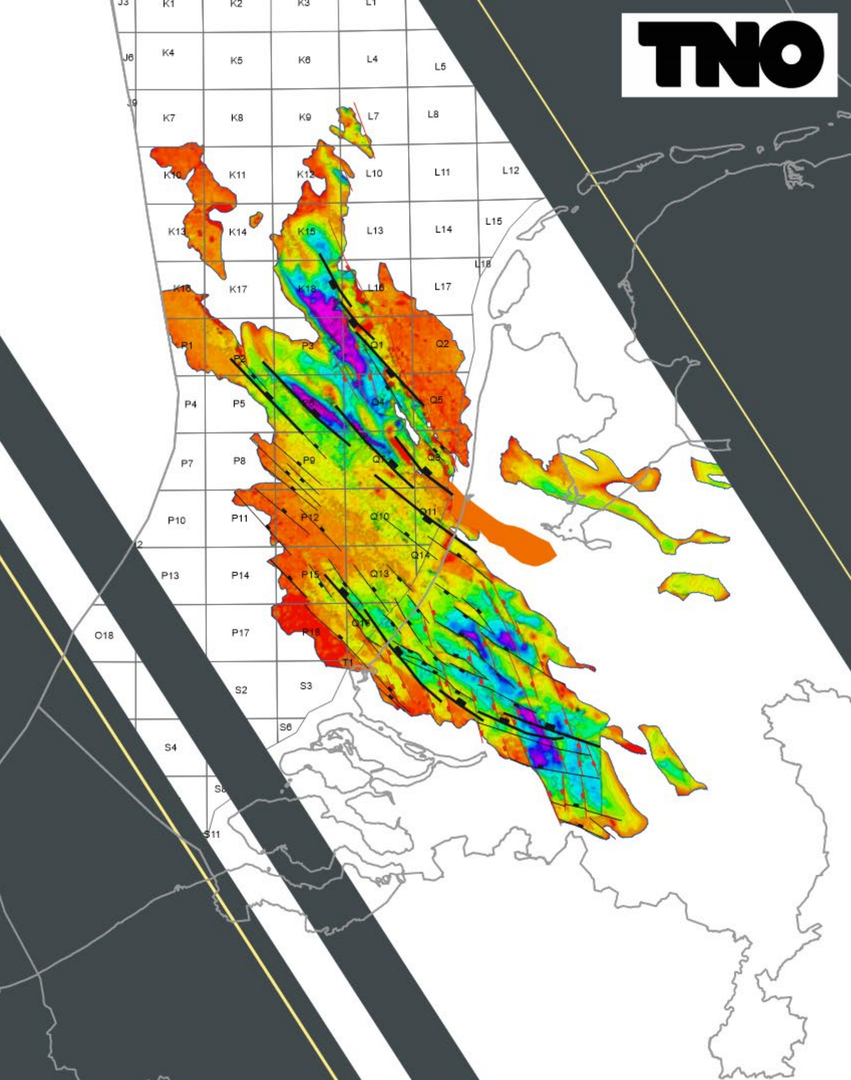
DEVLI PROJECT

Stratigraphy and tectonostratigraphy of the Delfland and Vlieland subgroups, Upper Jurassic and Lower Cretaceous -
Broad Fourteens Basin, West Netherlands Basin and neighbouring areas



A project by TNO: Renaud Bouroullec, Roel Verreussel, Stefan Peeters, Anuska Kaliar, Dario Ventra and Darren Jones
in collaboration with **EBN**: Sibren Dieters and Esmée Boter

TNO Report: TNO 2024 R12075

DEVLI Project: Stratigraphy and tectonostratigraphy of the Delfland and Vlieland subgroups, Upper Jurassic and Lower Cretaceous - Broad Fourteens Basin, West Netherlands Basin and neighbouring areas.

Date: 20-11-2024

Report Number: TNO 2024 R12075

Authors: Renaud Bouroullec, Roel Verreussel, Stefan Peeters, Anuska Kaliar, Dario Ventra, Darren Jones, Sibren Dieters and Esmée Boter

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Energising the transition

Reference:
Bouroullec, R., Verreussel, R. M. C. G., Peeters, S., Kaliar, A., Ventra, D., Jones, D., Dieters, S. and Boter, E., 2024, DEVLI Project: Stratigraphy and Tectonostratigraphy of the Delfland and Vlieland subgroups, Upper Jurassic and Lower Cretaceous - Broad Fourteens Basin, West Netherlands Basin and neighbouring areas. TNO Report 2024 R12075.

The Team

Project Management

Simona Bottero (TNO) and **Marloes Kortekaas (EBN)**

Project Team

TNO

Renaud Bouroullec (Lead Scientist) – Geology, seismic interpretation, core description, integration

Roel Verreussel – Geology, stratigraphy, integration

Stefan Peeters – Geology, seismic interpretation, integration

Anuska Kaliar – Seismic interpretation

Dario Ventra – Core description

Darren Jones – Seismic interpretation

EBN

Sibren Dieters – Seismic interpretation

Esmée Boter – Seismic interpretation

Acknowledgements

- EBN for the support and collaboration.
- Simona Bottero (TNO) and Marloes Kortekaas (EBN) for the project management.
- Thanks to colleagues from EBN and TNO for the fruitful discussion: Bas van Es, Harald de Haan, Aart-Peter van den Berg van Saparoea, Sjoukje de Vries, Michael Nolten, Sabine Korevaar, Nico Janssen, Sander Houben and Jeroen van der Molen.
- Special thanks to Daan den Hartog and Richard Porter for the review of the report

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Project title: **DEVLI** (standing for **De**lfland and **Vli**eland subgroups)

This project has been carried out as an update on the stratigraphy and tectonostratigraphy of the Upper Jurassic to Lower Cretaceous in southern part of the Dutch Offshore and in the western part of the Dutch onshore.

This project helps to support the **EBN/TNO GEODE Jurassic Play update project (2024-2025)** by providing new stratigraphic and structural constrains as well as a homogeneous extension to the 2021 Geode Jurassic Play element maps.

Additionally, the results provide new insights on the geology of the southern Dutch rift system with application for multiple resource applications.

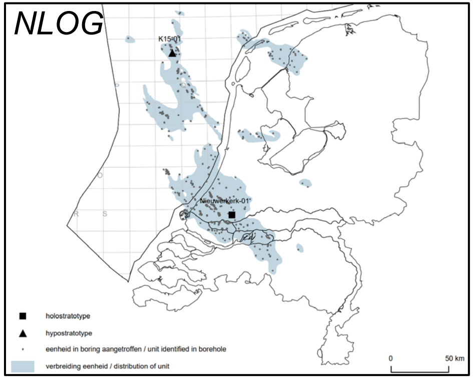
This project consists of an updated stratigraphic framework based on the integration of revisited legacy and newly acquired palynological information, as well as a new seismic interpretation effort focused on tectonostratigraphic megasequences (TMS-1 to TMS-4, as defined by Verreussel et al., 2018) mapping.

Introduction – DEVLI Study Area

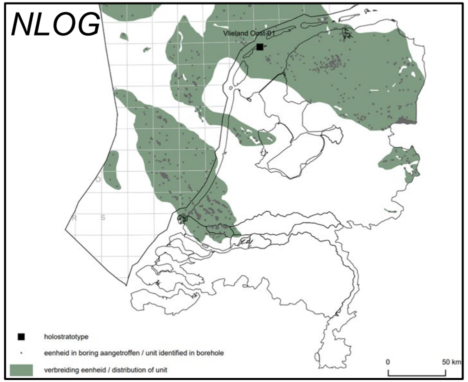
The study area extends from

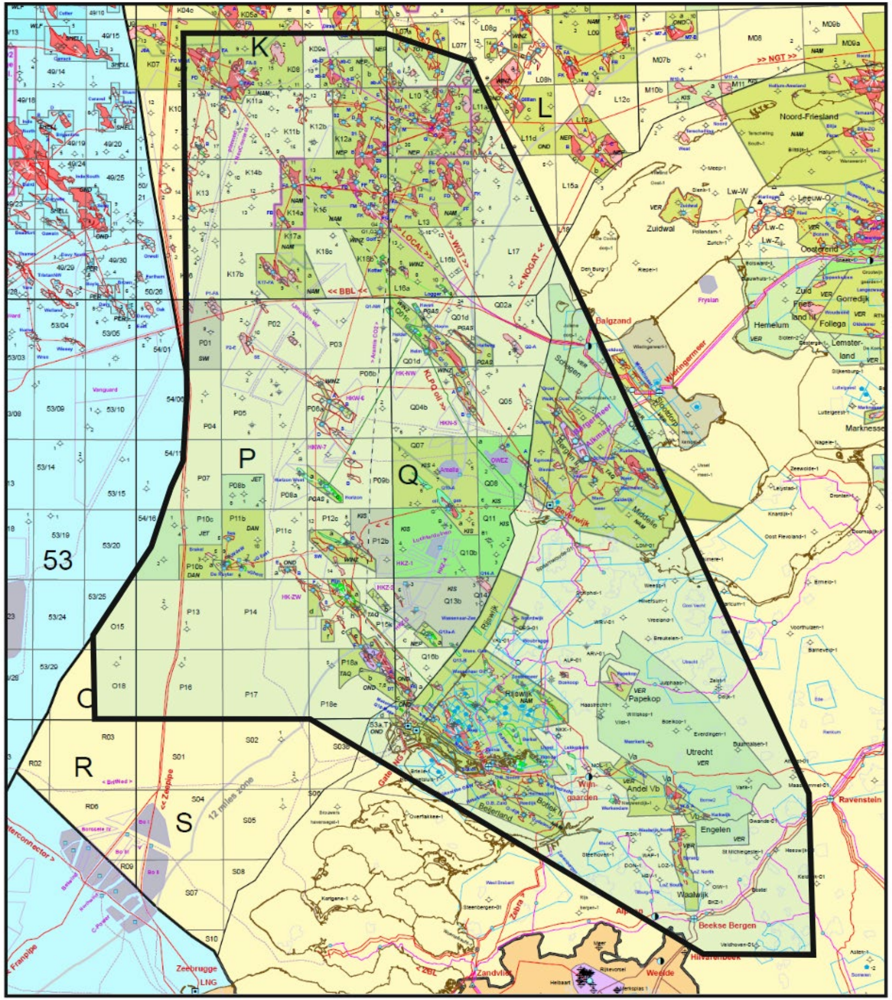
- The onshore (northern part of South Holland, southern part of North Holland, western part of Utrecht and western part of Gelderland), to
- the offshore (K Blocks (07-18), L (07, 10, 13, 14, 16, 17), O, P and Q).

Delfland Subgroup



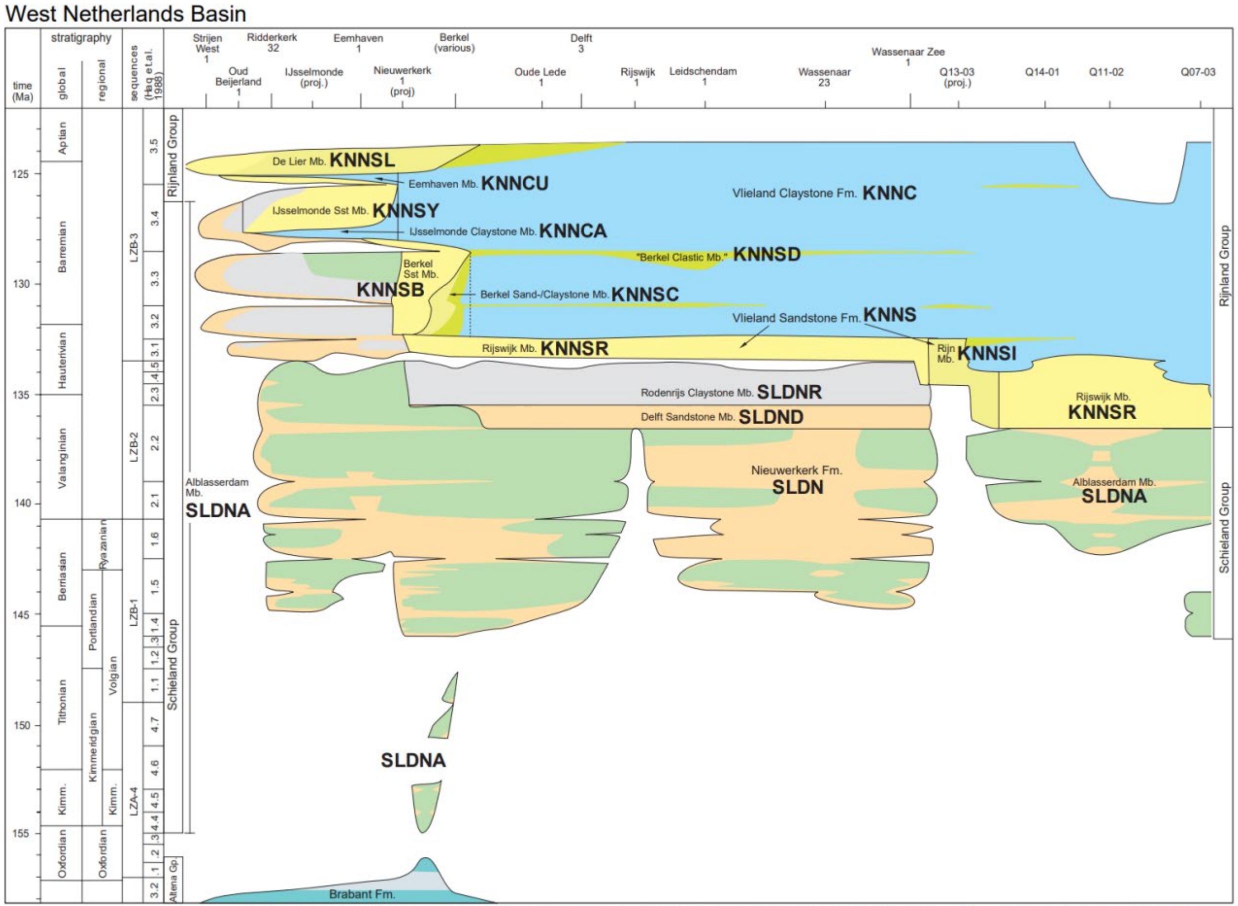
Vlieland Sandstone Formation





Lithostratigraphic framework of the Upper Jurassic and Lower Cretaceous of the West Netherlands Basin

The Schieland Group primarily represents continental depositional systems while the Rijnland Group represents coastal to fully marine depositional systems

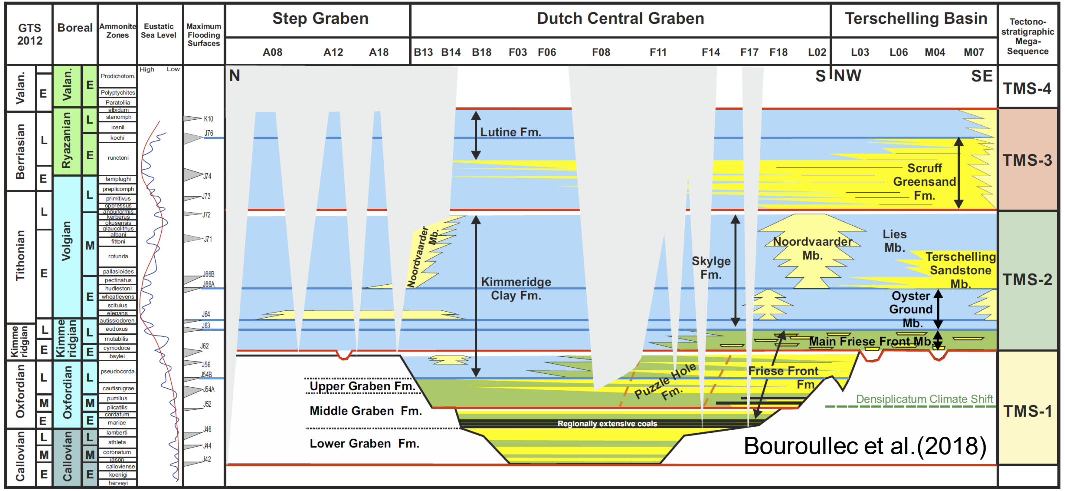


Source: Van Adrichem Boogaert & Kouwe (1993). Stratigraphic nomenclature: Section G - Upper Jurassic and Lower Cretaceous - Mededelingen Rijks Geologische Dienst 50

Introduction – Regional geological context: Stratigraphy

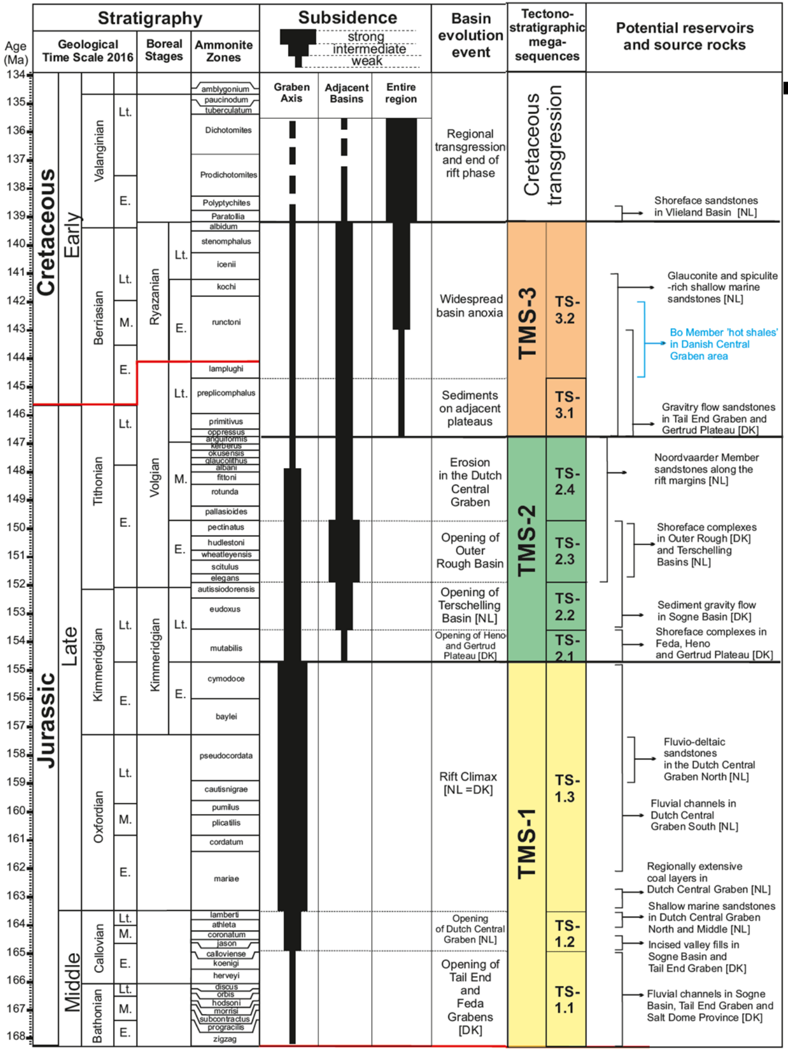
The project aims at extending the chronostratigraphic (TMS 1-3) and tectonostratigraphic stratigraphic constraints from past studies in the Dutch northern offshore (TNO Focus, Maxim reports) to the Broad Fourteens and West Netherlands basins and neighbouring platforms.

