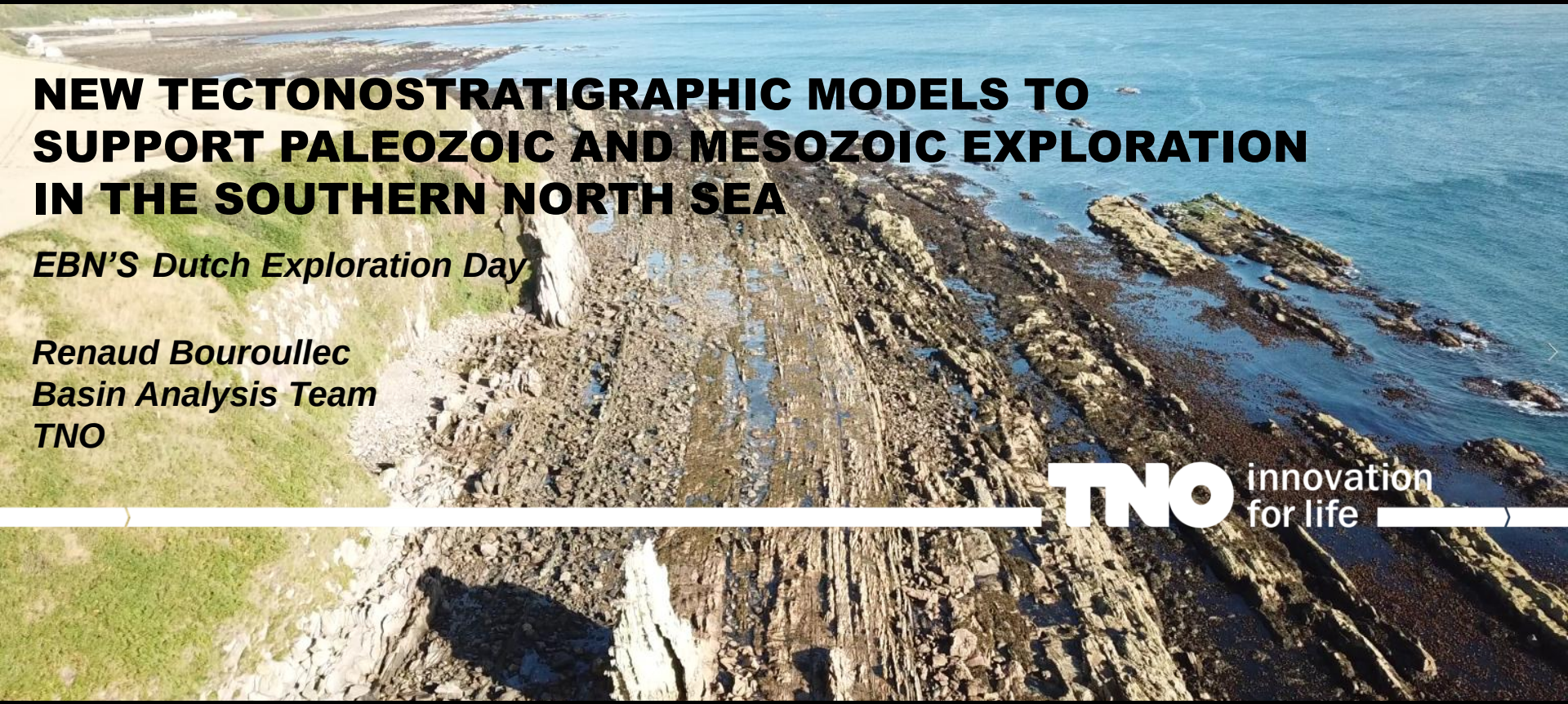


NEW TECTONOSTRATIGRAPHIC MODELS TO SUPPORT PALEOZOIC AND MESOZOIC EXPLORATION IN THE SOUTHERN NORTH SEA

EBN'S Dutch Exploration Day

Renaud Bouroullec
Basin Analysis Team
TNO

TNO innovation for life

PARTNERS: 2015-2018 NORTH SEA PROJECTS

TNO innovation for life

Ministerie van Economische Zaken

British
Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

THE BASIN ANALYSIS TEAM: AGS AND GDN

Renaud Bouroullec

Geert de Bruin

Rader Abdul Fattah

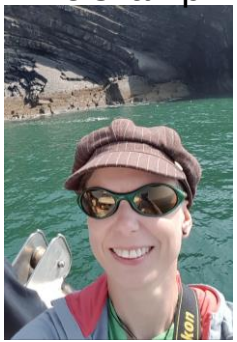
Kees Geel

Sander Houben

Nico Janssen

Tanya Goldberg

Susanne Nelskamp



Friso Veenstra

Dario Ventra

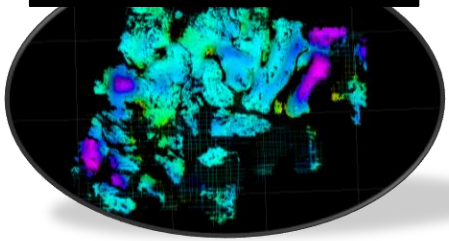
Roel Verreussel

++: Active in North Sea, Middle East and Africa. Focused on O&G, Geothermal and CCS topics

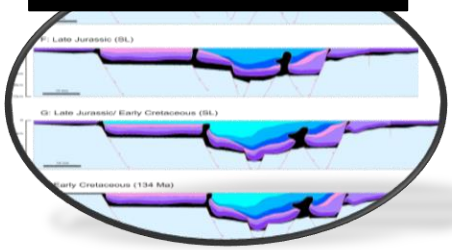
LARGE ARRAY OF TECHNIQUES

TNO innovation for life

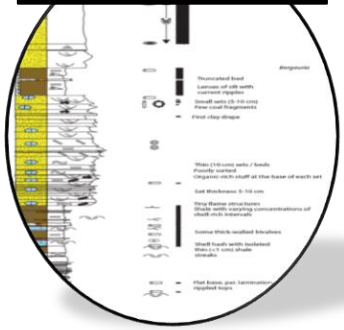
Seismic interpretation and mapping



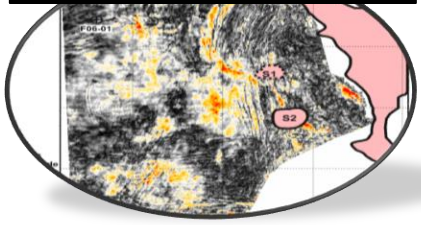
Structural restoration



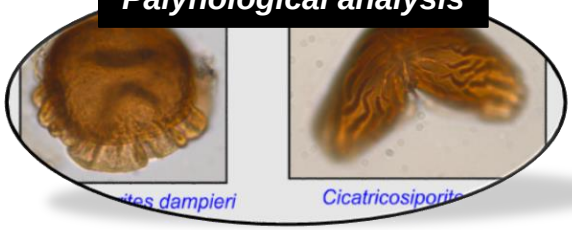
Core description



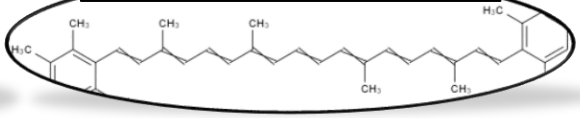
Amplitude analysis



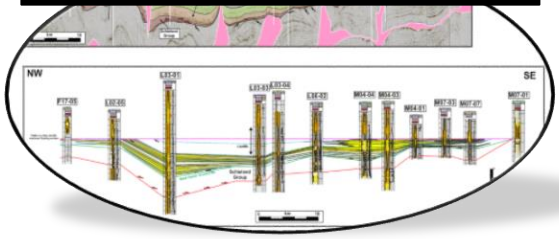
Palynological analysis



Organic geochemistry

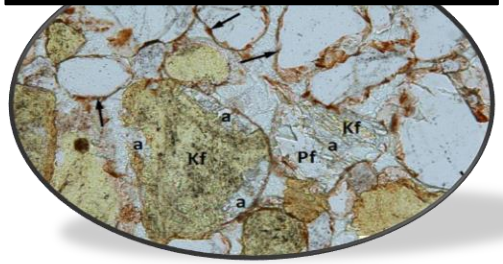


Tectono-stratigraphic analyses



Outcrop characterisation

Source to sink, Petrography



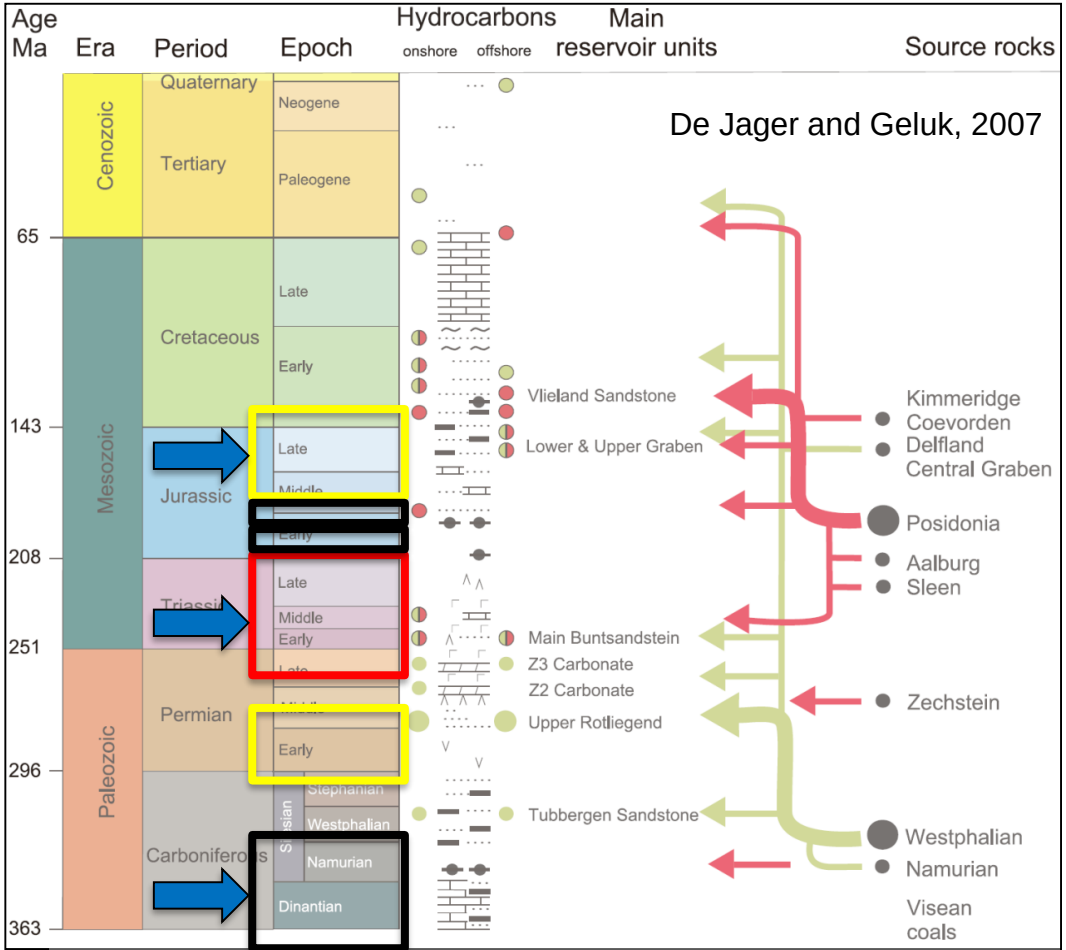
TNO NORTH SEA EXPLORATION PROJECTS

TNO innovation for life

Most of our projects have a strong tectonostratigraphic component, to help resolve the intricate relationships between active structures and deposition systems.

