

Petroleum Systems Modeling of the Salt Province and Outer Margin Offshore Essaouira (Atlantic Margin of Morocco)*

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Search and Discovery Article #30386 (2014)**

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Abstract

The Atlantic margin offshore Morocco can be characterized as a frontier area where hydrocarbon exploration is very immature. While the onshore Essaouira Basin hosts some small fields, offshore exploration resulted in sub-commercial discoveries only. Recent deepwater wells failed to find viable reservoirs so far, however, numerous hydrocarbon shows have been encountered, and a variety of different potential traps are related to salt tectonics. In addition, the relative success of the conjugate Atlantic margin of Nova Scotia is encouraging. The Atlantic margin offshore Morocco recently gained the interest of international oil companies again, and an aggressive drilling program is planned for 2014. In the presented work, we used a crustal-scale model based on recently acquired 2D seismic reflection data (MIRROR experiment, 2011) for regional thermal modeling to investigate the temporal evolution of temperature and thermal maturity at potential source rock levels. The modeling took into account the geodynamic evolution from Early Mesozoic rifting and continental break-up to major Cenozoic events, such as the Canary Island hot spot and the Atlas orogeny. In a further analysis of the salt basin, we performed structural restoration, describing the diapiric salt rise and extrusion, and integrating the process of salt withdrawal and associated sediment deformation. Based on the obtained model, we carried out petroleum systems modeling to predict potential scenarios of source rock maturation,

hydrocarbon expulsion, migration, and accumulations in the context of the salt deformation through geologic time. The elements (source, reservoir, and seal rocks) and dynamic processes (trap formation, charge, and preservation) of different potential petroleum systems are discussed, and promising salt-related and other play types will be presented.

References Cited

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Tari, G., and H. Jabour, 2013, Salt tectonics along the Atlantic margin of Morocco in W.U. Mohriak, A. Danforth, P.J. Post, D.E. Brown, G.C. Tari, M. Nemcok, and S.T. Sinha (eds.), Conjugate Divergent Margins: Geological Society of London, Special Publications 369. dx.doi.org/10.1144/SP369.23.

Wygrala, B.P., 1989, Integrated study of an oil field in the southern Po basin, northern Italy: Ph.D. dissertation, Köln University, Jülich, Research Centre Jülich, Jul-Rep. 2313, ISSN 0366-0885, 217 p.

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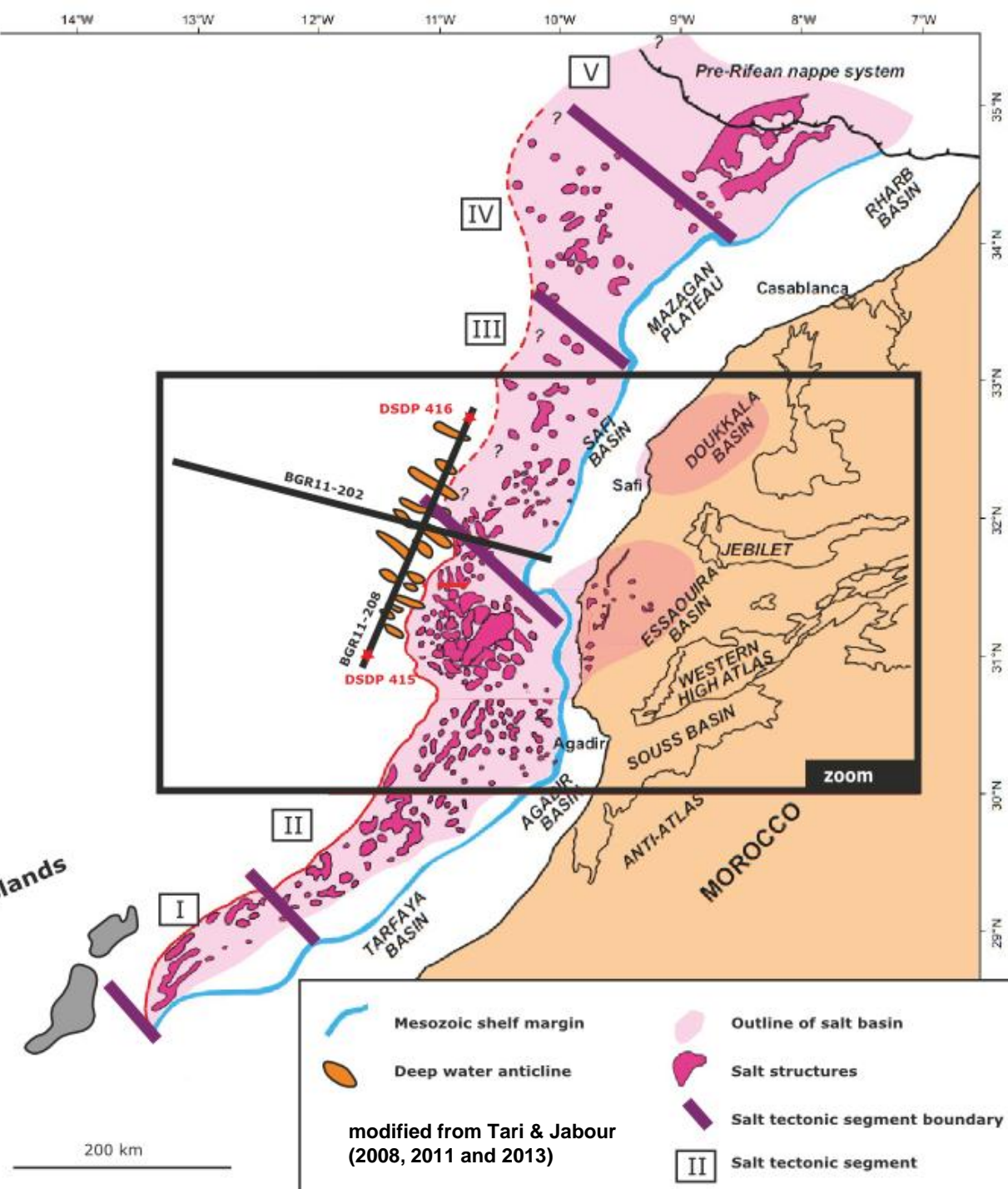


Introduction

- Passive Margin
- Atlas Mountain Belt



Canary Islands

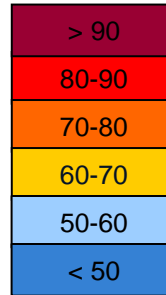


Introduction

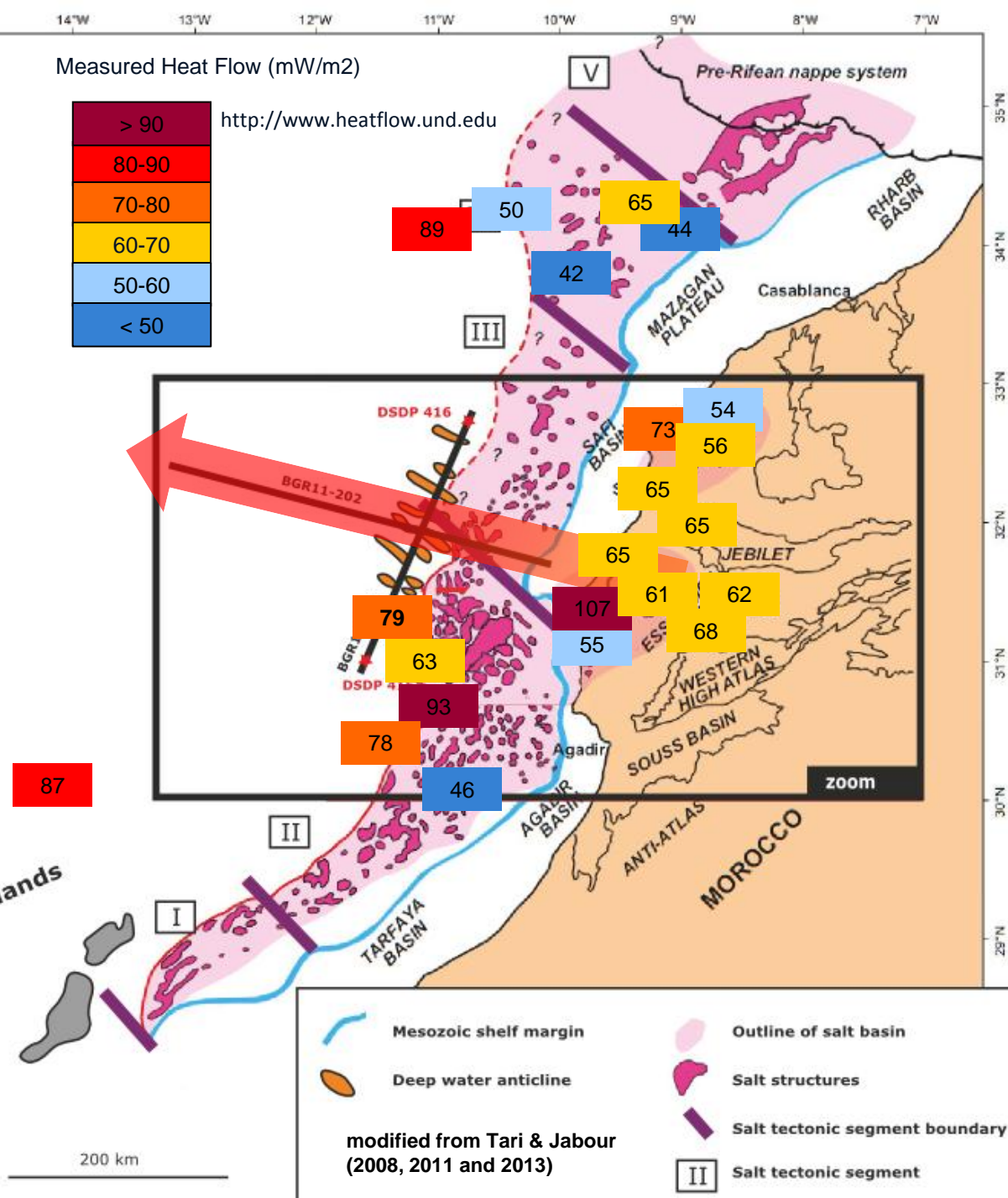
- Passive Margin
- Atlas Mountain Belt
- Canary Islands



Measured Heat Flow (mW/m²)

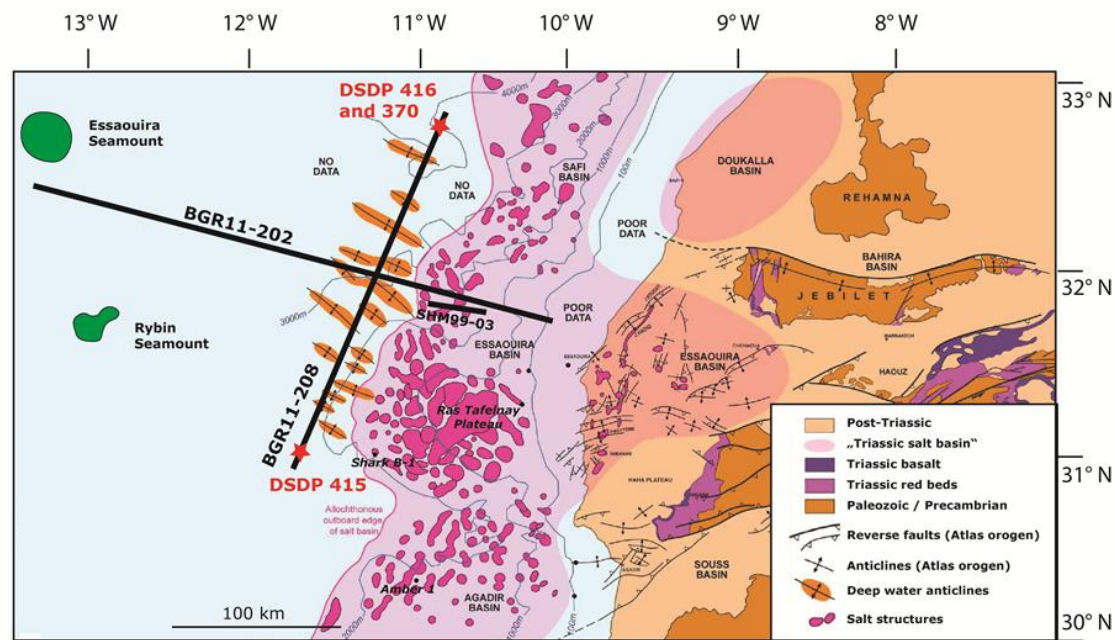


<http://www.heatflow.und.edu>



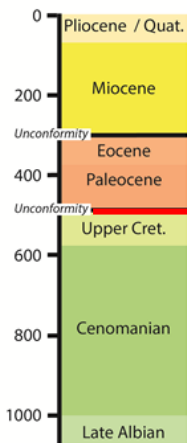
Introduction

- Outer Margin
 - Deep-water folds

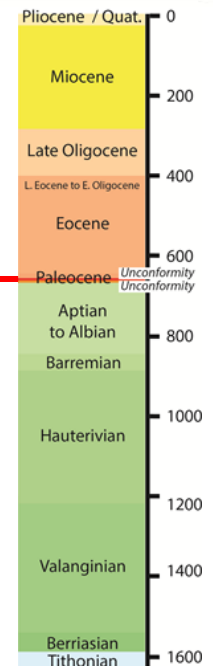
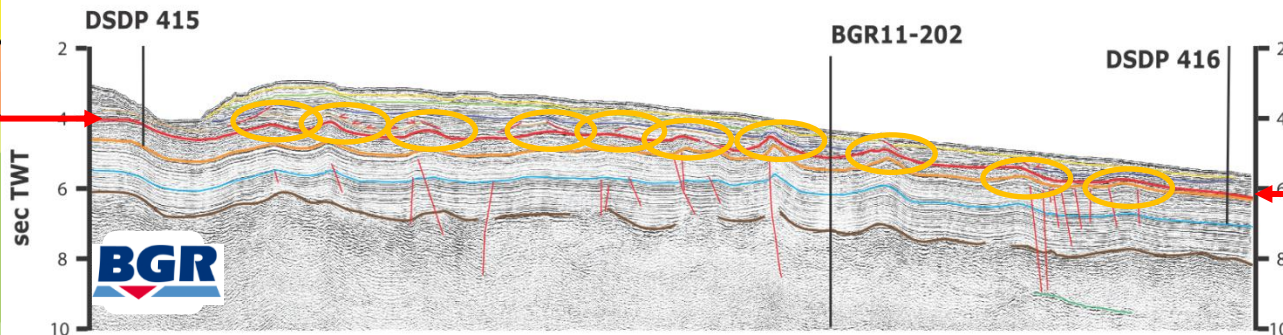


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Depth (m bml)

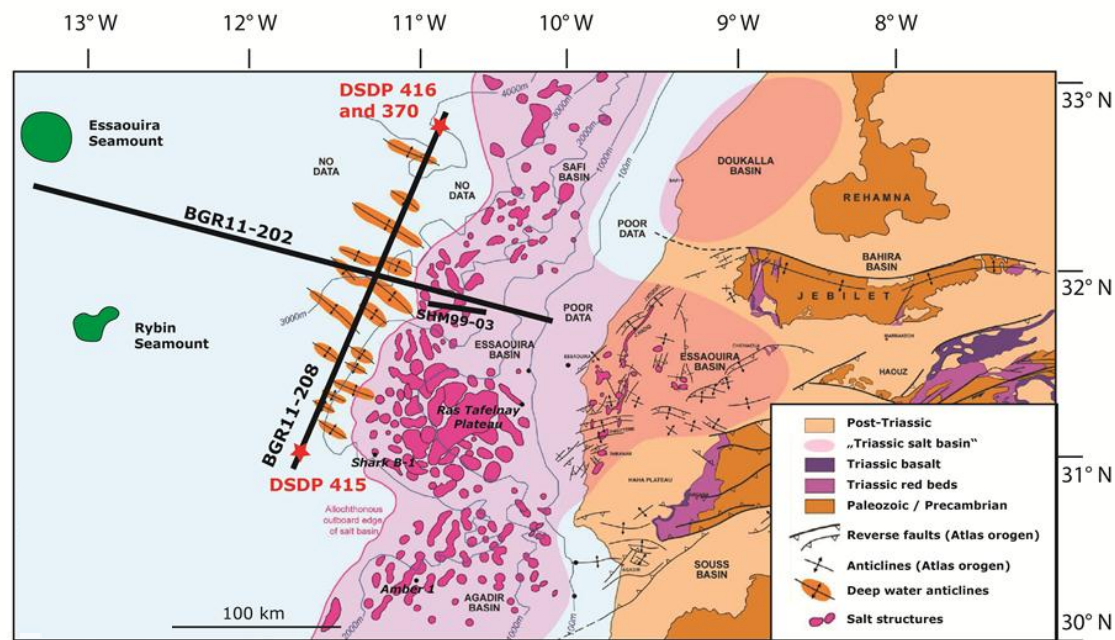


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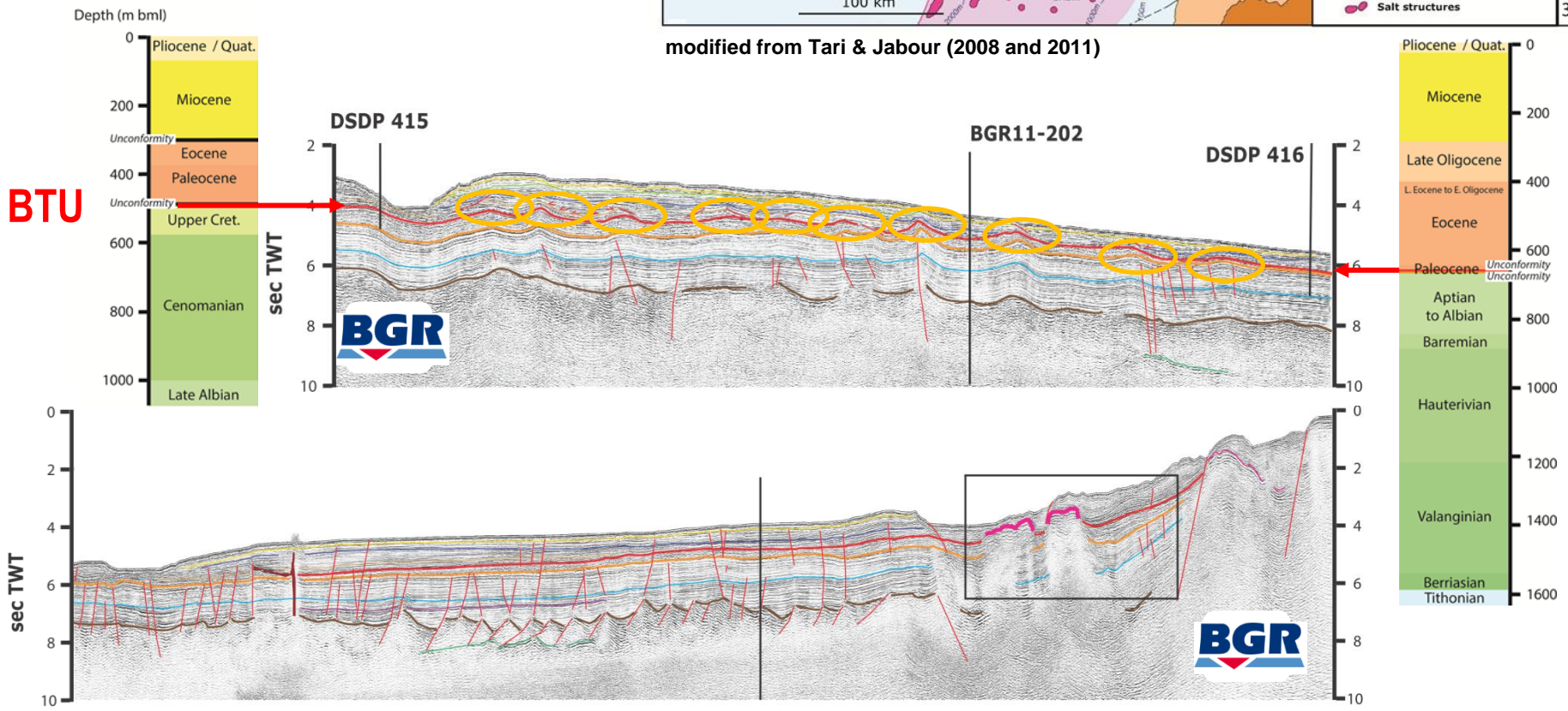