The Valanginian, Hauterivian and Barremian were also added to the Devli Project (TMS-4)



Bouroullec et al.(2018)

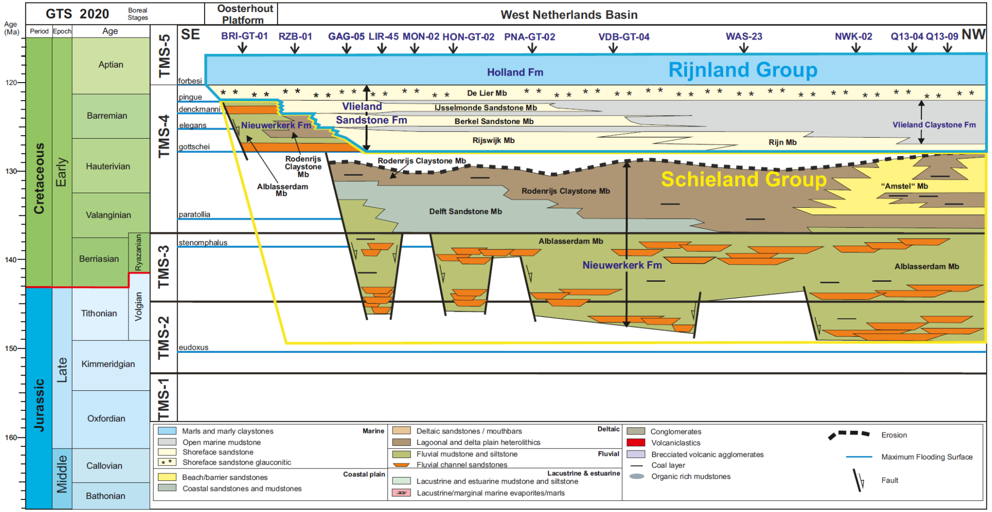
Verreussel et al.(2018)

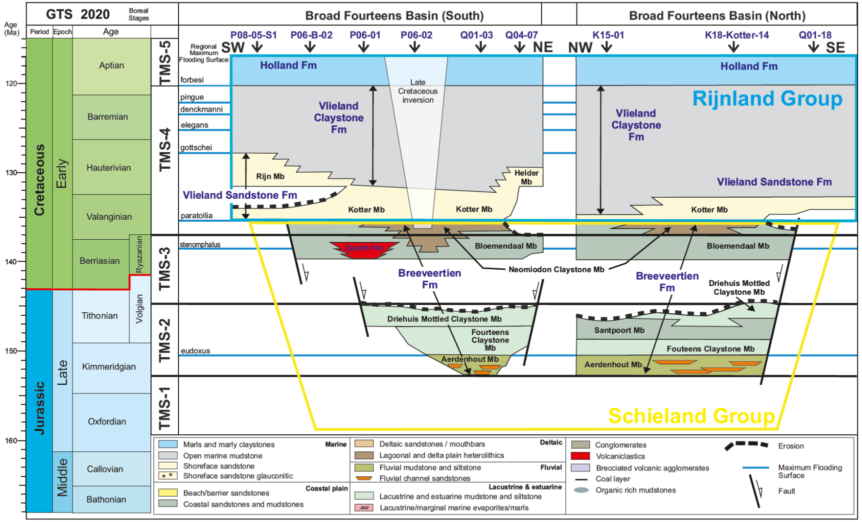


Introduction – Regional Geological Context: Stratigraphy

The recently revised stratigraphy (Verreussel et al., in press) provides a more refined calibration of the lithostratigraphic units in the West Netherland Basin and Broad Fourteens Basin.

The DEVLI project provides new biostratigraphic, sedimentological, stratigraphic and seismic information to further calibrate the various depositional systems as well as the litho- and sequence stratigraphic units.

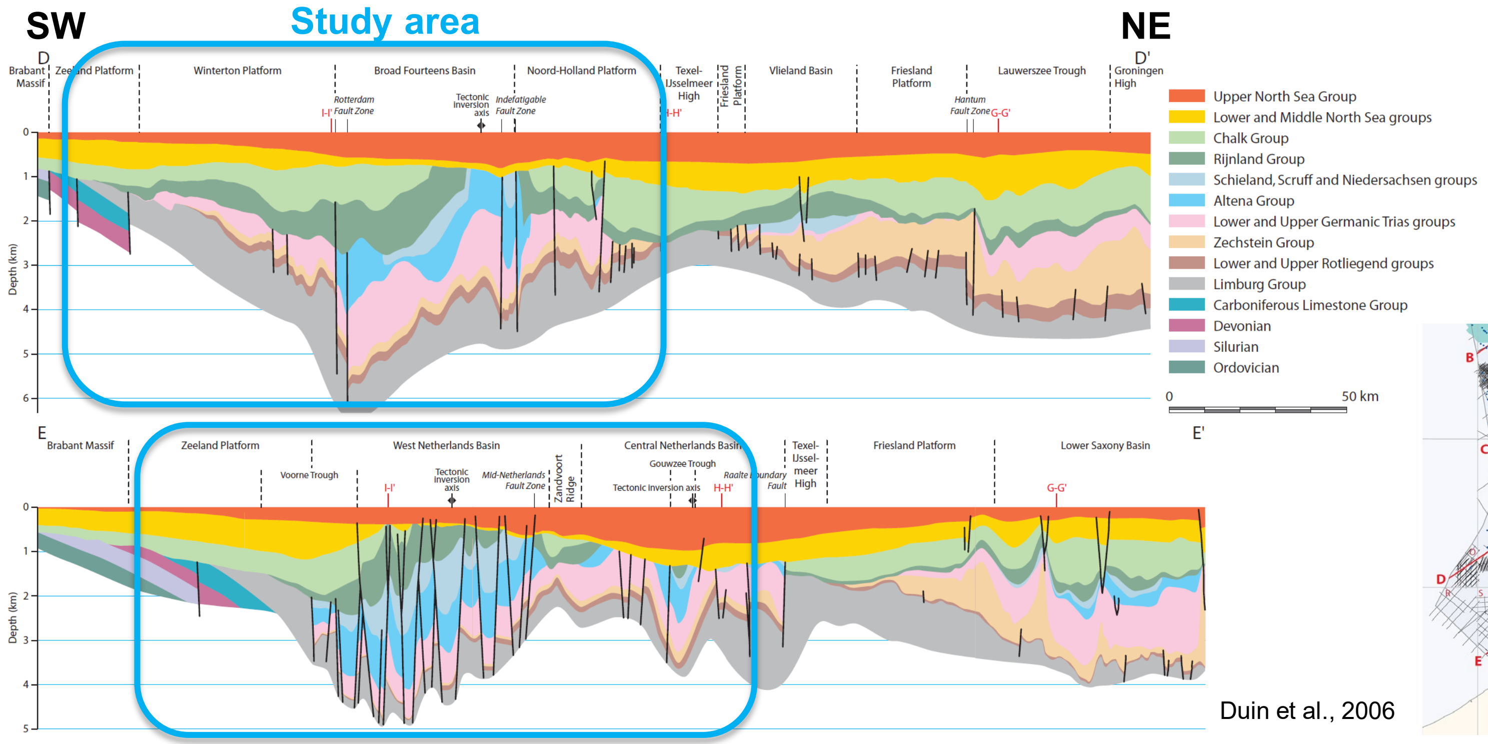


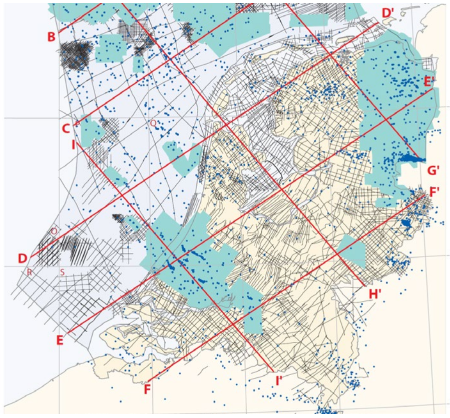


Verreussel et al, (in press) in the new book: Geology of the Netherlands to be published in 2025

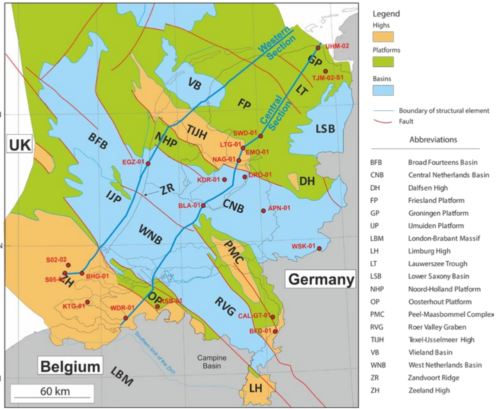
1 Introduction – Regional Geological Context: Tectonics

Both the West Netherlands and Broad Fourteens basins are failed rift basins (Jurassic to Early Cretaceous) that were inverted during the Late Cretaceous to early Cenozoic.
Note that the uplift and erosion was most prominent in the northeastern parts of both basins.

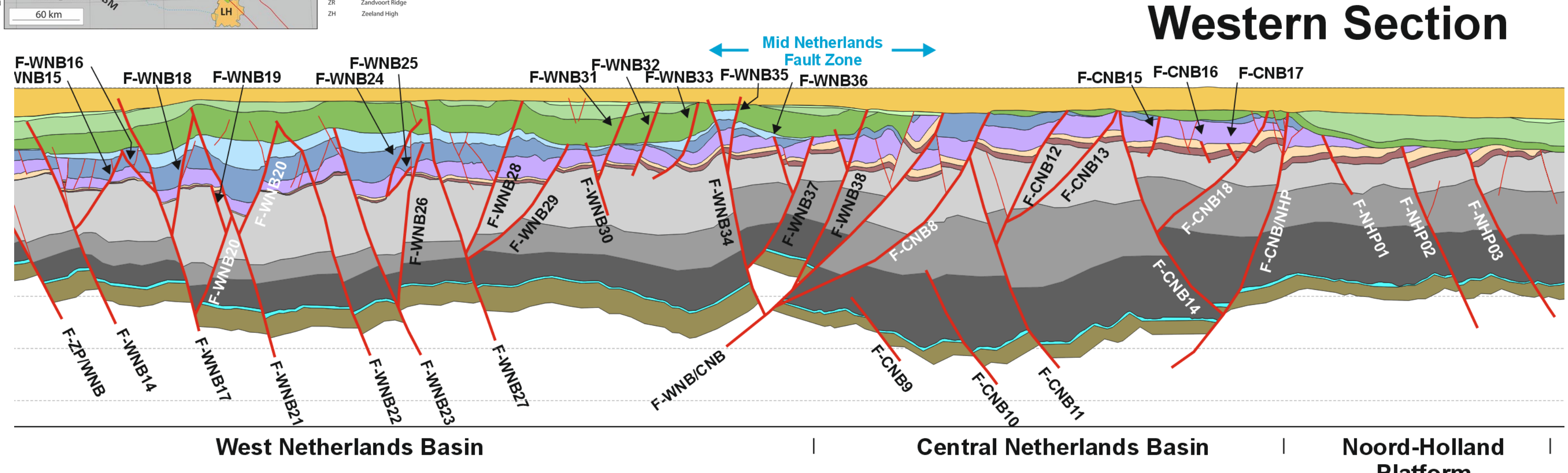




Duin et al., 2006



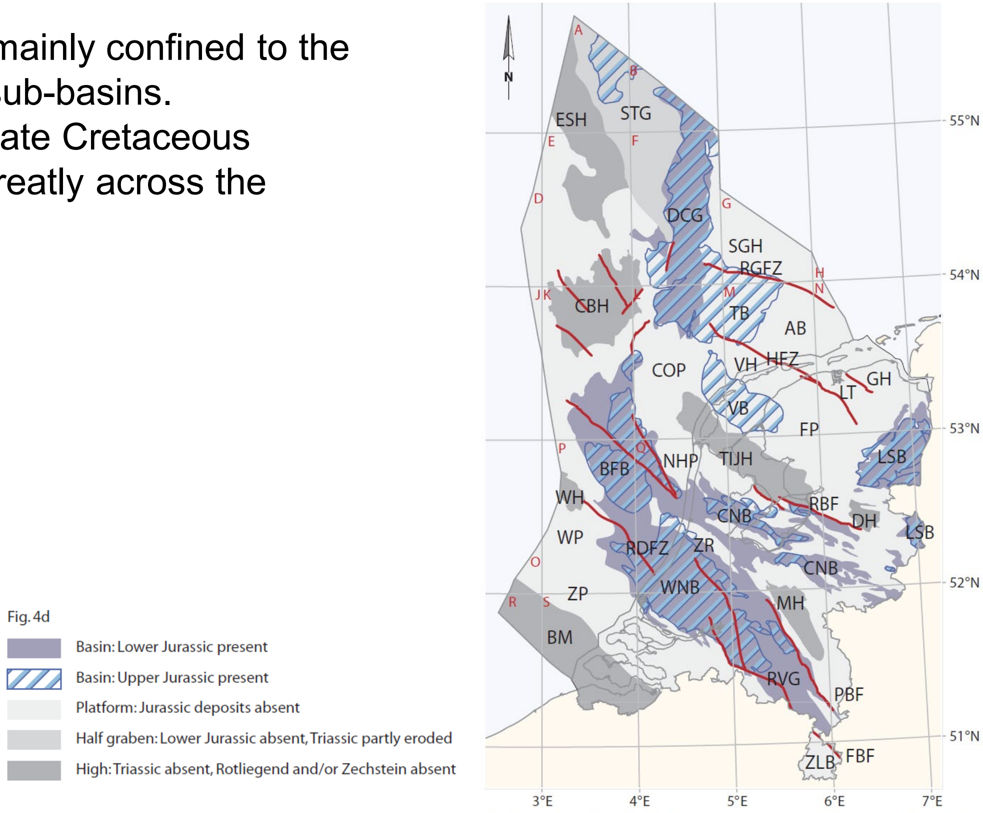
The transition between the West and Central Netherlands basin is structurally complex. The area is known as the Mid Netherlands Fault Zone and extends to the SE into the Peel-Maasbommel Complex.



Northern part of the Western section shown on the inset map. From Bouroullec et al., 2019

1 Introduction – Regional geological context: Tectonics

The Upper Jurassic is mainly confined to the partially preserved rift sub-basins.
The orientation of the Late Cretaceous inversion axis, varies greatly across the country.



d. *Late Jurassic - Early Cretaceous structural elements (Late Kimmerian phases)*

Duin et al., 2006

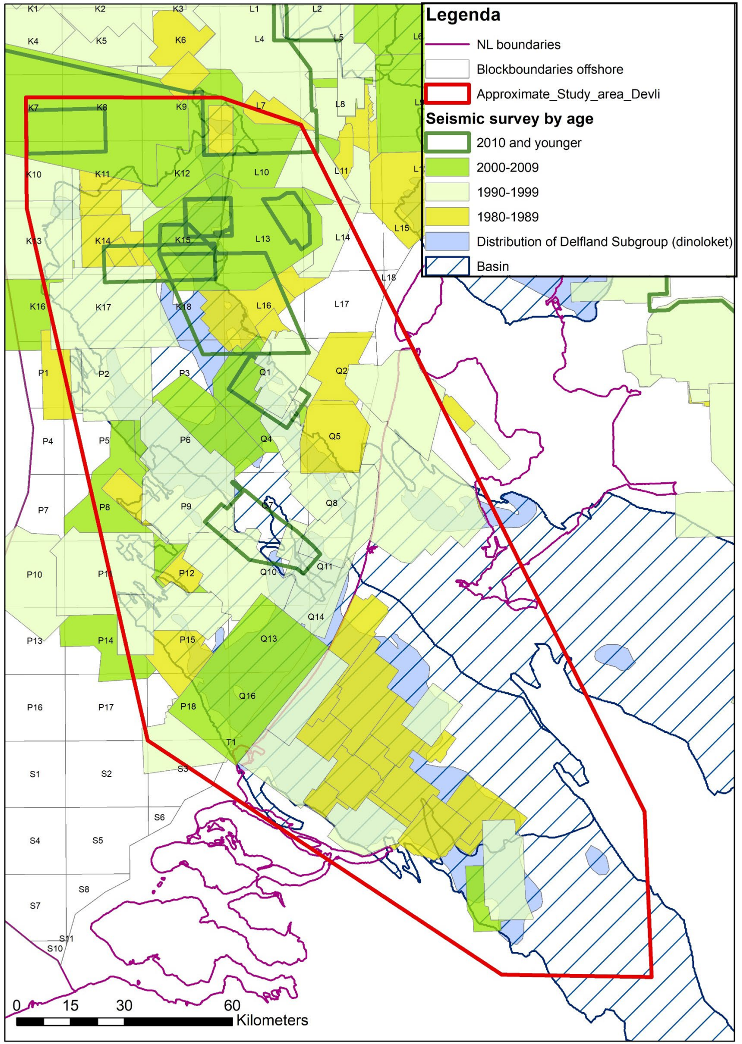
Ameland Block	AB
Brabant Massif	BM
Broad Fourteens Basin	BFB
Campine Basin	CB
Central Netherlands Basin	CNB
Central Offshore Platform	COP
Cleaver Bank High	CBH
Dalfsen High	DH
Dutch Central Graben	DCG
Elbow Spit High	ESH
Ems Low	EL
Friesland Platform	FP
Groningen High	GH
Kijkduin High	KH
Lauwerszee Trough	LT
Lower Saxony Basin	LSB
Maasbommel High	MH
Mid North Sea High	MNSH
Netherlands High	NH
Netherlands Swell	NS
Noord-Holland Platform	NHP
North Sea Basin	NSB
Peel Block	PBL
Rhenish Massif	RM
Roer Valley Graben	RVG
Schill Grund High	SGH
Southern Permian Basin	SPB
Step Graben	STG
Terschelling Basin	TB
Texel-IJsselmeer High	TIJH
Venlo Block	VBL
Vlieland Basin	VB
Vlieland High	VH
Voorne Trough	VT
West Netherlands Basin	WNB
Winterton High	WH
Winterton Platform	WP
Zandvoort Ridge	ZR
Zeeland Platform	ZP
Zuiderzee Low	ZZL
Zuid-Limburg Block	ZLB

Data and Methods – Seismic data

The coverage of 3D seismic surveys within the Devli study area is extensive: more than 50 surveys of different vintage and quality.

EBN kindly provided a mega-merge seismic cube (Terracube) for use in the DeVli study.

In addition, 2D seismic surveys located in the study area (including Scan data) were used as well (See next page).



Data and Methods – Seismic data

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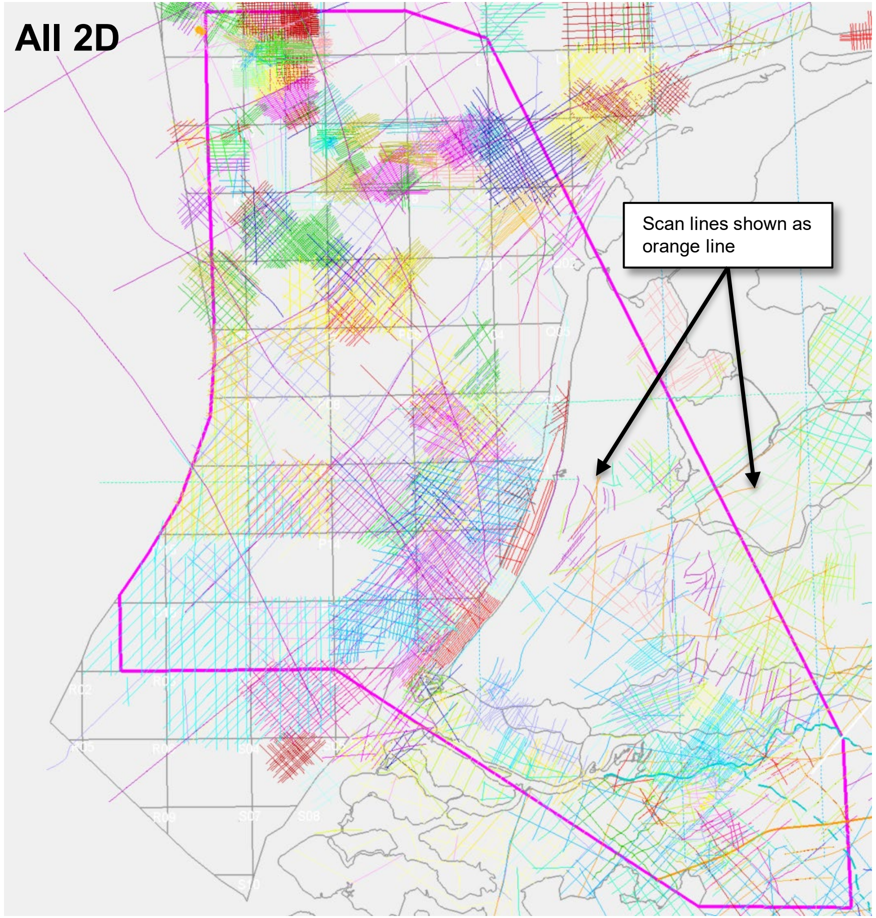
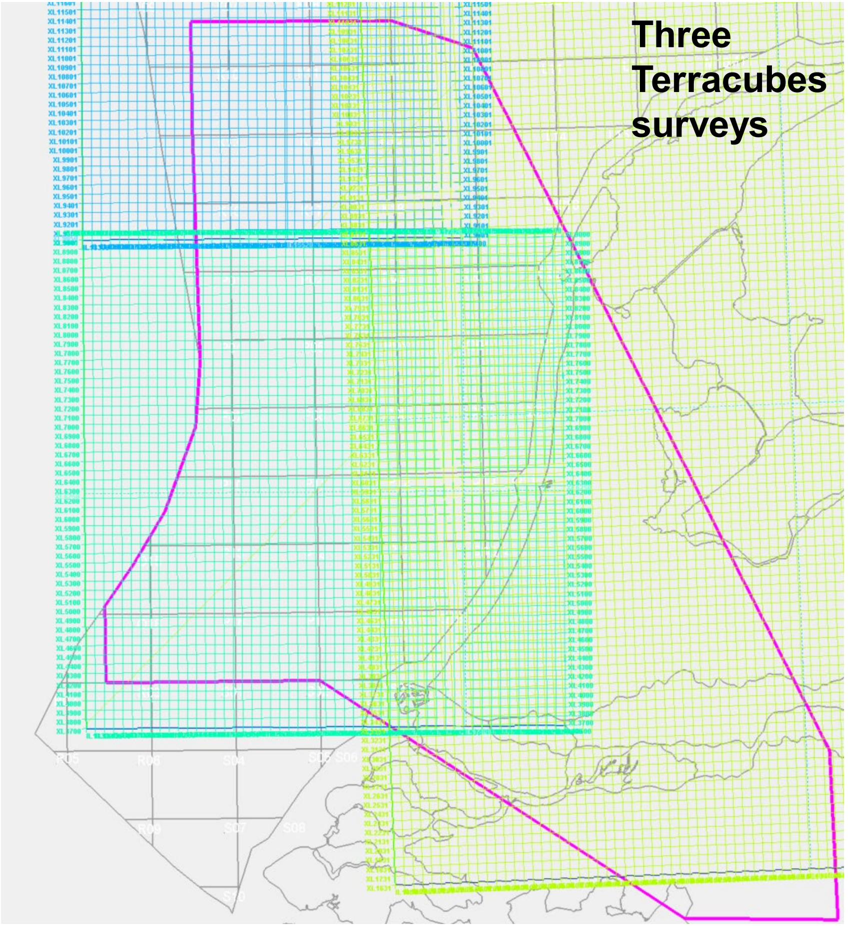
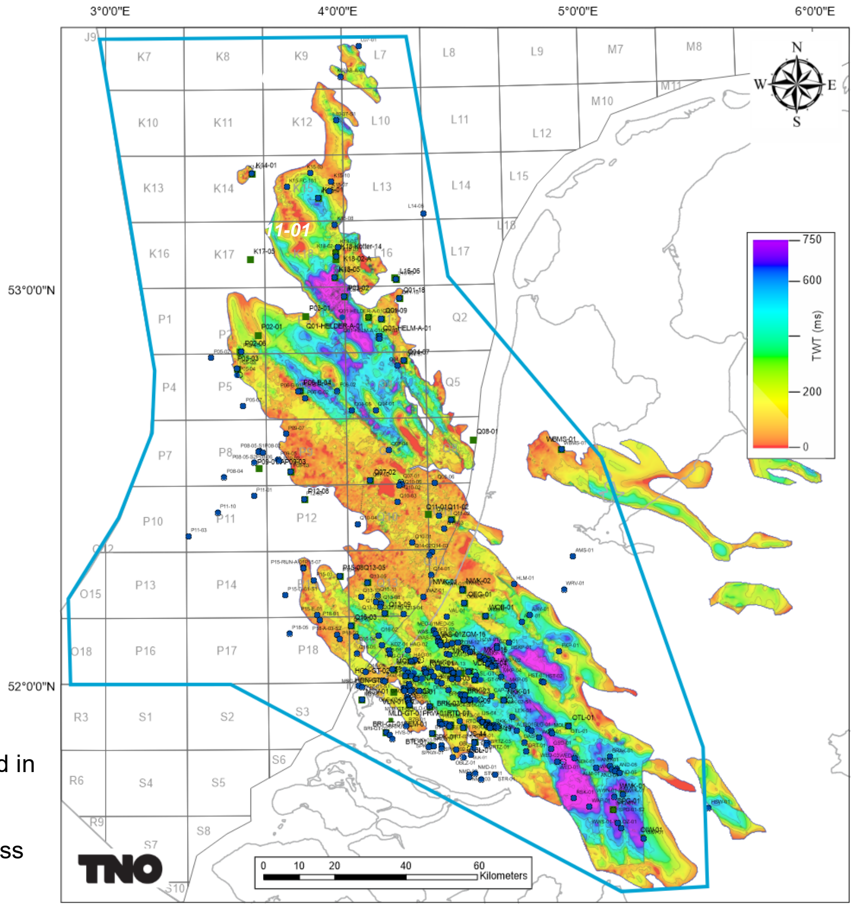




