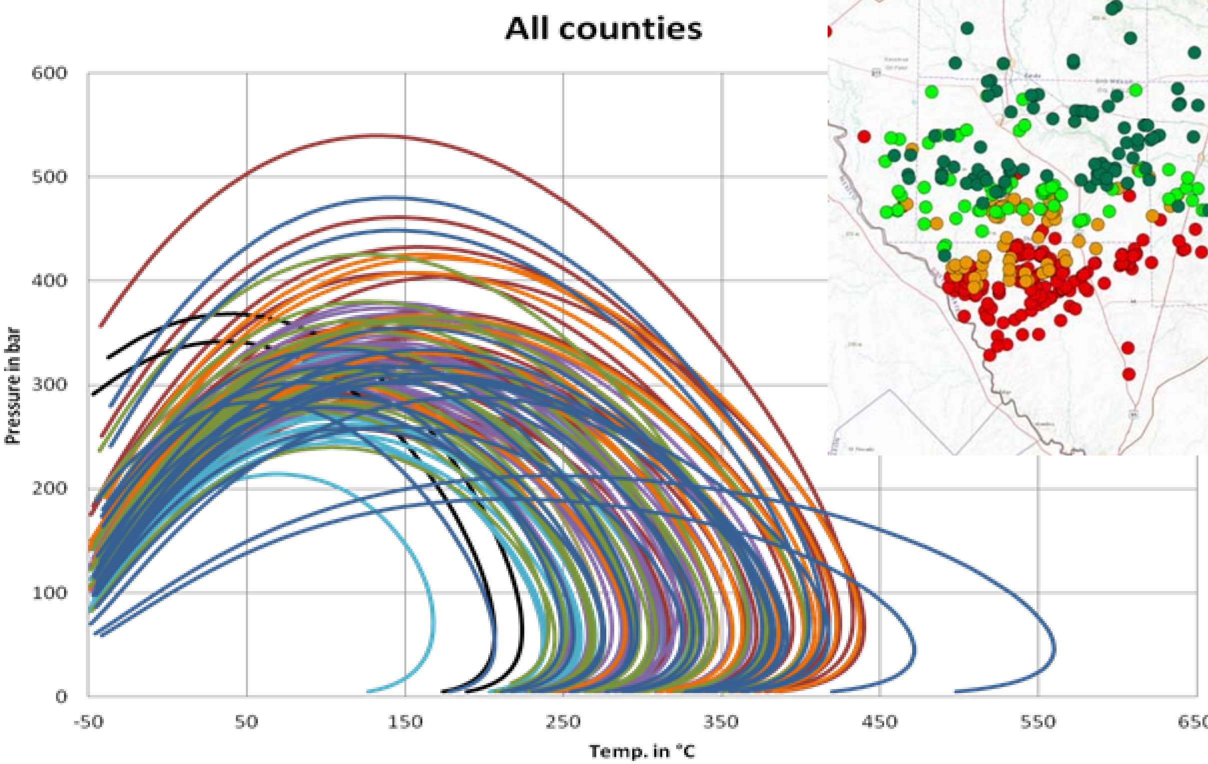
Conventionals

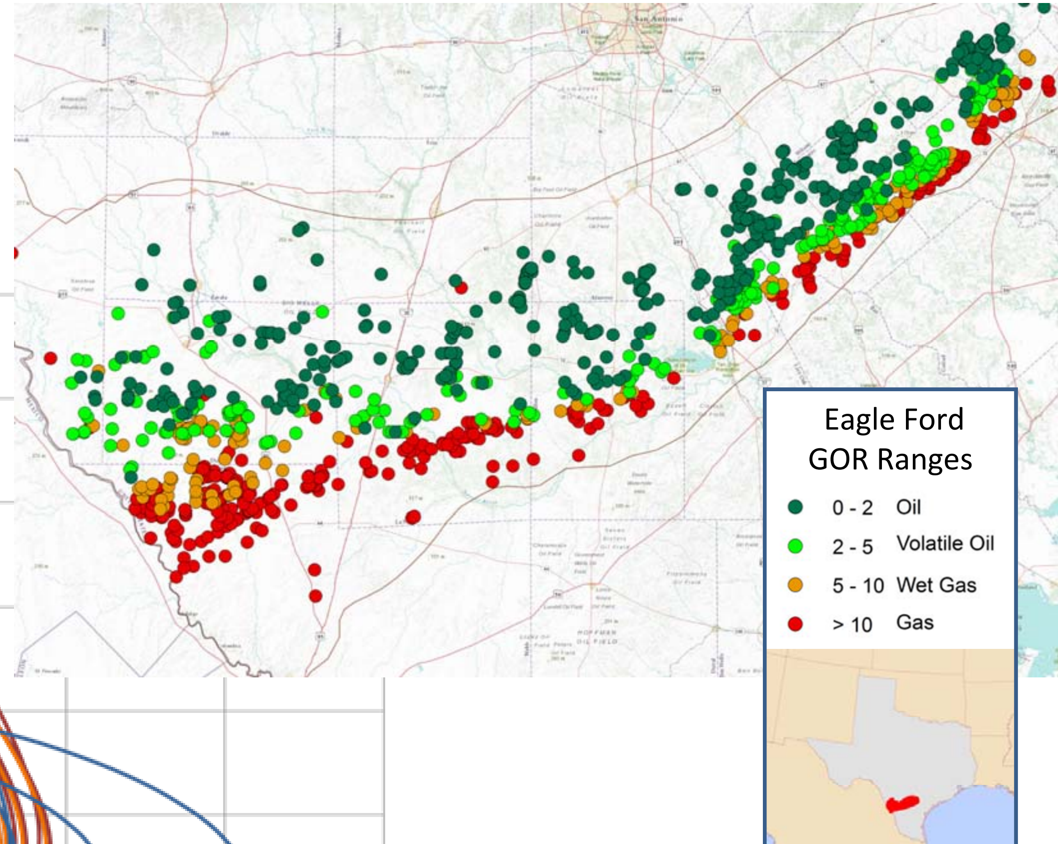
- Events and pathways
- Geological time
- Risk reduction
- Seeking gushers

Shale Resources

- Events and pathways
- Human time
- Induced and natural
- Seeking optimisation
- An engineering solution