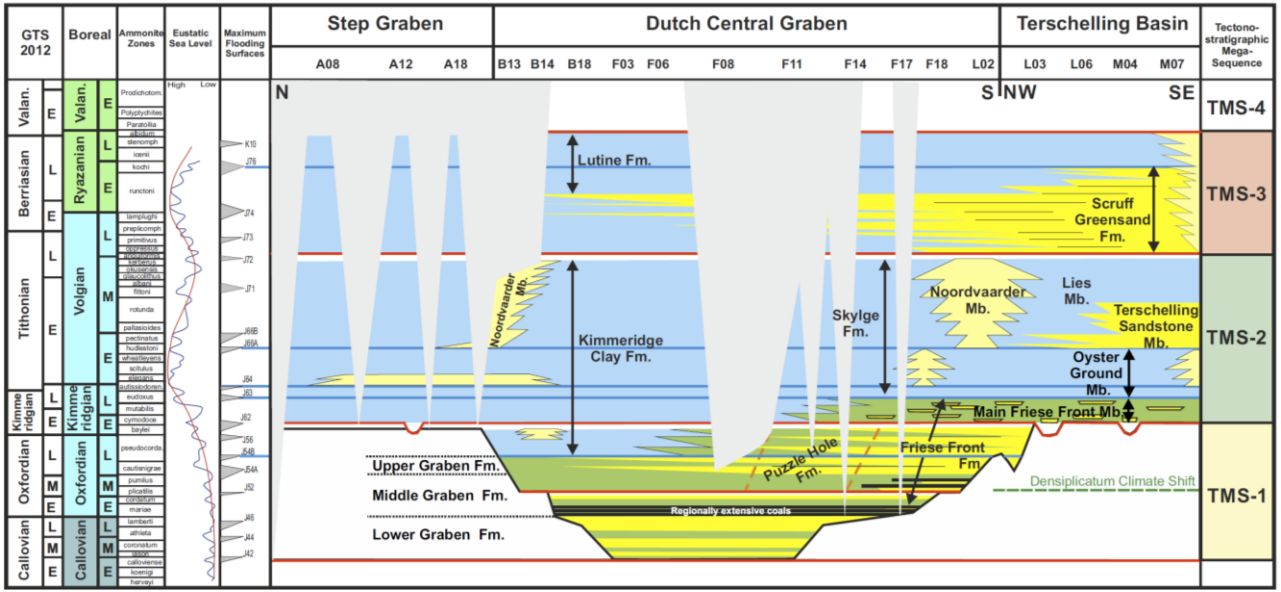
Today's presentation regarding recently completed and on-going research

Reservoir focused
Source rock focused
Salt tectonics focused

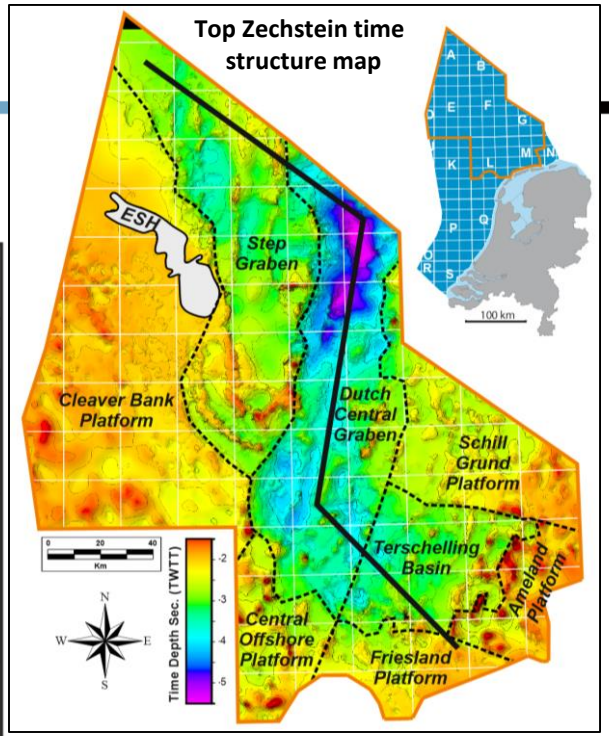


1) MID. JURA. - L. CRETACEOUS

A new lithostratigraphic framework for the Middle Jurassic-Lower Cretaceous

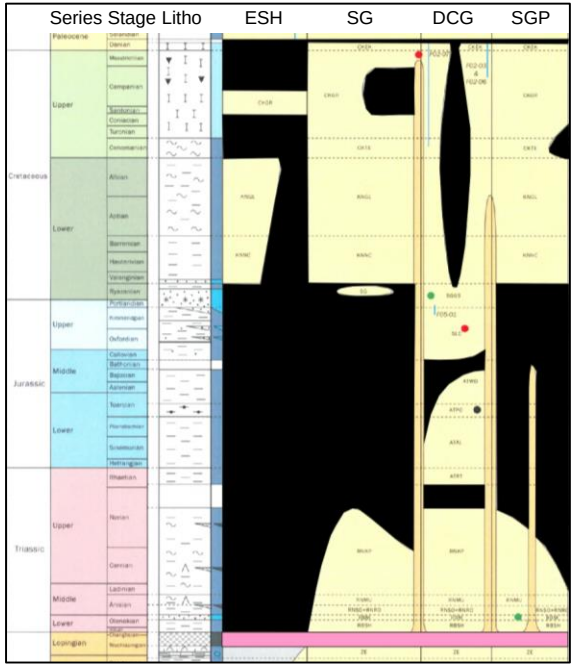


Bouroullec et al.(2018)

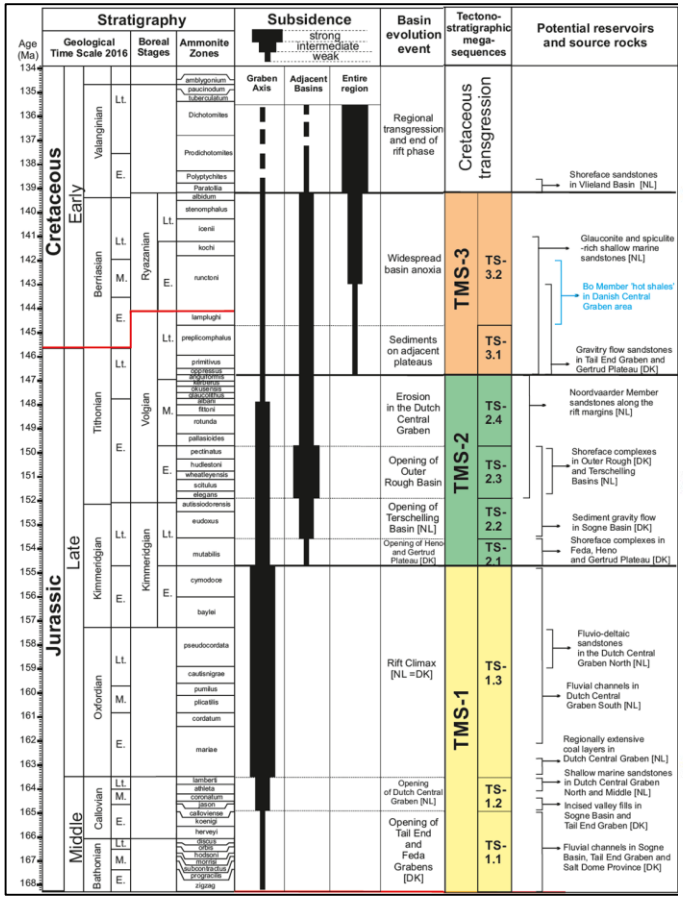


1) MIDDLE JURASSIC-LOWER CRETACEOUS

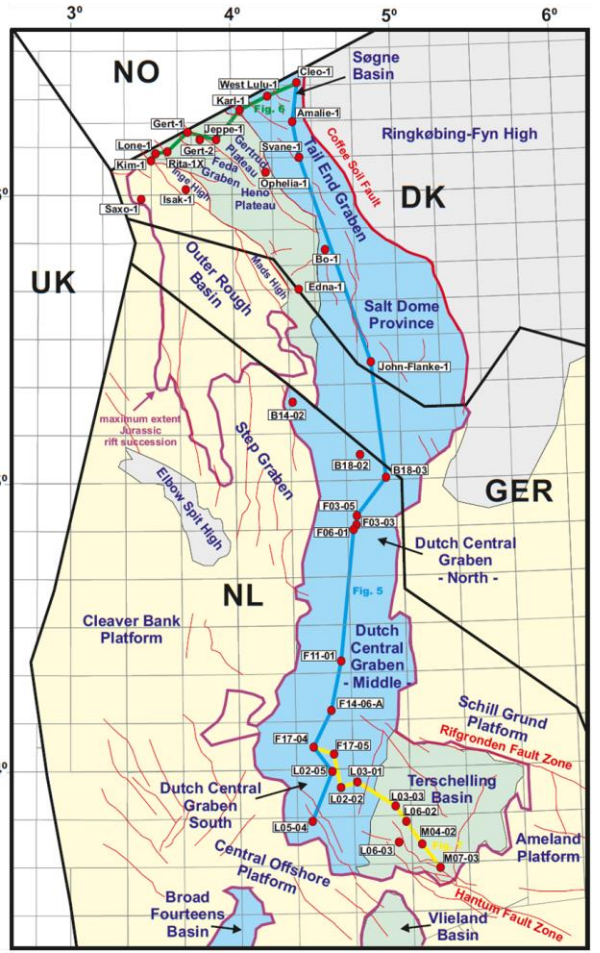
Period of rifting, continued salt movements and erosion.



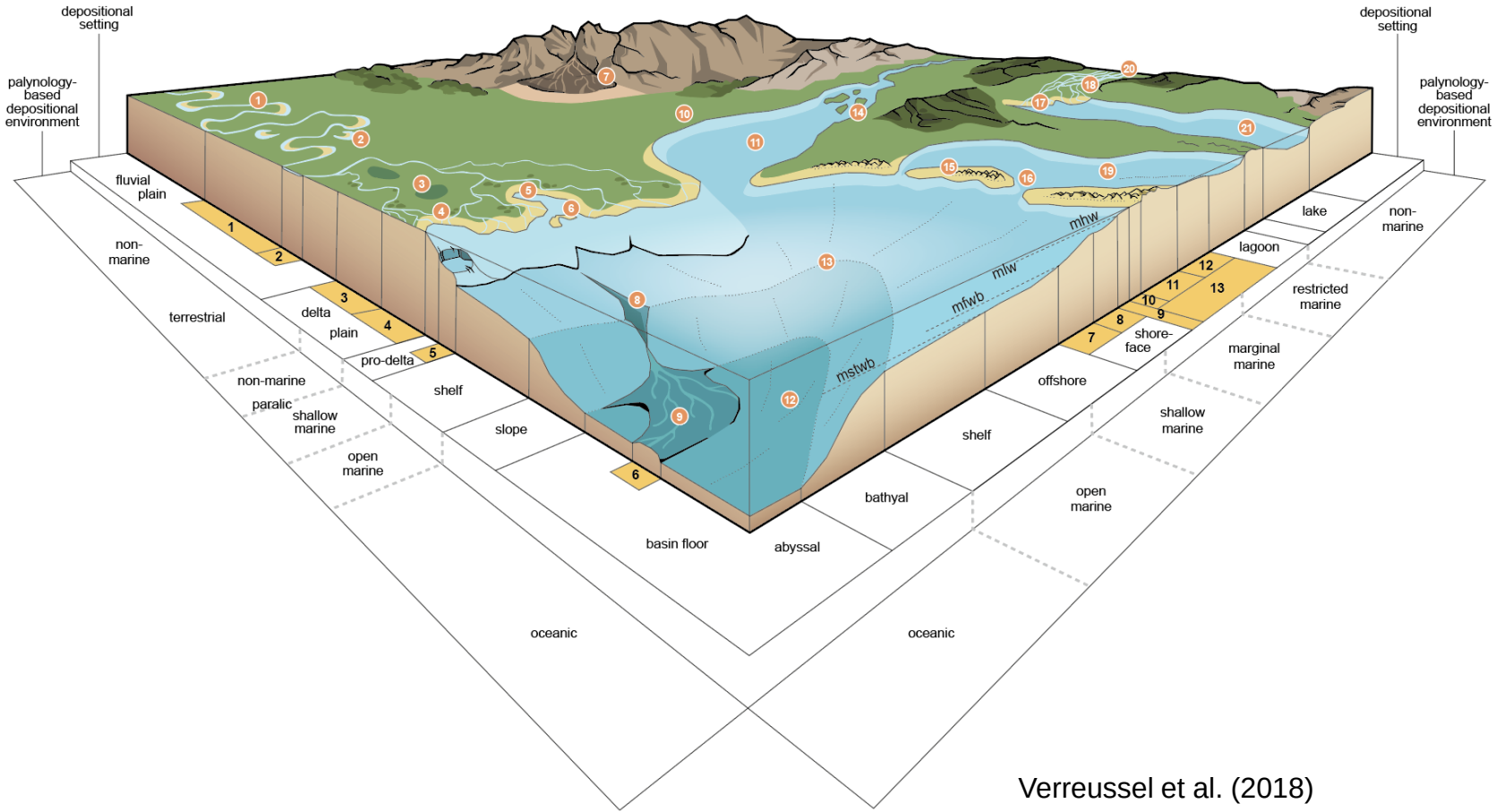
TNO (2011)