358 wells are listed in the following tables. These wells have stratigraphic relevance to the DEVLI project and are included in the Petrel project. Wells listed in red were not yet in the public domain at time of this publication. The meta-data that are associated with the wells are tabulated in eight columns:

1) The **Basin** in which the well is located.
2) The **DEVLI panel** in which the well is included.
3) The **Wheeler diagram** in which the well is included.
4) If the well is used for a **Seismic-to-well tie.**
5) If **core description** and interpretation was carried out within the DEVLI Project.
6) If **Palynological analyses** and interpretations were carried out within the DEVLI Project.
7) If **biostratigraphic data** are available.
8) If any **cored interval** is present in the Vlieland Subgroup (KNN) or in the Delfland Subgroup (SLD).



Map to the right shows all wells used in this study. Green squares are wells with biostratigraphic information. Background map is the time thickness map of TMS-1, -2 and -3 combined

2 Data and Methods – Well list

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Abbreviations and codes

Basin

- WNB = West Netherlands Basin
- BFB = Broad Fourteens Basin
- CNB = Central Netherlands Basin
- GT = Gouwzee Trough

Wheeler diagram

- WNB = WNB-across
- BFB = BFB-across
- BFB-WNB-along

Seismic-to-well tie

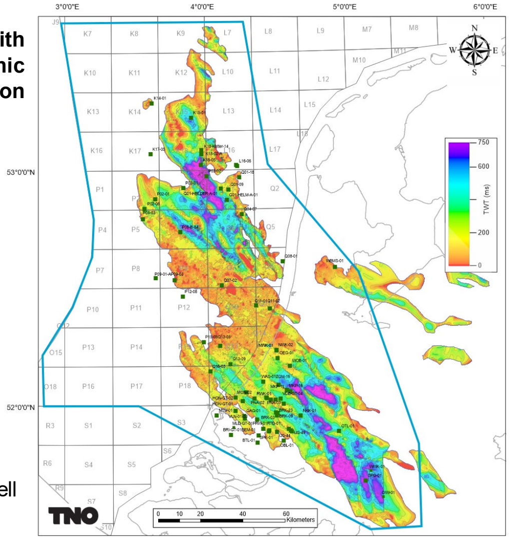
- SYN = Synthetic generation included
- DT = based on velocity via Sonic or checkshot
- Near = based on velocity via Sonic or checkshot of nearby well

Legacy biostratigraphic data

1 = Munsterman reports (TNO)
2 = Duxbury reports (NAM)
3 = JUSTRAT (TNO report)
4 = various reports on NLOG
5 = Jeremiah et al. 2010 paper

NAM reports (van der Zwan et al., 1990 and Den Hartog Jager et al., 1991) were also consulted for additional age control

Wells with biostratigraphic information



Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
ALD-01	WNB	DeVli-6		near				YES
ALM-01	WNB	DeVli-6	BFB-WNB					
ALP-01	WNB							
AMS-01	CNB	DeVli-4	WNB					YES
AND-01	WNB							
AND-03-S2	WNB							
AND-04	WNB							
AND-05	WNB							
AND-06	WNB	DeVli-6						
ARV-01	CNB	DeVli-4	WNB					
BLG-01	WNB							
BLG-02	WNB							YES
BLK-01	WNB							
BRAK-01	WNB							YES
BRI-GT-01	WNB	DeVli-4	WNB				1	
BRI-GT-02	WNB							
BRK-01-S1	WNB							
BRK-02	WNB					YES	2	YES
BRK-03	WNB						2	
BRK-04	WNB							
BRK-07	WNB							
BRK-09	WNB						2	
BRK-12	WNB							
BRK-13	WNB							
BRK-23	WNB						2	
BRT-01	WNB			SYN			2	YES
BRT-02-S1	WNB			DT				
BRTZ-01	WNB							
BRTZ-02-S3	WNB							
BRTZ-03	WNB							
BSKP-01	WNB	DeVli-4	WNB					YES
BTL-01	WNB						2	YES
CAP-01	WNB							
DEL-02	WNB					YES		
DEL-03	WNB							YES
DEL-08	WNB							
DEL-GT-01	WNB					YES		
DEL-GT-02	WNB							
DRT-01	WNB	DeVli-6		near				
EEM-01	WNB	DeVli-6	BFB-WNB	SYN			5	YES
GAG-01	WNB						2	YES
GAG-02-S1	WNB							
GAG-03	WNB	DeVli-4						
GAG-04	WNB							
GAG-05	WNB	DeVli-4	WNB					
GOU-01	WNB					YES		YES
GSD-01	WNB							
HAG-01	WNB						2	
HAG-02	WNB							
HAG-GT-01	WNB							
HAG-GT-02	WNB							

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Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
HEI-01	WNB							
HLM-01	WNB							
HON-GT-01	WNB	DeVli-6		SYN			1	
HON-GT-01-S1	WNB							
HON-GT-01-S2	WNB							
HON-GT-02	WNB	DeVli-6					1	
HST-01	WNB							
HST-02	WNB		WNB					
HSW-01	WNB							
HVS-01	WNB	DeVli-4						
HZW-01	WNB	DeVli-4	WNB			YES		YES
IJS-01	WNB						2	YES
IJS-02	WNB						2	
IJS-02-S1	WNB							
IJS-41-S1	WNB							
IJS-44	WNB						2	
IJS-49	WNB	DeVli-6					2	YES
IJS-57-S1	WNB							YES
IJS-64	WNB							
IJS-64-S2	WNB							
K09AB-A-03	BFB	DeVli-1						
K14-01	BFB						3	
K15-01	BFB	DeVli-1	BFB-WNB	SYN		YES	5	YES
K15-03	BFB							
K15-07	BFB	DeVli-1						
K15-10	BFB	DeVli-1						
K15-FG-101	BFB	DeVli-1						
K17-05	BFB	DeVli-5						
K18-01	BFB	DeVli-1						
K18-02-A	BFB	DeVli-1	BFB-WNB	DT	YES		5	YES
K18-03	BFB	DeVli-1						YES
K18-05	BFB	DeVli-1					4	
K18-08	BFB	DeVli-1						
K18-Kotter-14	BFB	DeVli-1		DT			3	
KDZ-01	WNB							
KDZ-01	WNB							
KDZ-02-S1	WNB	DeVli-6						
KHL-GT-01	WNB	DeVli-4 DeVli-6						
KHL-GT-02	WNB	DeVli-6	WNB BFB-WNB					
L07-01	BFB	DeVli-1	BFB-WNB					
L10-37-S1	BFB	DeVli-1						
L14-06	BFB	DeVli-2	BFB					
L16-06	BFB				YES		3	
L16-Logger-02	BFB	DeVli-2	BFB				5	YES
LED-01	WNB							
LED-02	WNB							
LED-03	WNB							
LEK-01	WNB							
LIR-01-S3	WNB							
LIR-02-S1	WNB						2	
LIR-14	WNB							
LIR-19	WNB							

Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
LIR-40	WNB							
LIR-45	WNB	DeVli-4	WNB	SYN				YES
LIR-46	WNB						2	
LIR-GT-01	WNB	DeVli-6						
LIR-GT-02	WNB	DeVli-6	BFB-WNB					
LOZ-01	WNB	DeVli-6						
LSL-GT-01	WNB			DT			1	
LSL-GT-02	WNB							
MED-01	WNB							
MED-02	WNB							
MED-05	WNB							
MID-101	GT			DT				
MID-201	GT			DT				
MKP-01	WNB							YES
MKP-02	WNB							YES
MKP-03	WNB							
MKP-04	WNB							
MKP-05	WNB							YES
MKP-06-S1	WNB							
MKP-09-S1	WNB							YES
MKP-10	WNB							YES
MKP-11	WNB						2	YES
MKP-12	WNB							
MKP-13	WNB							
MKP-14	WNB							
MKP-14	WNB							
MKP-16	WNB	DeVli-4	WNB				2	YES
MLD-GT-01	WNB						1	
MLD-GT-01-S1	WNB	DeVli-4						
MLD-GT-02	WNB							
MLD-GT-02-S1	WNB							
MLD-GT-02-S2	WNB							
MOL-01	WNB							YES
MOL-02-S2	WNB							
MON-01	WNB							
MON-02	WNB						1	YES
MON-03	WNB							
MON-GT-01	WNB							
MON-GT-02	WNB							YES
MSD-GT-01	WNB							
MSD-GT-02	WNB							
MSD-GT-03	WNB							
MSD-GT-03-S1	WNB							
MSD-GT-03-S2	WNB							
MSD-GT-04	WNB							
MSD-GT-05	WNB							
MSD-GT-06	WNB							
MSD-GT-06-S1	WNB							
MSG-01	WNB							
MSG-02	WNB							
MSV-01	WNB						2	
NDK-01	WNB							
NKK-01	WNB						2	YES
NKK-02-S1	WNB							

Data and Methods – Well list

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Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
NLW-GT-01	WNB	DeVli-4	WNB					
NLW-GT-02	WNB							
NLW-GT-02-S1	WNB							
NLW-GT-03	WNB							
NLW-GT-03-S1	WNB							
NLW-GT-04	WNB							
NMD-01	WNB							
NMD-02	WNB							
NMD-03	WNB							
NWK-01	WNB						2	
NWK-01	WNB						2	YES
NWK-02	WNB						4	YES
NWK-02-DOWN	WNB							
OAS-01	WNB							
OBL-01	WNB						2	
OBLZ-01	WNB							
OEG-01	WNB						2	
OIW-01	WNB	DeVli-6	BFB-WNB			YES	4	YES
OLE-01	WNB							
OTL-01	WNB						4	
P02-01	BFB	DeVli-1 DeVli-5						
P02-06	BFB	DeVli-1	BFB-WNB				3	YES
P03-01	BFB	DeVli-1						
P03-02	BFB						5	YES
P05-01	BFB	DeVli-1						
P05-02	BFB							
P05-03	BFB	DeVli-1					3	
P05-04	BFB							
P05-07	BFB							
P06-B-01	BFB	DeVli-2						
P06-B-04	BFB	DeVli-2	BFB				4	
P06-C-02	BFB							
P06-02	BFB	DeVli-2 DeVli-5	BFB					
P08-02	BFB							
P08-03	BFB						3	YES
P08-04	BFB							
P08-05-S1	BFB							
P08-05-S2	BFB							
P08-06	BFB							
P09-01	BFB							
P09-01-A	BFB	DeVli-2						
P09-02	BFB							
P09-03	BFB	DeVli-2	BFB		YES		3	YES
P09-05	BFB							
P09-07	BFB	DeVli-2						
P11-01	BFB	DeVli-2	BFB					
P11-03	BFB	DeVli-2						
P11-10	BFB	DeVli-2	BFB					
P12-08	BFB						3	
P15-01	BFB							
P15-07	BFB					YES		
P15-08	BFB						4	YES

Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
P15-E-01	BFB							
P15-G-01-S1	BFB							
P15-RIJN-A-01	BFB							
P18-01	WNB							
P18-02	WNB							
P18-05	WNB	DeVli-3						
P18-A-03-S2	WNB	DeVli-3						
PKP-01	WNB							
PLD-GT-01	WNB							
PLD-GT-02	WNB							
PNA-02	WNB						2	
PNA-03	WNB						2	YES
PNA-04	WNB							
PNA-13	WNB			SYN				
PNA-15	WNB							
PNA-GT-01	WNB						1	
PNA-GT-02	WNB	DeVli-4	WNB	near			1	
PNA-GT-03	WNB							
PNA-GT-03-S1	WNB							
PNA-GT-03-S2	WNB							
PNA-GT-04	WNB							
PNA-GT-05	WNB							
PNA-GT-05-S1	WNB							
PNA-GT-06	WNB							
PNA-GT-06-S1	WNB							
PNA-GT-06-S2	WNB							
PNA-GT-06-S3	WNB							
PRN-01-S1	WNB	DeVli-6					2	YES
PRW-01	WNB						2	
PRW-01-S1	WNB							
PRW-02	WNB							
PRW-04	WNB							
PRW-05	WNB							
Q01-03	BFB	DeVli-2	BFB BFB-WNB					
Q01-09	BFB						5	YES
Q01-18	BFB						3	YES
Q01-HELDER-A-0	BFB	DeVli-2	BFB				4	YES
Q01-HELM-A-01	BFB	DeVli-2	BFB BFB-WNB				3	YES
Q04-01	BFB	DeVli-5	BFB-WNB					
Q04-04	BFB							
Q04-06	BFB	DeVli-5						
Q04-07	BFB						3	
Q07-01	BFB	DeVli-5						
Q07-02	BFB						5	
Q07-04	BFB	DeVli-5						
Q08-01	BFB	DeVli-3						
Q08-06	BFB							
Q10-01	BFB							
Q10-02	BFB							
Q10-03	BFB	DeVli-5						
Q10-04	BFB							
Q10-06	BFB	DeVli-5	BFB-WNB					

2 Data and Methods – Well list

TNO innovation for life

Abbreviations and codes

Basin

- WNB = West Netherlands Basin
- BFB = Broad Fourteens Basin
- CNB = Central Netherlands Basin
- GT = Gouwzee Trough

Wheeler diagram

- WNB = WNB-across
- BFB = BFB-across
- BFB-WNB-along

Seismic-to-well tie

- SYN = Synthetic generation included
- DT = based on velocity via Sonic or checkshot
- Near = based on velocity via Sonic or checkshot of nearby well

Legacy biostratigraphic data

1 = Munsterman reports (TNO)
2 = Duxbury reports (NAM)
3 = JUSTRAT (TNO report)
4 = various reports on NLOG
5 = Jeremiah et al. 2010 paper

Well	Basin	DeVli panels	Wheeler diagram	Seismic-to-well	DeVli core description	DeVli palynology	Biostrat data	CORE in KNN or SLD
Q11-01	BFB						2	
Q11-02	BFB	DeVli-3					5	YES
Q11-03	BFB	DeVli-3 DeVli-5						
Q13-02	WNB							YES
Q13-04	WNB	DeVli-3						
Q13-05	WNB						1	YES
Q13-07-S2	WNB							
Q13-08	WNB							YES
Q13-09	WNB	DeVli-3			YES		4	YES
Q13-10	WNB							
Q13-11	WNB							
Q14-01	WNB	DeVli-3						YES
Q14-02	WNB	DeVli-3						
Q14-03	WNB	DeVli-3						
Q16-01	WNB							
Q16-02	WNB	DeVli-3 DeVli-6		SYN				
Q16-03	WNB			DT			4	YES
Q16-04	WNB	DeVli-3						YES
Q16-05	WNB			DT				YES
Q16-08	WNB							
RDK-01	WNB							
RKK-01	WNB							
RKK-02	WNB							YES
RKK-03	WNB							
RKK-10-S1	WNB							
RKK-11	WNB							
RKK-13	WNB							
RKK-18	WNB							
RKK-19	WNB							
RKK-32	WNB	DeVli-6						
RKK-32-S3	WNB							
RSK-01	WNB							
RTD-01	WNB			SYN			2	YES
RTD-06	WNB							YES
RWK-01	WNB						2	YES
RWK-04	WNB							
RWK-06	WNB							
RWK-18-S1	WNB							
RZB-01	WNB	DeVli-4						
SGZ-01-S1	WNB							
SGZ-02	WNB							
SPG-01	WNB						4	
SPG-01-S2	WNB	DeVli-6						
SPK-01	WNB						2	YES
SPKO-01	WNB							
SPKO-02	WNB							
SPKO-02-S1	WNB							
SPKO-03	WNB							
SPKW-01	WNB							
SRM-02	GT			DT				
STH-01	WNB							
STR-01	WNB							YES
STW-01	WNB							
STW-01	WNB							
TNT-GT-01	WNB							
TNT-GT-01-S1	WNB							
TNT-GT-02	WNB							
VAL-01	WNB							
VDB-GT-01	WNB							
VDB-GT-01-S1	WNB							
VDB-GT-02	WNB							
VDB-GT-02-S1	WNB							
VDB-GT-03	WNB							
VDB-GT-04	WNB	DeVli-4					1	
VLN-01-S1	WNB	DeVli-6					2	
SPG-01-S2	WNB							
WAA-01	WNB	DeVli-6						
WAP-01	WNB							
WAS-01	WNB						2	YES
WAS-02	WNB							YES
WAS-05	WNB							YES
WAS-08	WNB							
WAS-13	WNB							
WAS-23	WNB							YES
WAS-23-S2	WNB							YES
WAS-28-S3	WNB							
WAS-43-S1	WNB							
WAS-46	WNB							
WAZ-01	WNB	DeVli-3		DT				
WBMS-01	GT			DT			5	
WED-01	WNB							
WED-02	WNB	DeVli-6						
WED-03	WNB			DT				
WGD-01	WNB							
WNMS-01	WNB							
WOB-01	WNB			DT			2	YES
WRV-01	WNB	DeVli-4						
WWK-01	WNB			DT			4	
WWN-01-S2	WNB	DeVli-6						
WWS-01-S1	WNB	DeVli-6						
ZOM-02-S1	WNB							
ZOM-08	WNB							
ZOM-09	WNB							
ZOM-12	WNB							
ZOM-16	WNB						2	
ZOM-17-S1	WNB							
ZOM-34	WNB							

Lithostratigraphy

In general, the lithostratigraphy of the wells in the project is adopted from NLOG. Isolated cases of obviously wrong interpretations have been adjusted. In addition, some existing lithostratigraphic concepts were rejected and have been changed accordingly. This particularly pertains to:

- The **Nieuwerkerk Formation**. A new and more logically constrained model for the Nieuwerkerk Fm is proposed in this project.
- The NLOG assignments to the **Rijn Member** in the offshore part of the West Netherlands Basin (P15, P18, Q16, Q13 blocks) are rejected and replaced by the Rijswijk Member. NLOG assignments to the Rijn Member in the offshore part of the Broad Fourteens Basin (P02, P05, P06, P09 blocks) are maintained.