Introduction

- Outer Margin
 - Deep-water folds
- Salt Province

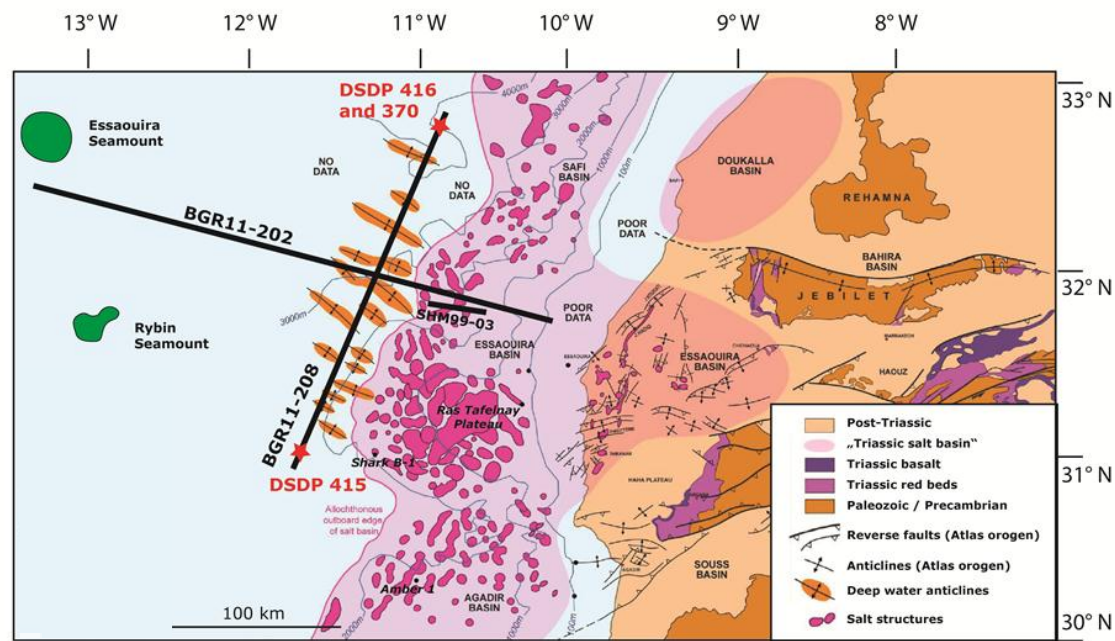


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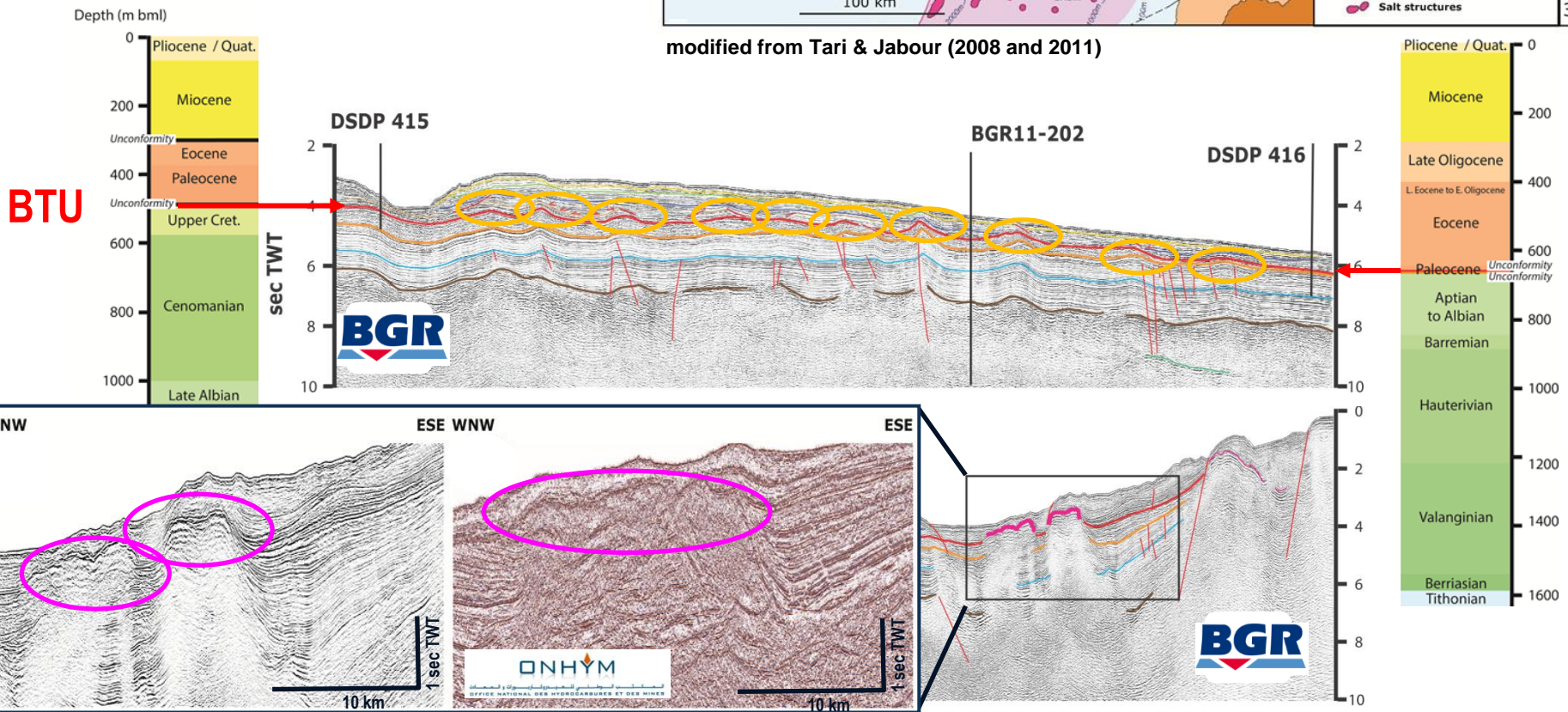


Introduction

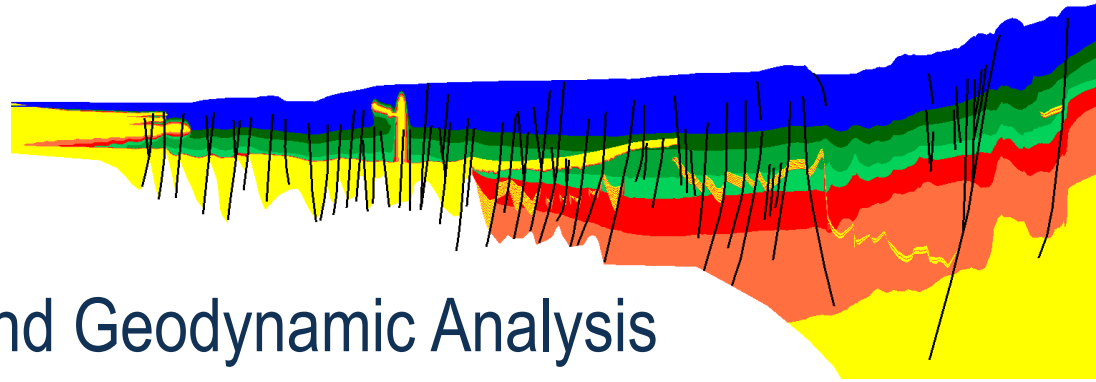
- Outer Margin
 - Deep-water folds
- Salt Province



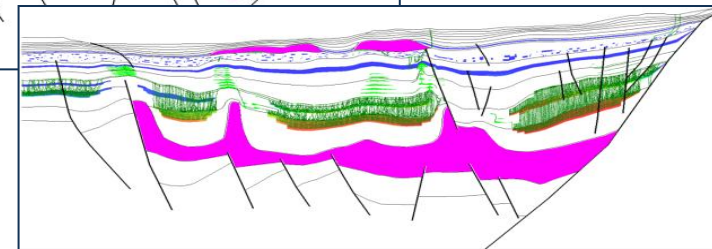
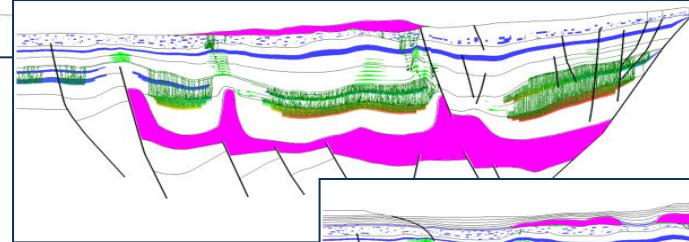
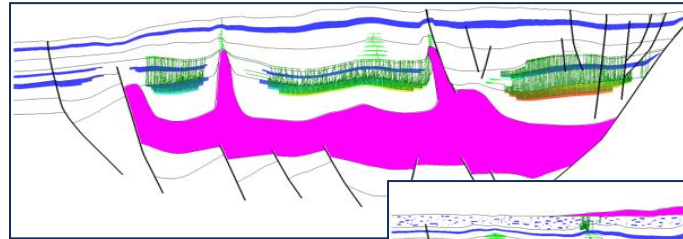
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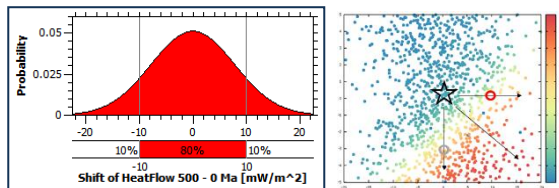
Workflow Summary



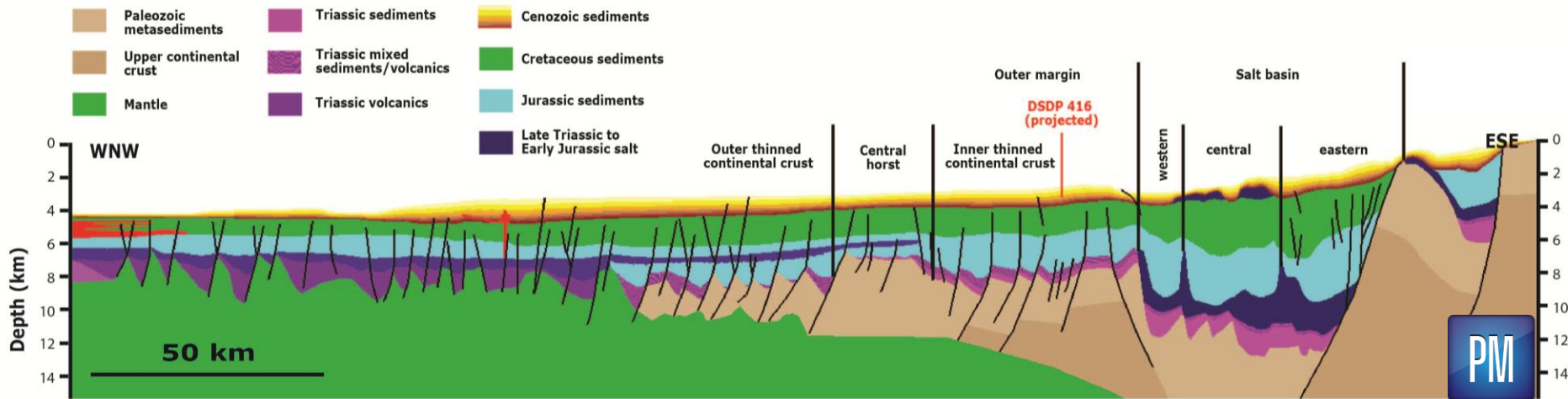
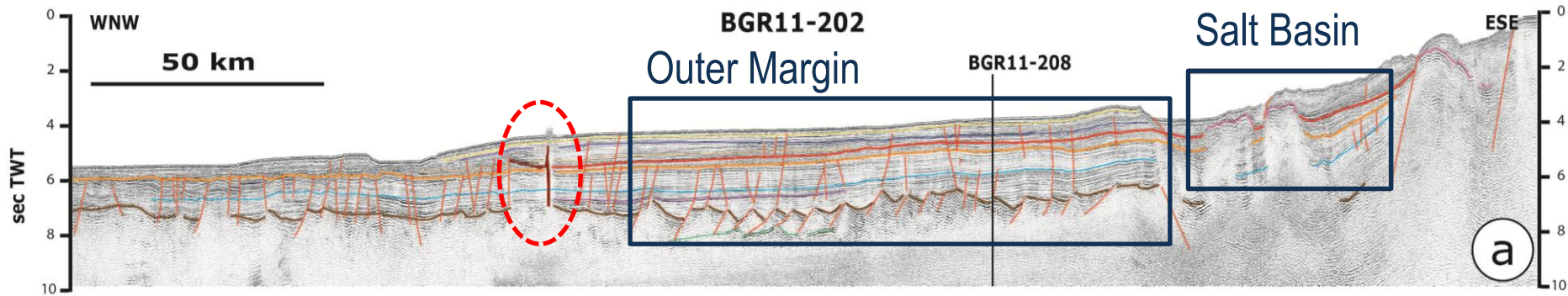
- Seismic Interpretation and Geodynamic Analysis
- Regional Thermal Modeling



- Structural Restoration
- Petroleum Systems Modeling
- Monte Carlo Uncertainty Analysis



Regional Basin Model



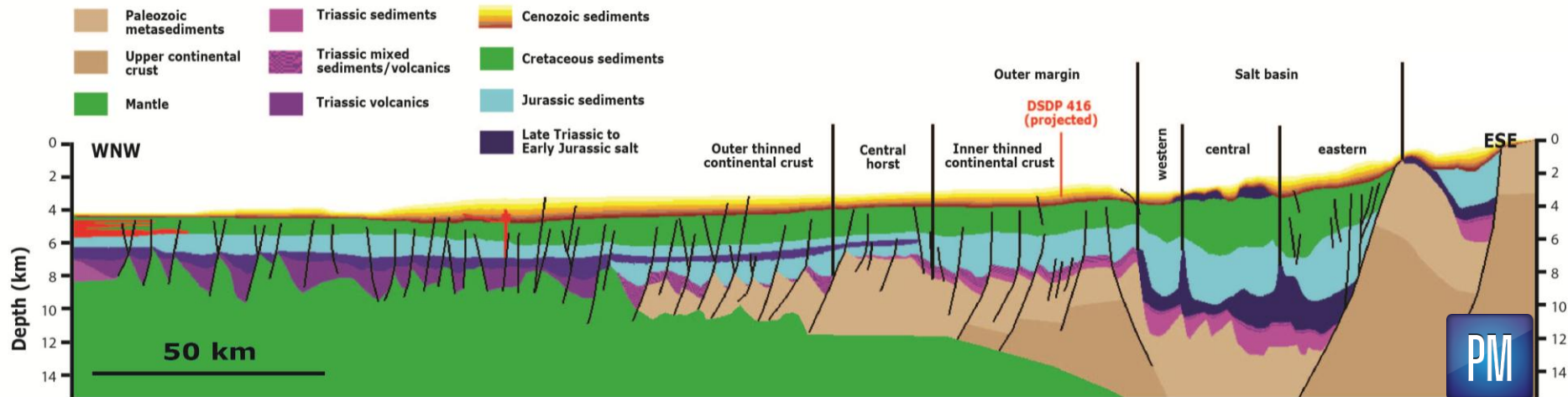
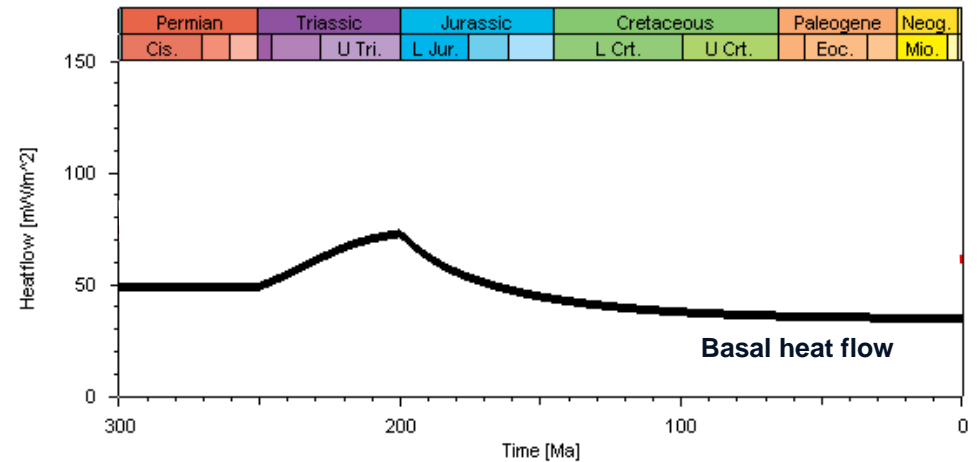
Regional Basin Model