Verreussel et al. (2018)



1) MIDDLE JURASSIC-LOWER CRETACEOUS

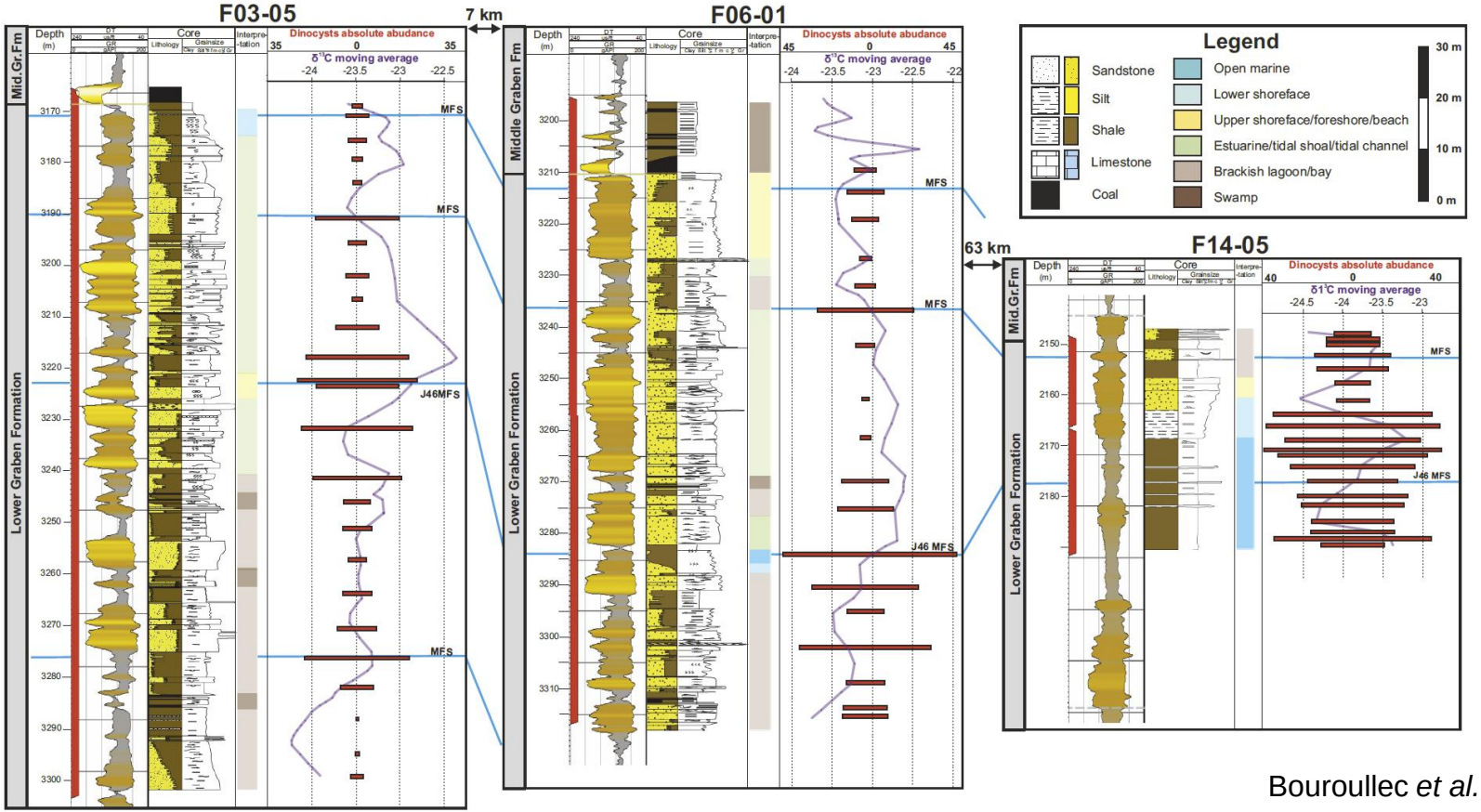


Verreussel et al. (2018)