Workflow stratigraphy

1. Set up a Petrel project with key wells and selected wireline logs.
2. Data mining NLOG and other sources for age assessments.
3. Core description of selected wells.
4. Palynological analyses of selected wells.
5. Populate Petrel Stratigraphic project with biostratigraphically constrained ages, observed faults (from composite log and seismic interpretation) and other observations (e.g. presence of volcanics, coals).
6. Integrate the stratigraphy with the seismic interpretation.
7. Establish lithostratigraphic subdivisions (TMSs) for each well.
8. Construct well panels along and across main basins (WNB and BFB).

TNO innovation for life

Core description

The core descriptions were carried out by R. Bouroullec and D. Ventra at the TNO core store facility in Zeist. New core descriptions were obtained for wells P09-03, L16-06, Q13-09 on a 1:50 or 1:100 scale. For well K18-02-A the core interpretation from CNOC/Core Lab (1990) was used as foundation and revised.

The following sedimentological parameters were logged: composition and texture, average grain size, sedimentary structures (lamination, cross-bedding, rip-up clasts, etc), diagenetic minerals and bioturbations. Special attention was paid to the description of the various ichnofacies present in the cores.

Six main lithologies are distinguished: sandstone, siltstone, shale, limestone, coal and gravel. The depositional environments, derived from the core descriptions, are classified in six main categories: open marine, lower shoreface, upper shoreface/beach/foreshore, estuarine/tidal, brackish lagoon/bay and fluvial/ swamp.

Well	Basin	Length (m)	Unit	Depositional environments
P09-03	Broad Fourteens	176	Rijn Member, Vlieland Sandstone Formation - TMS-4 Lower	Upper shoreface to Lower offshore
L16-06	Broad Fourteens	30	Kotter Mb. (Vlieland Sst. Fm.) and Vlieland Clst. Fm. - TMS-4 Lower	Upper Shoreface to lower offshore
K18-02-A, Core 1	Broad Fourteens	80	Bloemendaal Member, Breeveertien Formation - TMS-3	Fluvial
K18-02-A, Core 2	Broad Fourteens	90	Kotter Member, Vlieland Sandstone Formation - TMS-4 Lower	Upper shoreface, lower shoreface, tidal
Q13-09	West Netherlands	146	Nieuwerkerk Fm. (TMS-4 Lo.) and Vlieland Sst. Fm. (TMS-4 Up.)	Fluvial, estuarine, tidal, lagoonal, shoreface and offshore

Well selection palynological analyses

The **original plan** for the palynological analyses was to sample and analyse cored sections with a high resolution and focus on cored intervals of the DEL-GT and AMS-01 wells. In the course of the project it appeared that it was not feasible to timely obtain sample material from the DEL-GT wells and that palynological data of the AMS-01 were already available through 3rd party analyses by PetroStrat.

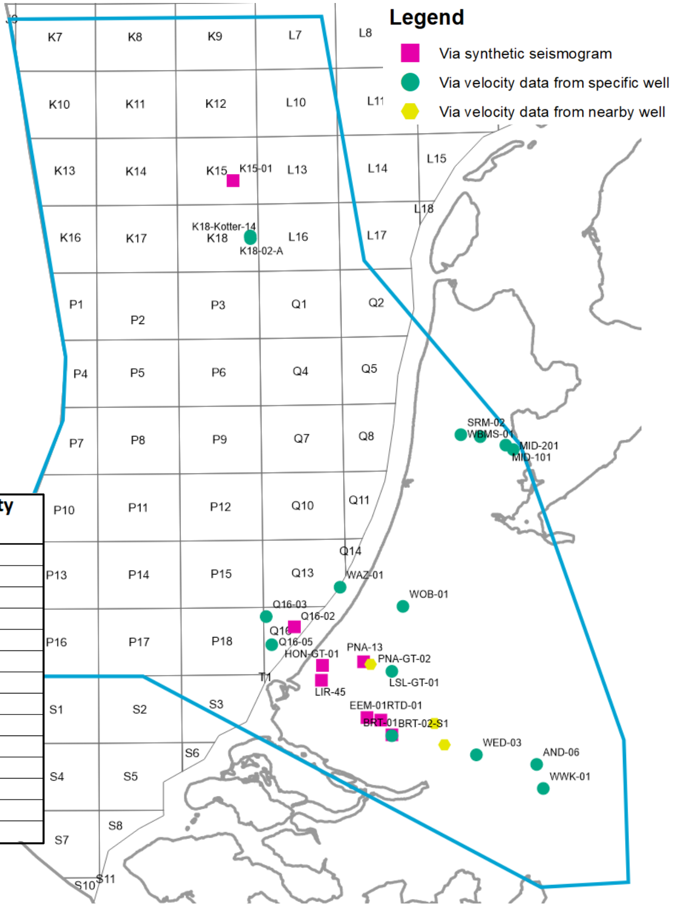
As a consequence, an **alternative plan** for the palynological analyses was proposed and executed. For the alternative plan, it was decided to focus on spot samples from cored sections of the Delfland Subgroup and include wells from the northern part of the West Netherlands Basin.

well	Samples	Type	Target
GOU-01	7	CORE	Nieuwerkerk?
HZW-01	10	CORE	Nieuwerkerk?
BRK-02	5	CORE	Delft Sandstone & Alblasserdam
DEL-02	2	CORE	Rodenrijs
OIW-01	11	CORE	"Old" Alblasserdam
K15-01	8	CORE	Delfland-Vlieland transition
P15-07	5	CORE	Nieuwerkerk or Breeveertien?
total	**48**		

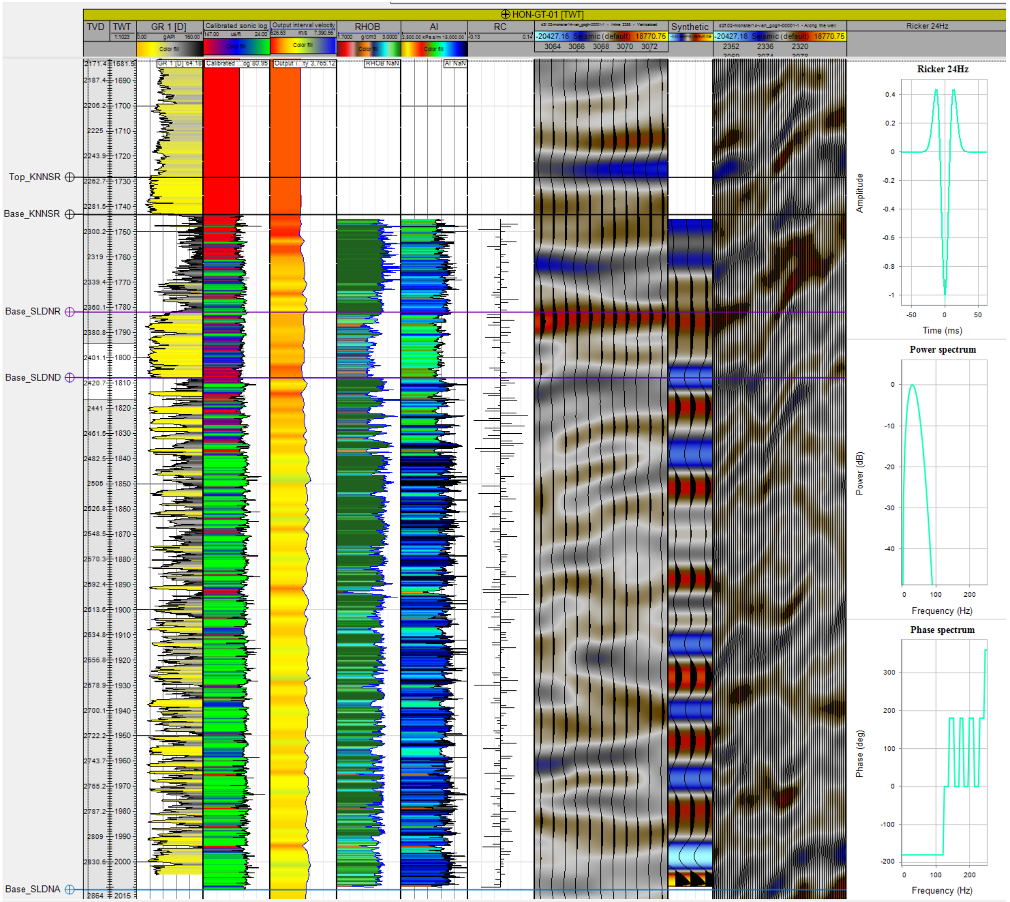
Seismic to well ties were created to tie well depths (in m) to seismic data (in ms TWT). This was done via:

- Creation of synthetic seismograms (8 wells)
- Tying the well data to seismic data by using known tie points (e.g. base Chalk, Base Holland, Posidonia) and velocity data from that specific well (including sonic or checkshot data) (14 wells)
- Tying the well data to seismic data by using known tie points (e.g. base Chalk, Base Holland, Posidonia) and velocity data from a nearby well (3 wells)

Seismic to well tie including synthetic generation	Seismic to well tie based on velocity estimate via sonic or checkshot data of that specific well	Seismic to well tie based on velocity estimate via sonic of nearby well
PNA-13	WOB-01	ALD-01
HON-GT-01	BRT-02-S1	DRT-01
BRT-01	LSL-GT-01	PNA-GT-02
LIR-45	MID-101	
Q16-02	MID-201	
EEM-01	SRM-02	
RTD-01	WBMS-01	
K15-01	K18-02-A	
	K18-Kotter-14	
	WAZ-01	
	WWK-01	
	WED-03	
	Q16-03	
	Q16-05	



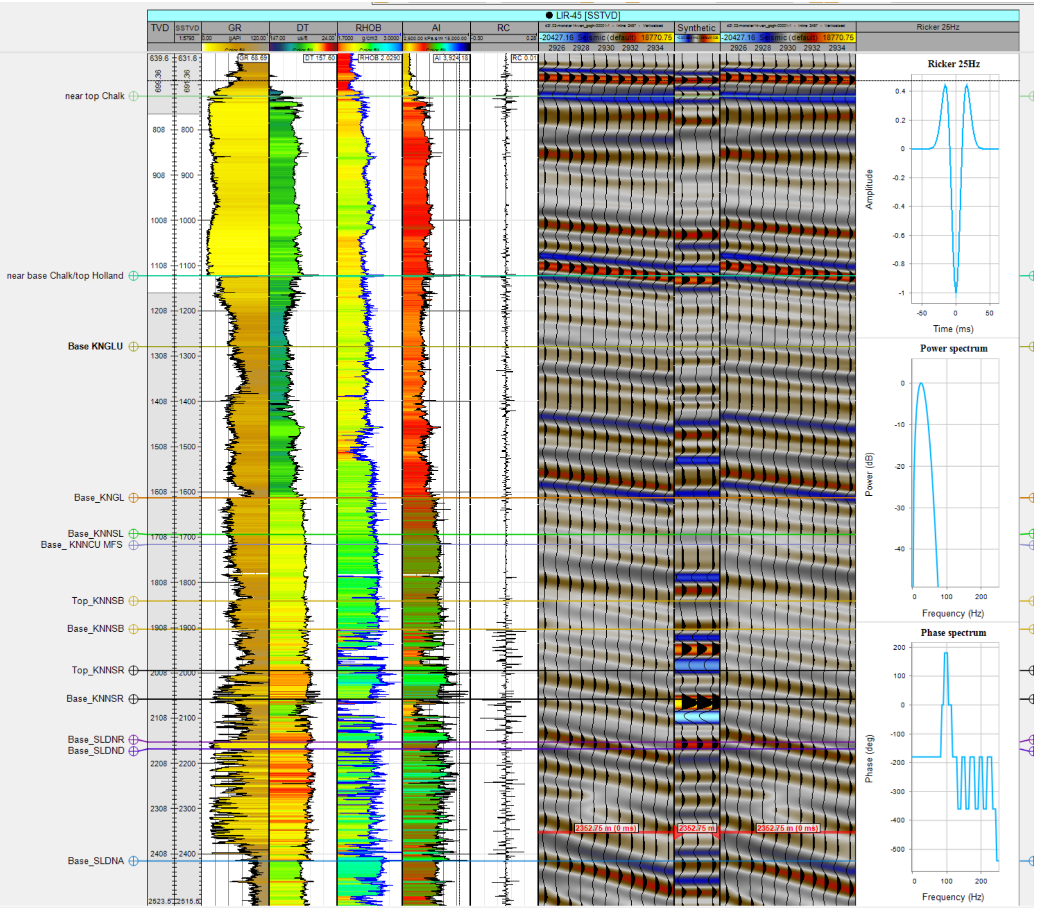
2 Data and Methods – Synthetics



Well: HON-GT-01

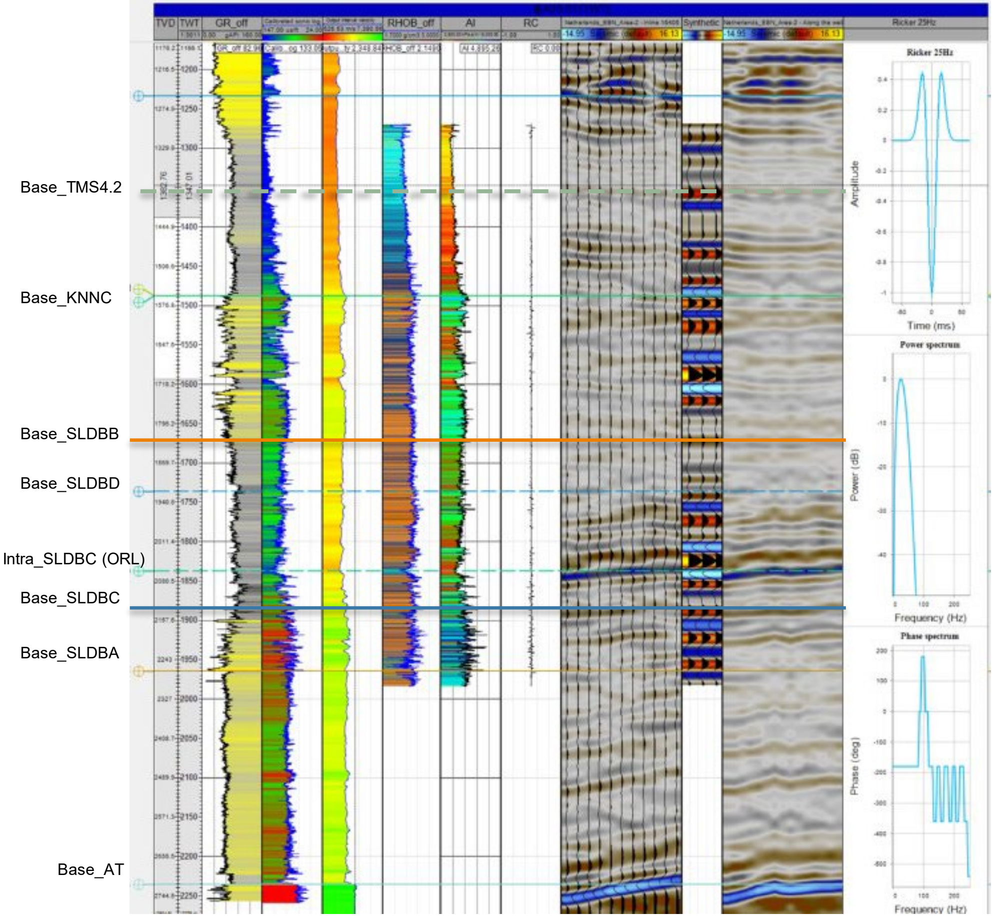
- Base Rijswijk Mb. (KNNSR) (i.e. base TMS-4 Upper) = Soft kick (when underlain by Rodenrijs Claystone Mb. (SLDNR)
- Base Rodenrijs Claystone Mb. = Soft kick
- Base Delft Sandstone Mb. (SLDND) (i.e. Base TMS-4 Lower) = hard kick, only visible if Delft sandstone Mb. is relatively thick (compare HON-GT-01 with LIR-45).
- Base Alblasserdam Mb. (SLDNA) (Base TMS-2 or TMS-3) is generally a soft kick, but this may vary depending on Alblasserdam Mb. and underburden lithologies (see next slide).
- It is noted that TMS-2 aged Alblasserdam Mb. is expected to be present in deeper parts of the half grabens within the WNB, especially when the Alblasserdam Mb. concordantly overlays strata Brabant Fm. (TMS-1) or Altena Group. In most of the WNB, this assumption is not anchored by biostratigraphic data.
- Synthetic created by using artificial checkshots, tied at: :
  - Base Chalk
  - Base Upper holland Marl
  - Base Holland fm.
  - Base Rijswijk.

2 Data and Methods – Synthetics



Well: LIR-45

- Base Holland Fm. (KNGL) (i.e. base TMS-5) = hard kick.
- Base Rijswijk Mb. (KNNSR) corresponds to top Rodenrijs Claystone Mb. (i.e. base TMS-4 Upper) = soft kick.
- Base Delft Sandstone Mb. (SLDND) (i.e. Base TMS-4 Lower) = generally hard kick, but at well LIR-45 the Delft sandstone Mb. is not thick enough to recognize top and base on seismic data.
- Base Alblasserdam Mb. (SLDNA) (i.e. Base TMS-2 and -3) is generally a soft kick if underlain by Werkendam shales. If cemented sandstones and/or limestones of Brabant Fm (=TMS-1) underly the Alblasserdam Mb., which base is a hard kick.
- Base Brabant Fm. (base TMS-1) (not shown here): = soft kick.
- Synthetic created by using artificial checkshots, tied at:
  - Top Chalk Group
  - Base Chalk Group
  - Base Upper Holland Marl Mb.
  - Base Holland Fm.
  - Base Alblasserdam Mb.



Well: K15-01

- Base TMS-4.2 Upper is an intra-Vlieland Claystone Fm. Horizon, which is hardly recognizable in well data, its position is extrapolated from southern areas
- Base Vlieland Claystone Fm. (KNNC; corresponding here to top Bloemendaal Mb.) is a hard kick. In this well, the Helder/Kotter mbs. sands are absent, placing Base TMS-4 Lower at the base of the Vlieland Claystone Fm.
- Base Bloemendaal Mb. (SLDBB) = soft kick. In this well, the Base Bloemendaal Mb. is corresponding to the Base of TMS-3. In more central parts of the BFB, where a larger interval of the Driehuis Mottled Claystone Mb. (SLDBD). Is preserved, Base TMS-3 is positioned intra SLDBD and harder to recognize.
- Within the Fourteens Claystone Mb. (SLDBC) a series of continuous bright, generally parallel reflectors are recognized. The lowest of these bright reflectors is a hard kick caused by a marine shale rich in organic matter/organic rich layer (ORL). This reflector is an easy to recognize regional seismic marker.
- Base Aerdenhout Mb. (SLDBA) (i.e. Base TMS-2) is a soft kick, but depends on lithology of underburden.

The main focus of the seismic analysis is twofold:

- 1) A series of regional scale seismic transects were constructed to cover all the study area. Six regional seismic sections (DeVli Panel 1 to 6) have been constructed using a combination of 2D and 3D seismic lines. On each of these seismic panels, key seismic horizons and structures (faults, folds, salt bodies) were interpreted in Petrel and exported to a drafting package for edits. Starting out with correlation between the available wells in the area. Below is the list of horizons and structures interpreted.
- 2) A regional 3D seismic mapping was carried out across the entire study area and consisted of the interpretation of six horizons. Time structure maps were produced and are shown in high resolution in Appendix A. Each horizon is shown with a specific colour throughout this report.
    - Base of TMS-1 Lower (yellow)
    - Base of TMS-2 Lower (light green)
    - Base of TMS-3 (orange)
    - Base of TMS-4 Lower (dark green)
    - Base of TMS-4 Upper (green)
    - Base of TMS-5 (blue)

- In addition to the interpretation of key horizons and structures, possible stratal terminations were identified and mapped within the Upper Jurassic and Lower Cretaceous sequences. These include truncations, onlaps and downlaps, which are represented as black half arrows on the interpreted seismic panels.
- For each stratigraphic interval mapped, a time-thickness map was generated (Appendix A). The maps were produced by measuring the stratigraphic thickness rather than the vertical thickness, by calculating the thickness normal to the upper surface. This is an important step since many Upper Jurassic horizons have a steep dip present along the basin margins. Locally, some combination/merger of horizons was required to build proper time-thickness maps due to the lapping out configuration of some horizons. Using such techniques, the time-thickness maps are more meaningful along the basin margins.