Basal heat flow with Late Triassic rift peak

Surface temperature according to Wygrala (1989)

Additional heat sources

- Radiogenic heat (continental basement)
- Volcanic surface flows
- Volcanic intrusions
- Mantle heat (hotspot)



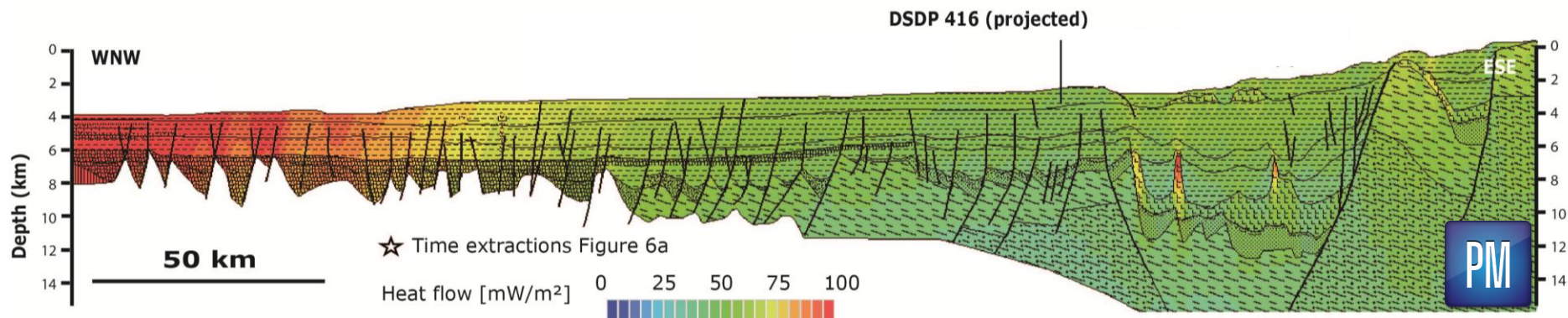
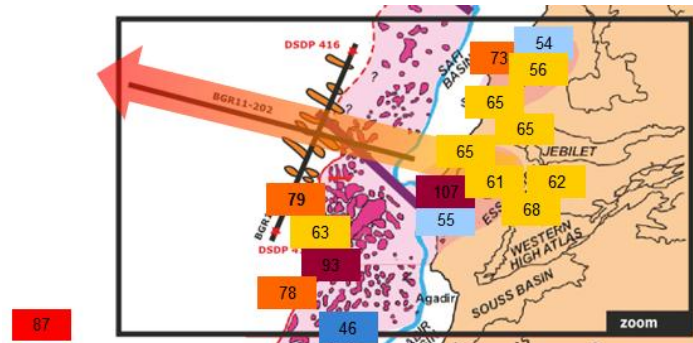
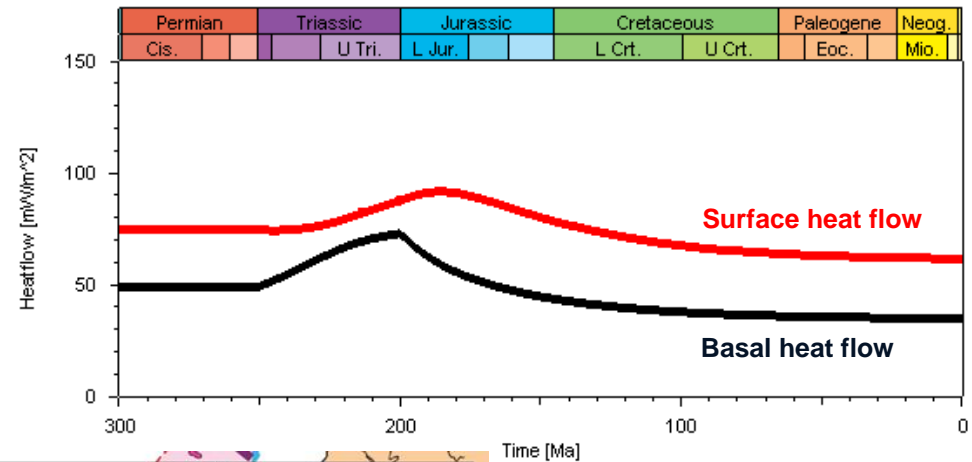
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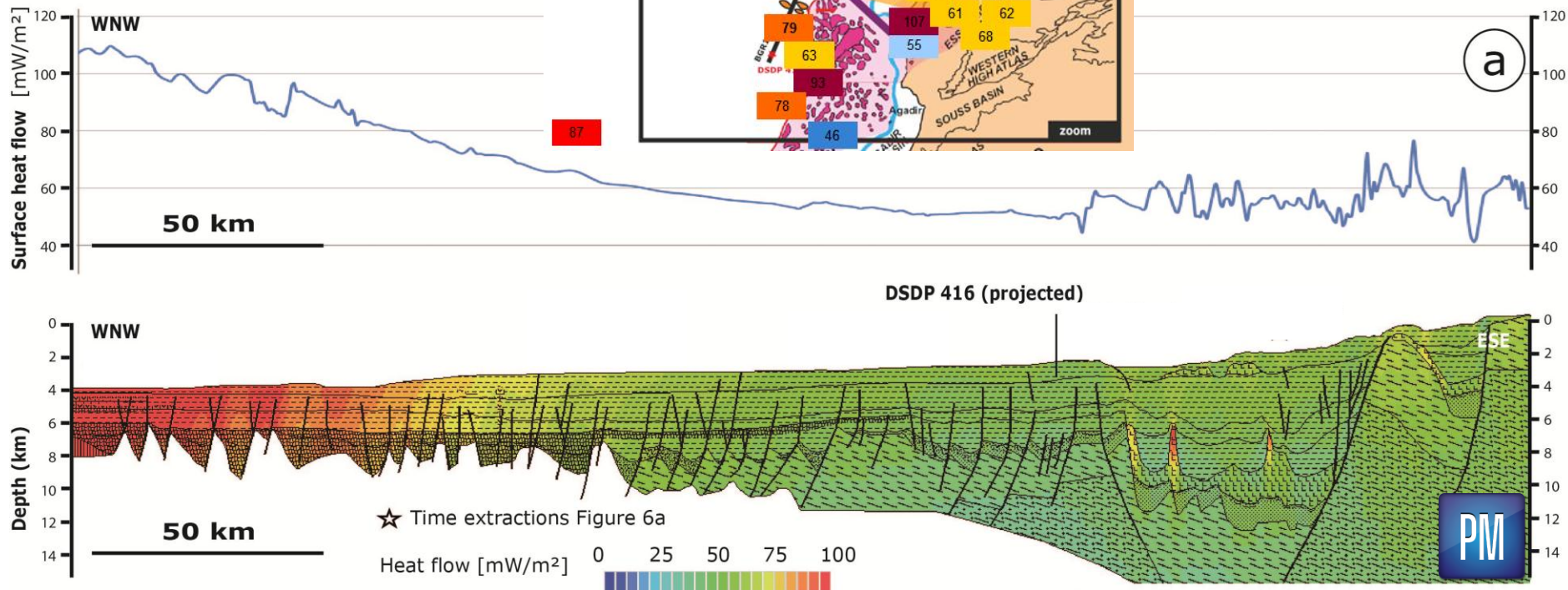
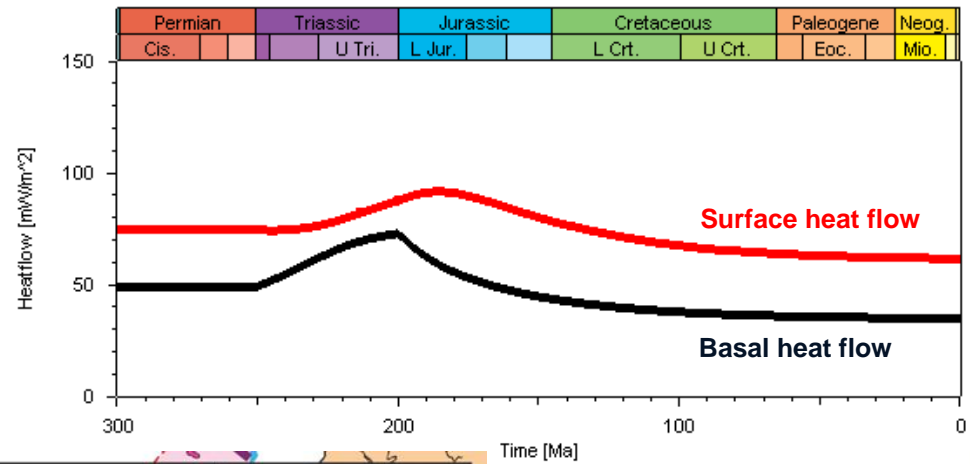
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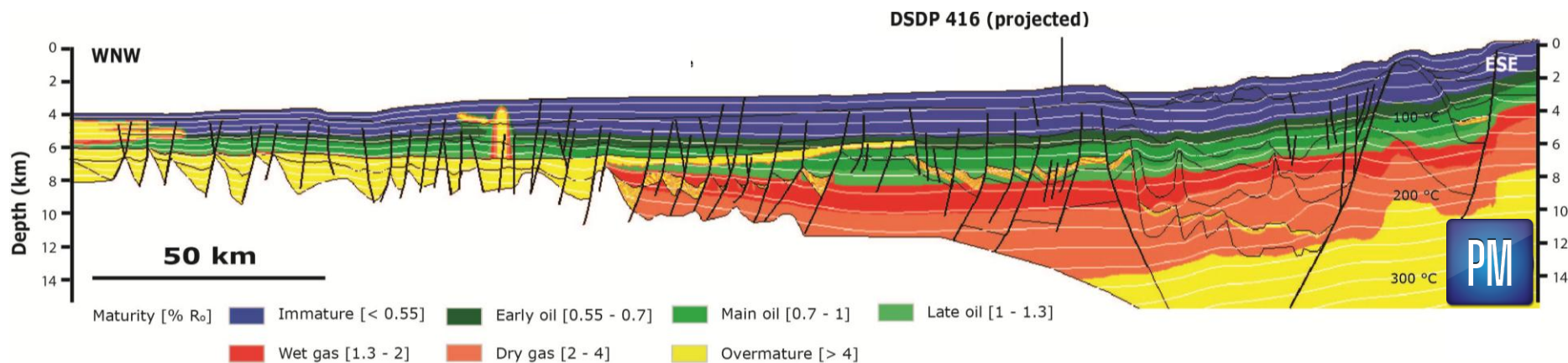
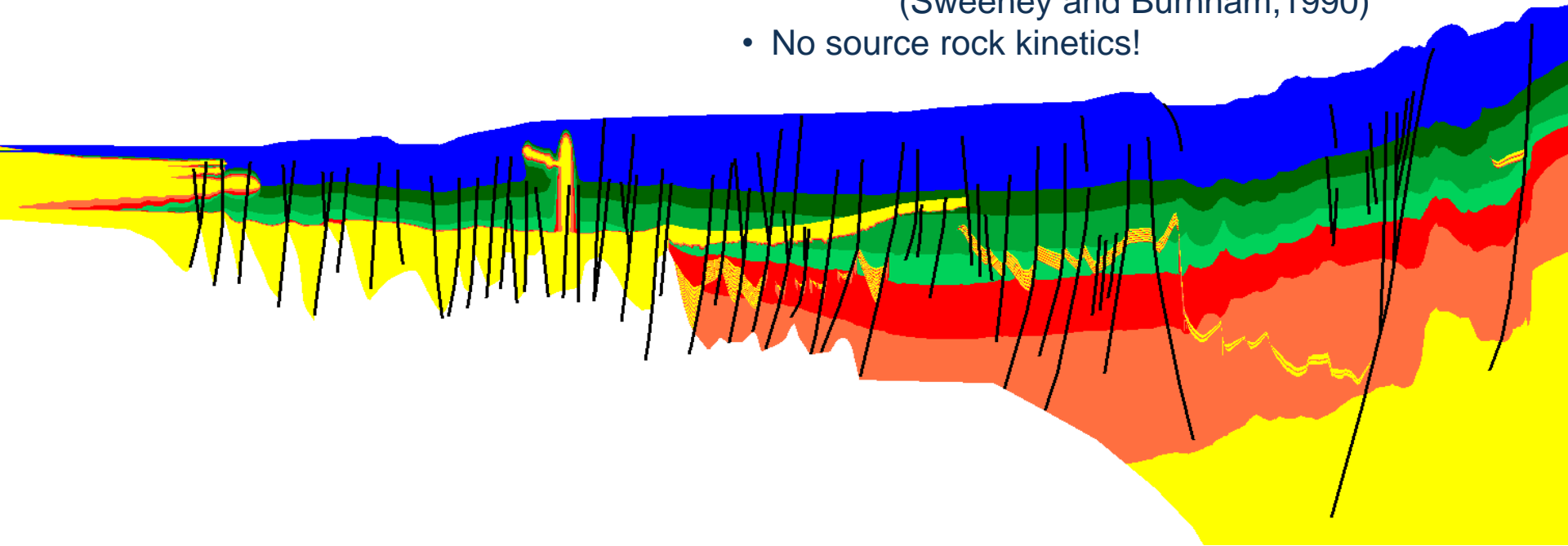
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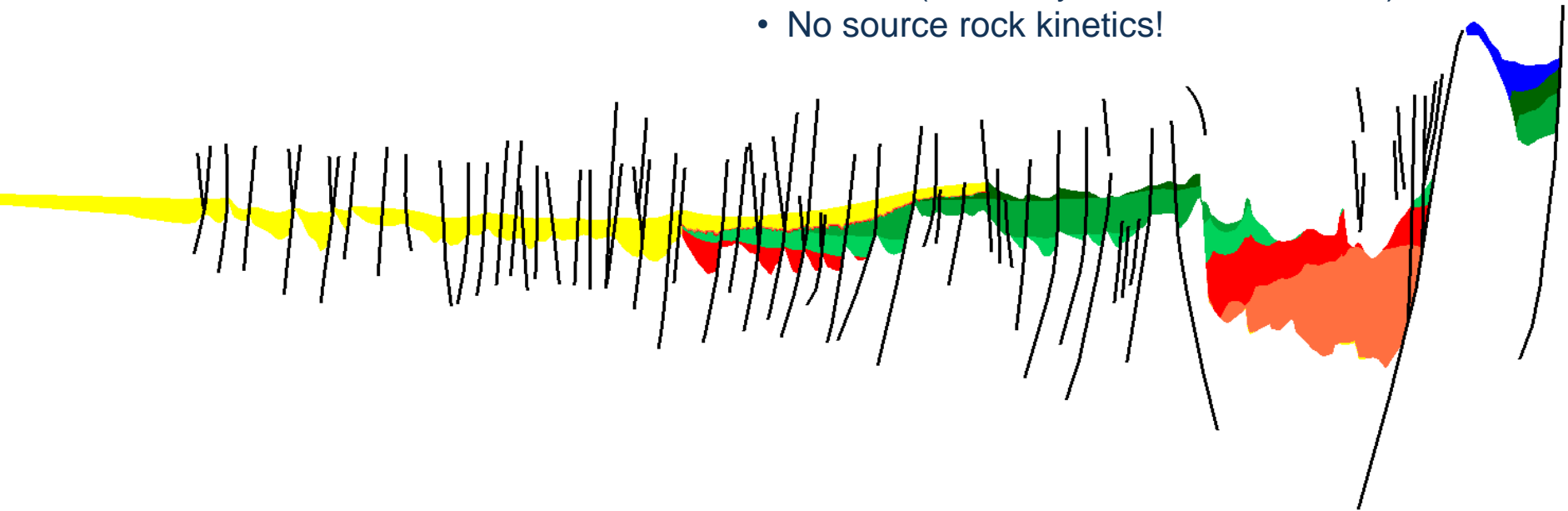
Regional Basin Model

- Regional thermal maturity
- Based on vitrinite reflectance kinetics (Sweeney and Burnham, 1990)
- No source rock kinetics!