1) MIDDLE JURASSIC-LOWER CRETACEOUS

LOWER GRABEN FORMATION

N

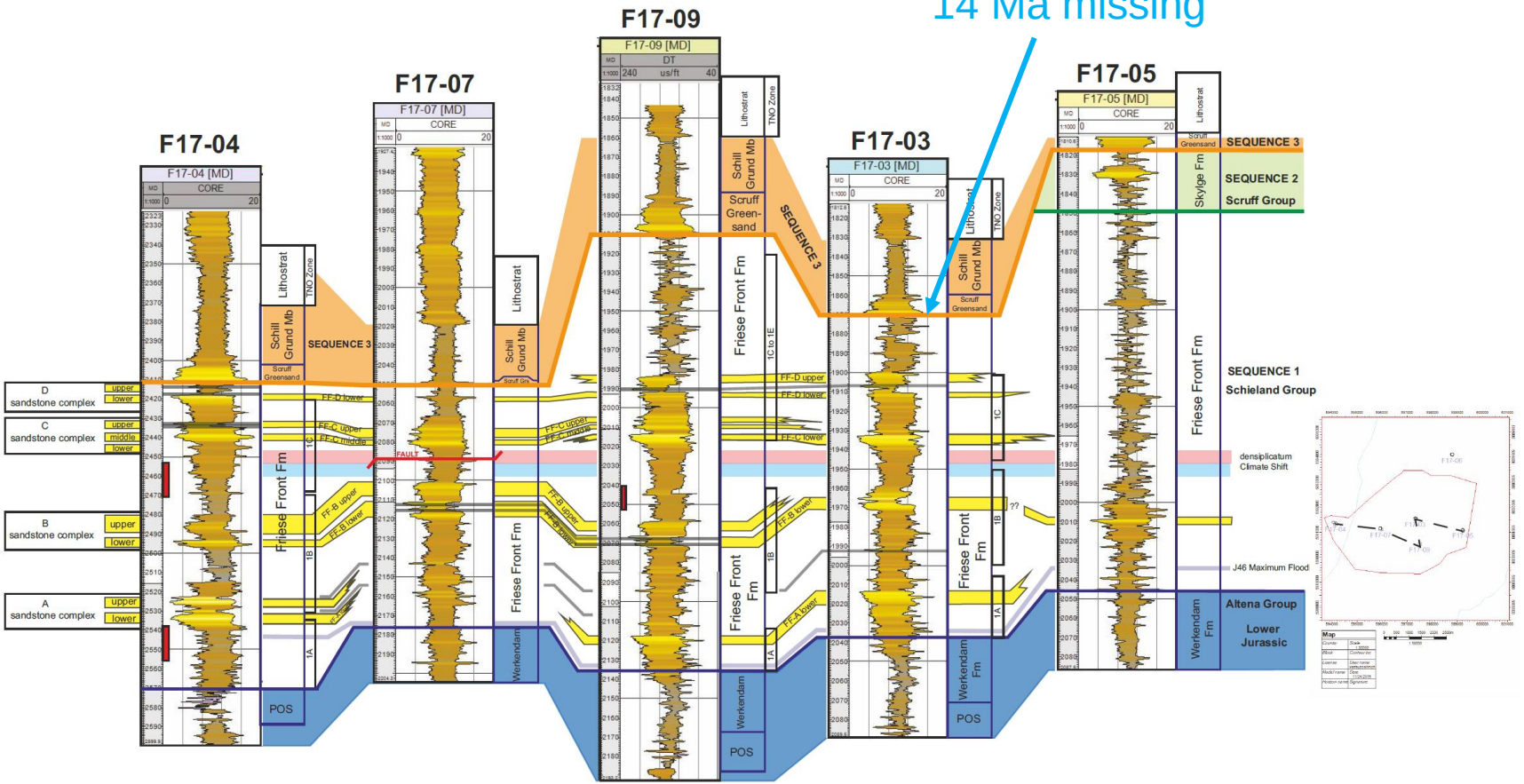


S

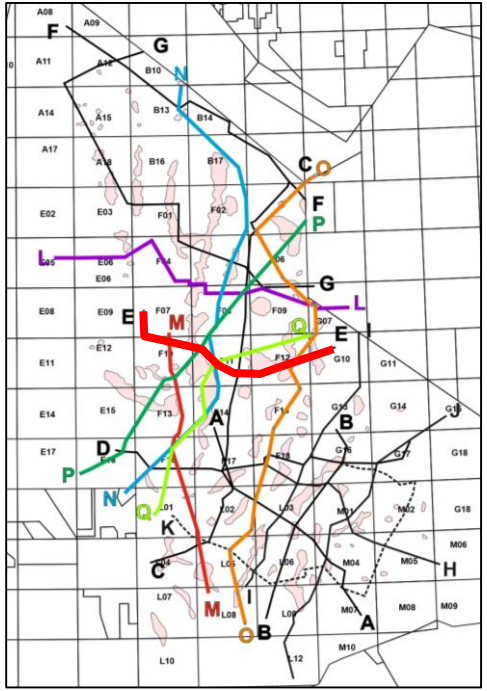
Bouroullec *et al., 2018*

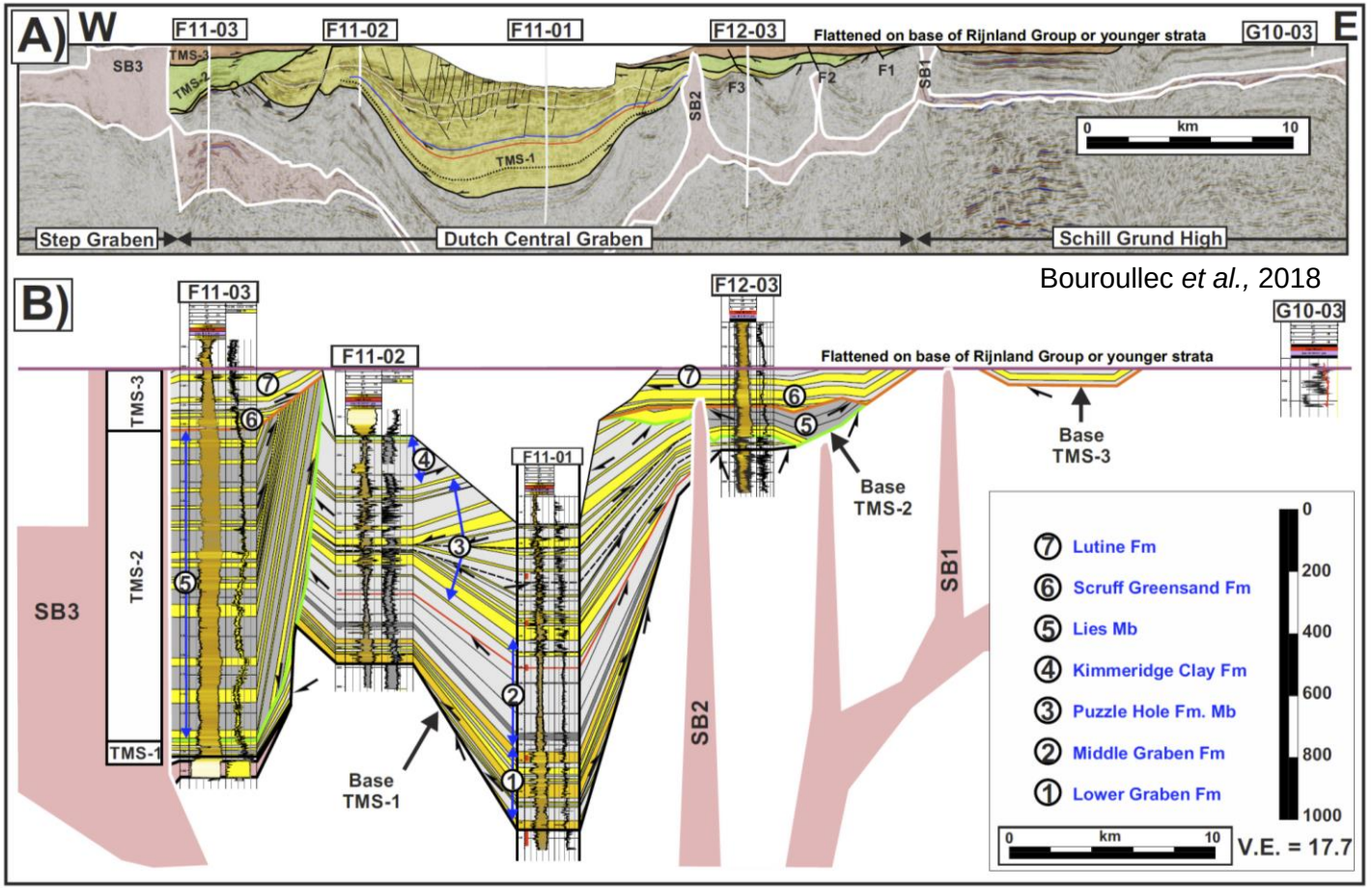
1) MIDDLE JURASSIC-LOWER CRETACEOUS

FRIESE FRONT FORMATION



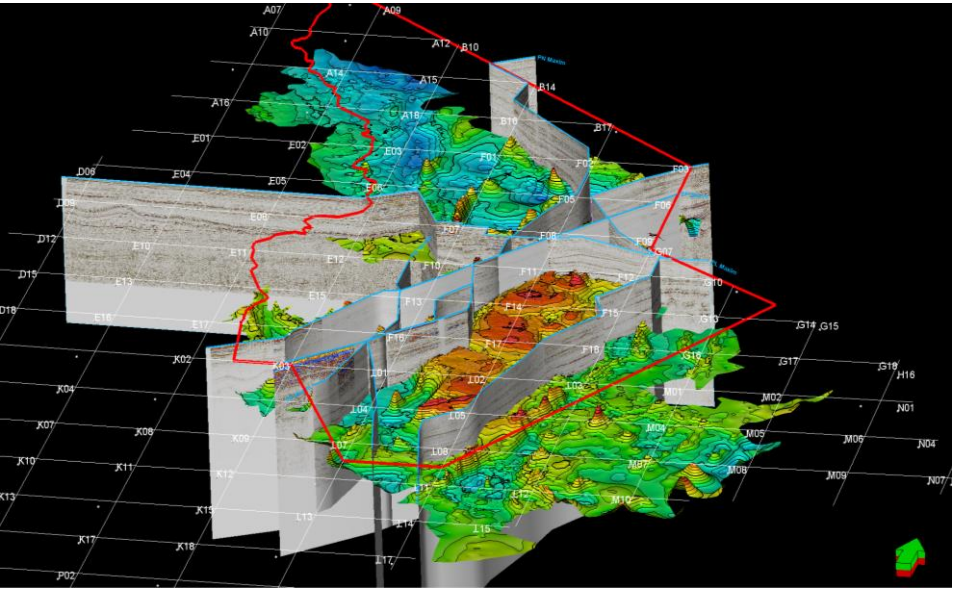
1) MIDDLE JURASSIC-LOWER CRETACEOUS



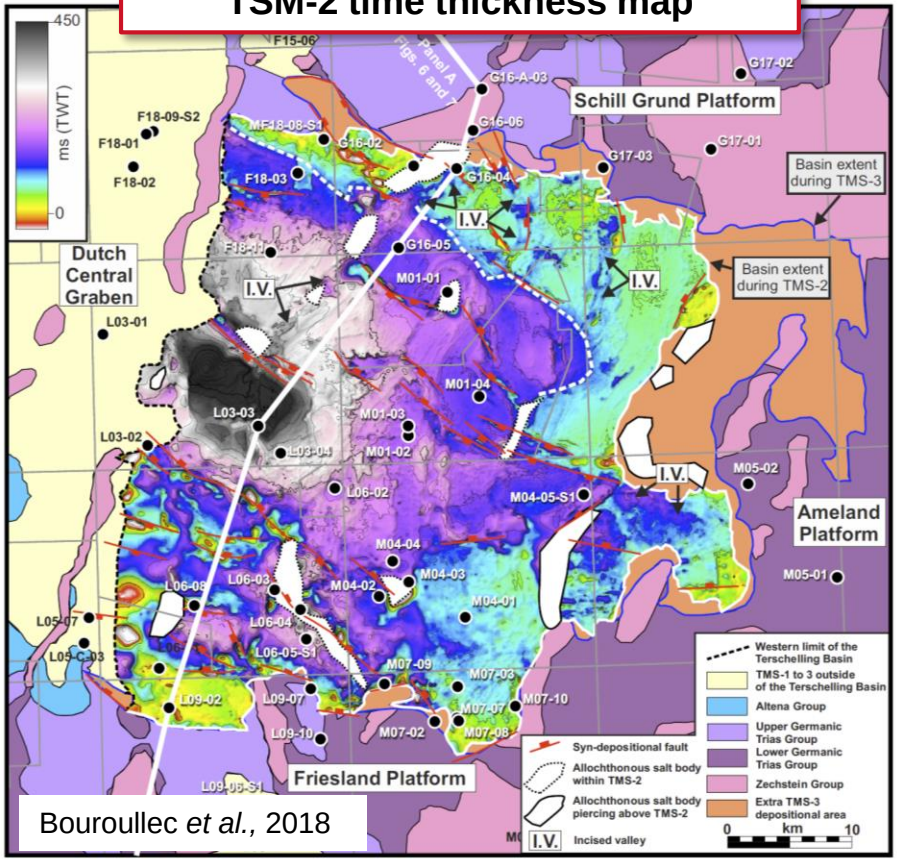


1) M. JURASSIC - L. CRET.

NEW 3D MAPPING



TSM-2 time thickness map

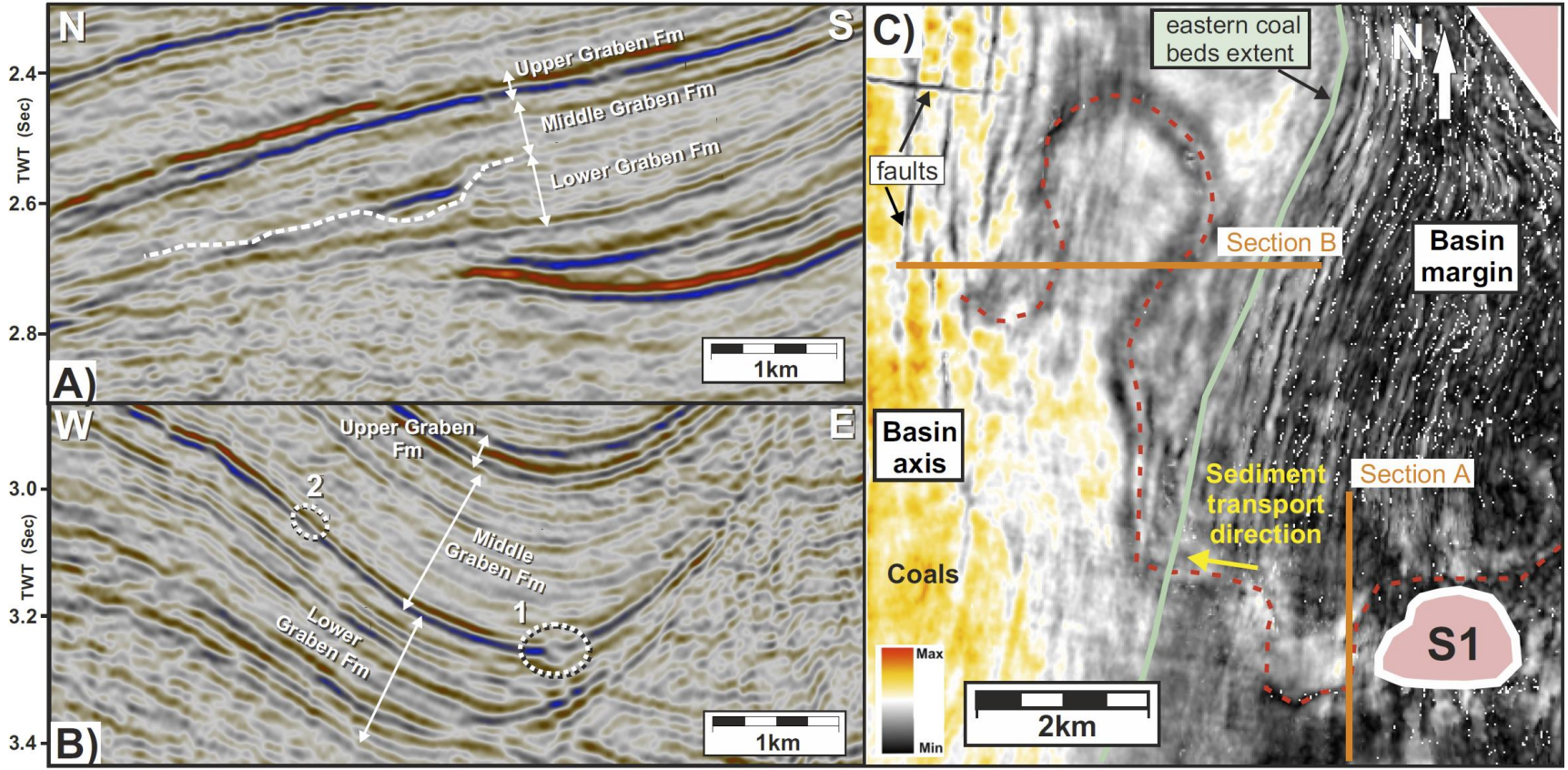


Bouroullec *et al.*, 2018

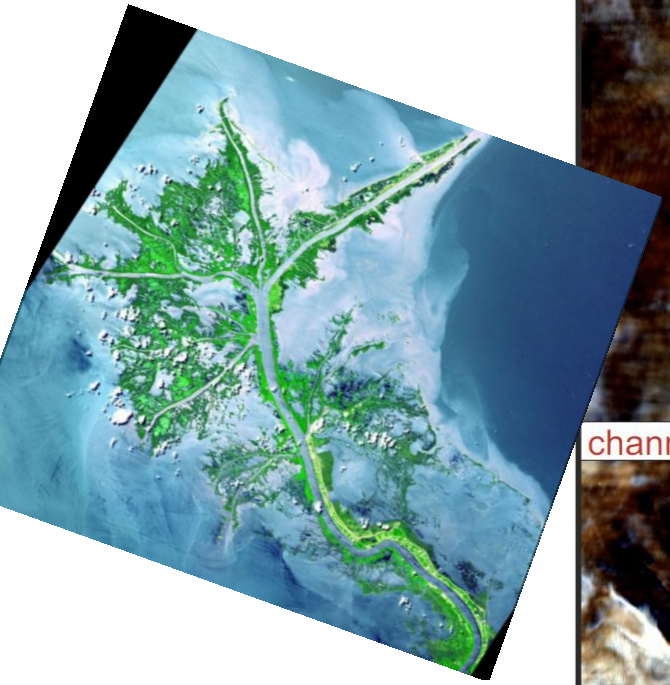
1) MIDDLE JURASSIC-LOWER CRETACEOUS

ATTRIBUTE MAPS – Middle Graben Fm (base coal)