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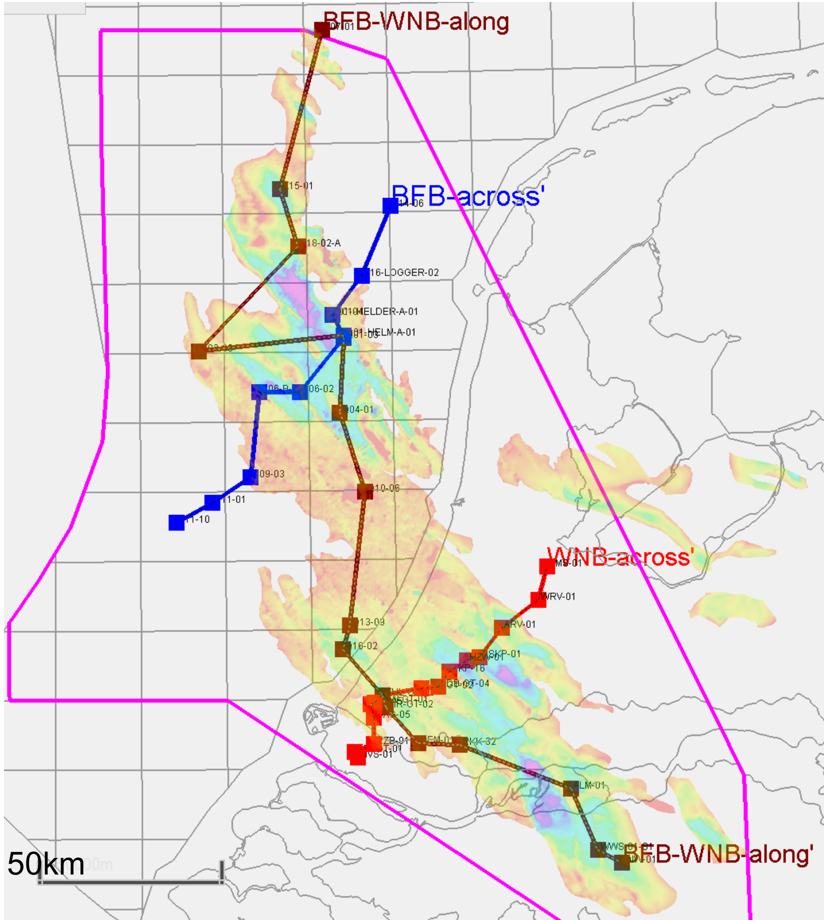
Wheeler diagrams

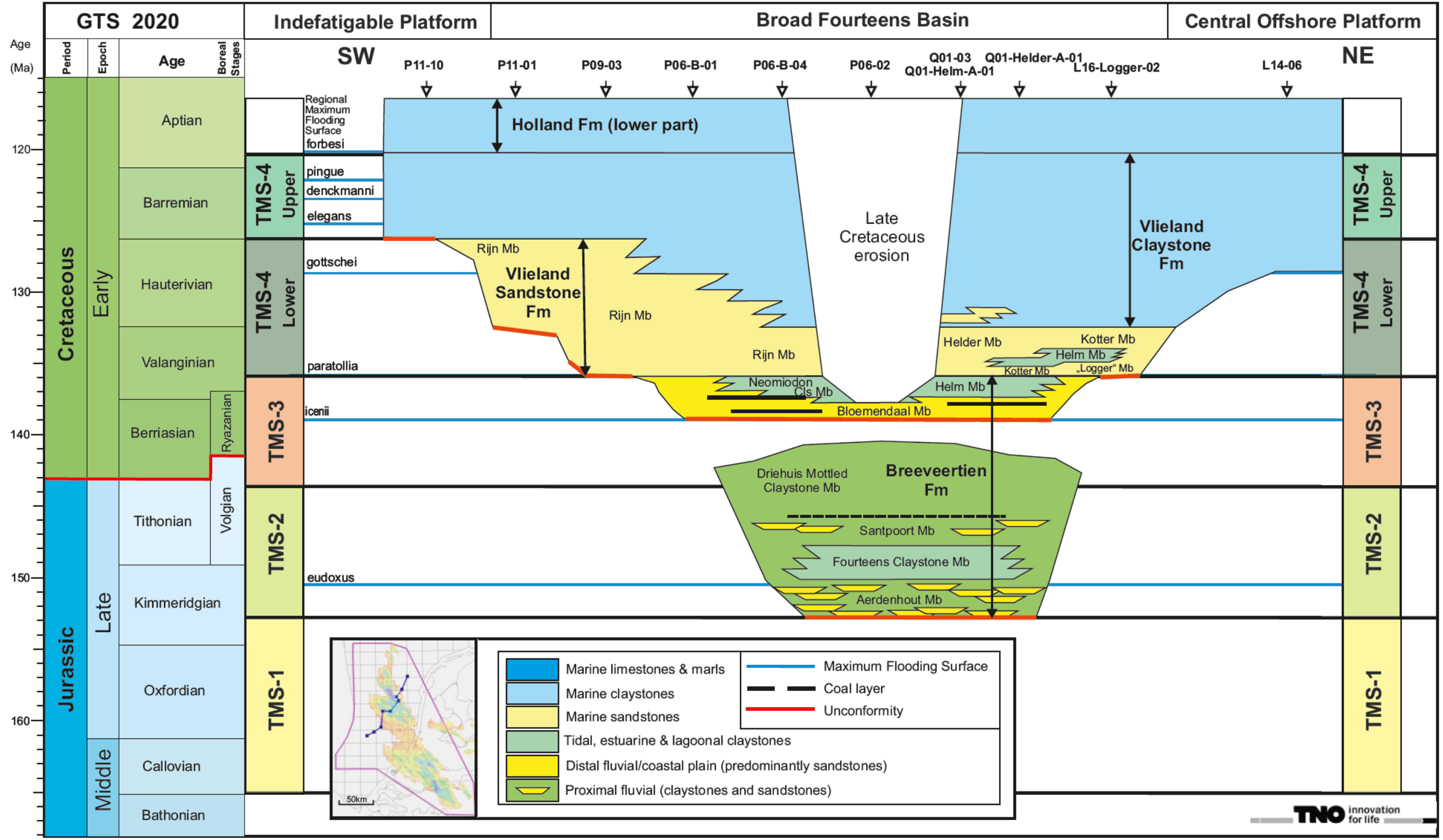
Three Wheeler diagrams (see next pages) were compiled within the DeVli project:

- WNB-across, across the West Netherlands Basin (indicated in red)
- BFB-across, across the Broad Fourteens Basin (indicated in blue)
- BFB-WNB-along, along the axis of both basins (indicated in brown)

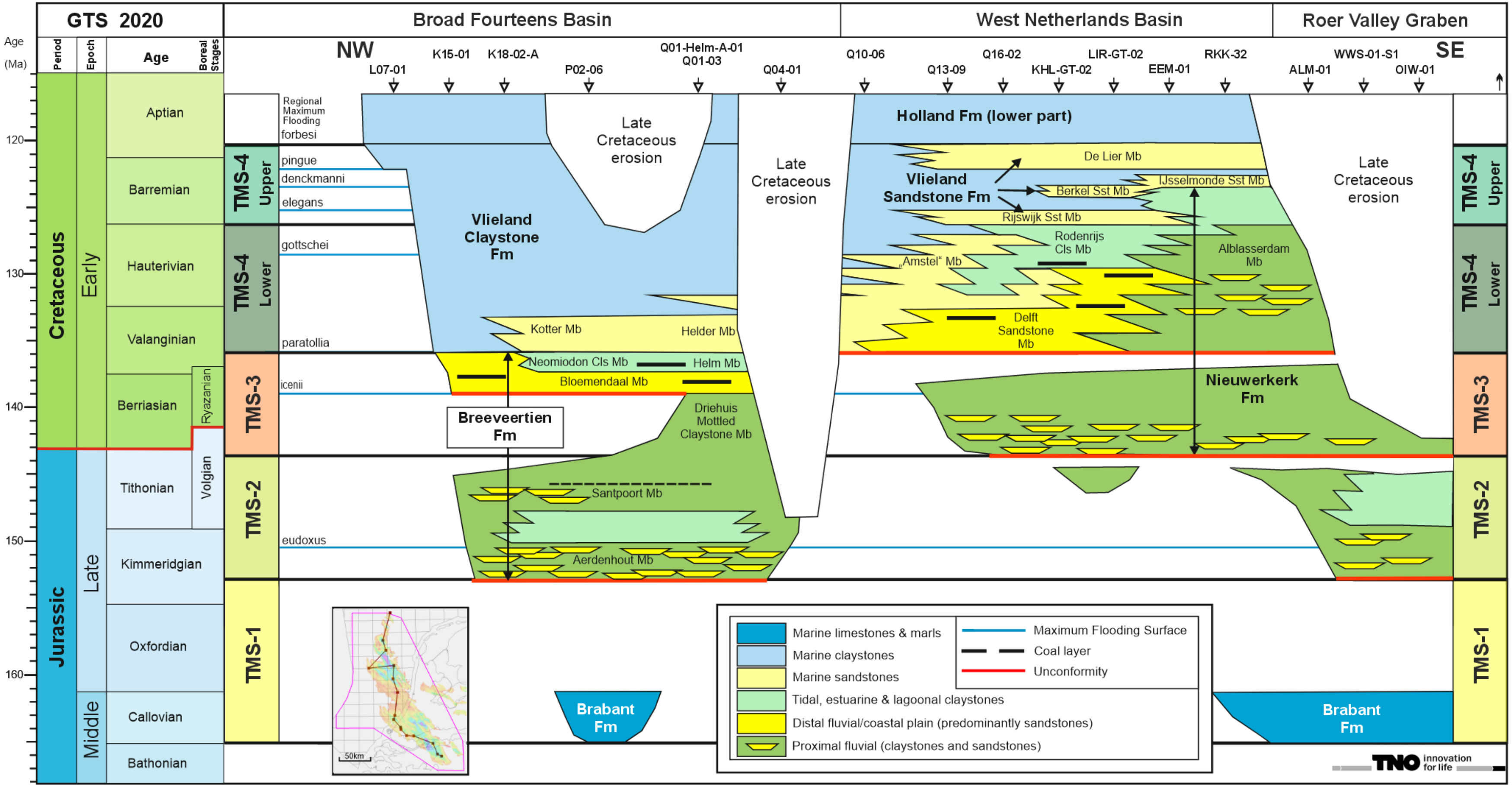


Background map displays time-thickness of TMS2 + TMS-3

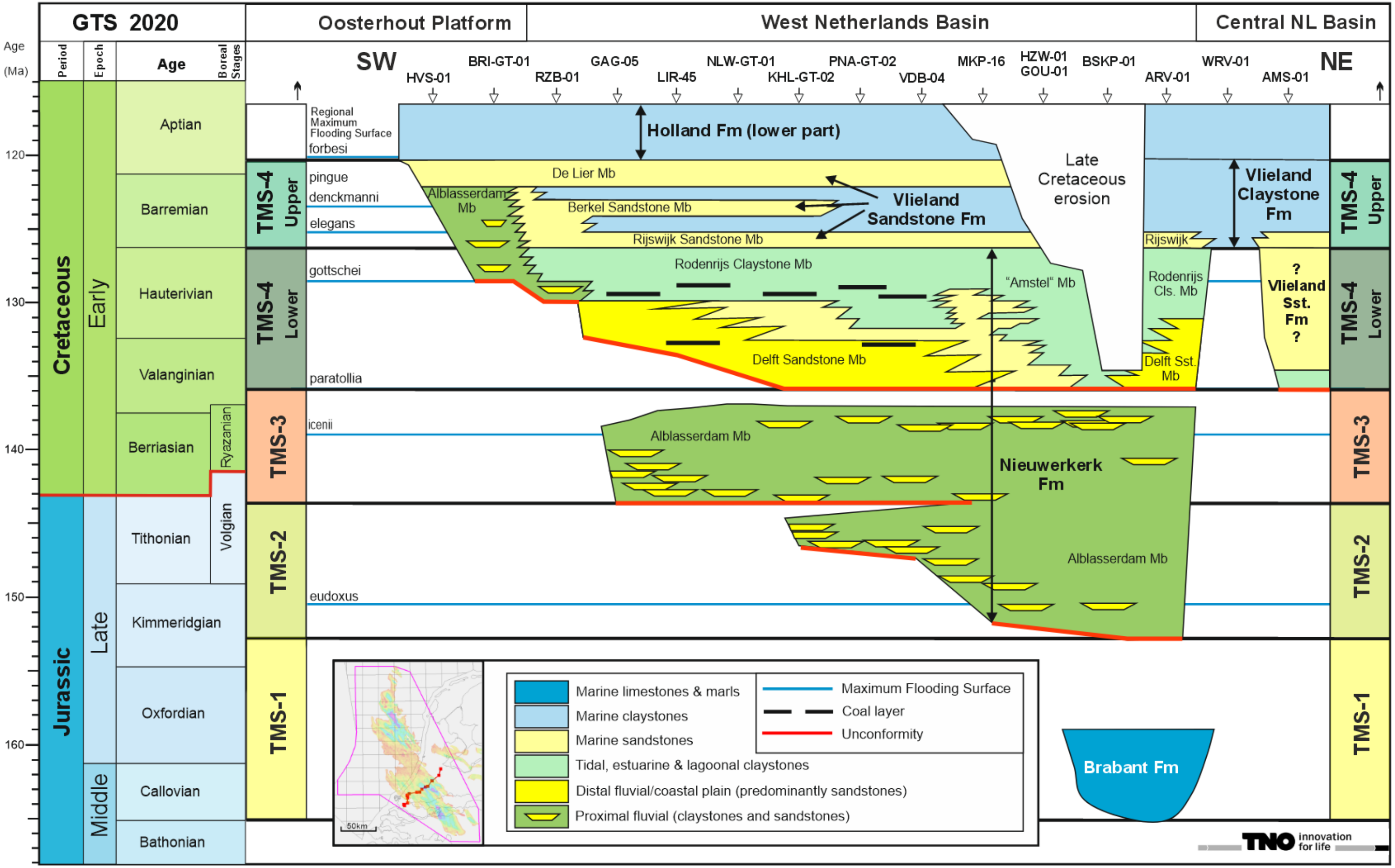
3 Stratigraphic Results – Wheeler Diagrams: BFB-across



3 Stratigraphic Results – Wheeler Diagrams: BFB-WNB along



3 Stratigraphic Results – Wheeler Diagrams: WNB across

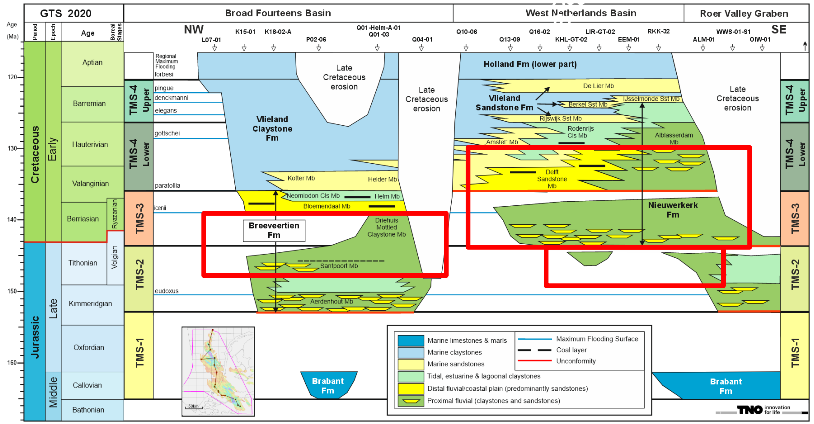


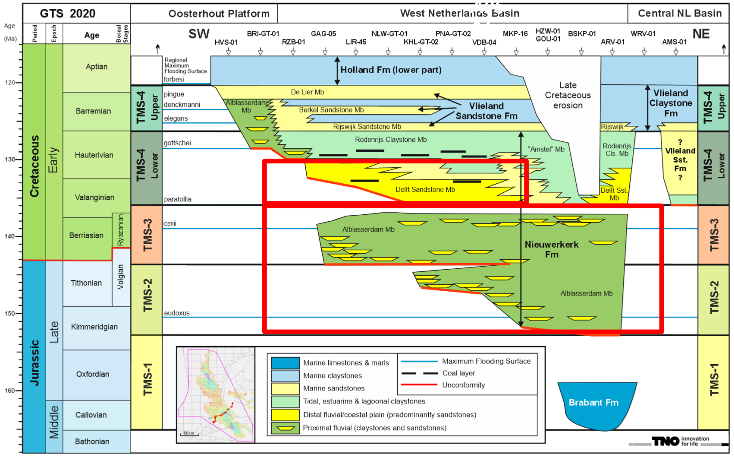
Confidence levels of the age calibration

Confidence levels for the age dating depend heavily on the depositional setting.

- The age dating of lithostratigraphic units with an open marine to marginal marine depositional setting, are in general precise and reliable.
- The age dating of lithostratigraphic units with a predominantly non-marine depositional setting, are in general broad and less reliable.

Particularly the age calibration for the Delft Sandstone and Alblasserdam members should be taken with great care. Areas and stratigraphic intervals shown in the red boxes (to the right) have a lower confidence level.

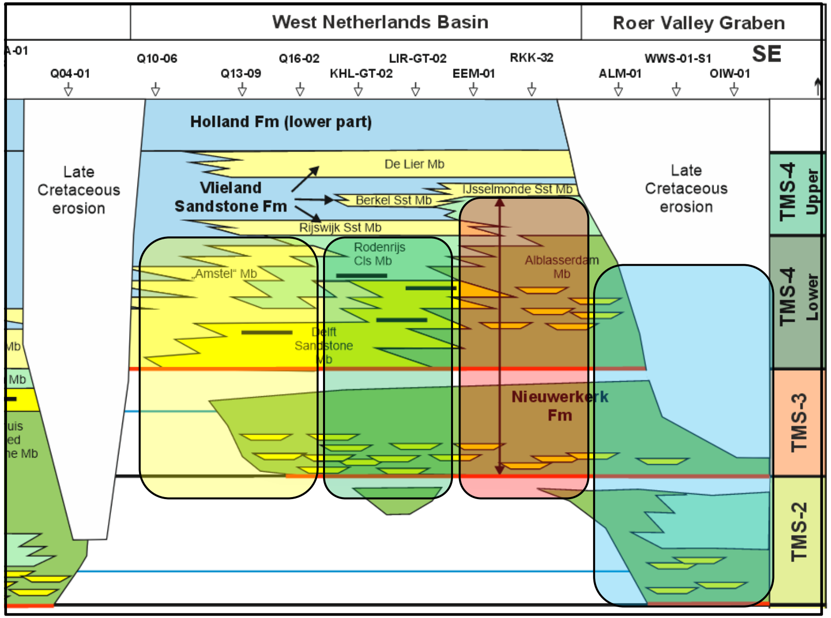


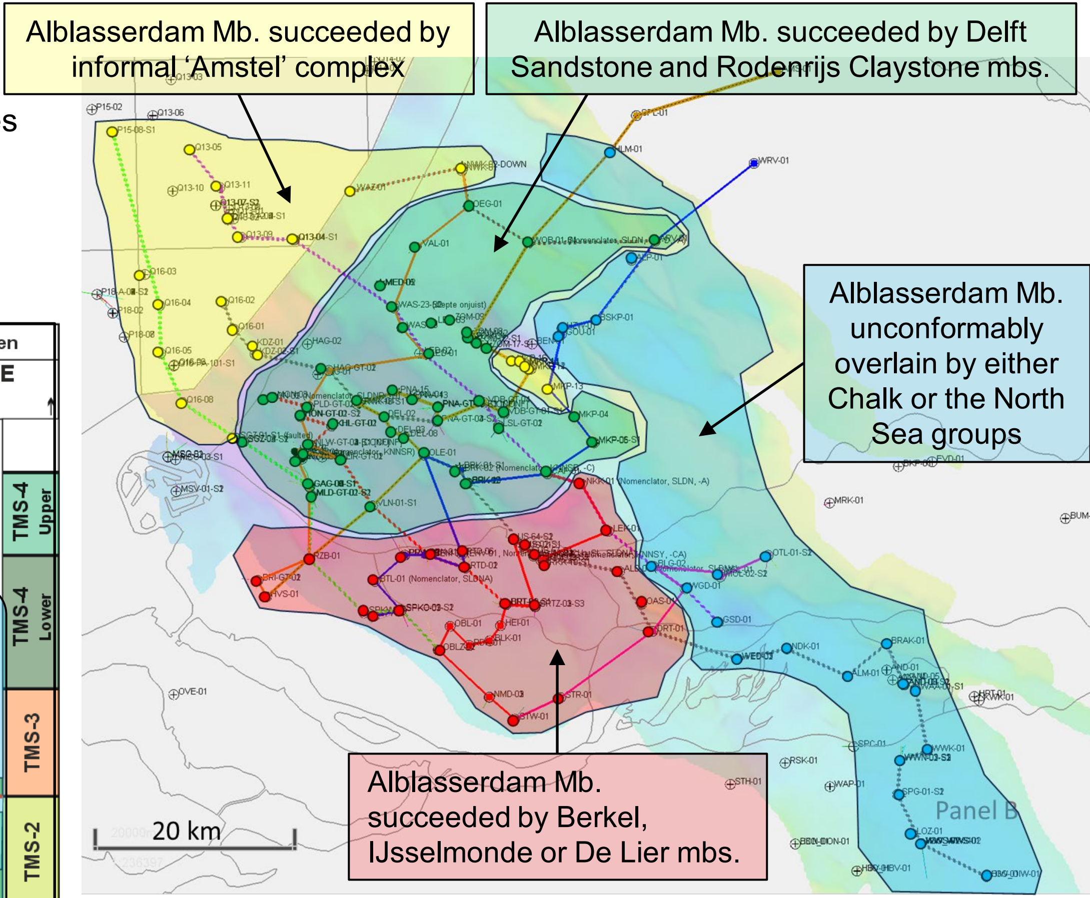


3 Stratigraphic Results – Lithostratigraphy

Nieuwerkerk Formation

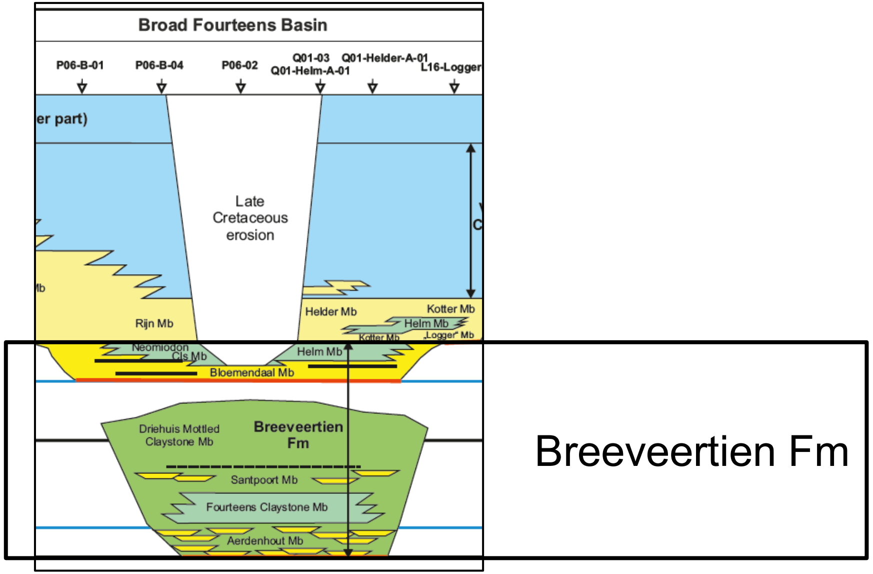
The lithostratigraphic subdivision and sedimentary facies of the Nieuwerkerk Formation change from NW to SE. The transitions from one type to the other are shown in the Wheeler diagram below. The areal extent of the different types is shown on the map.