Regional Basin Model

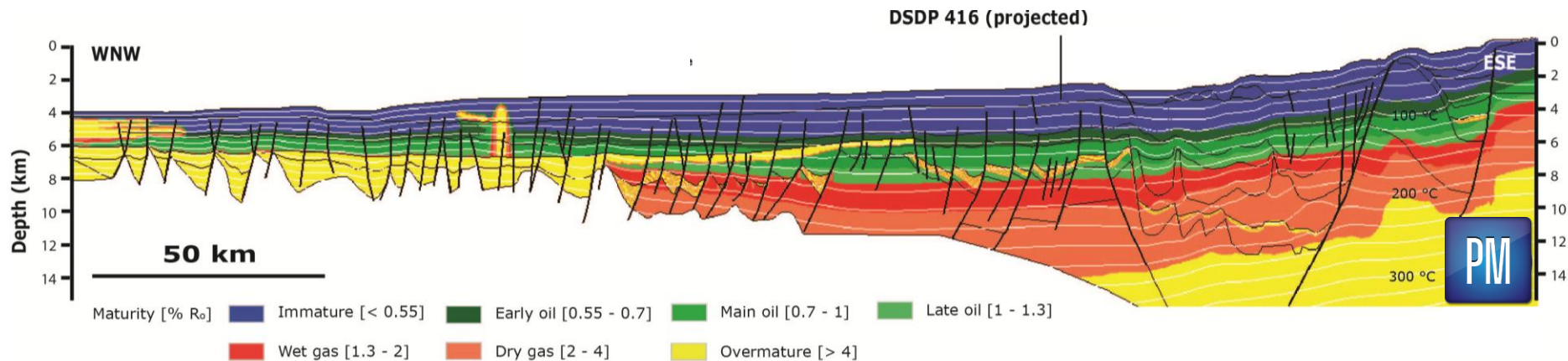
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Lower and Middle Jurassic

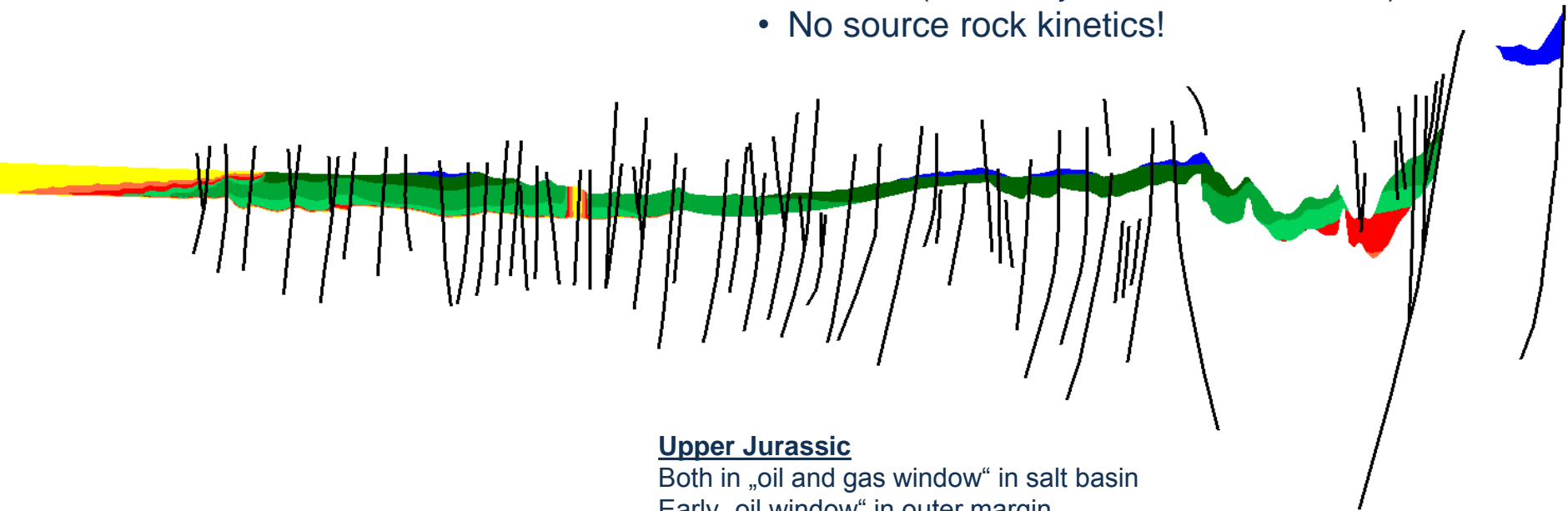
Mostly in „gas window“ in salt basin

Mostly in „oil window“ in outer margin



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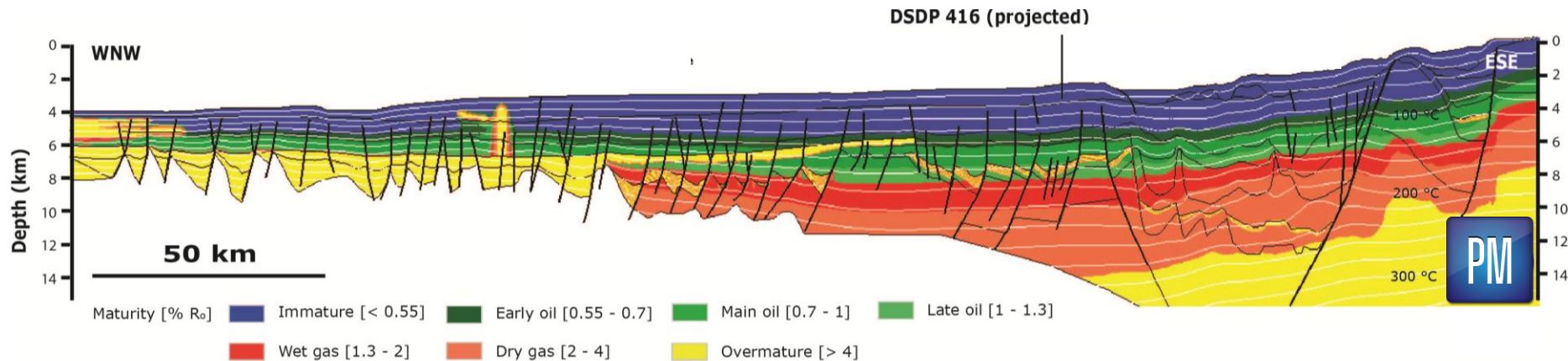


Upper Jurassic

Both in „oil and gas window“ in salt basin
Early „oil window“ in outer margin

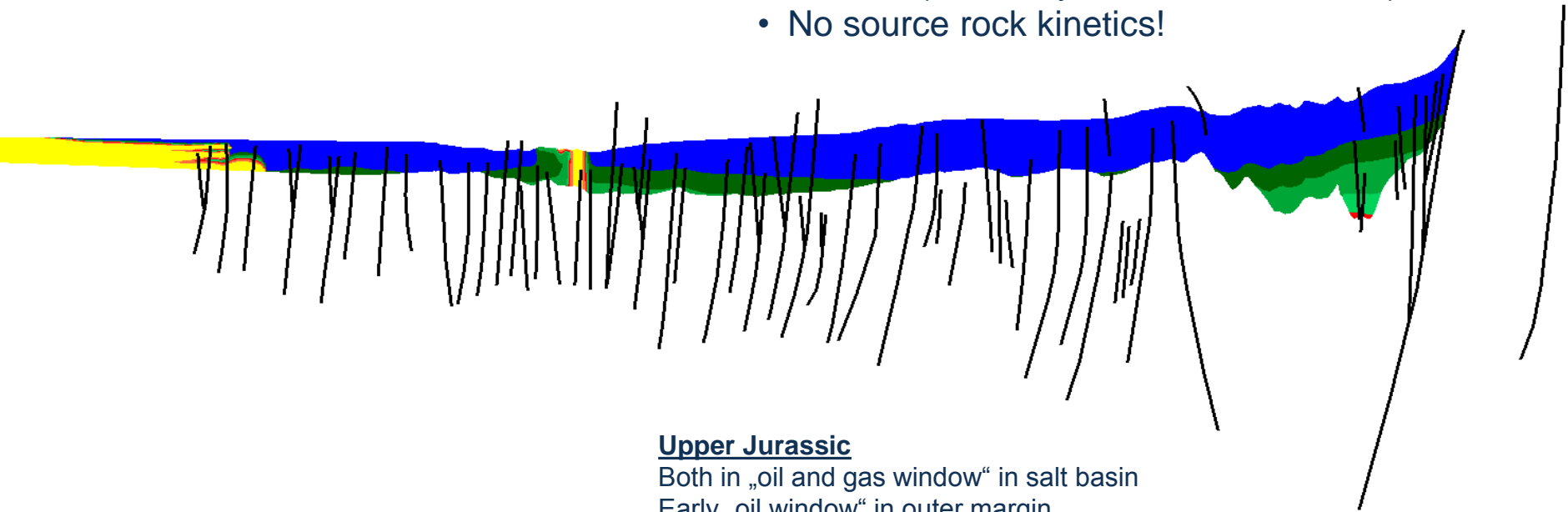
Lower and Middle Jurassic

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Upper Jurassic

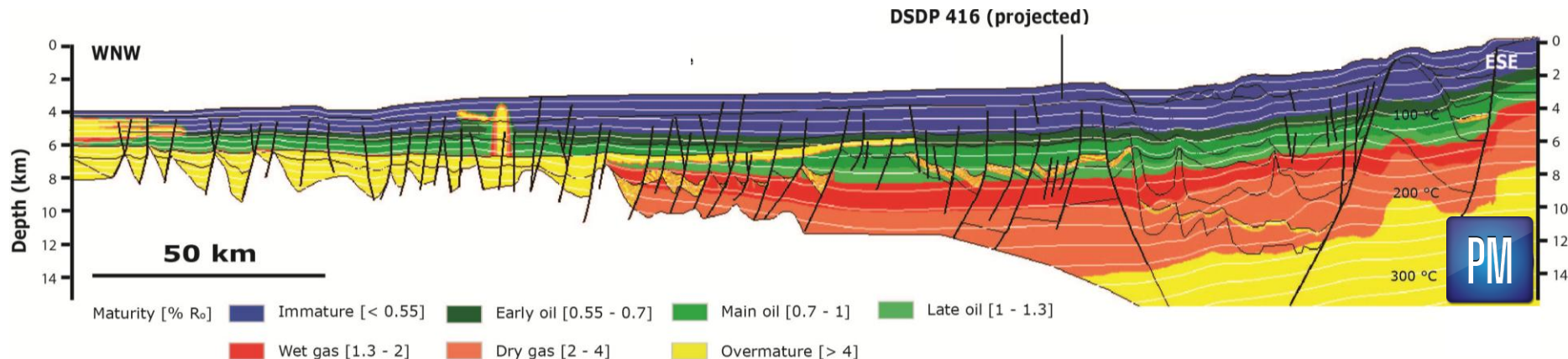
Both in „oil and gas window“ in salt basin
Early „oil window“ in outer margin

Cretaceous

Lower Cretaceous in „oil window“ in salt basin
Mostly immature in outer margin

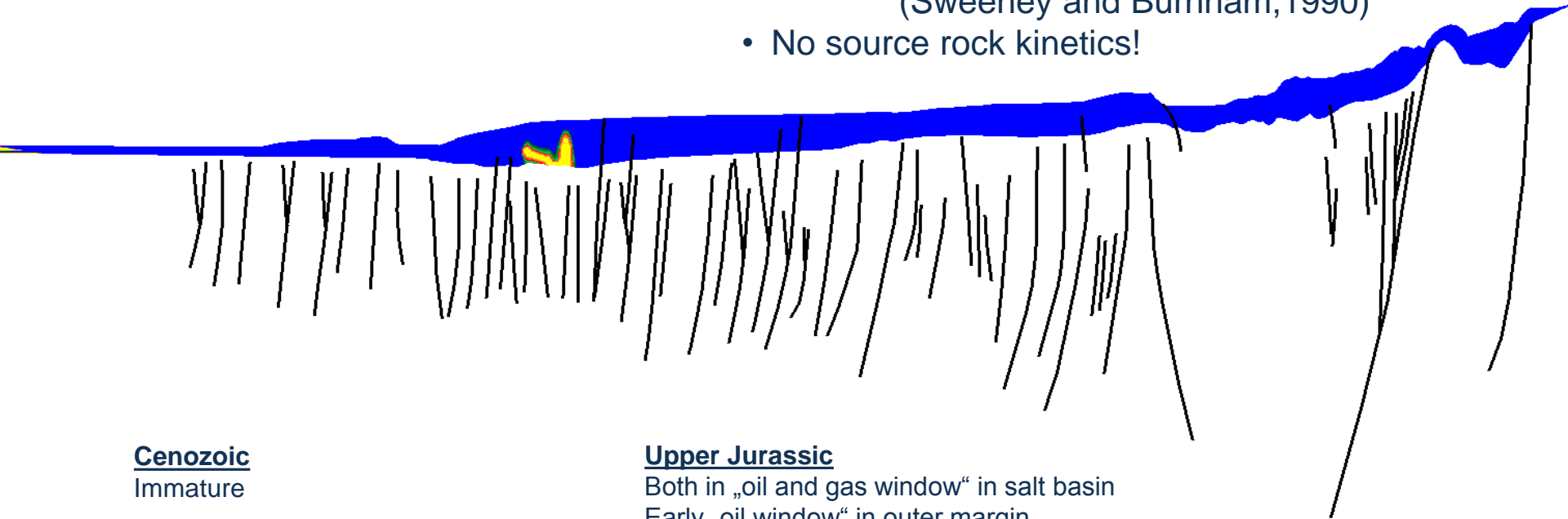
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Cenozoic
Immature

Upper Jurassic

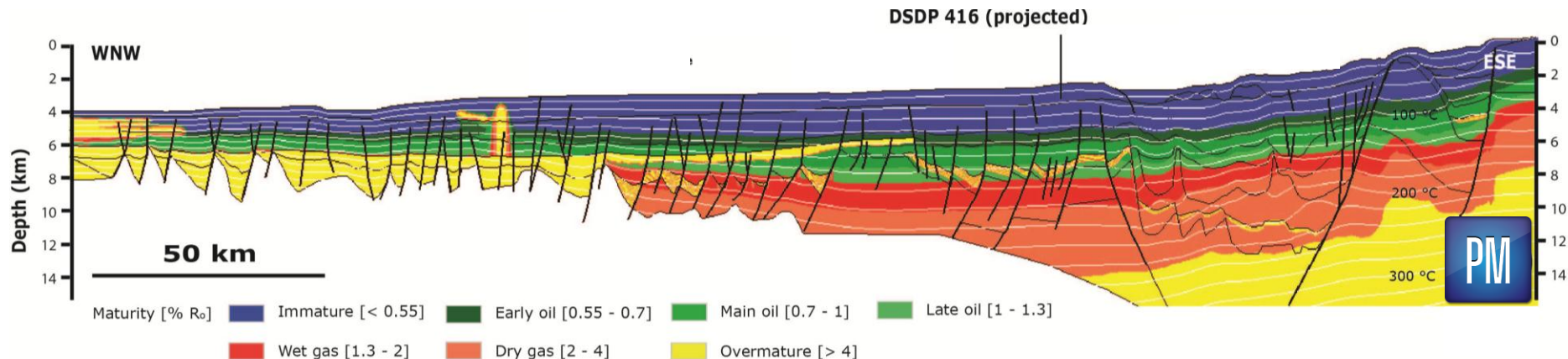
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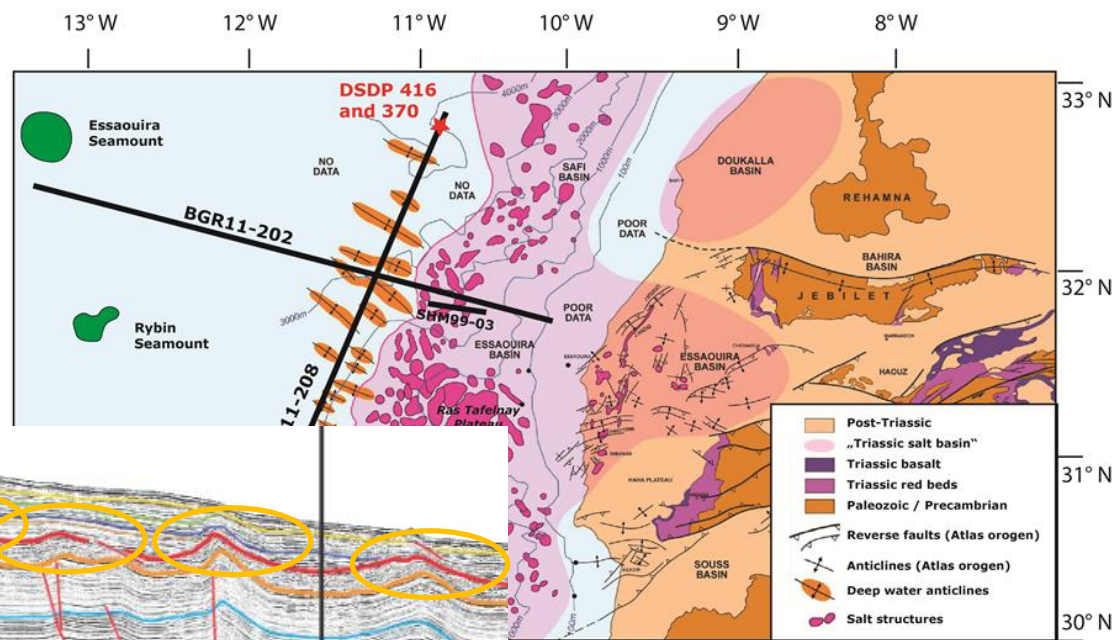
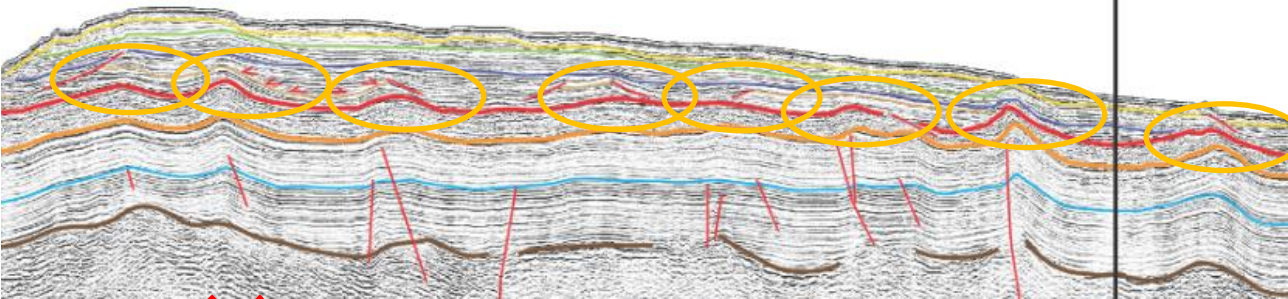
Lower and Middle Jurassic