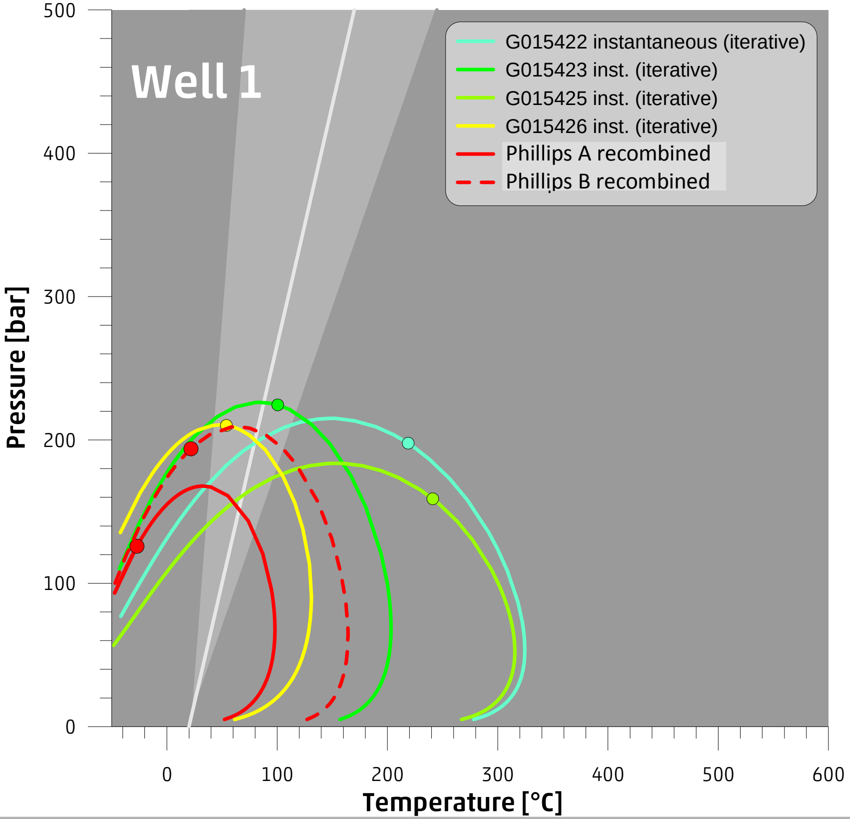
Eagle Ford of Texas

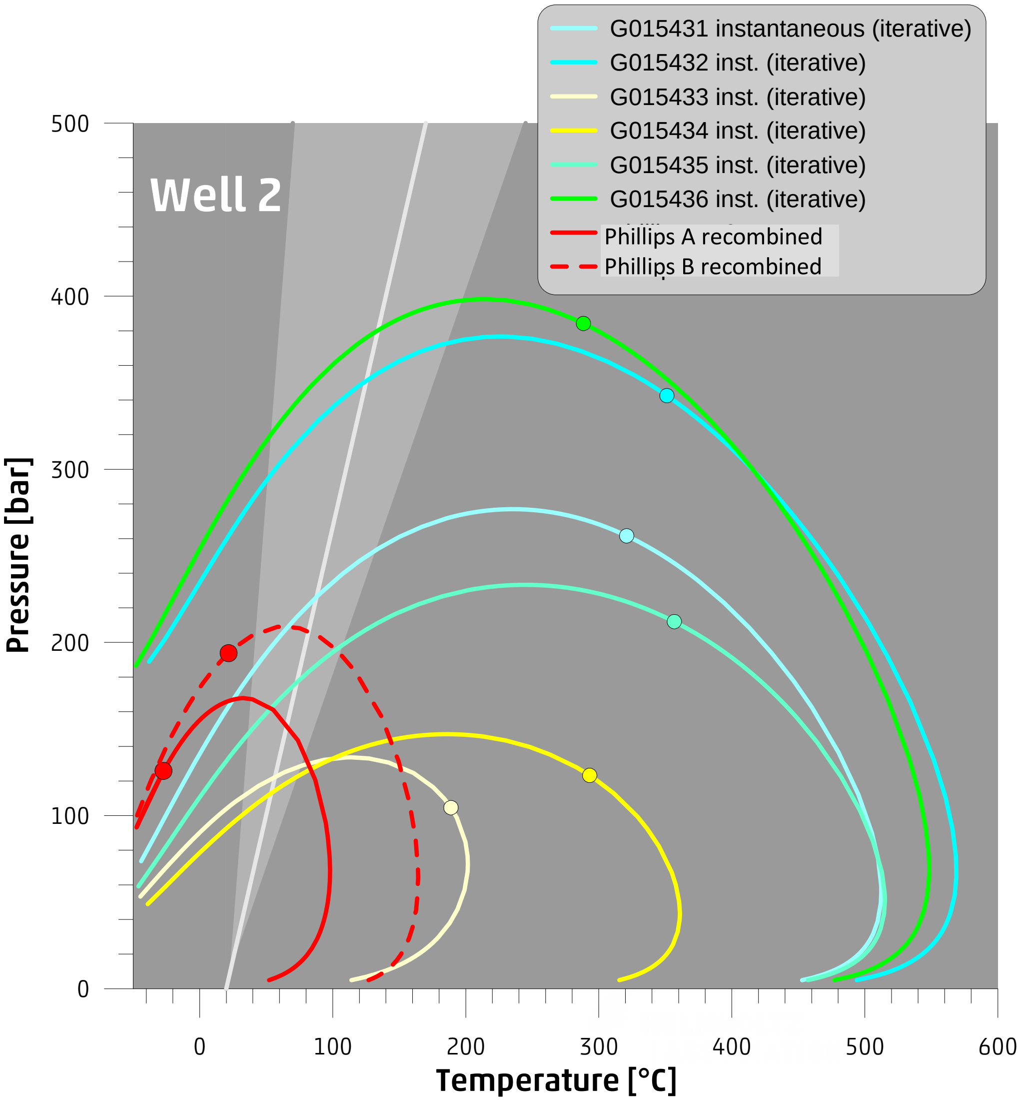




Wolfcamp of Texas

Instantaneously Generated Products 0.8 -> 0.95% Rm





Conclusions

- Bulk petroleum fluid prediction is a fundamentally important part of risk reduction
- PhaseKinetics protocols deliver sound predictions in a broad variety of petroleum provinces
- Source rocks and petroleum asphaltenes can be used – supplement with MSSV isotopes
- Applies to MENA conventionals

Conclusions

- Unconventionals are different!
- fluids have higher density and sorptive capacity than expelled crudes at same maturity
- Breakdown products will exhibit higher GORs and Psats
- PhaseKinetics and FT-ICR MS methodologies have an important role to play in optimising production efficiency