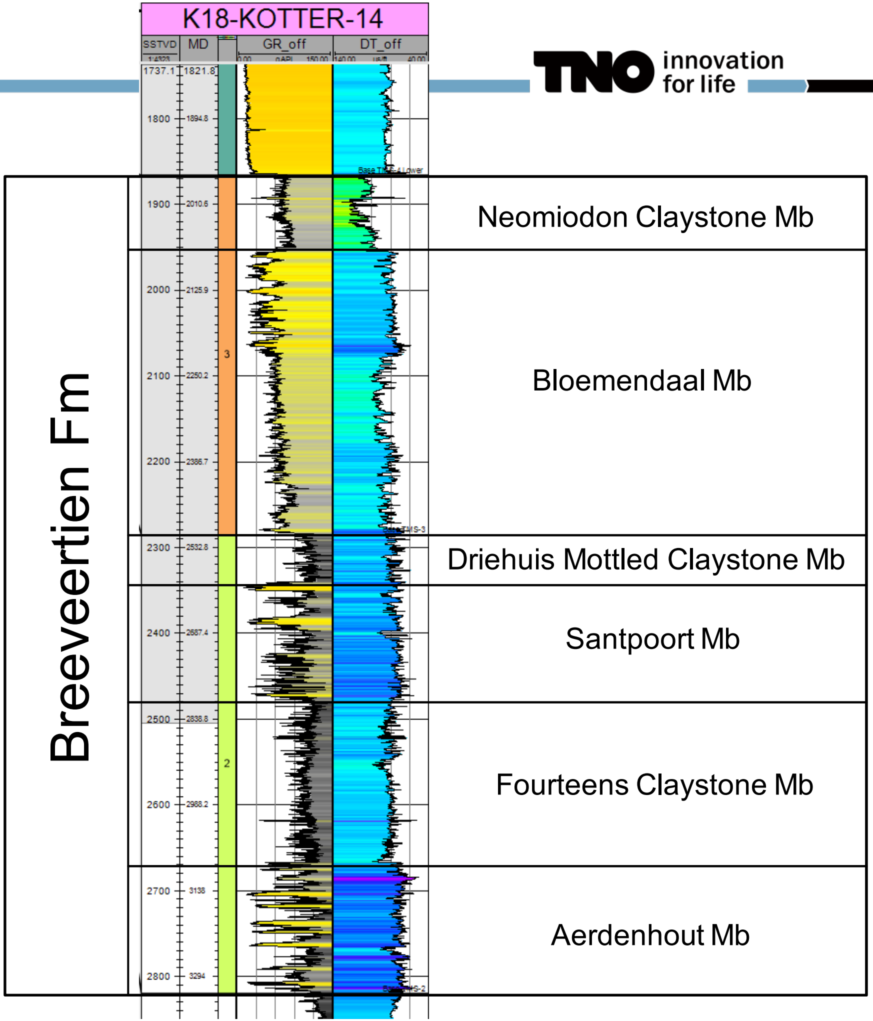




Breeveertien Formation

- The sandy Santpoort Mb. is often absent, making it very hard or to distinguish the muddy Driehuis Mottled Claystone Mb from the Fourteens Claystone Mb.
- The distinction between the Bloemendaal and Neomiodon members is not always clear.





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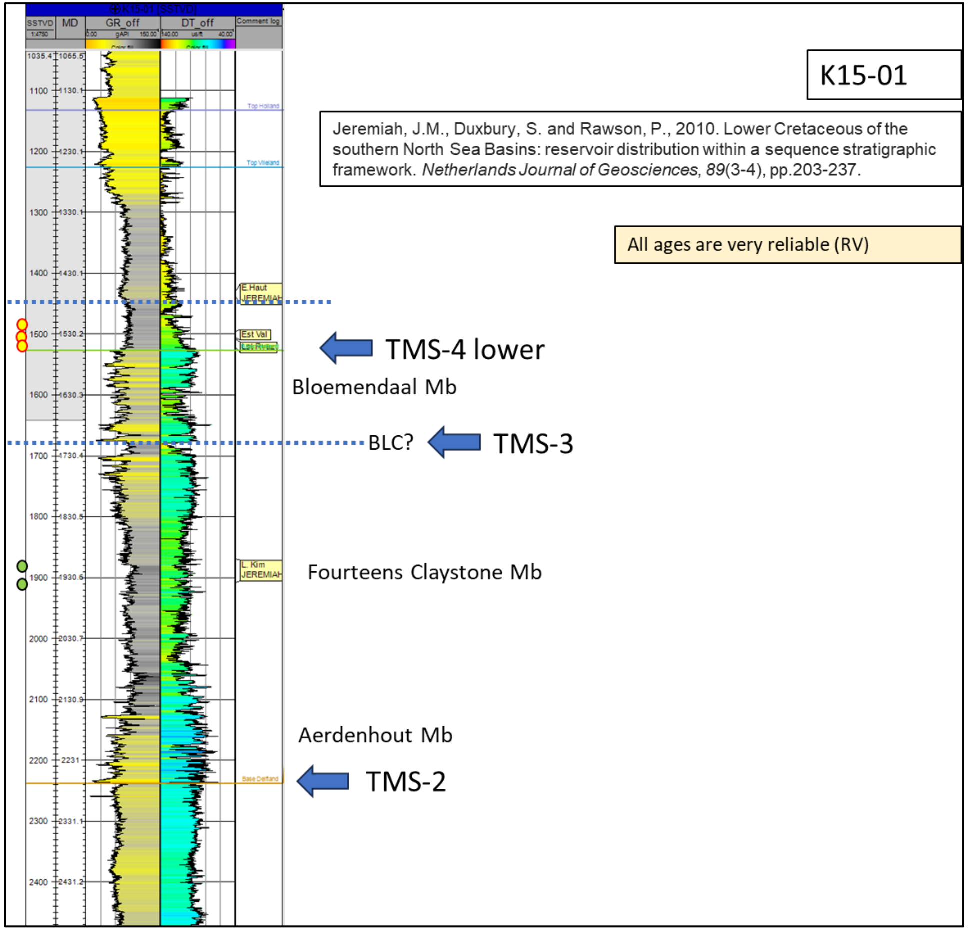
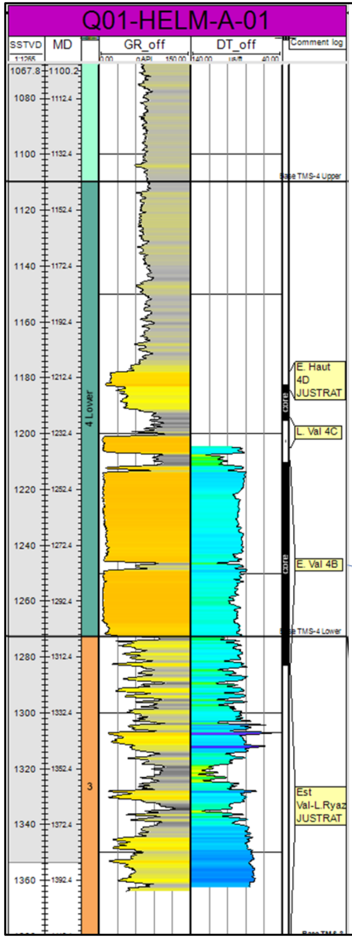


Breeveertien Formation

- The age of the Bloemendaal Mb of the Breeveertien Fm. is Ryazanian in age and fits with assignment to TMS-3.
- Part of the Fourteens Claystone Mb. is marine, which allows an accurate and confident Late Kimmeridgian age dating, reflecting TMS-2.
- The Neomiodon Claystone and Helm members are characterized by acme occurrences of the euryhaline dinocyst *Cantulodinium speciosum*, indicating restricted marine, back-barrier conditions, and a Late Ryazanian to earliest Valangian age (TMS-3 or TMS-4 Lower).



Q01-Helm-A-01

JUSTRAT report 2015
Verreussel, Houben, Munsterman, Janssen, Kerstholt-Boegehold

TNO report TNO 2015 R10343 New stratigraphic framework for the Upper Jurassic-Lower Cretaceous in the southern North Sea using integrated novel techniques.

Sample/Interval	Age
1226.61-1237.48 mCO	Early Cretaceous: Late Valanginian, TNO SubSubzone 4C, *tuberculata* Subzone to *amblygonium* Ammonite Subzone

- FOD *Gonyaulacysta/Nelchinopsis kostromiensis* at 1226.1 mCO
- FOD *Muderongia staurota* at 1226.1 mCO
- LOD *Muderongia extensiva* at 1226.1 mCO

Sample/Interval	Age
1242.2-1316.52 mCO	Early Cretaceous: Early Valanginian, TNO-SubSubzone 4B, *Polyptichites/Paratollia* Ammonite Subzone

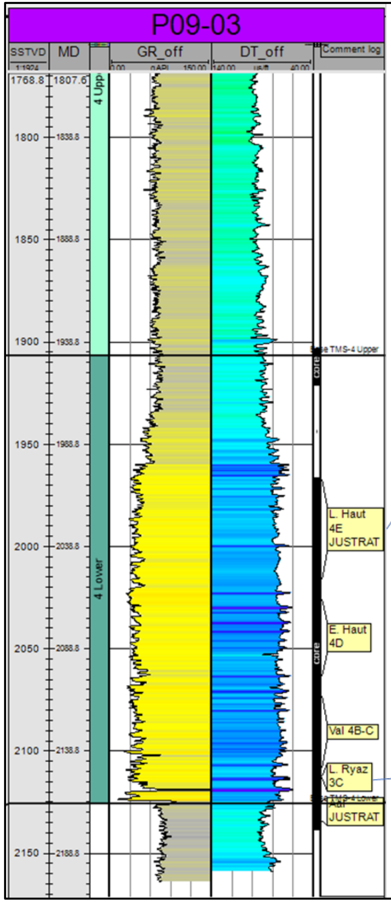
- LOD *Batioladinium* cf. *varigranosum* at 1242.2 mCO
- FOD *Muderongia extensiva* at 1258.28 mCO
- FOD *Spiniferites* spp. (*ramosus* cpx) at 1258.25 mCO
- LOD *Canningia compta* at 1258.25 mCO
- FOD *Ctenidodinium elegantulum* at 1311 mCO
- FOD *Hystrichosphaerina schindewolfii* at 1314.15 mCO
- FOD *Pseudoceratium pelliferum* at 1316.57 mCO

Remark: A variety of *Muderongia* forms (*M. simplex*, *M. simplex* ssp. *microperforata*, *M. extensiva*) and *Cantulodinium* speciosum reach high abundance in this interval.

The ages are very reliable (RV)

Vlieland Sandstone Formation (for Blocks K18, P03, Q01)

- The age of the massive sandstone units of the Vlieland Sandstone Fomation in the K18, P03 and Q01 blocks is **Valanginian** (TMS-4 Lower).
- The Kotter, Helder and informal Logger Sandstone members are all the same age and share a common genetic origin.
- The thick sandstone layers with a blocky GR signature are often separated by claystone intervals that may reflect back-barrier depositional settings. These claystones are sometimes (not always) assigned to the Helm Member.
- A thinner and more 'dirty' sandstone layer often succeeds the blocky sandstones in the Q01 and L16 blocks. This sandstone is Early Hauterivian in age (TMS-4 Lower).



P09-03

JUSTRAT report 2015
Verreussel, Houben, Munsterman, Janssen, Kerstholt-Boegehold

TNO report TNO 2015 R10343 New stratigraphic framework for the Upper Jurassic-Lower Cretaceous in the southern North Sea using integrated novel techniques.

Sample/Interval	Age
2006-2054.7 mCO	Early Cretaceous; Late Hauterivian, TNO SubSubzone 4E, *gottschei* to *variabilis* Ammonite Subzones

- LOD *Canningia* cf. *reticulata* at 2006 mCO
- FOD *Odonotochitina operculata* at 2006 mCO
- LOD *Nelchinopsis/Gonyaulacacysta kostromiensis* at 2006 mCO
- LOD *Kleithriasphaeridium corrugatum* at 2006 mCO
- FOD *Meiourogonyaulax sagena* at 2016 mCO
- FOD *Diphasiosphaera stolidata* at 2016 mCO
- LOD *Cribroperidinium confossum* at 2032 mCO
- FOD *Subtilisphaera perlucida* at 2054.7 mCO
- FOD *Cribroperidinium confossum* at 2054.7 mCO.

Sample/Interval	Age
2151.1 mCO	Early Cretaceous; Possibly Late Ryazanian, TNO SubSubzone 3C, *stenomphalus-albidum* Ammonite Subzones

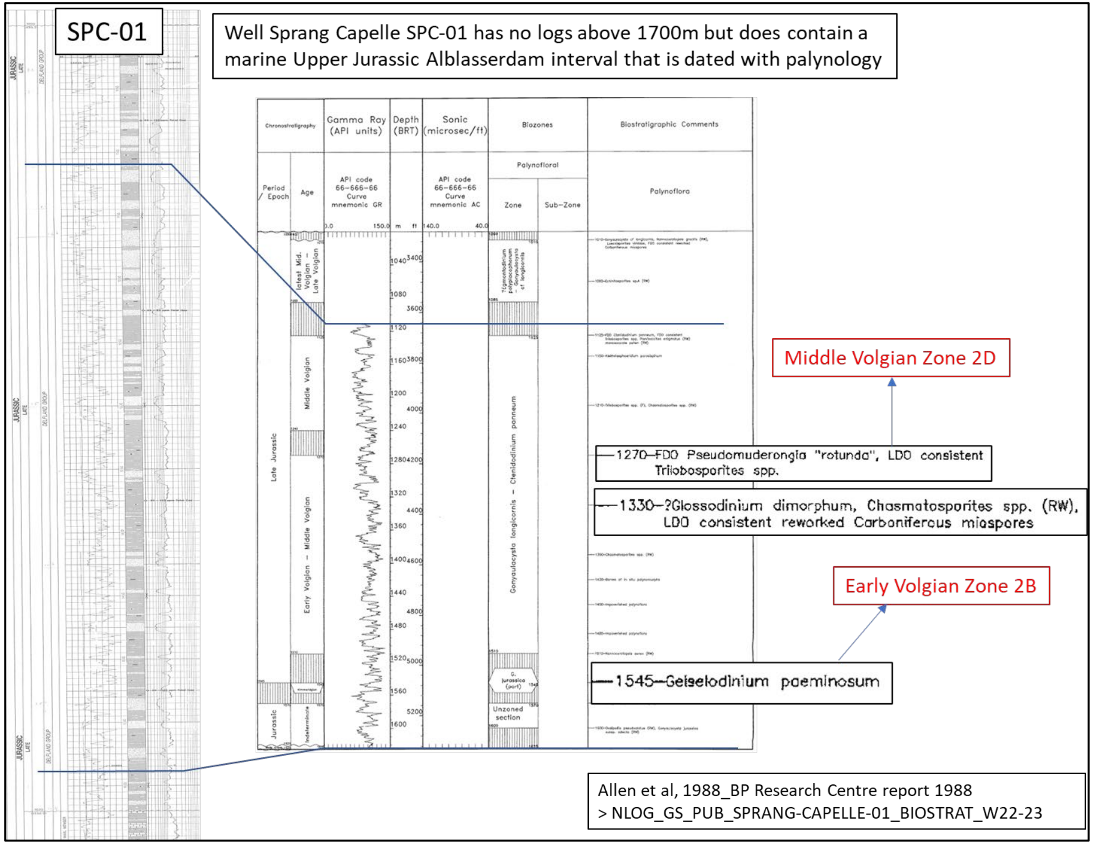
- LOD *Dichadogonyaulax culmula* at 2151.1 at mCO
- LOD *Egmontodinium torynum* at 2151.1 at mCO
- FOD *Pseudoceratium brevicornutum* at 2151.1 mCO

Probably earliest Valanginian 4A (RV)

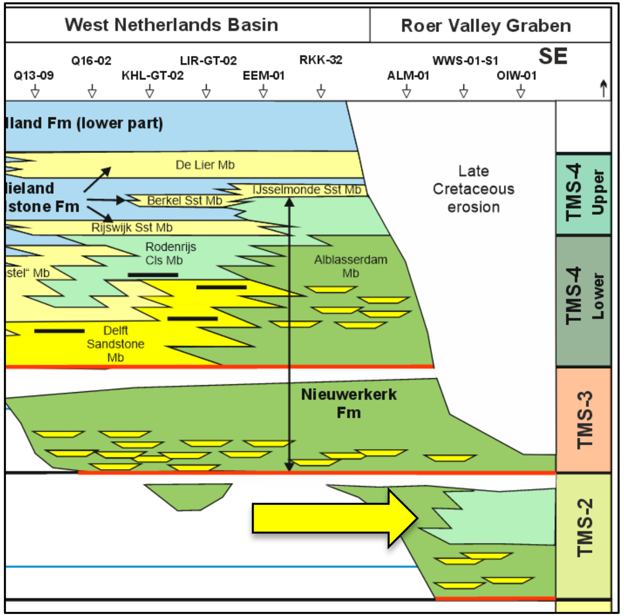
Vlieland Sandstone Formation (in block P09)

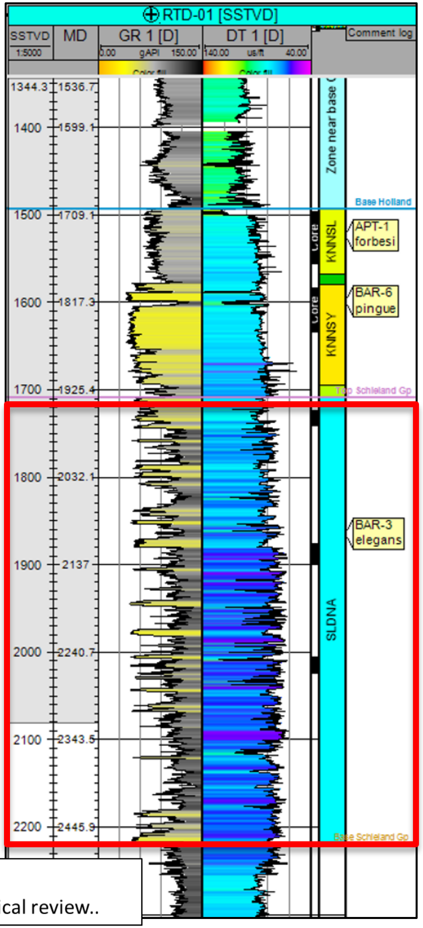
- The age of the thick ‘dirty’ sandstone in the P09 block is Valangian to Hauterivian.
- These sandstones are assigned to the Rijn Mb.