Mostly in „gas window“ in salt basin
Mostly in „oil window“ in outer margin



Regional Basin Model

- Outer Margin
 - Deep-water folds

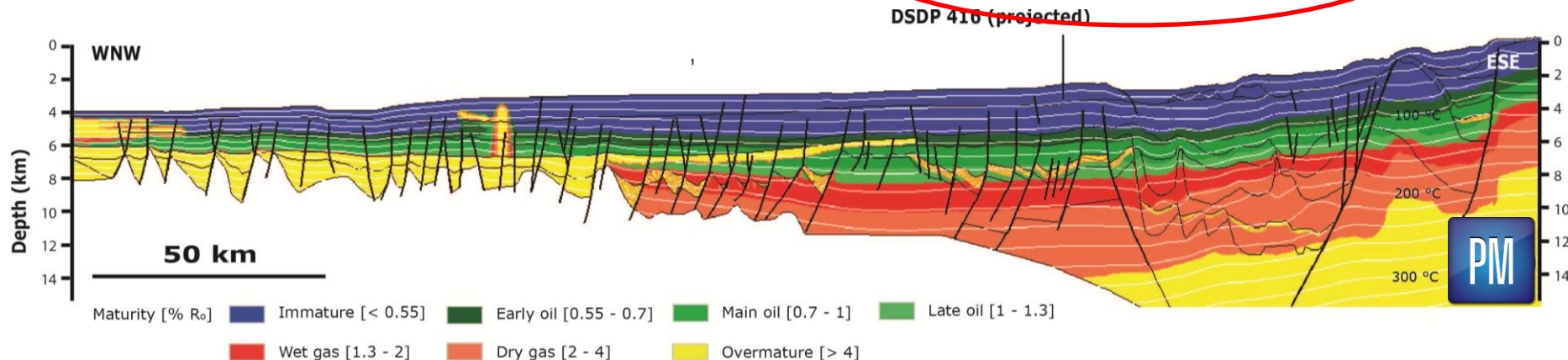


Cenozoic
Immature

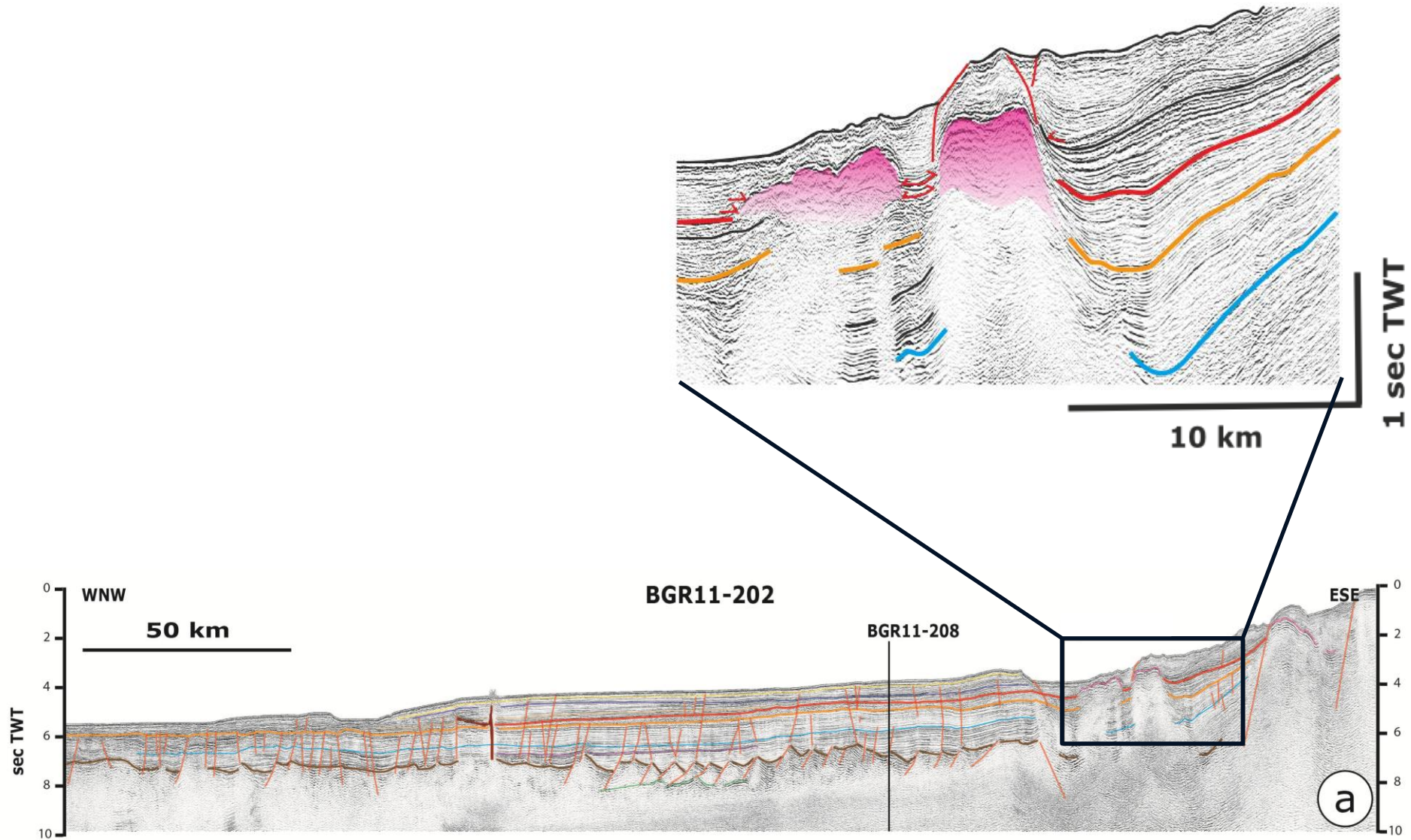
Upper Jurassic
Both in „oil and gas window“ in salt basin
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Cretaceous
Lower Cretaceous in „oil window“ in salt basin
Mostly immature in outer margin

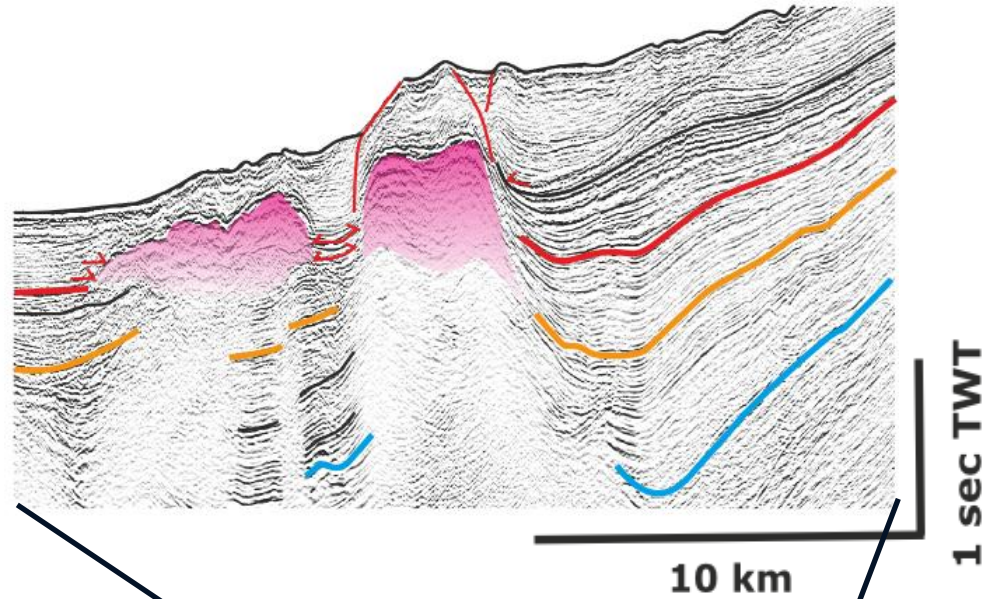
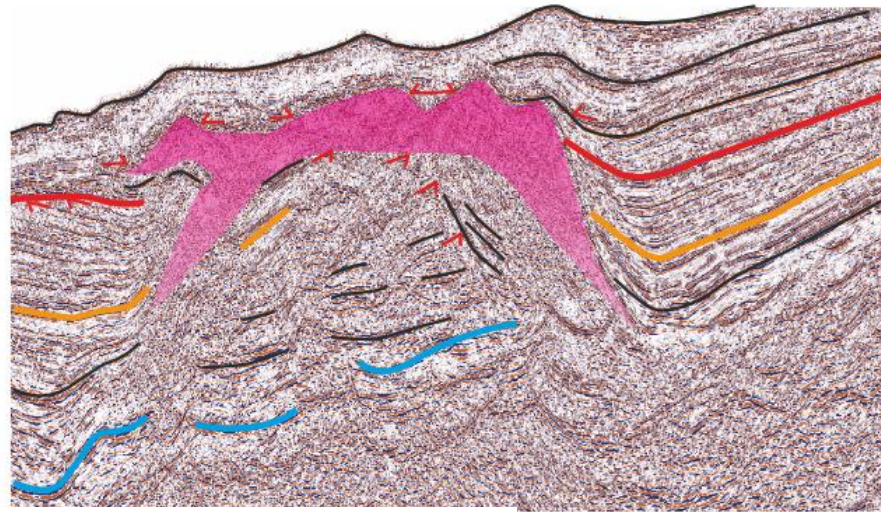
Lower and Middle Jurassic
Mostly in „gas window“ in salt basin
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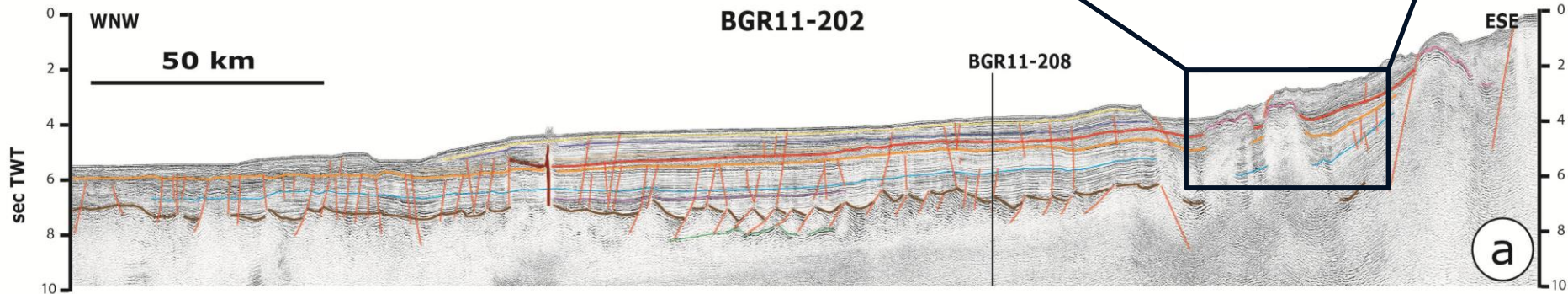
Salt Basin



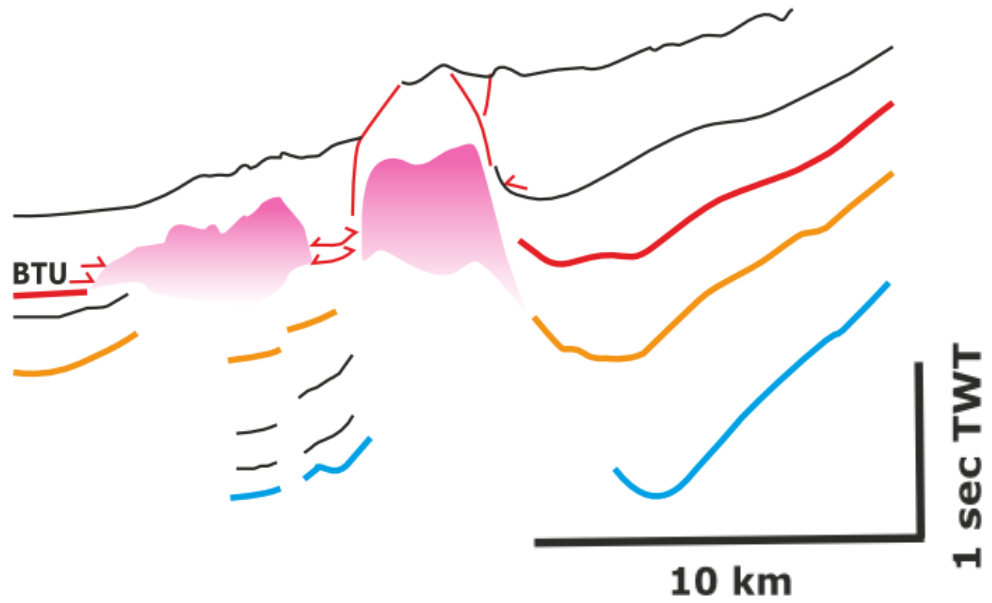
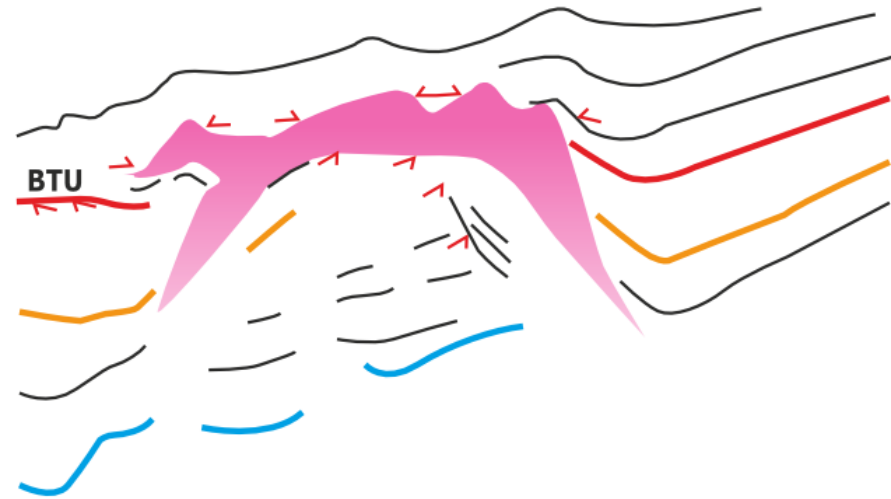
Salt Basin



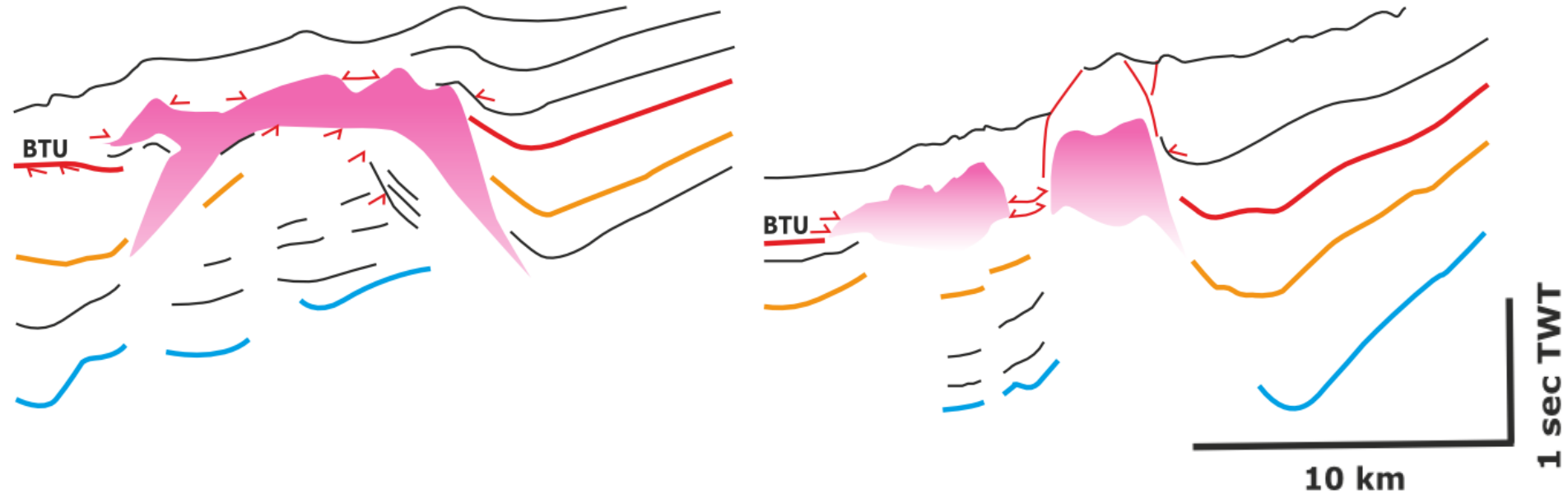
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Salt Basin



Salt Basin



*Middle Jurassic to
Early Cretaceous*

*Cenomanian to
Coniacian (?)*

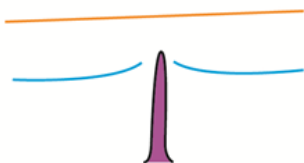
Late Cretaceous

Cenozoic

Continuous burial

Sedimentation hiatus

Minor burial



Diapiric salt rise

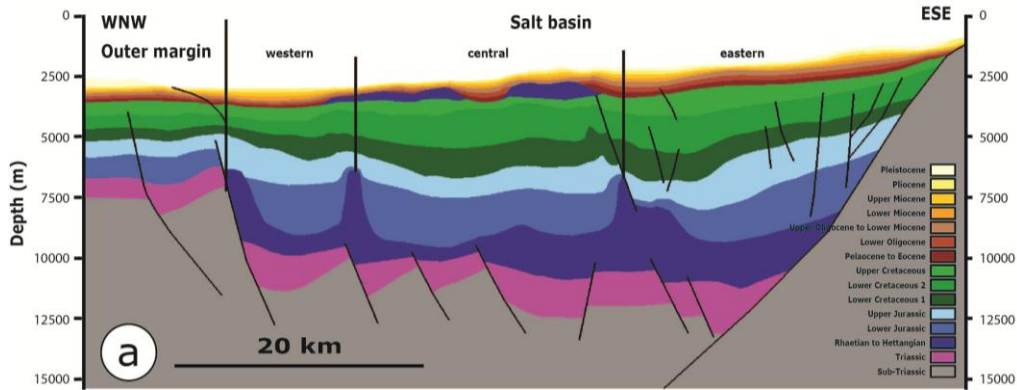
Submarine salt extrusion

Massive dissolution and cap rock building

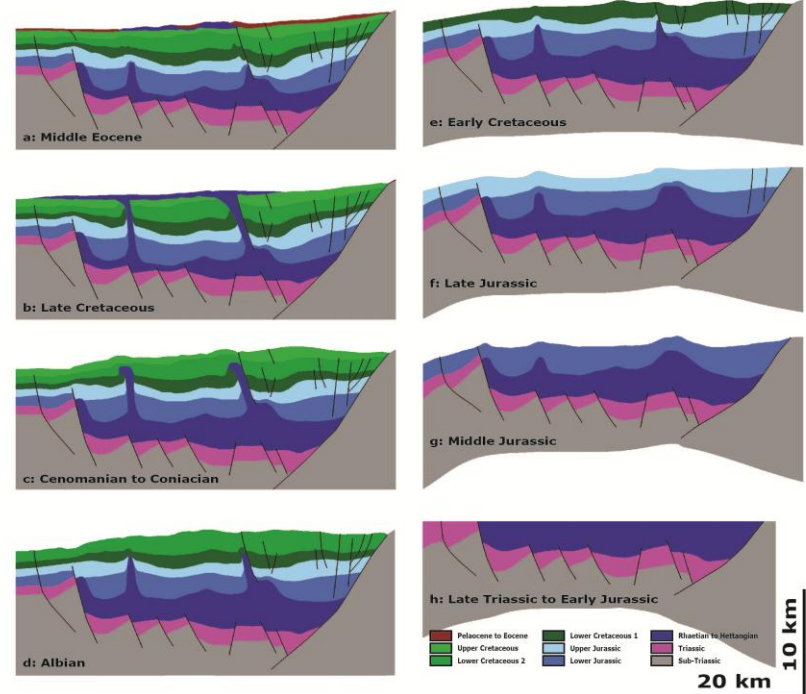
Limited remobilization

Salt Basin

■ Structural restoration



■ Dynel



*Middle Jurassic to
Early Cretaceous*

*Cenomanian to
Coniacian (?)*

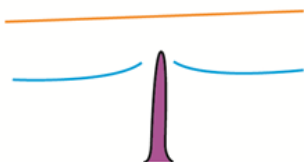
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Diapiric salt rise