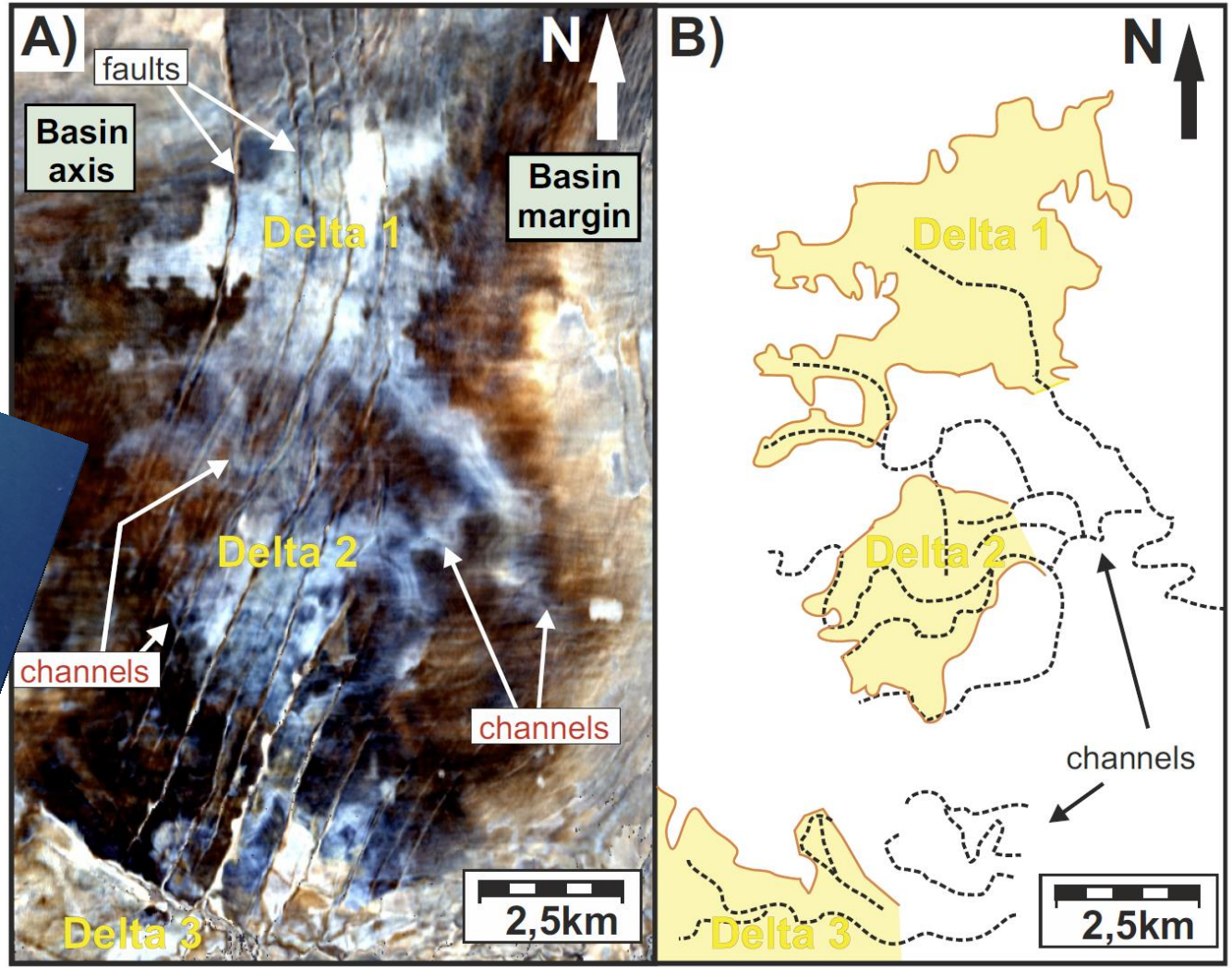
Bouroullec *et al.*, 2018



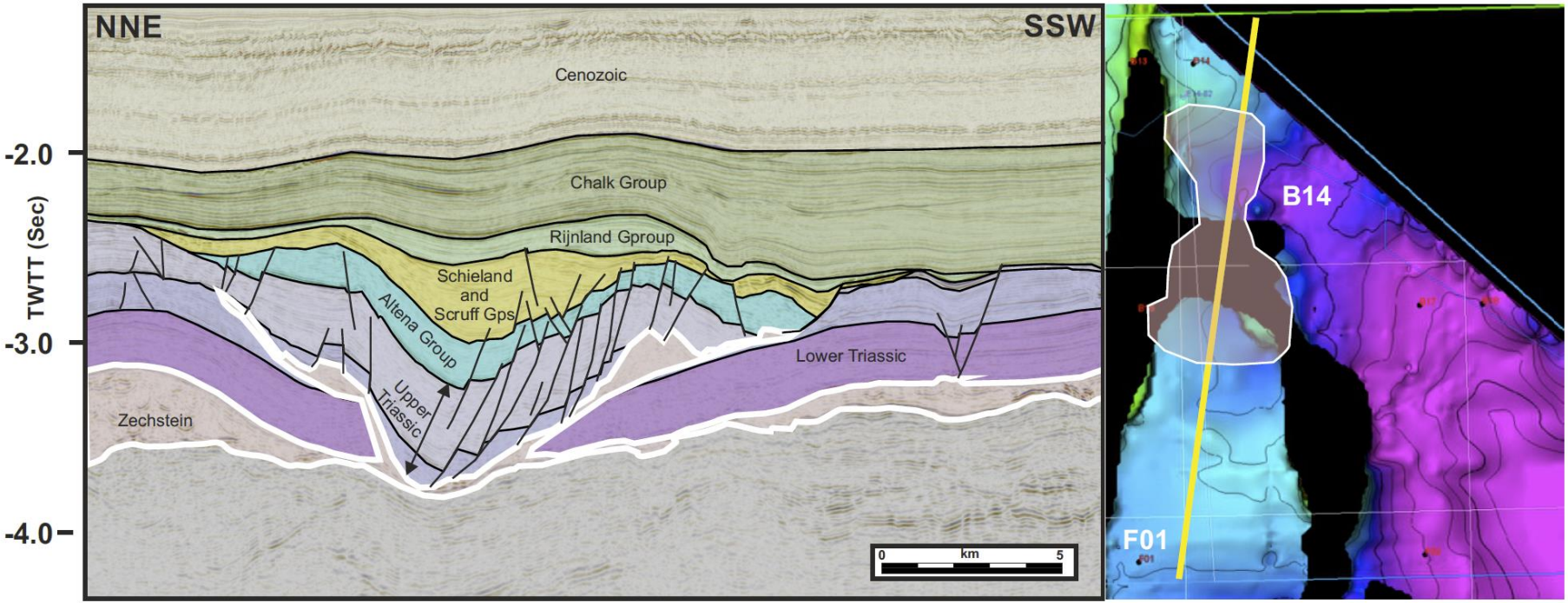
ATTRIBUTE MAPS
Upper Graben Fm.



Bouroullec *et al.*, 2018

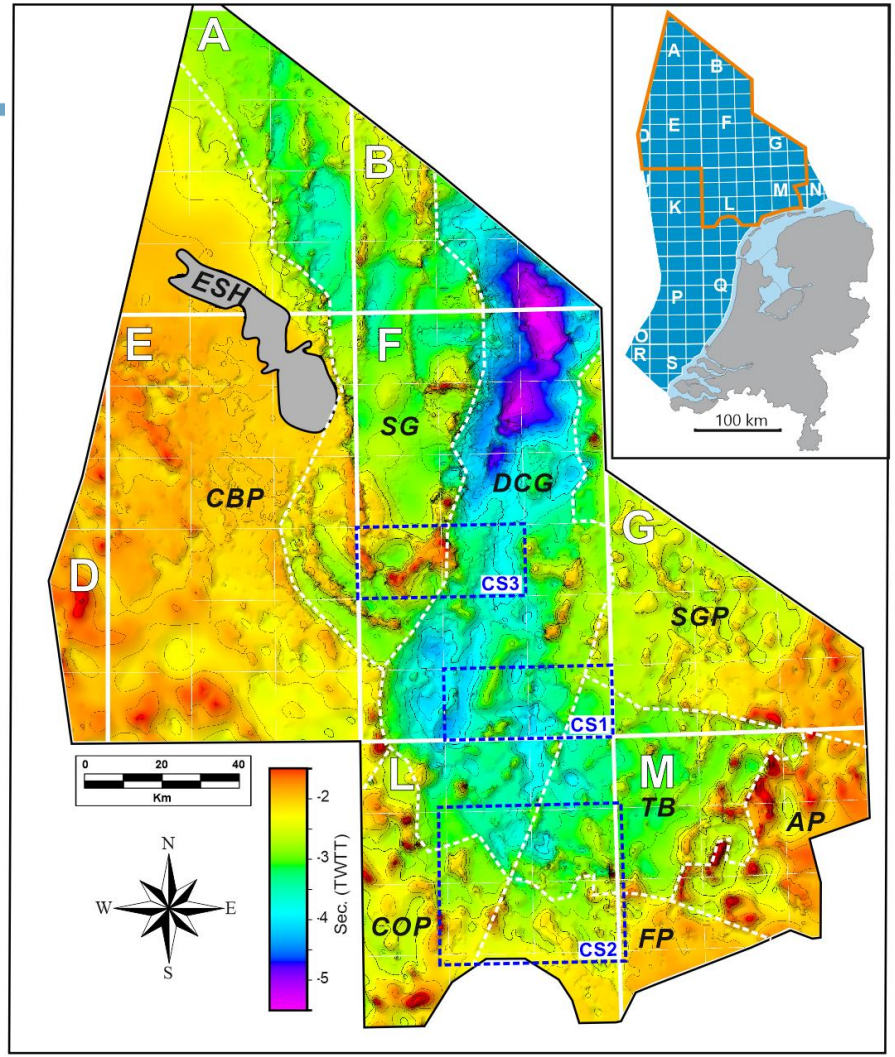


2) TRIASSIC SALT TECTONICS

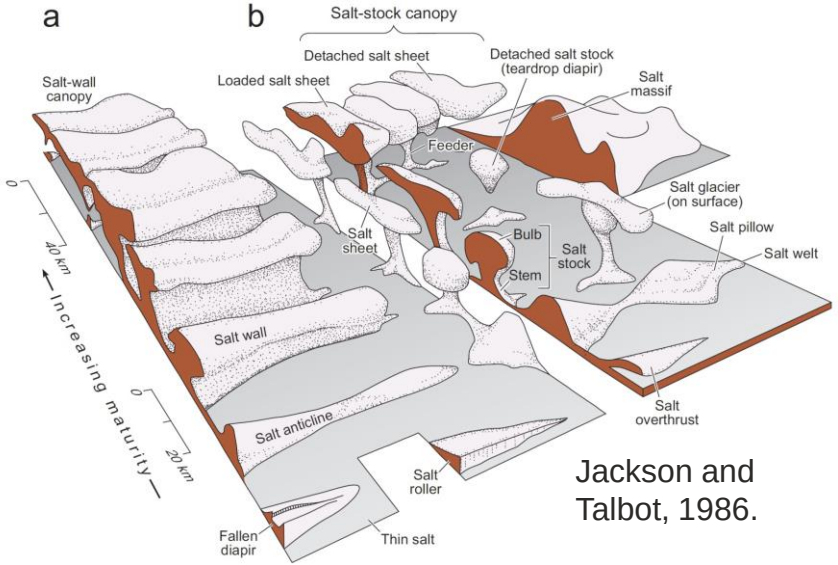


2) TRIASSIC SALT TECTONICS

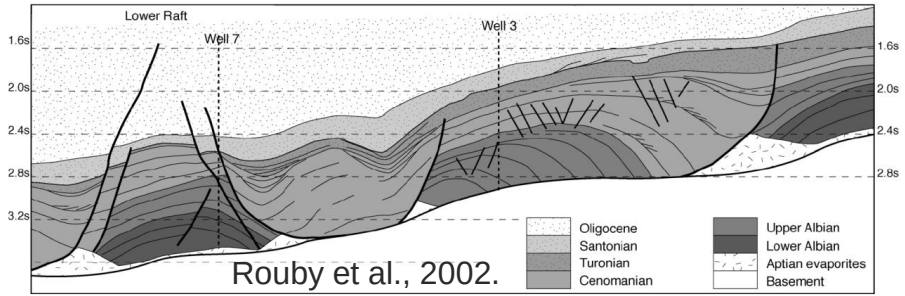
- The STEM Project (*Salt Tectonics Early Movements*) provides a new structural framework for the Triassic in the Dutch offshore.
- New regional mapping of Zechstein and Lower Triassic horizons based on modern salt tectonics models.
- Three case studies and respective 2D structural restorations.
- A new structural model for the Triassic in the study area, including gravitational gliding systems, collapse salt bodies, squeezed diapirs and extruded salt systems



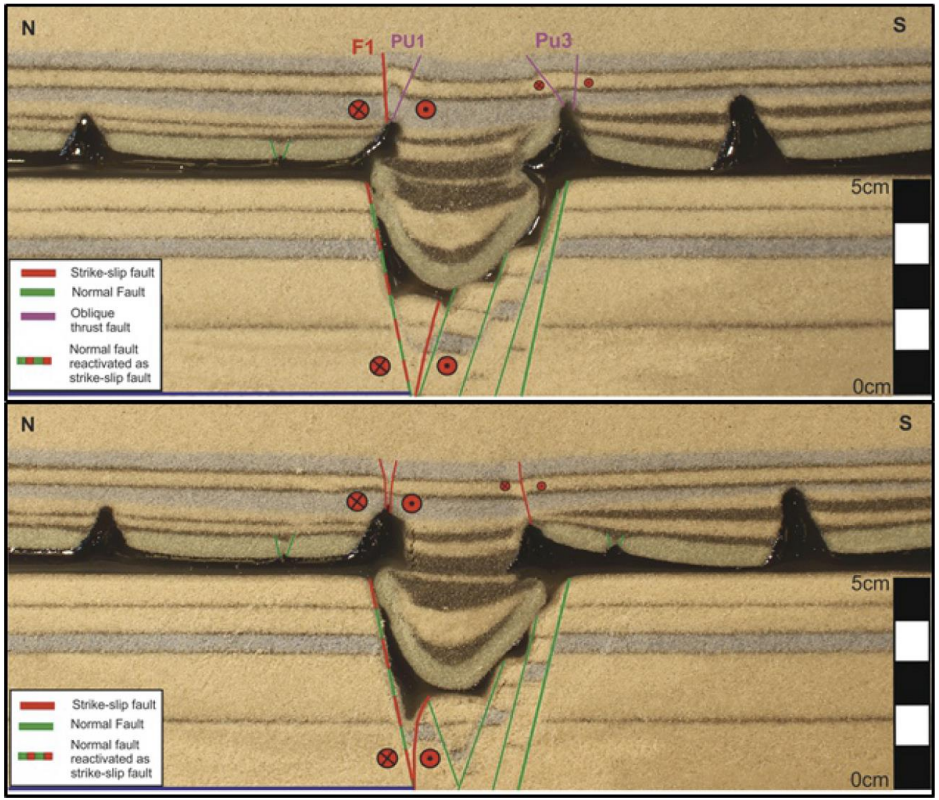
2) TRIASSIC SALT TECTONICS



Jackson and Talbot, 1986.