Alblasserdam Mb of the Nieuwerkerk Fm (in the Roer Valley Graben)



The Alblasserdam Mb. in the southeastern part of the study area is partially marine and is dated Early to Middle Volgian, corresponding with a TMS-2 interpretation

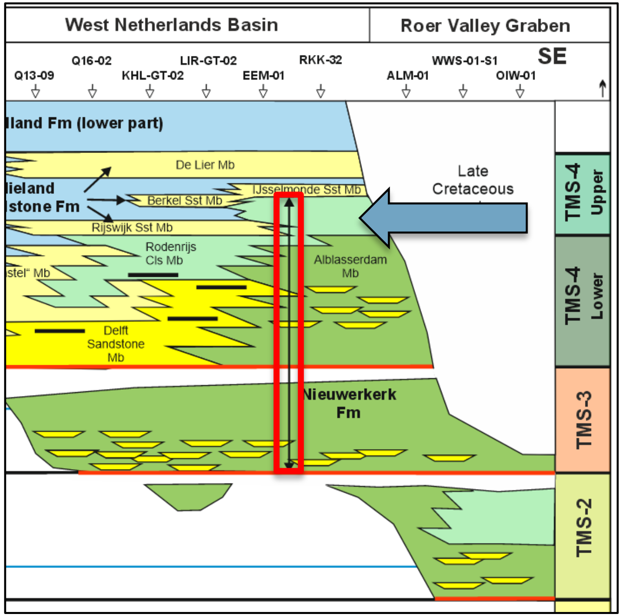




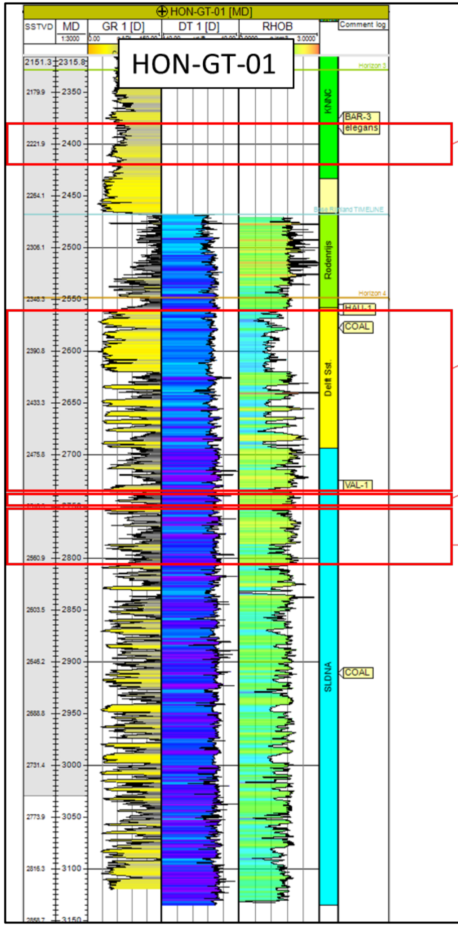
Duxbury report 2000
> West Netherlands Basin: a biostratigraphical review..

Alblasserdam Mb, Nieuwerkerk Fm, southern part WNB

The top of the Alblasserdam Mb in the southern part of the West Netherlands Basin is marginal marine and is dated Barremian, corresponding with TMS-4 Upper.



Nieuwerkerk Fm, Delft Sandstone Mb, central part WNB



Monster/Interval 2380-2420 m: laat Vroeg Barremien, *elegans* Ammonieten Zone, of ouder

De datering is gebaseerd op:

- LOD *Muderongia crucis/tetracantha* op 2380 m
- LOD *Rhynchodiniopsis* cf. *cladophora* sensu Duxbury *(1977)* op 2380 m
- LOD *Kleithriasphaeridium corrugatum* op 2400 m
- LOD *Muderongia simplex subsp. microperforata* op 2400 m

Monster/Interval 2560- 2730 m: Valanginien

De datering is gebaseerd op:

- LOD *Batioladinium cf.* sp. I sensu Davey (1982) op 2560 m
- LOD *Aequitriradites verrucosum* op 2640 m
- LOD *Pareodinia* sp I sensu Davey (1982) op 2660 m

Opmerking: de presentie van *Batioladinium varigranosum* op 2630 m indiceert een ouderdom in het vroeg(ste) Hauterivien of ouder en past bij de huidige datering.

Monster/Interval 2740 m: vroeg(ste) Valanginien

De datering is gebaseerd op:

- LOD *Canningia compta*
- LOD *Perisseiasphaeridium insolitum*

Monster/Interval 2750-2810 m: Laat Ryzanien (post-*kochi* Ammonieten Zone)

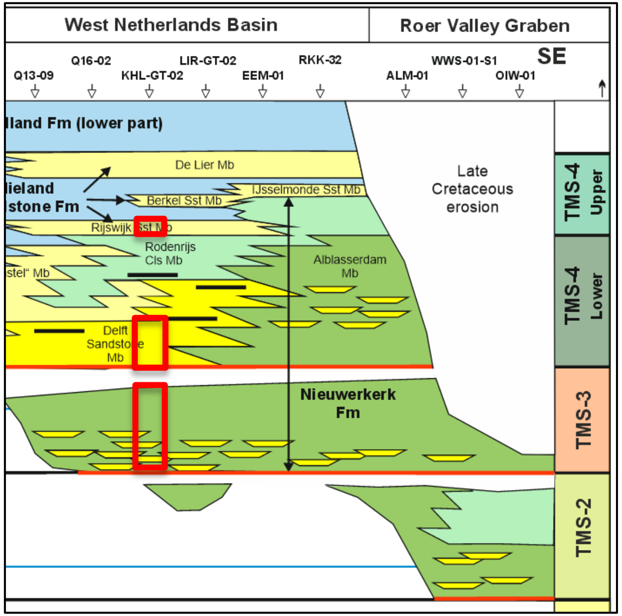
De datering is gebaseerd op:

- LOD *Batioladinium pomum* at 2750 m

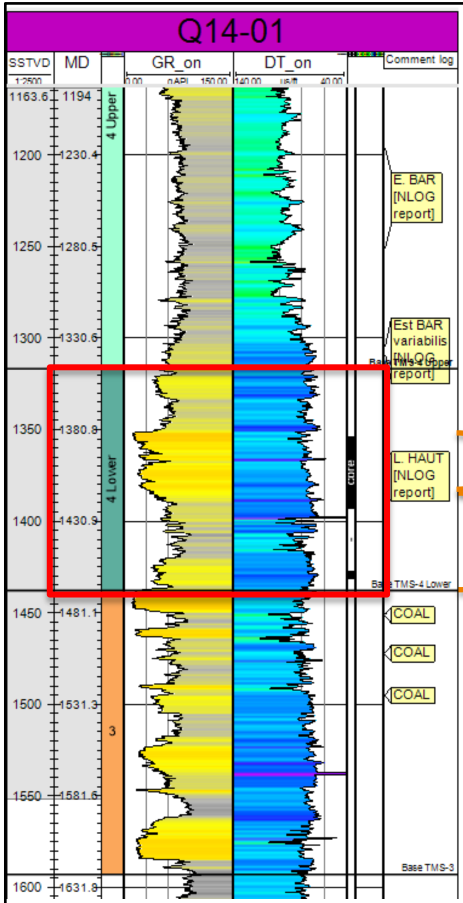
Opmerking: de "climate shift" in de *kochi* Ammonieten Zone van het Vroeg Ryazanien wordt niet bereikt. Het sporomorfengenus *Classopollis* blijft namelijk tot-en-met einddiepte zeer laag in waarde.

Munsterman rapport
> TNO 2015 R11740 Palynology
HON-GT-01 and PNA-GT-02

- The Delft Sandstone Mb is dated Valanginian and corresponds to TMS-4 Lower.
- The underlying Alblasserdam is dated Ryazanian in HON-GT-01, corresponding with TMS-3.



3 Stratigraphic Results – Biostratigraphy



1,380m-1,420.3m Hauterivian (undifferentiated)

Microfauna: No in-situ microfaunas have been recorded from this interval. Macrofaunal shell debris occurs at some levels.

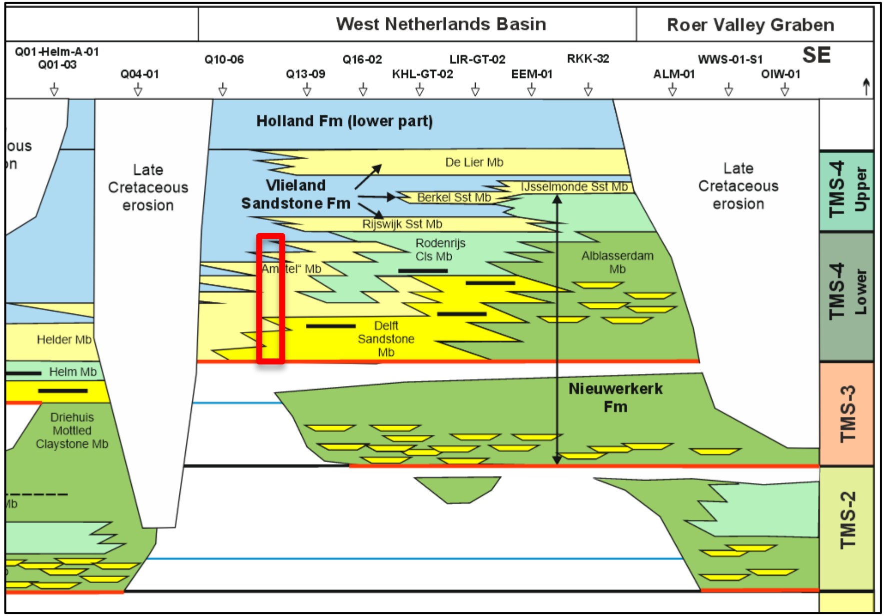
Microflora: The upper limit of this interval is taken at the appearance of sandstones (of the Rijswijk Sandstone Member) at 1,380m. Many of the core samples examined from this depth to 1,420.3m contained at best only a very sparse flora, others however, yielded moderately diverse assemblages which indicate that this part of the sequence is Hauterivian in age. Ophiobolus sp. A. Davey, a taxon restricted to the Hauterivian stage, occurs in the core samples at 1,397.7m and 1,416m, whilst Hystrichodinium furcatum and H. ramoides are present at 1,386.5m and Gardodinium trabeculosum occurs down to 1,420.3m. These latter three taxa do not range below the Early Hauterivian and the basal occurrence of G. trabeculosum is used to define the lower limit of this interval (and Subzone MC3b).

1,420.3m-c.1,485m Early Hauterivian-?Valanginian

Paleoservices Ltd. report 1984/1339 for Bow Valley Industries >> on NLOG

"Amstel" Mb, Nieuwerkerk Fm, western part WNB

The informal "Amstel" Mb is dated Valanginian to Hauterivian, corresponding to TMS-4 Lower.



3 Stratigraphic Results – Depositional Environments

Open marine
Dominance of dinoflagellate cysts indicates open marine environments, in particular when the dinoflagellate cyst assemblages are highly diverse (many species).

Restricted marine
Dinoflagellate cyst associations of the type High Dominance – Low Diversity indicate a restricted marine environment, such as a lagoon, embayment or estuary.

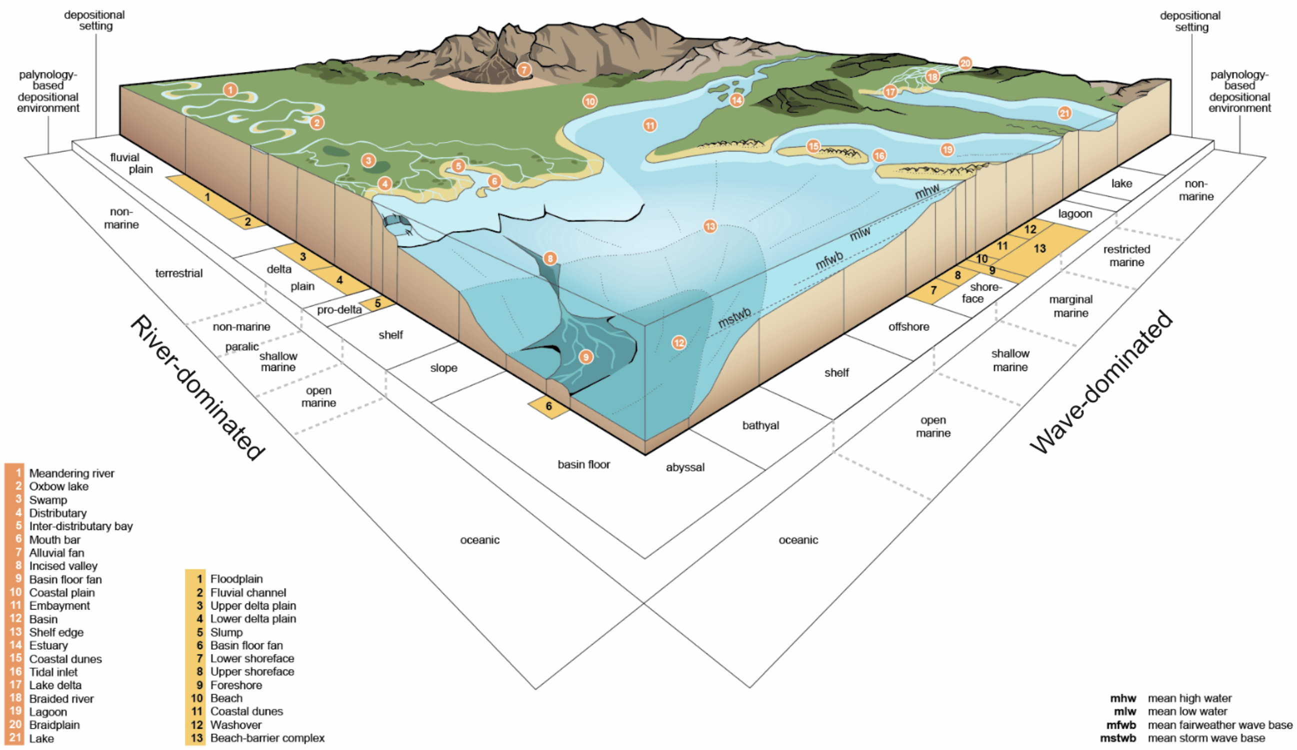
Non-marine
Absence or near-absence of dinoflagellate cysts generally indicates non-marine or marginal marine environments.

Transgression
An increase in the ratio between dinoflagellate cysts and pollen and spores indicates a sea level rise.

Regression
A decrease in the ratio between dinoflagellate cysts and pollen and spores indicates a sea level fall.

Low energy conditions
Excellent physical preservation of palynomorphs and other organic matter particles may indicate low energy conditions such as for instance a lagoon or a lake.

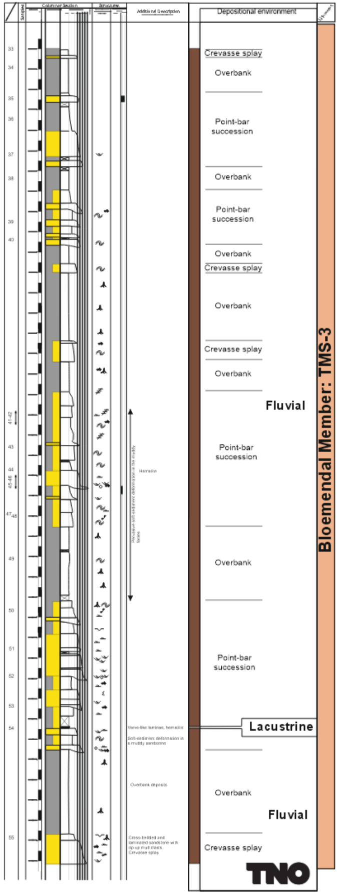
High energy conditions
Poor physical preservation of palynomorphs may indicate high energy conditions such as for instance a river channel, basin floor fan or a beach.



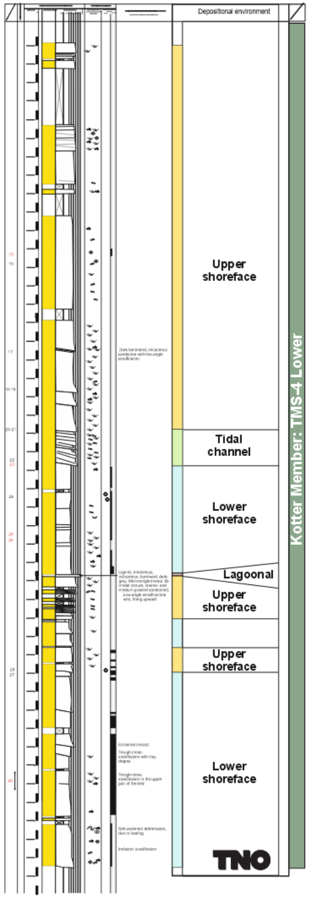
Depositional environments (modified after Verreussel et al., 2018). An array of depositional environments in the marine, continental and transitional realm is displayed. At the base of the scheme, the extent of the depositional environments inferred from palynological analysis are compared with the detailed depositional setting, as can be inferred for instance from core description analysis.

Stratigraphic Results – Depositional Environments: Cores

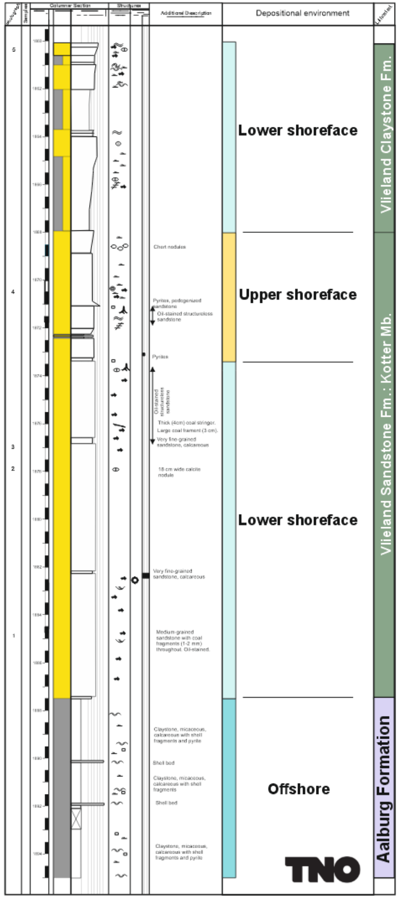
K18-02-A: Core 1



K18-02-A: Core 2



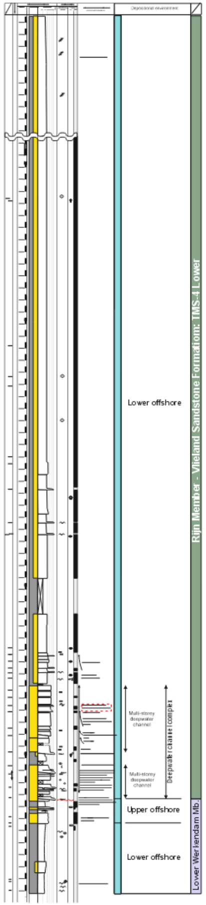
L06-06



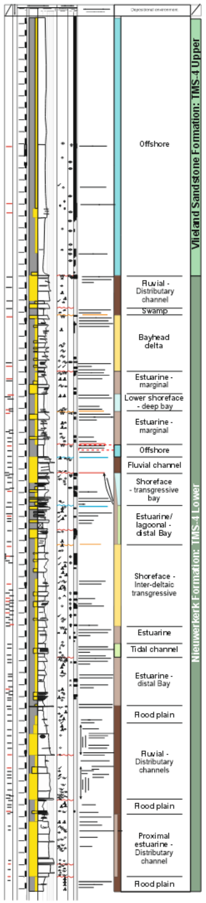
High resolution version of the core descriptions, with annotated photos, are presented in Appendix C.