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Massive dissolution and cap rock building

Limited remobilization

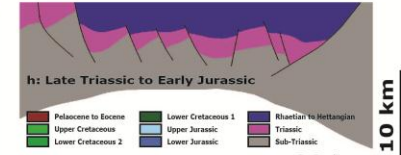
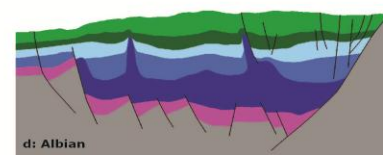
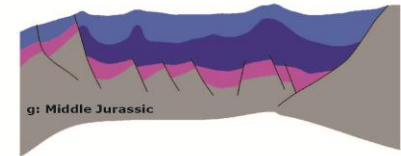
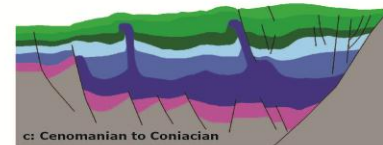
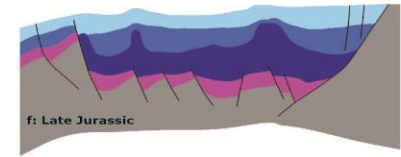
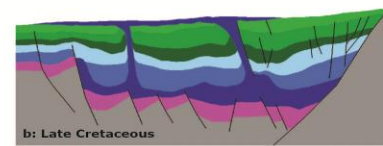
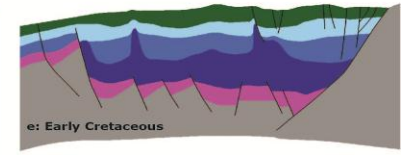
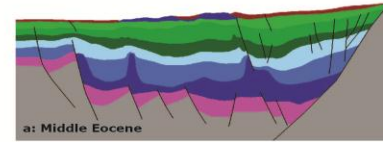
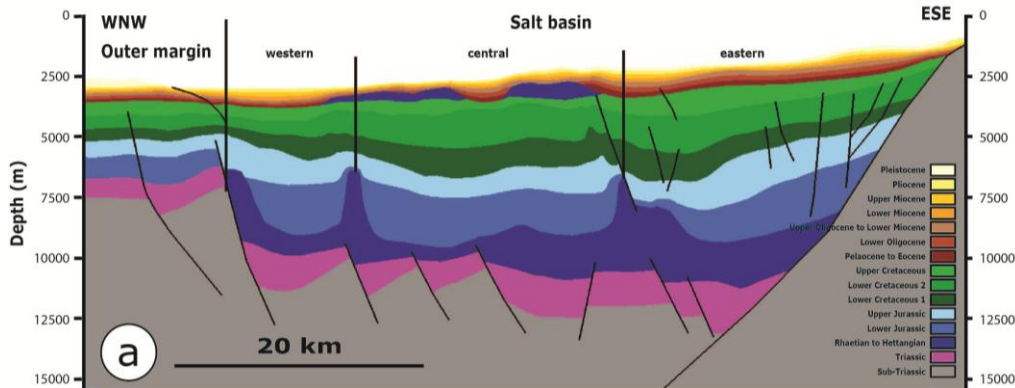
Salt Basin

- Structural restoration
- Basin and petroleum systems modeling

Dynel



PetroMod* TecLink



*Middle Jurassic to
Early Cretaceous*

*Cenomanian to
Coniacian (?)*

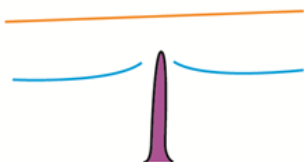
Late Cretaceous

Cenozoic

Continuous burial

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Minor burial



Diapiric salt rise



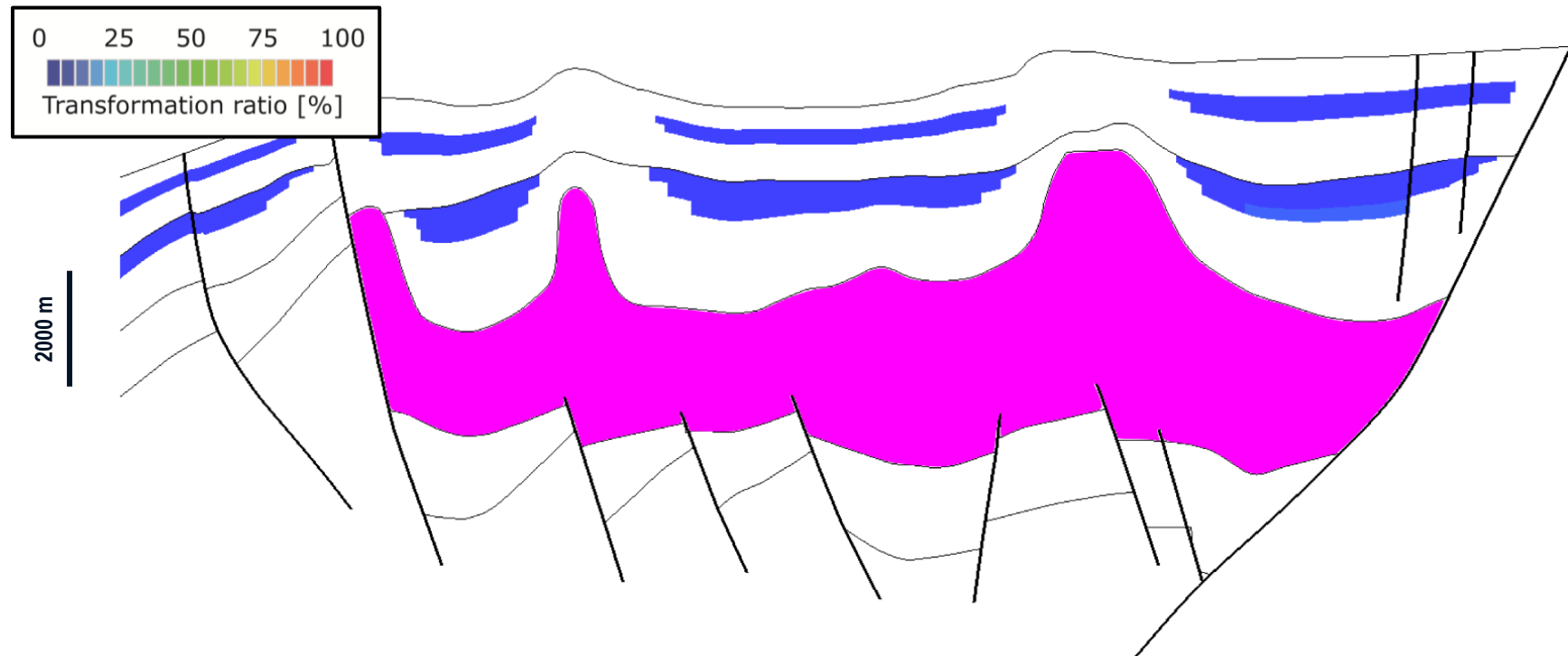
Submarine salt extrusion

Massive dissolution and cap rock building



Limited remobilization

Salt Basin – Petroleum Systems Model



Jurassic

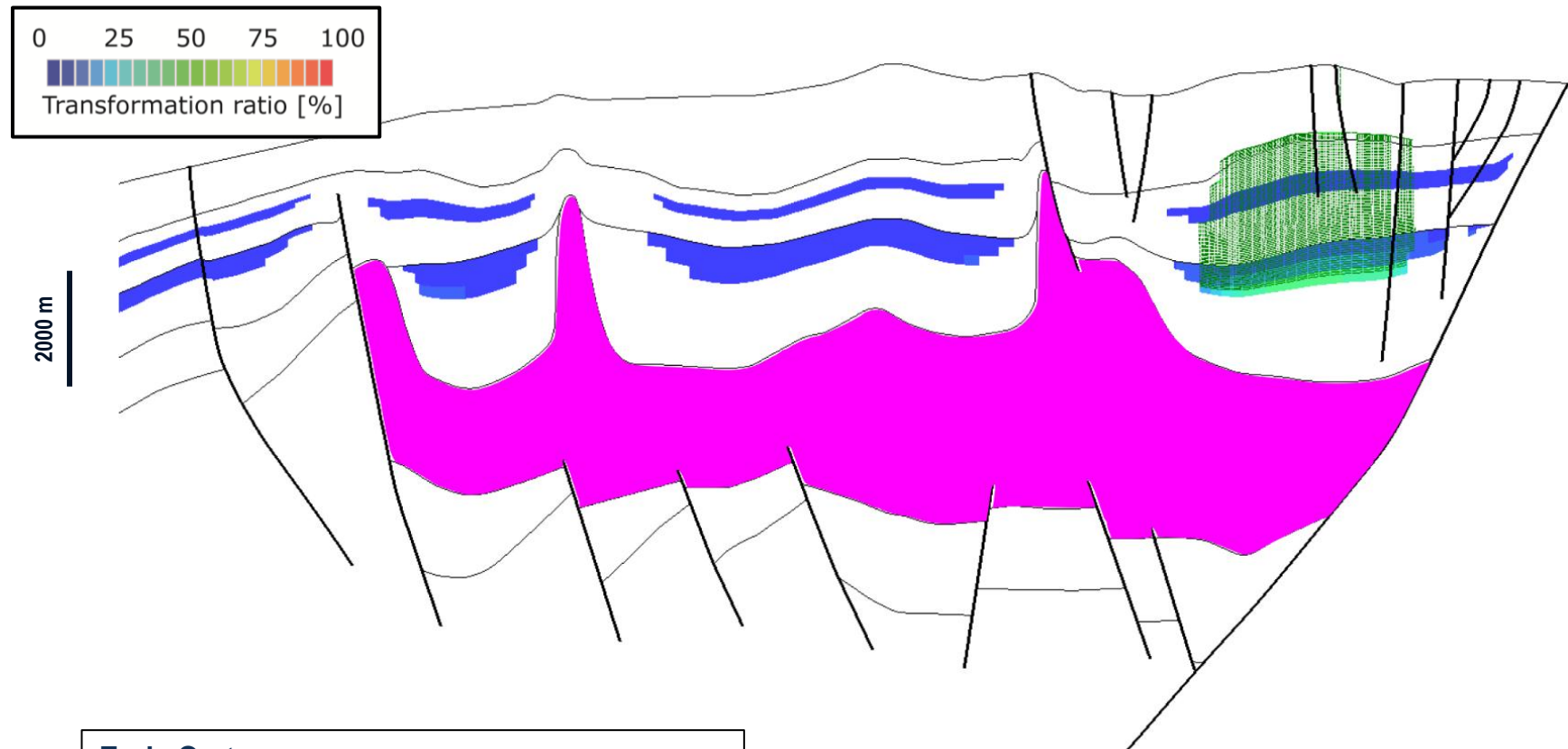
- Deposition of Toarcian and Oxfordian source rocks in basinal lows



PetroMod* TecLink

10 km

Salt Basin – Petroleum Systems Model



Early Cretaceous

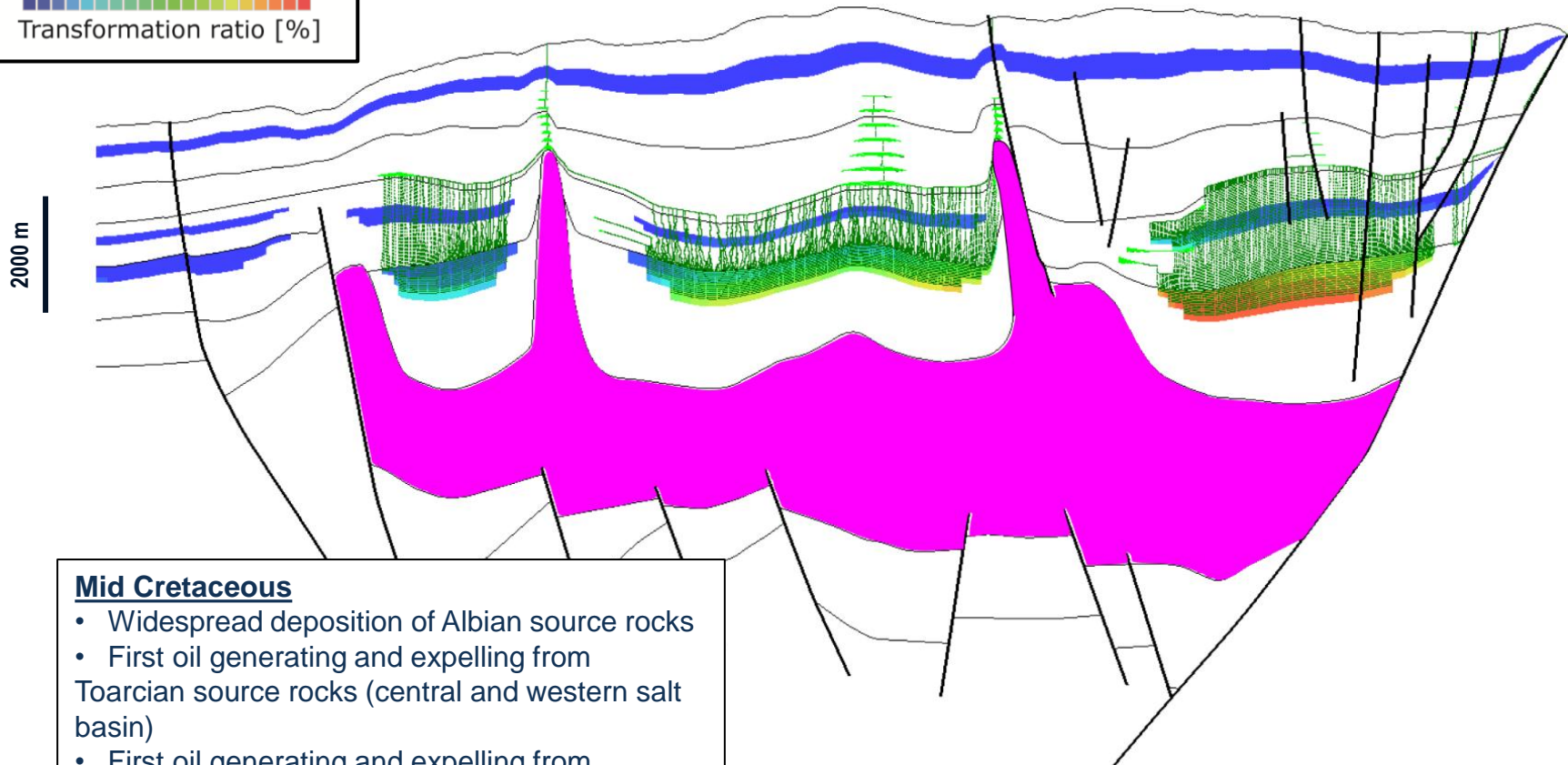
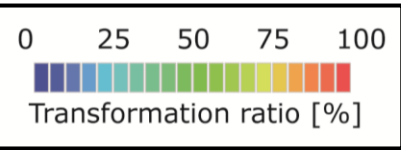
- First oil generating and expelling from Toarcian source rocks (eastern salt basin)



PetroMod* TecLink

10 km

Salt Basin – Petroleum Systems Model



Mid Cretaceous

- Widespread deposition of Albian source rocks
- First oil generating and expelling from Toarcian source rocks (central and western salt basin)
- First oil generating and expelling from Oxfordian source rocks (eastern salt basin)