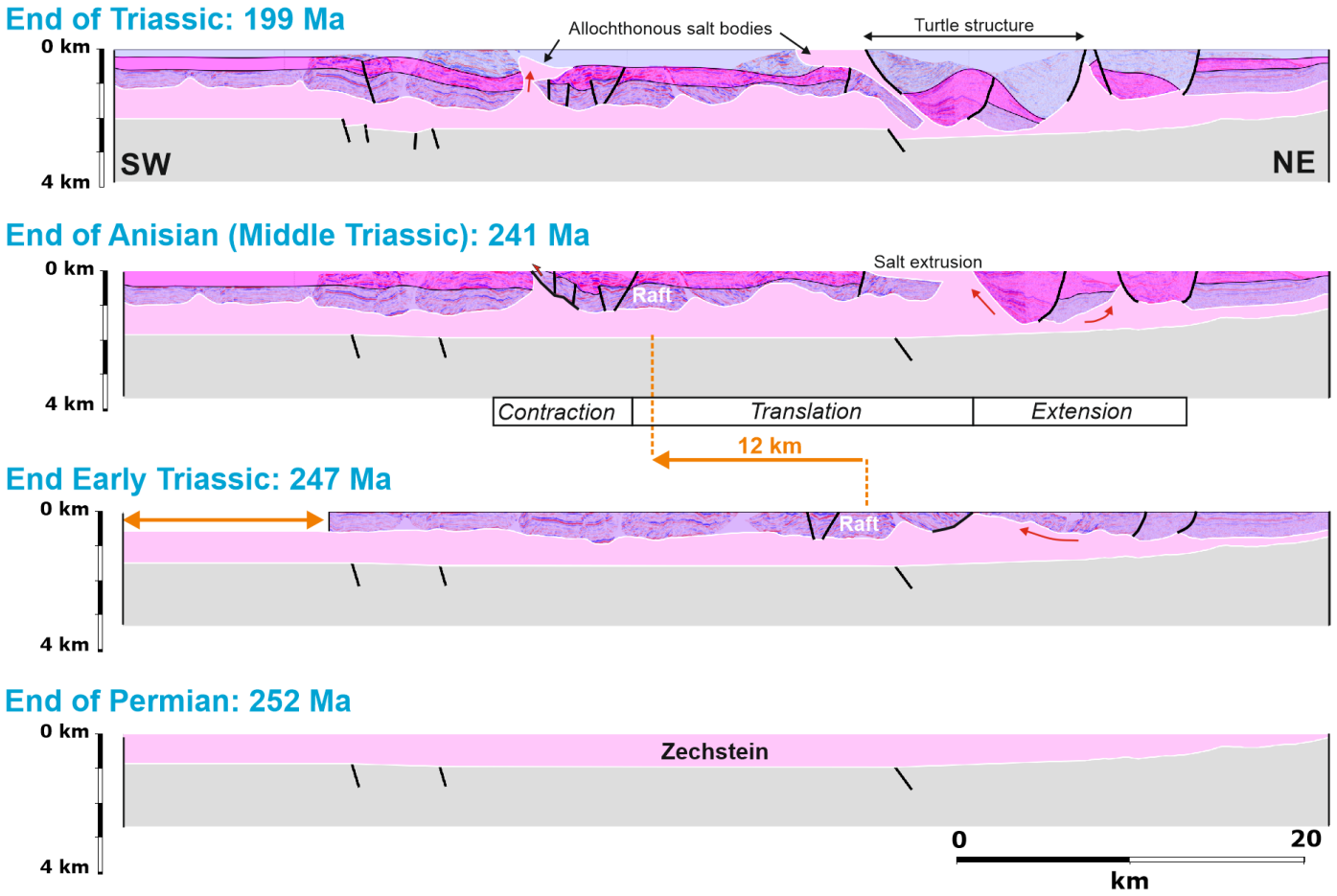


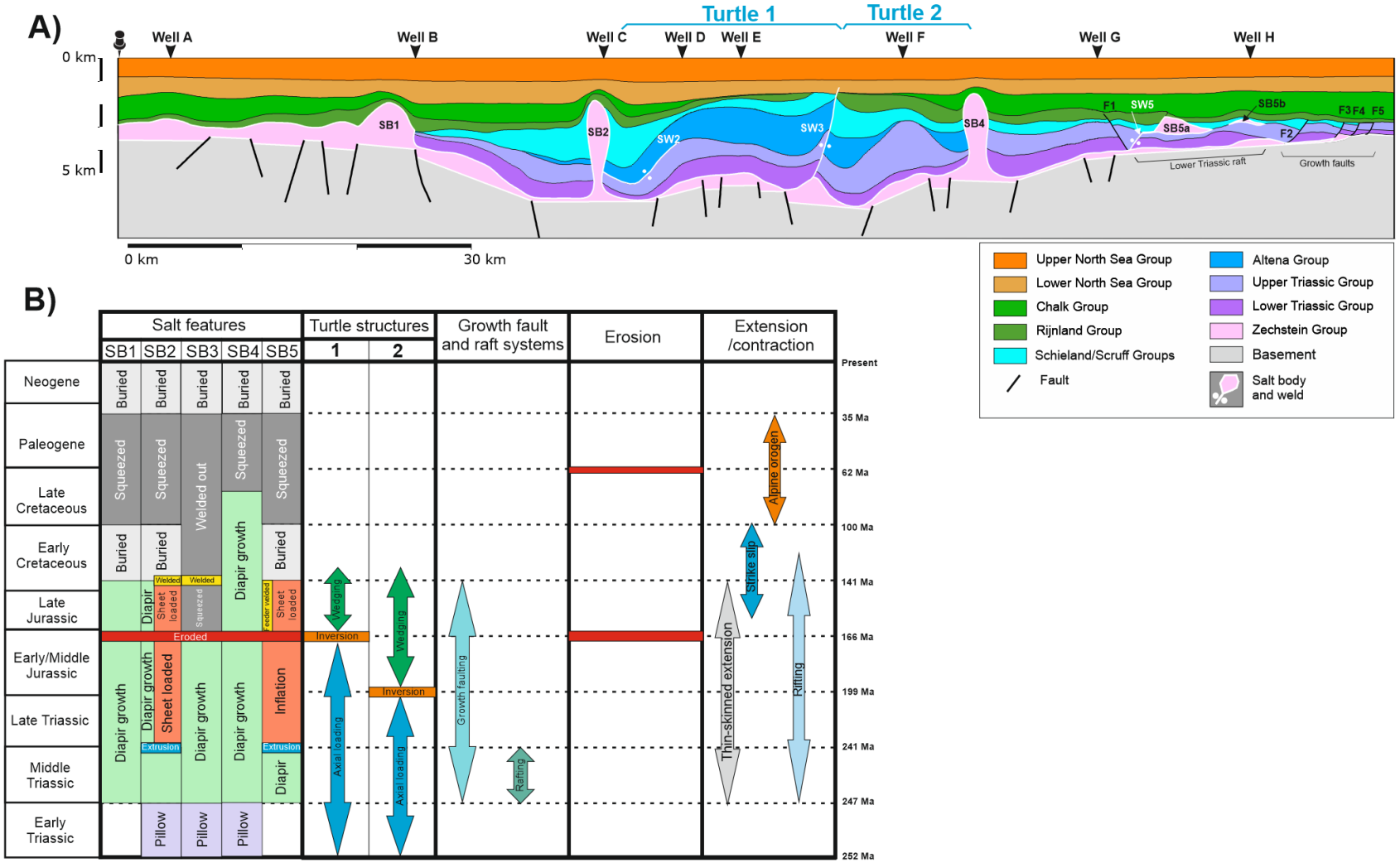
Rouby et al., 2002.



Stefan Peeters, TNO-UU, 2016

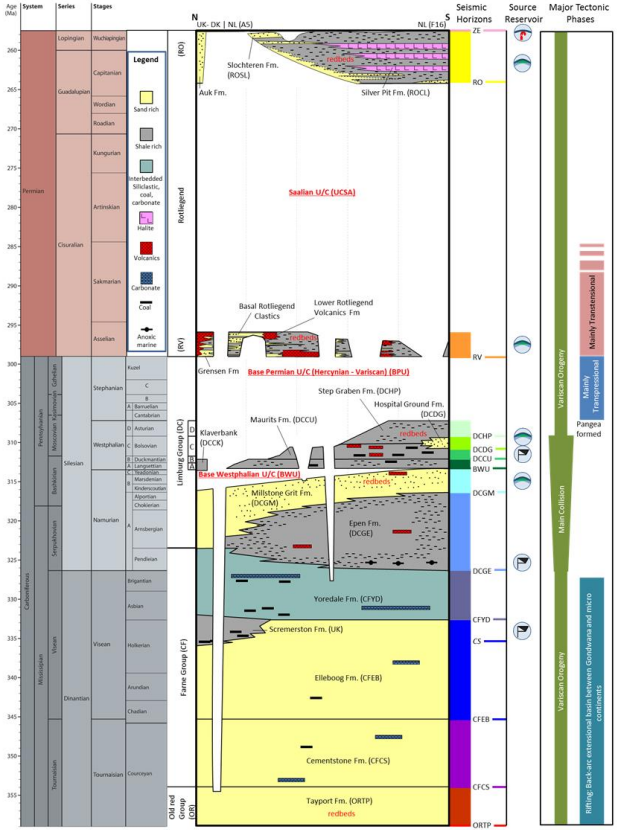
2) TRIASSIC SALT TECTONICS



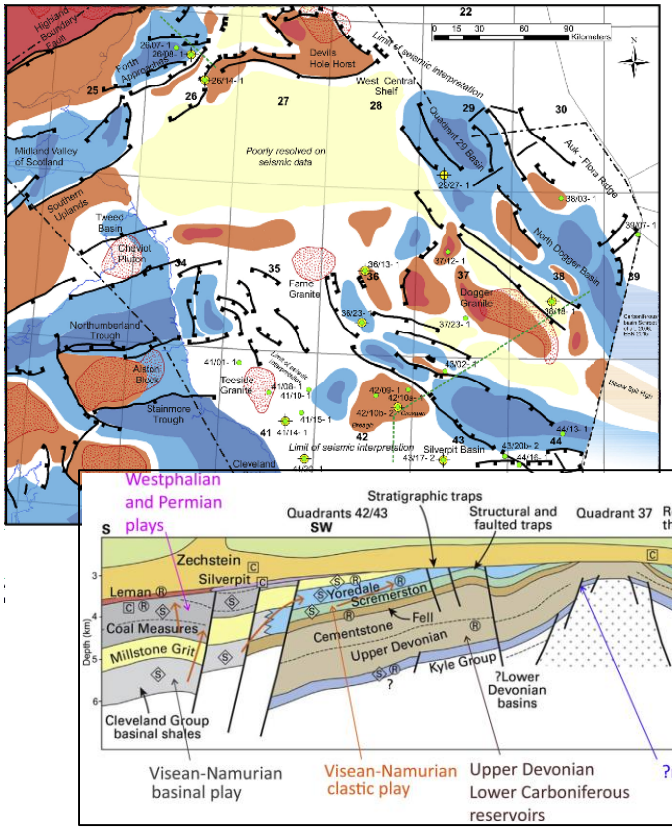

A)
Turtle 1
Turtle 2
Well A
Well B
Well C
Well D
Well E
Well F
Well G
Well H
0 km
5 km
SB1
SB2
SW2
SW3
SB4
F1
SW5
SB5b
F3F4 F5
SB5a
F2
Lower Triassic raft
Growth faults
0 km
30 km
Upper North Sea Group
Lower North Sea Group
Chalk Group
Rijnland Group
Schieland/Scruff Groups
Fault
Altena Group
Upper Triassic Group
Lower Triassic Group
Zechstein Group
Basement
Salt body and weld
B)
Salt features
SB1
SB2
SB3
SB4
SB5
Turtle structures
1
2
Growth fault and raft systems
Erosion
Extension /contraction
Neogene
Paleogene
Late Cretaceous
Early Cretaceous
Late Jurassic
Early/Middle Jurassic
Late Triassic
Middle Triassic
Early Triassic
Buried
Squeezed
Welded out
Diapir growth
Diapir
Sheet loaded
Welded
Squeezed
Feeder welded
Eroded
Inversion
Wedging
Axial loading
Inflation
Extrusion
Pillow
Growth faulting
Rafting
Alpine orogen
Strike slip
Thin-skinned extension
Rifting
Present
35 Ma
62 Ma
100 Ma
141 Ma
166 Ma
199 Ma
241 Ma
247 Ma
252 Ma

3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

TNO Northern Offshore Project (2016)



BGS 21st Century Project (2016)

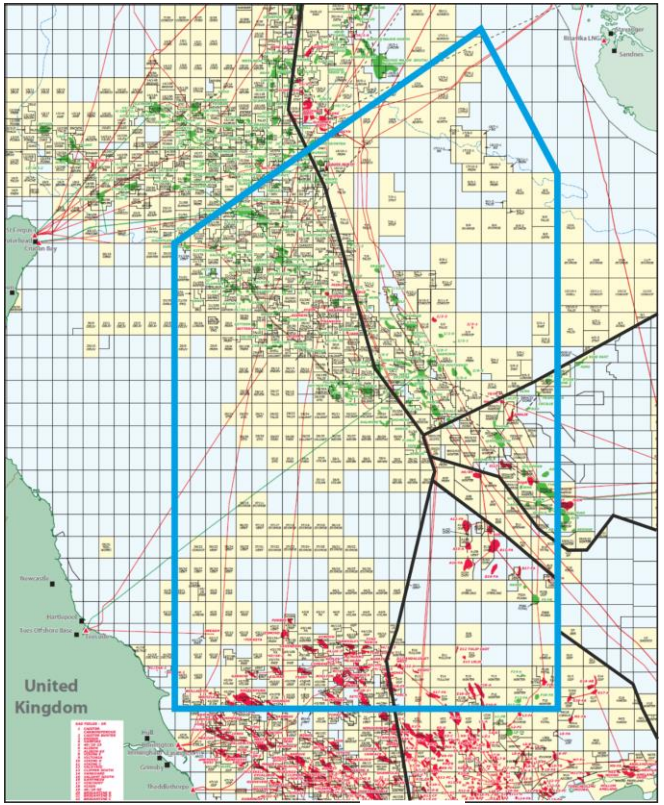


- Alison Monaghan
- Dave Millward
- Margaret Stewart

2) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

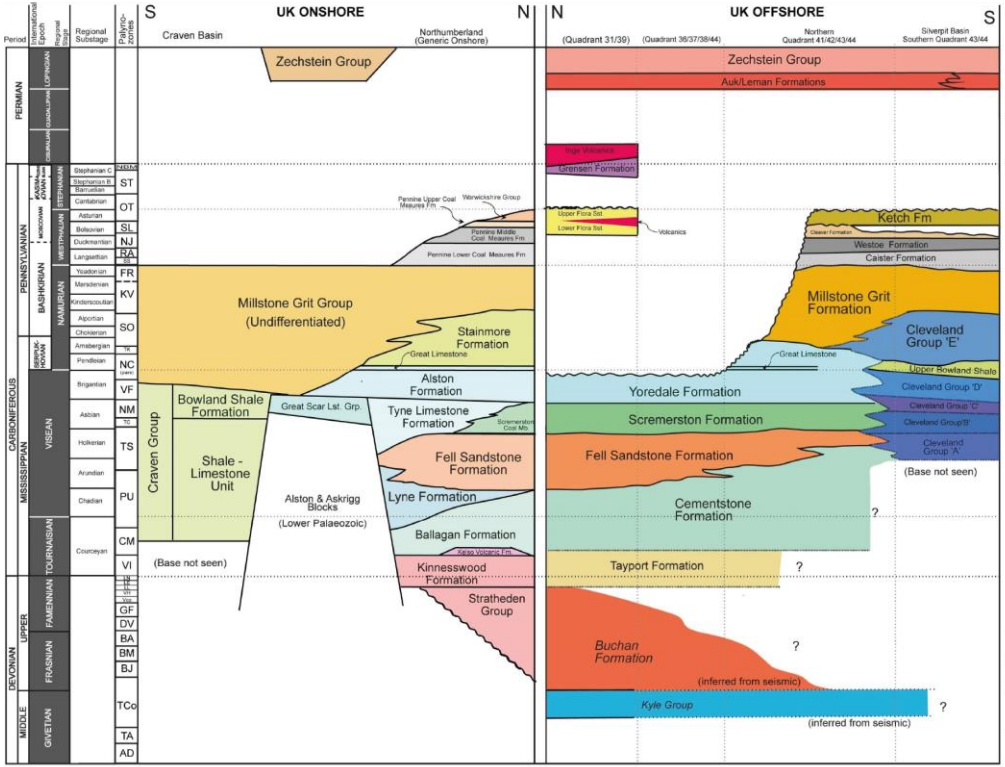
Paleo-Five Project, Southern and Central North Sea.

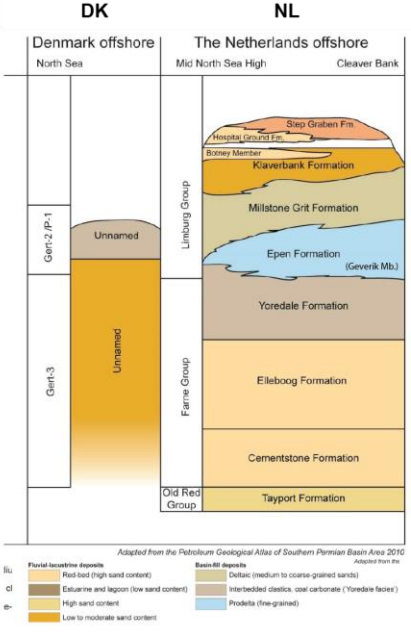
- **Predictive models** for source rock occurrence based on tectonostratigraphic and paleoecological information.
- To establish a new cross-border **stratigraphic** scheme based on existing and new **biostratigraphic** analysis.
- **Stratigraphic** correlation and subcrop maps based on key well and seismic data.
- **Outcrop- and core-based sedimentological and stratigraphic analysis.** 300 organic-rich rock samples and 1,4 km long measured section already acquired.
- **Organic and in-organic geochemical and palynological analysis:** typing of key source rocks

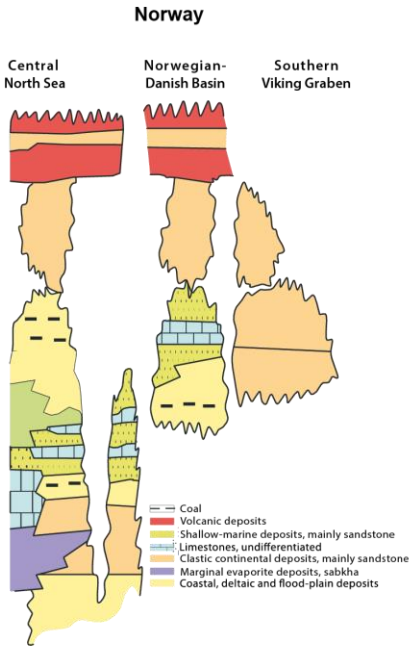


3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

Stratigraphic synchronization



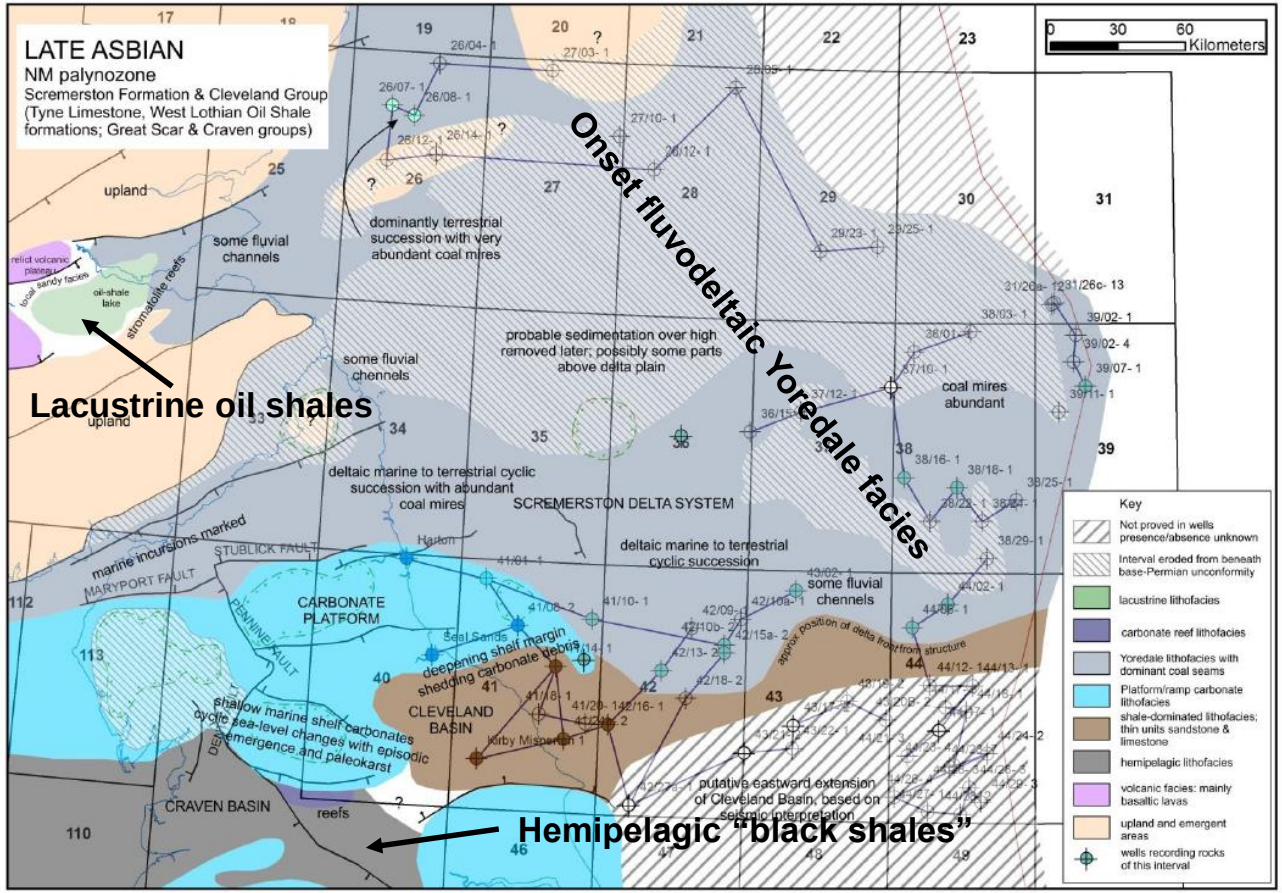




SPBA, 21CXRM, NPD-website

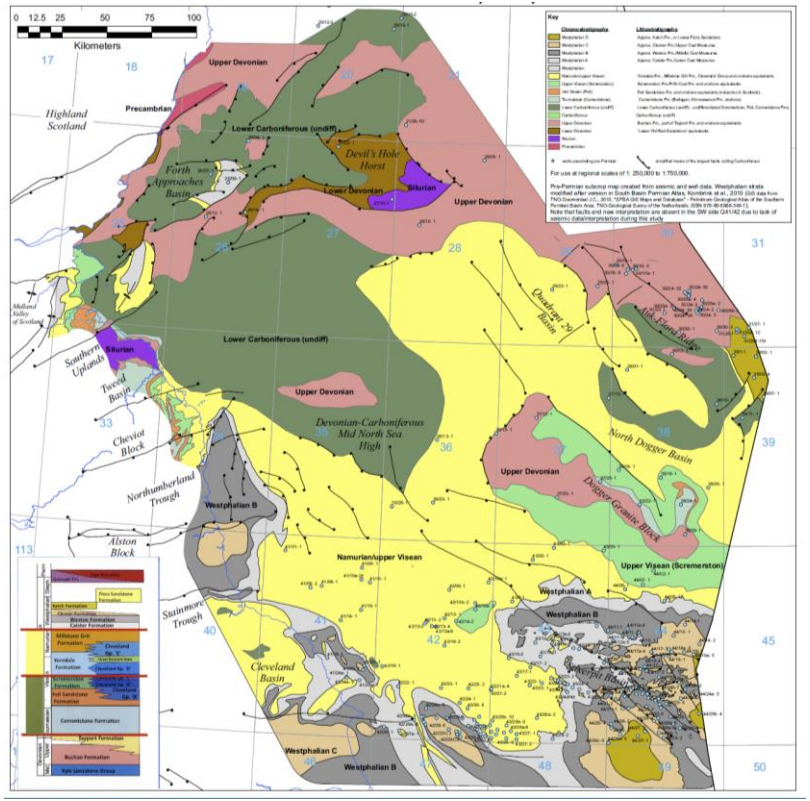
3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