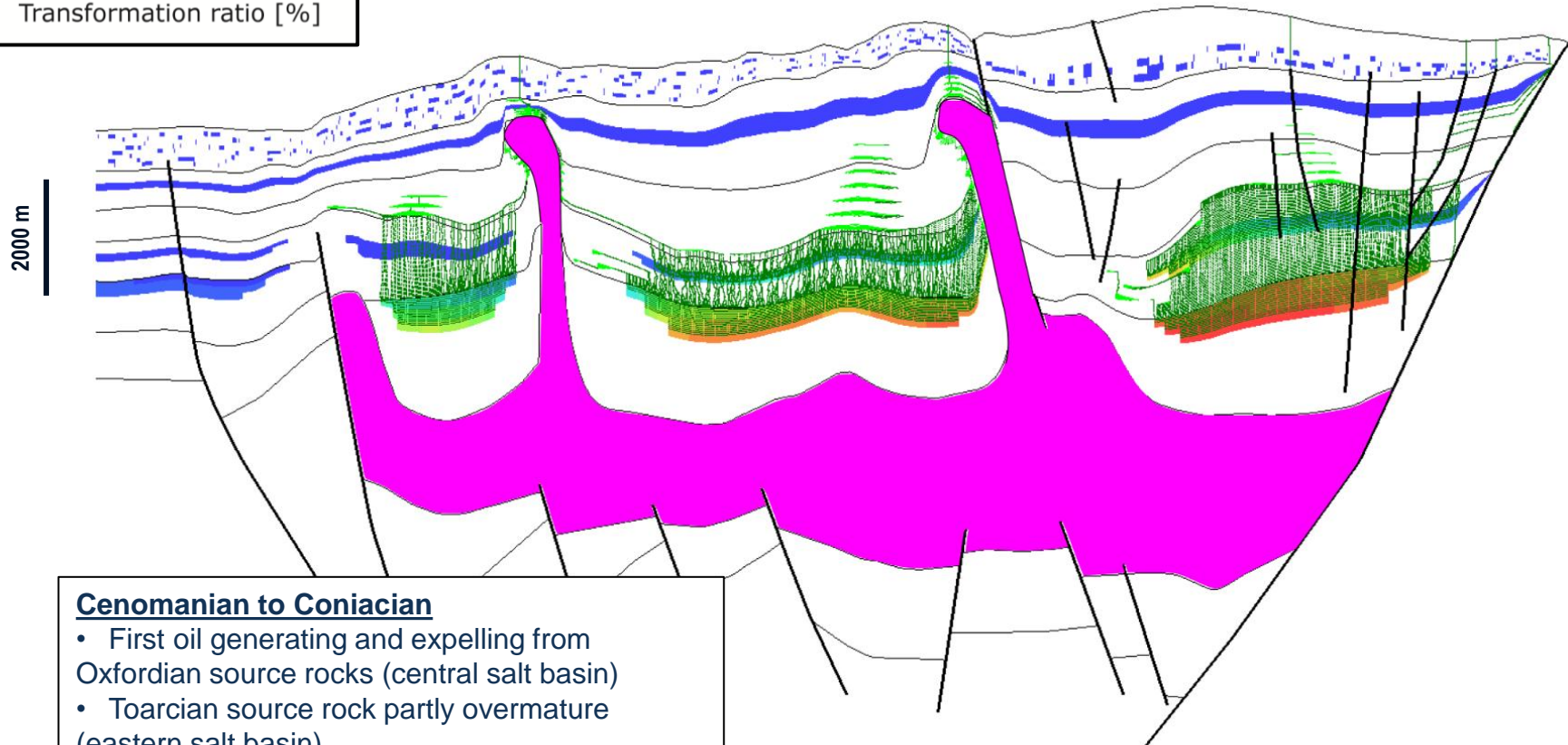
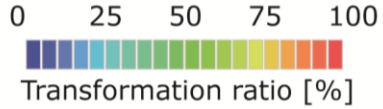
- Accumulation in Lower Cretaceous deltaic sandstones, in traps formed by salt withdrawal deformation and traps located above rising diapirs
- Focused surface leakage



PetroMod* TecLink

10 km

Salt Basin – Petroleum Systems Model



Cenomanian to Coniacian

- First oil generating and expelling from Oxfordian source rocks (central salt basin)
- Toarcian source rock partly overmature (eastern salt basin)

- Accumulation in Lower Cretaceous deltaic sandstones, in traps formed by salt withdrawal deformation and traps located above rising diapirs
- Focused surface leakage

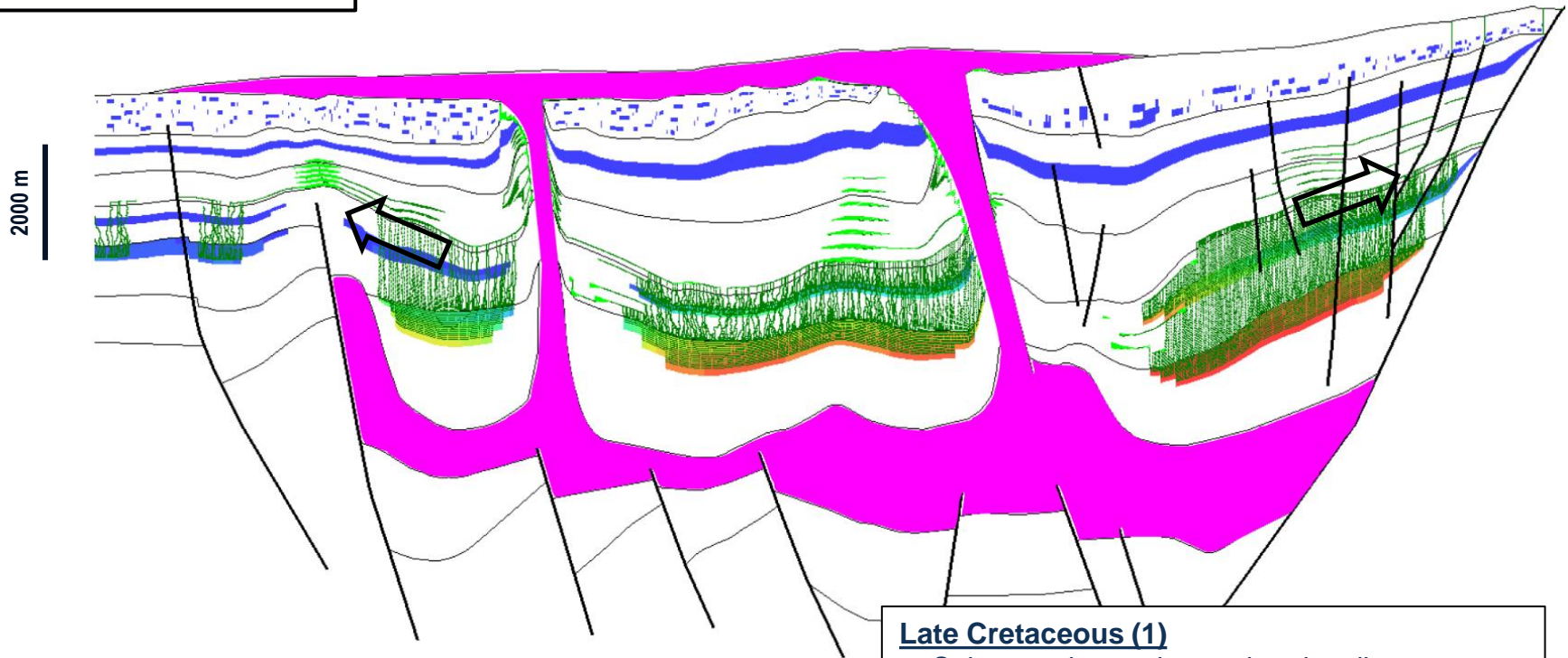


PetroMod* TecLink

10 km

Salt Basin – Petroleum Systems Model

0 25 50 75 100
Transformation ratio [%]



Late Cretaceous (1)

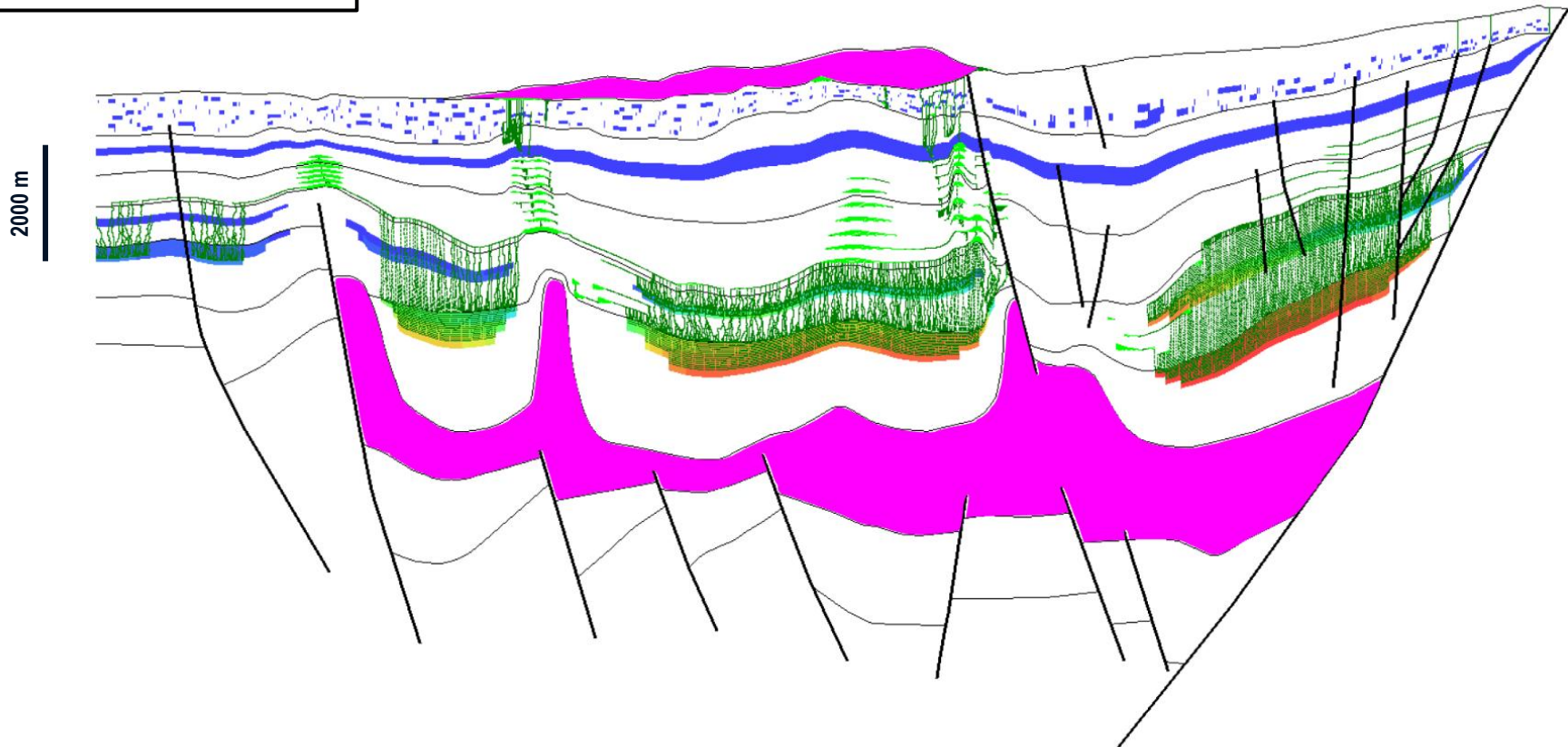
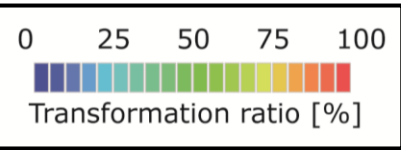
- Salt extrusion and associated sediment collapse (bathymetric change)
- Destruction of traps and existing accumulations
- Important remigration of HC to basin flanks; accelerated surface leakage
- Cenomanian sub-salt accumulations



PetroMod* TecLink

10 km

Salt Basin – Petroleum Systems Model

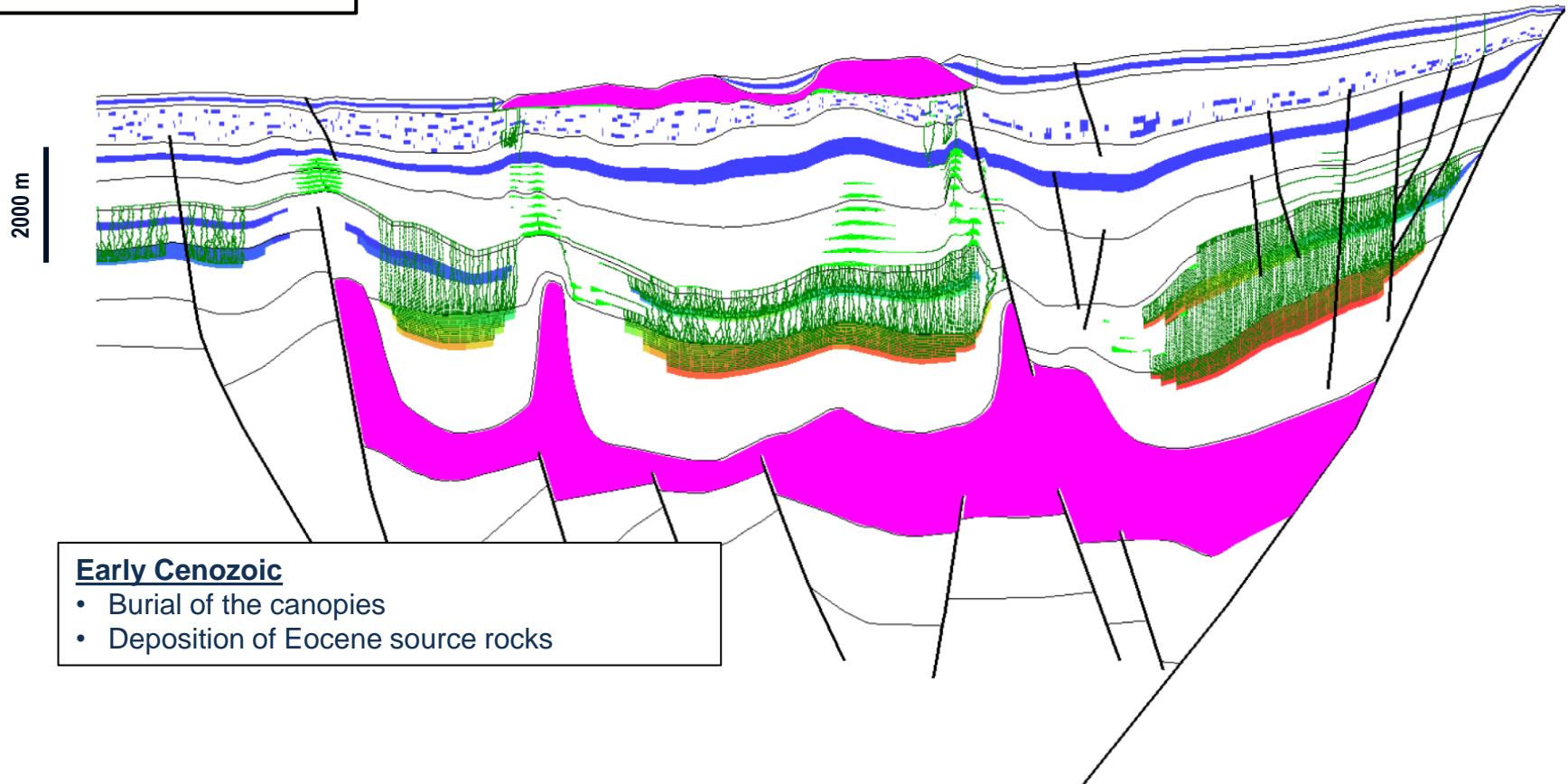
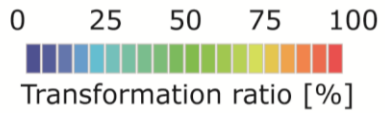


PetroMod* TecLink

Late Cretaceous (2)

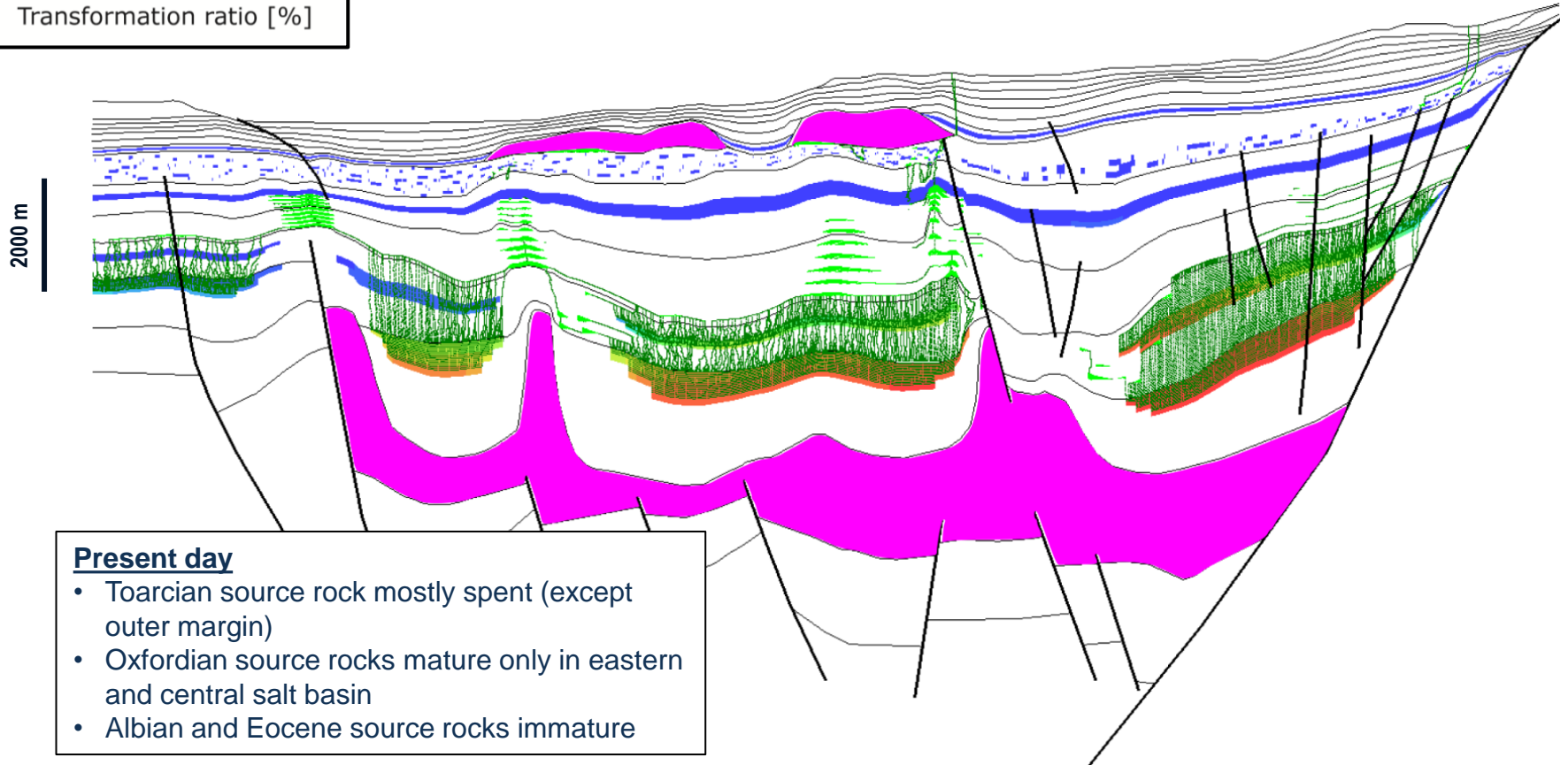
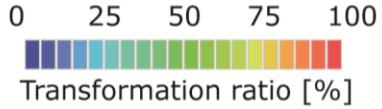
- Erosion/dissolution of allochthonous salt
- Sediment collapse into space previously occupied by diapirs

Salt Basin – Petroleum Systems Model



PetroMod* TecLink

Salt Basin – Petroleum Systems Model



Present day

- Toarcian source rock mostly spent (except outer margin)
- Oxfordian source rocks mature only in eastern and central salt basin
- Albian and Eocene source rocks immature

- Most accumulations in the Lower Cretaceous (oil)
- Subsalt accumulations (oil)
- Accumulations in deep Jurassic turbidites (gas)
- Overall accumulations primarily sourced by Toarcian



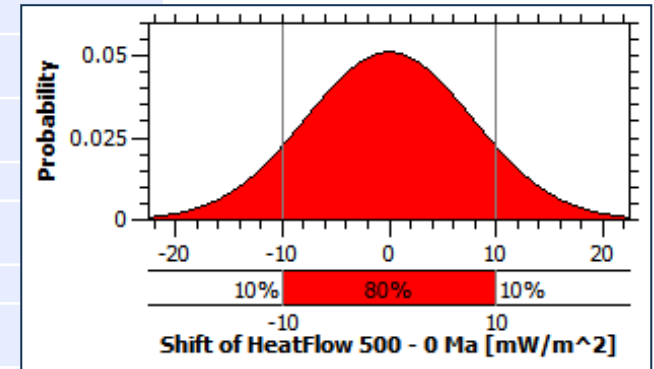
PetroMod* TecLink

Salt Basin – Uncertainty Analysis



PetroMod*
PetroRisk

Group	Parameter	Low	High	Distribution type
Thermal scenario	Basal heat flow	-10 mW/m ² (P10)	+ 10 mW/m ² (P90)	Gaussian
Albian source rocks	Kinetic (Activation energy)	-10 kcal/mol (Minimum)	+5 kcal/mol (Maximum)	Uniform
	TOC	4% (P10)	10% (P90)	Gaussian
Oxfordian source rocks	Kinetic (Activation energy)	-5 kcal/mol (Minimum)	+5 kcal/mol (Maximum)	Uniform
	TOC	1.5% (P10)	7.5% (P90)	Gaussian
Toarcian source rocks	Kinetic (Activation energy)	-10 kcal/mol (Minimum)	+2 kcal/mol (Maximum)	Uniform
	TOC	2% (P10)	8% (P90)	Gaussian

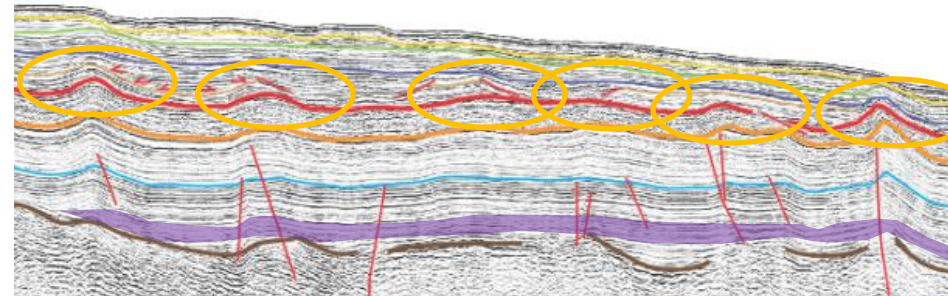
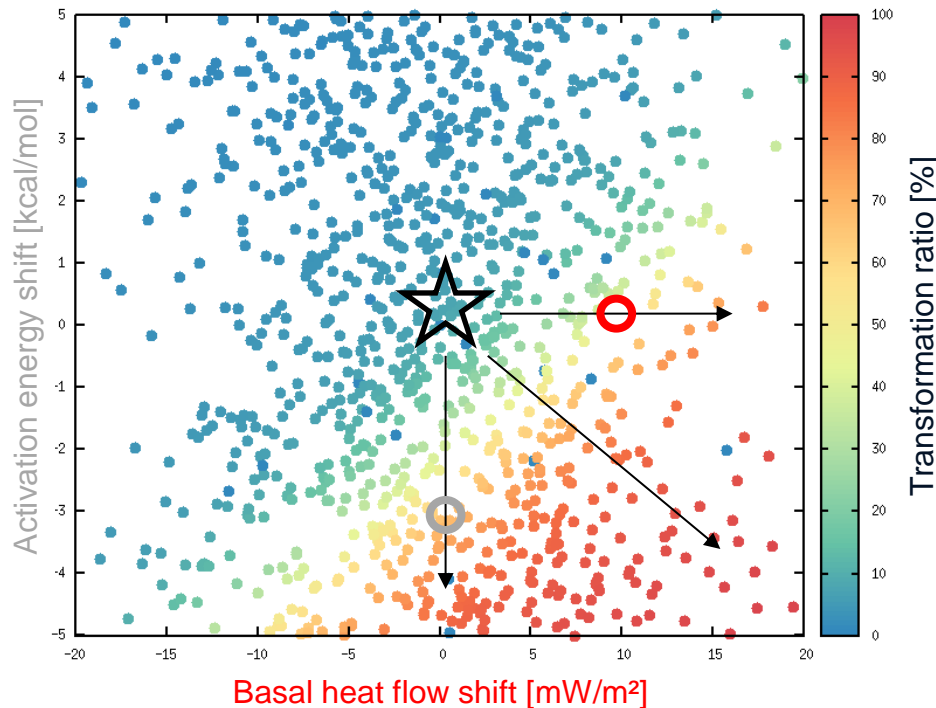
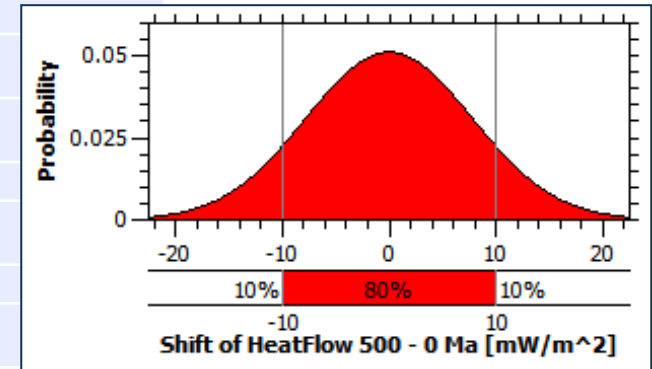


Salt Basin – Uncertainty Analysis



PetroMod*
PetroRisk

Group	Parameter	Low	High	Distribution type
Thermal scenario	Basal heat flow	-10 mW/m ² (P10)	+ 10 mW/m ² (P90)	Gaussian
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	TOC	2% (P10)	8% (P90)	Gaussian



Potential Toarcian source rocks in outer margin (Deep water folds)

- Relatively immature (TR=20%) in Master model ★
- Possible increase in basal heat flow (+10 mW/m²) would result in higher TR (50%) ○
- Possible shift in source rock kinetic activation energy (-3 kcal/mol) would result in higher TR (60%) ●

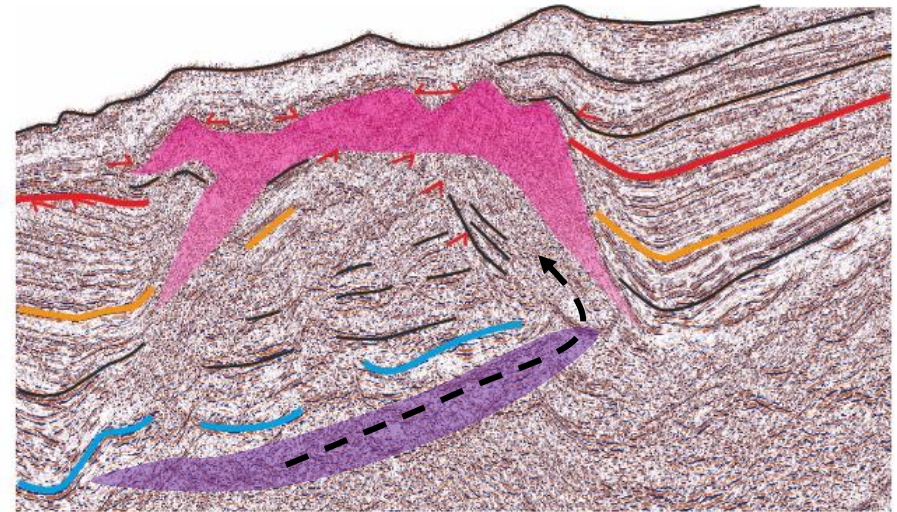
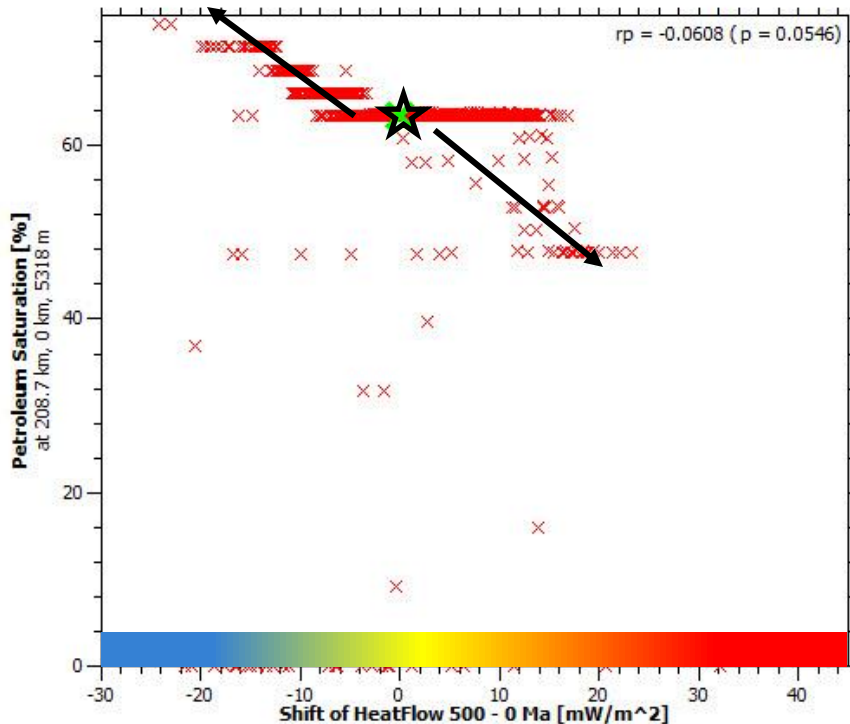
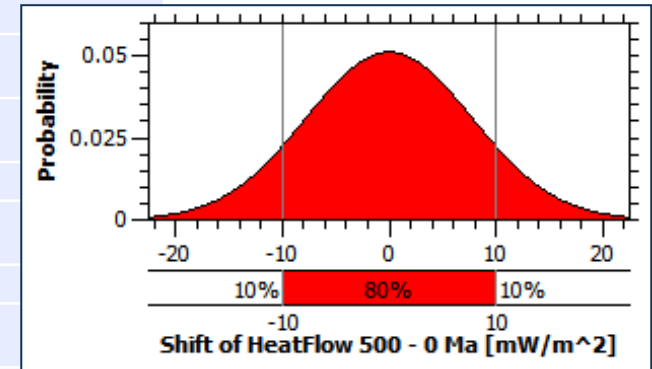
=> Toarcian source rock could be much more mature in outer margin!!

Salt Basin – Uncertainty Analysis



PetroMod*
PetroRisk

Group	Parameter	Low	High	Distribution type
Thermal scenario	Basal heat flow	-10 mW/m ² (P10)	+ 10 mW/m ² (P90)	Gaussian
Albian source rocks	Kinetic (Activation energy)	-10 kcal/mol (Minimum)	+5 kcal/mol (Maximum)	Uniform
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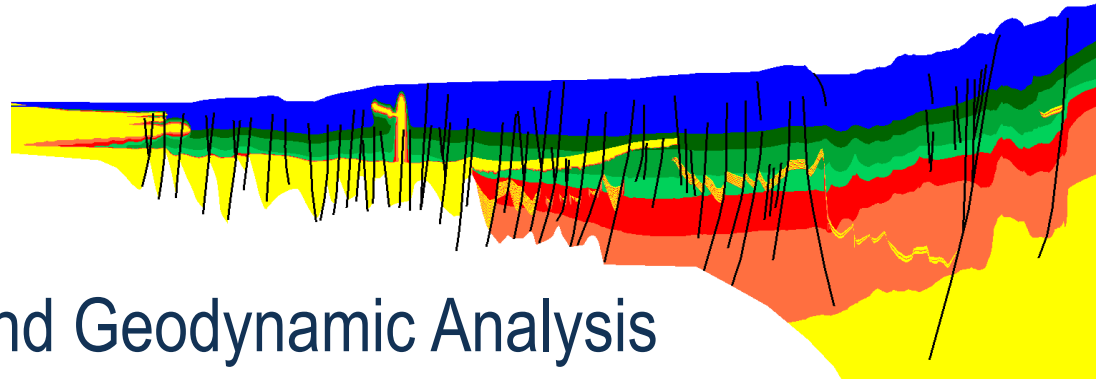


Potential Toarcian source rocks in salt basin
(Subsalt traps involving Lower Cretaceous reservoir)

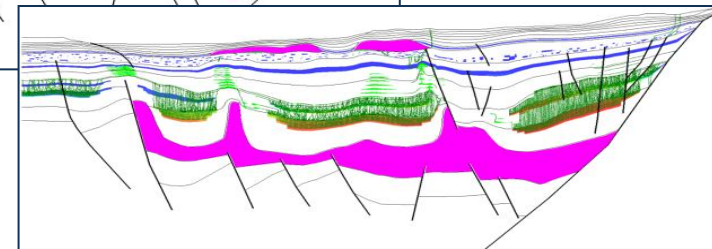
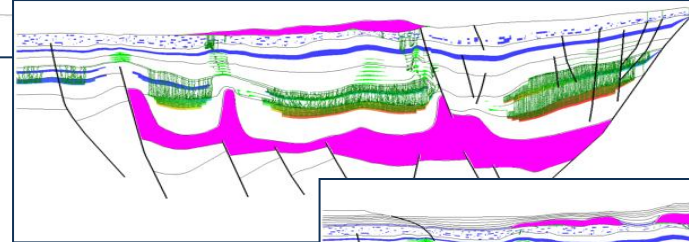
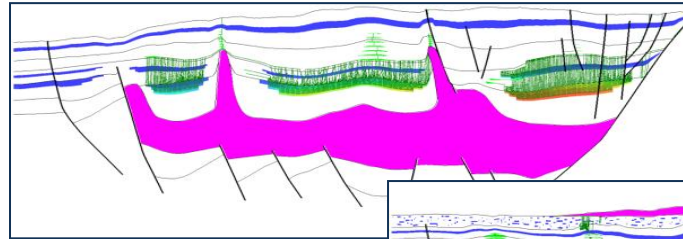
- The lower the basal heat flow, the higher the HC saturation!!

=> Potential (expulsion versus trap/seal) timing issues!!

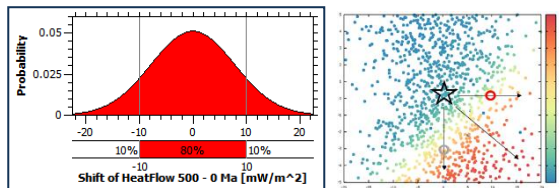
Workflow Summary



- Seismic Interpretation and Geodynamic Analysis
- Regional Thermal Modeling



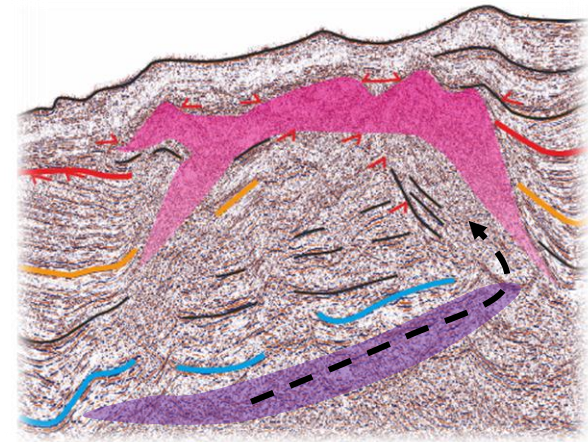
- Structural Restoration
- Petroleum Systems Modeling
- Monte Carlo Uncertainty Analysis



Conclusions for Exploration

■ Salt Basin Offshore Essaouira

- Best potential seen in **Lower Cretaceous**
- Good salt traps and seals
- Charged by speculative Jurassic Source Rocks?
- Upper Cretaceous and Cenozoic less prospective

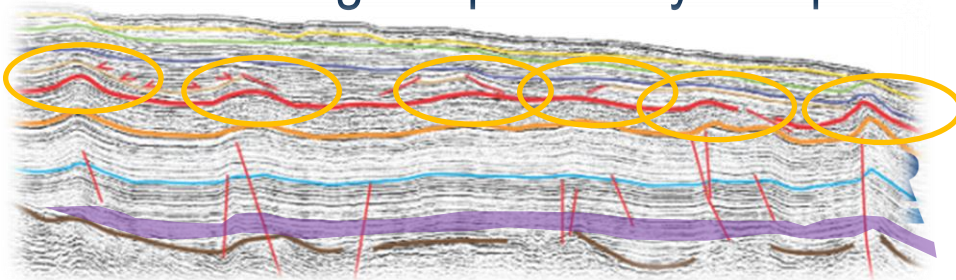


■ Increasing potential for Upper Cretaceous and Cenozoic towards the South

- Speculative Albian Source Rocks

■ Outer Margin

- High dependency on speculative Toarcian Source Rocks



Acknowledgement

- Haddou Jabour and Salim Lahsini (ONHYM Rabat, Morocco) for the permission to use seismic data (“block E”)