Stratigraphic and paleogeographic synchronization

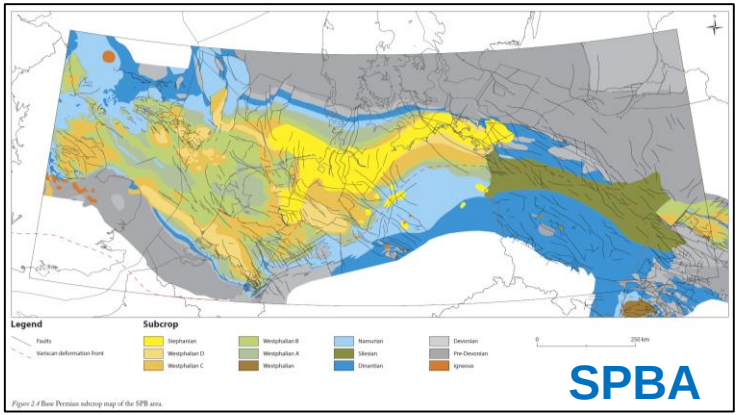


3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

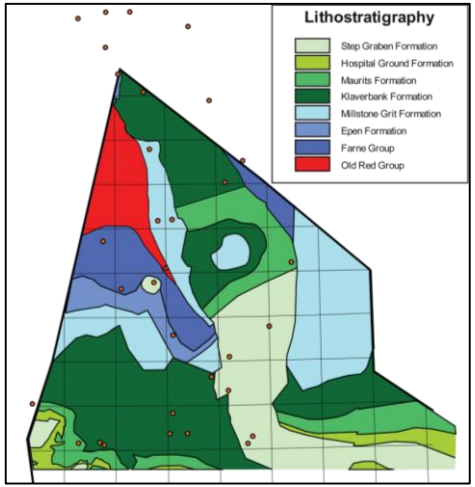
Subcrop map across five countries



BGS



SPBA

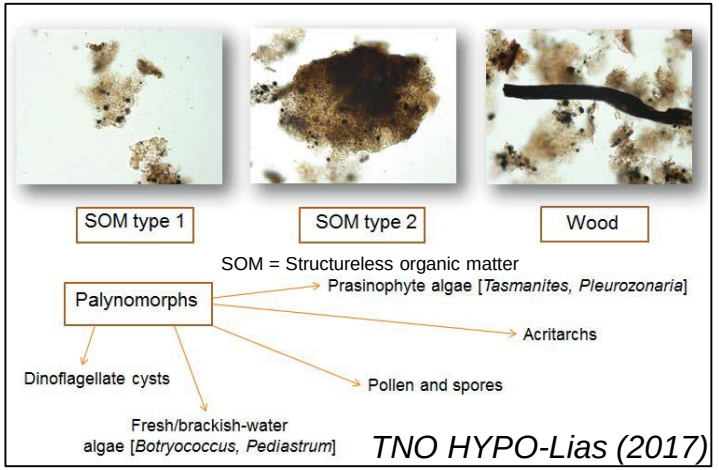


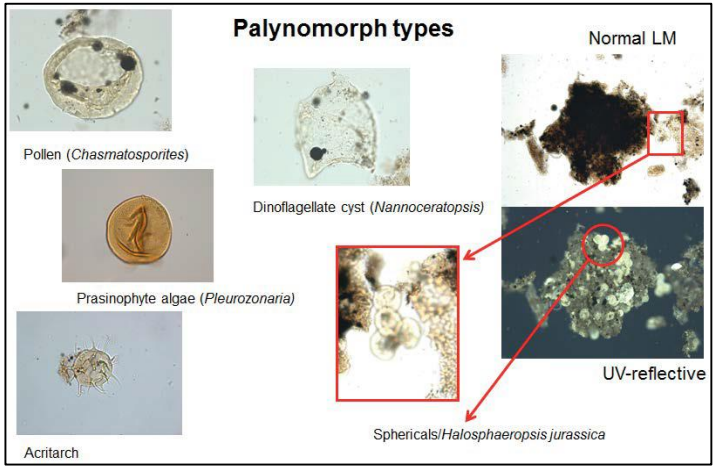
TNO

3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

Cores and outcrop samples used for multidisciplinary analyses

- High-resolution **paleoecological/ palynostratigraphical and palynofacies analysis** from source intervals.
- **Organic geochemical** (standard C_{15+} gas chromatography of the organic solvent extracts, saturate and aromatic fraction biomarker analyses and bulk, saturate and aromatic fraction isotope analyses) and **Rock-Eval analyses**.
- High-resolution **depositional facies analysis.**
- Conceptual models of lateral and vertical variation in source-rock development.

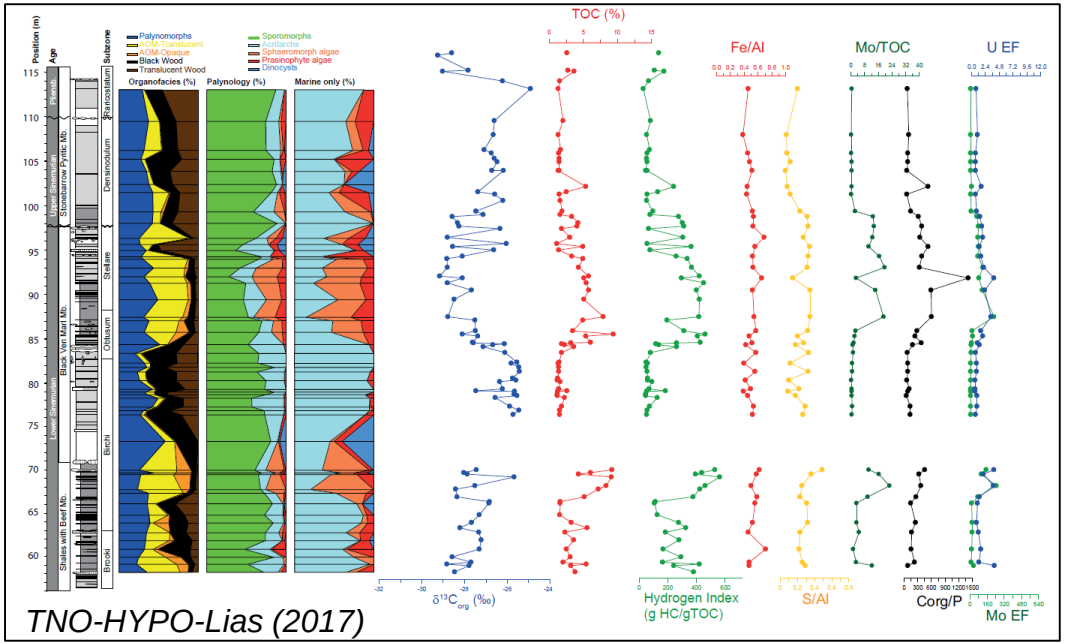




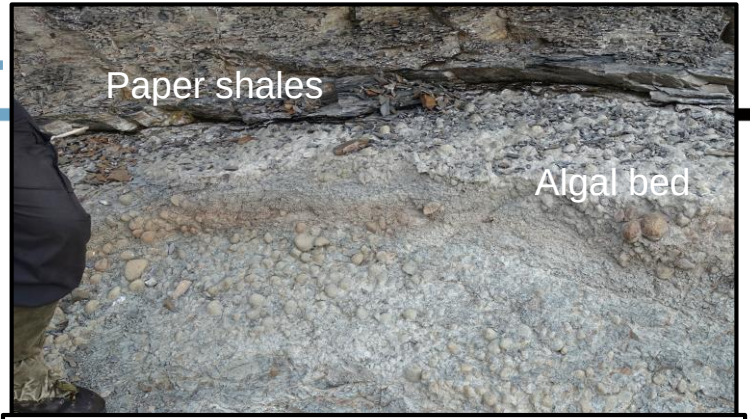
3) L. CARBONIFEROUS SR POTENTIAL

Paleoecology

- Identify oil-prone biofacies.
- Predict their occurrence on the basis of tectonostratigraphic and climate-stratigraphic settings.



TNO-HYPO-Lias (2017)



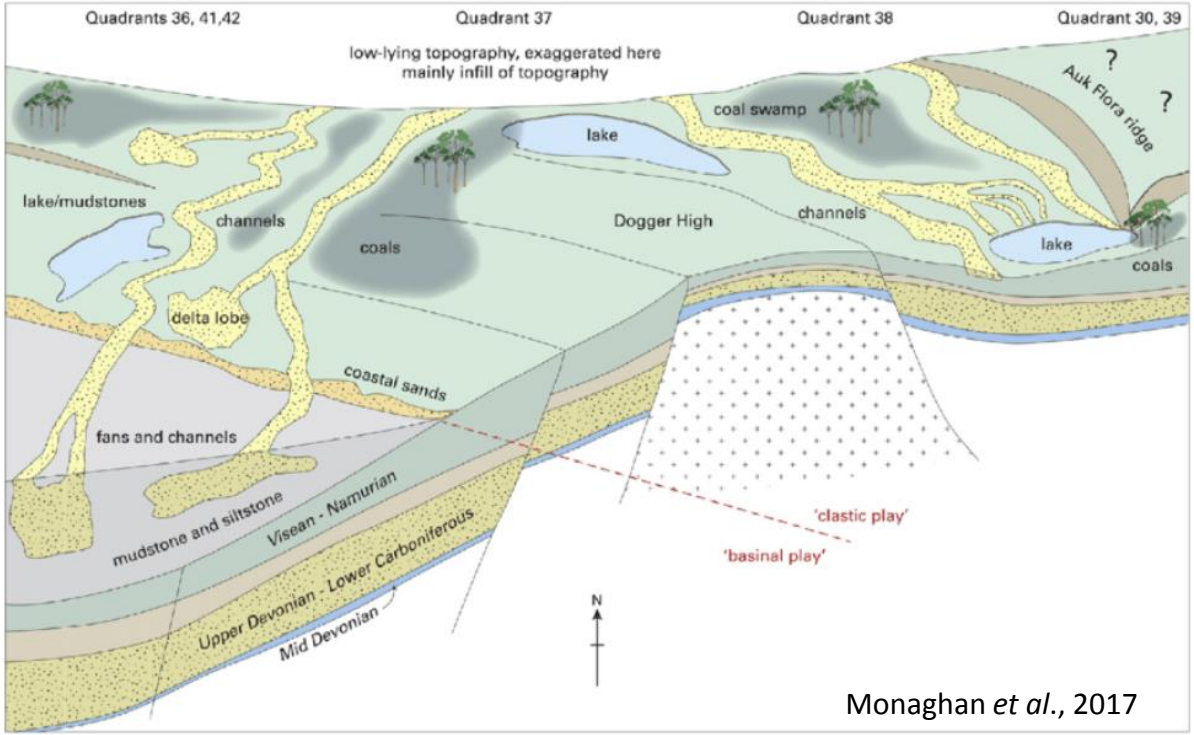
Tyne Limestone Formation, Asbian, which is time equivalent of Scremerston Formation offshore.

Alston Formation, Brigantian, which is time equivalent of Yoredale Formation offshore.

3) L. CARBONIFEROUS SOURCE ROCK POTENTIAL

Paleogeography through time

3D schematic block diagram of the generalized structure and lowstand depositional environments in the Scremerston/Yoredale Formations



Monaghan *et al.*, 2017

ANNOUNCEMENT

TNO is releasing five full reports in December 2018 on the NLOG website, including:

- One Carboniferous/Rotliegend report: **Northern Offshore Project.**
- Four Jurassic reports: **Focus, Justrat, Sweet Spot 1 and Sweet Spot 2 Projects.**

Thank you