Stratigraphic Results – Depositional Environments: Cores

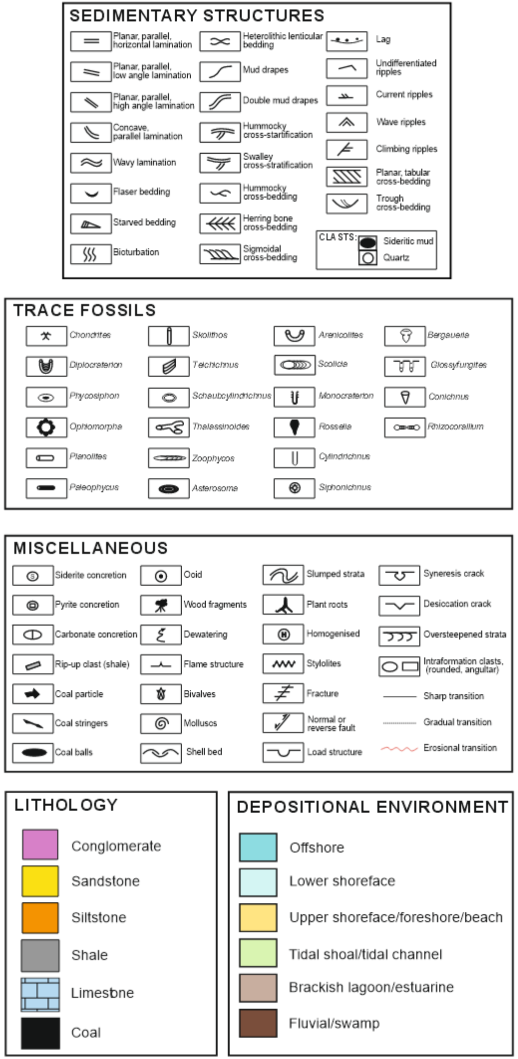
P09-03



Q13-09

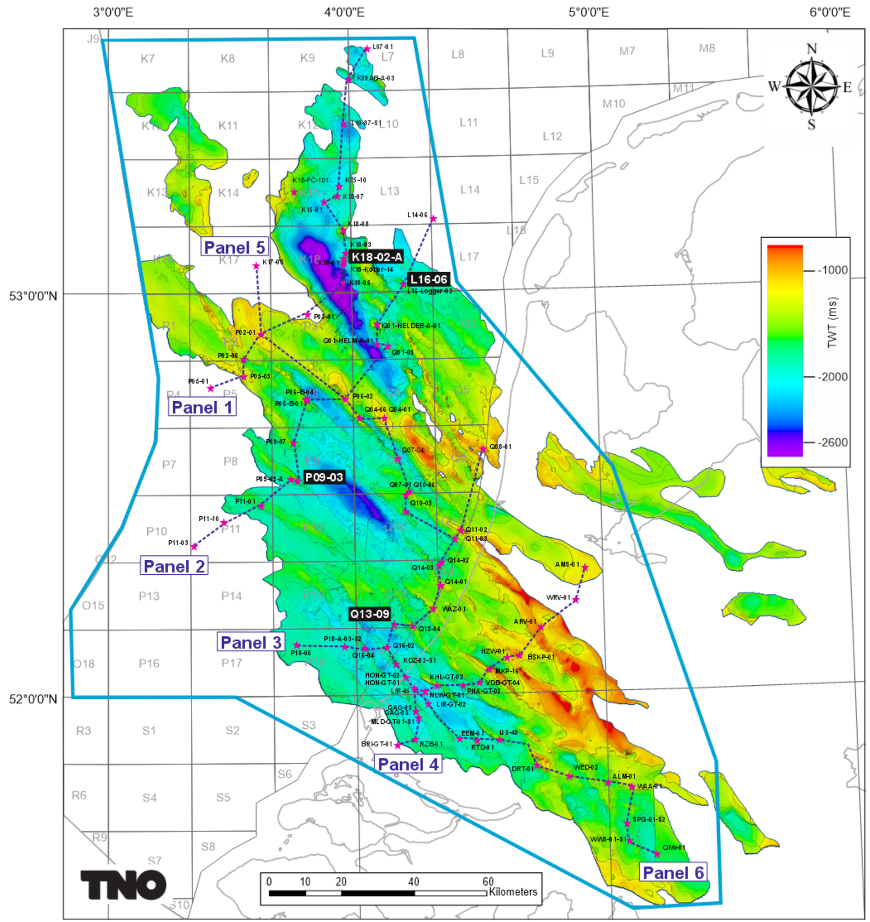


High resolution version of the core descriptions, with annotated photos, are presented in Appendix C.



4 Tectonostratigraphic Results – Seismic/Well Regional Panels

Tectonostratigraphic Results – Seismic/Well Regional Panels

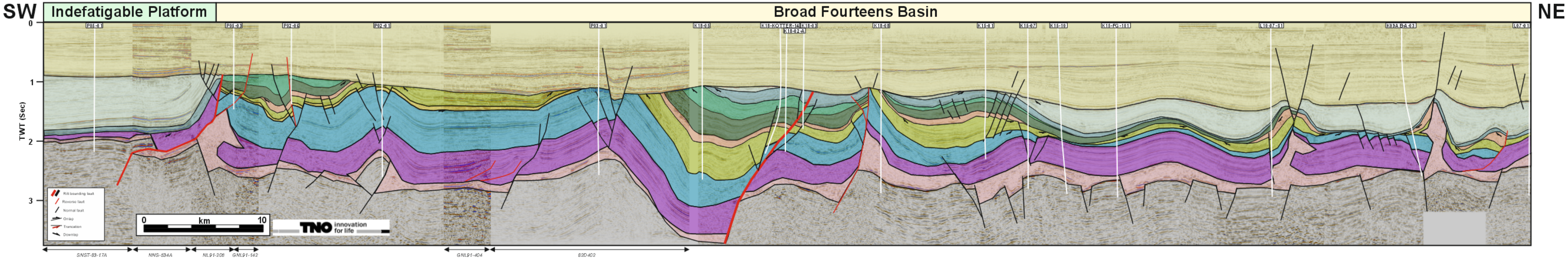


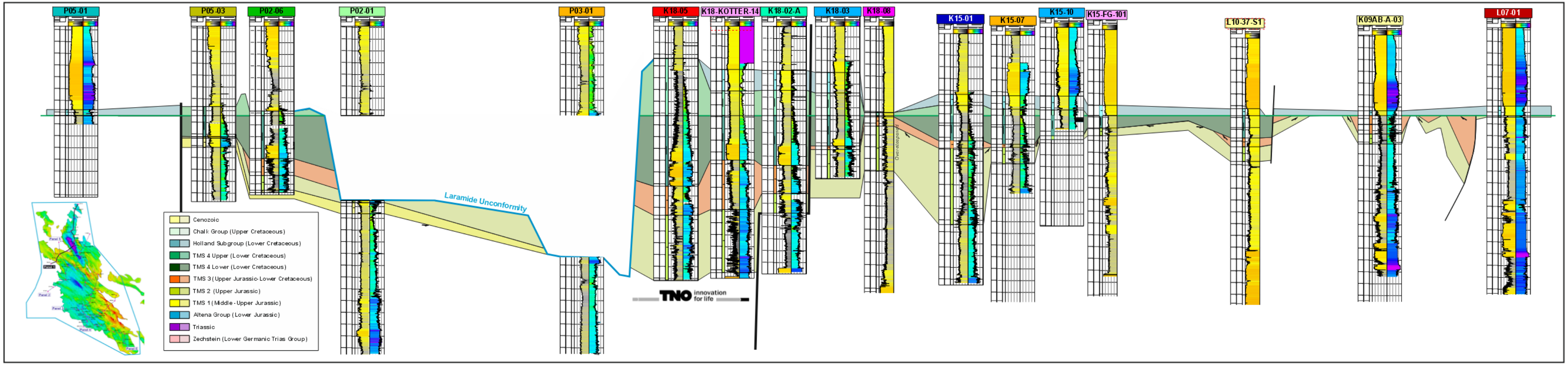
- Six regional seismic/well panels were constructed.
- Panels 1, 2, 3 and 4 are broadly oriented SW to NE, across the main basins and perpendicular to the main structural grain.
- Panels 5 and 6 are oriented NW-SE to capture the longitudinal trends within the BFB and WNB.
- Note that Panel 5 is located on the southwestern side of the BFB since most of the Upper Jurassic is missing in the axis of the BFB due to later erosion, hence the difficulty to represent the paleo-axis of the BFB in such a display.
- The panels are flattened on the Base of TMS-4 Upper, a period where the basins became less confined and when sediment accumulation started to occur more significantly on the platform areas.
- The panels are also locally adjusted to compensate from the Laramide Unconformity which differentially eroded some of the Middle Jurassic – Lower Cretaceous strata. To better reflext paleo-basinal trends, some of the wells were split into two parts, with the lower parts dropped to an estimated depth more reflective of the rifting stratigraphic geometries.
- Faults with evidence of growth during Middle Jurassic –Lower Cretaceous were also added in the well correlation part of the panel to highlight local syn-depositional trends.

Background map is the composite time structure map of TMS-1 to -4 Lower (composite unconformity)

Panel 1

High resolution version of the panels are presented in Appendix B.

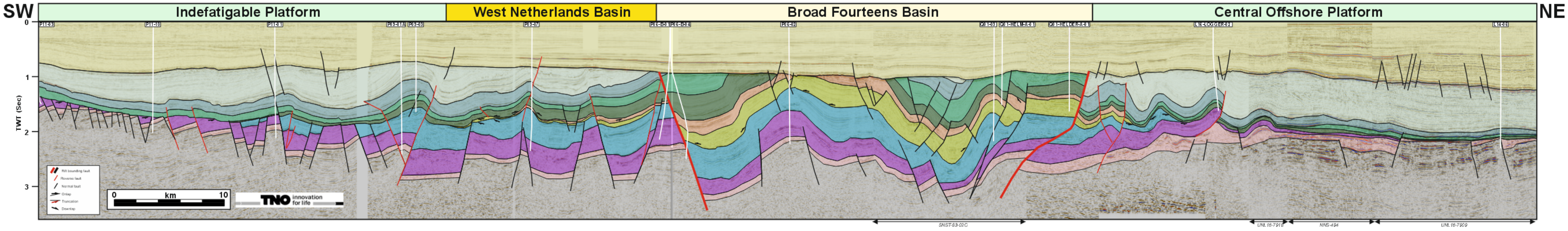


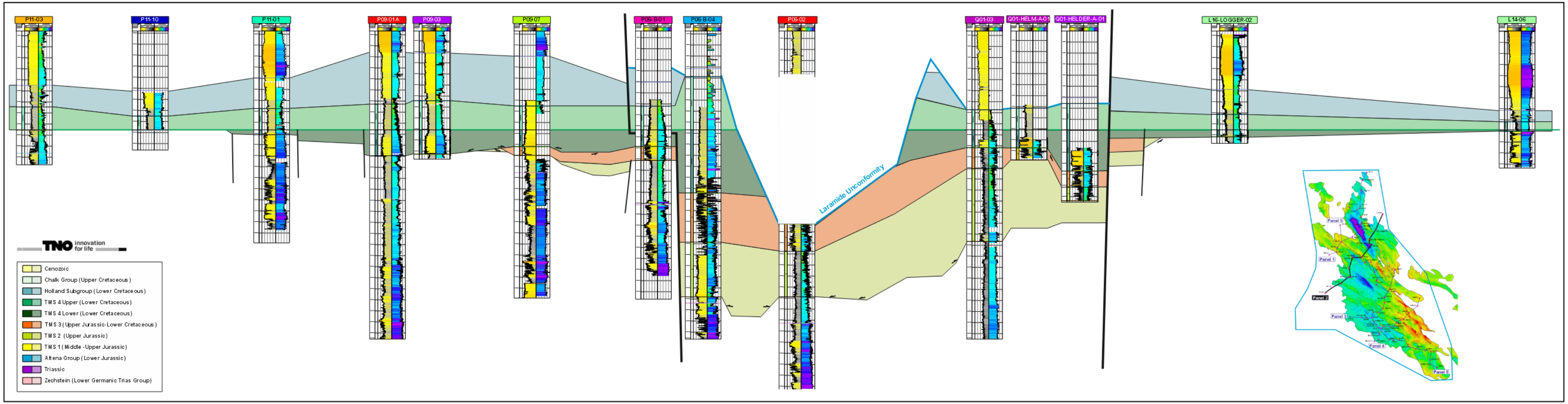


High resolution version is presented in Appendix B

Panel 2

High resolution version of the panels are presented in Appendix B.

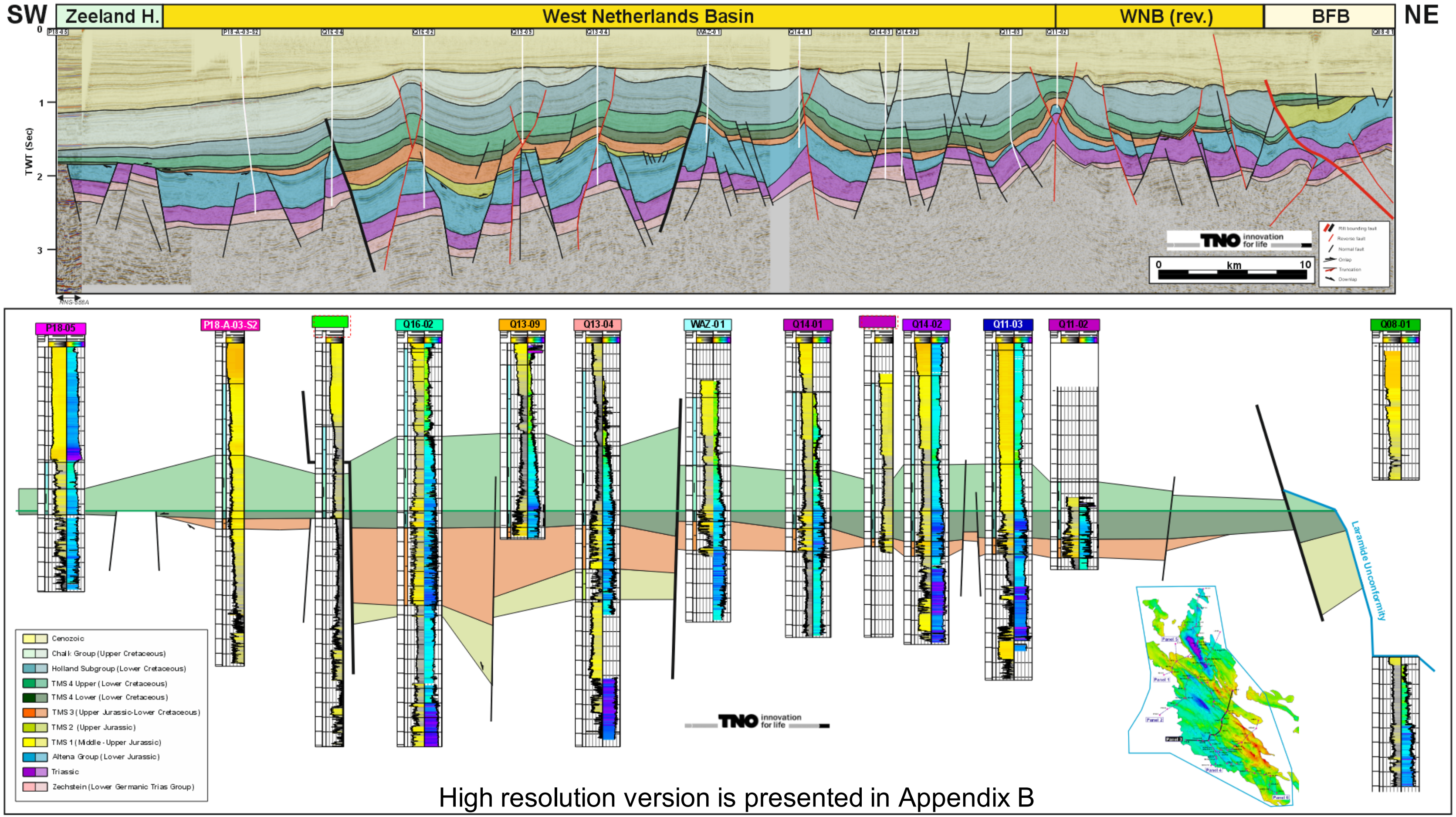




High resolution version is presented in Appendix B

4 Tectonostratigraphic Results – Seismic/Well Regional Panels

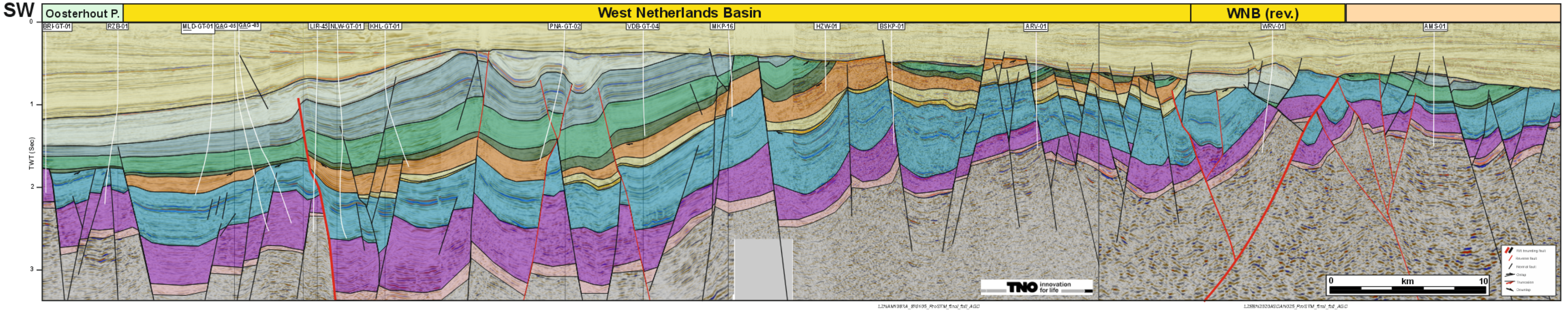
Panel 3

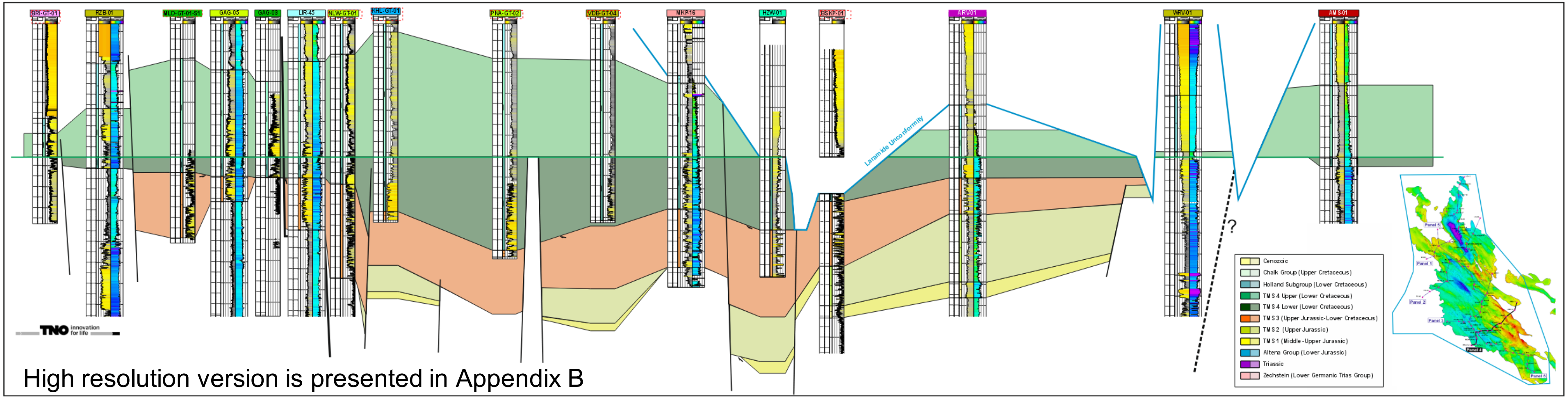


High resolution version is presented in Appendix B

Panel 4

High resolution version of the panels are presented in Appendix B.



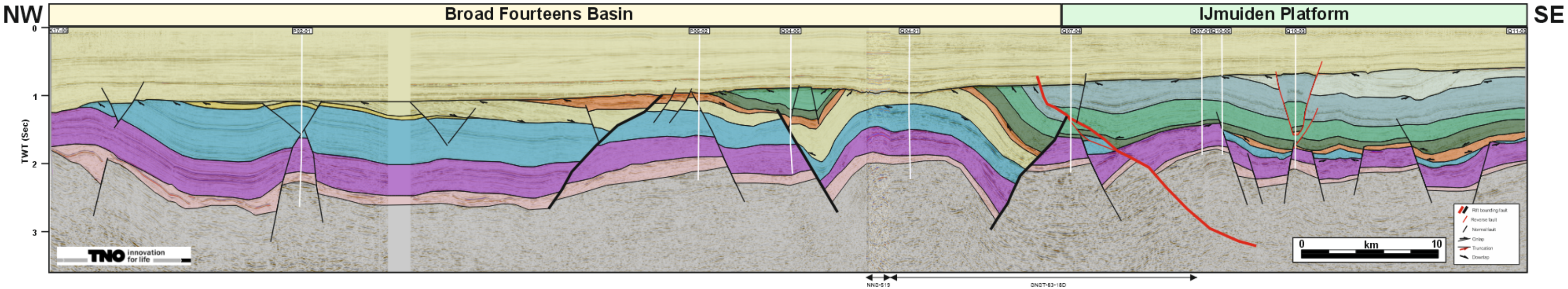


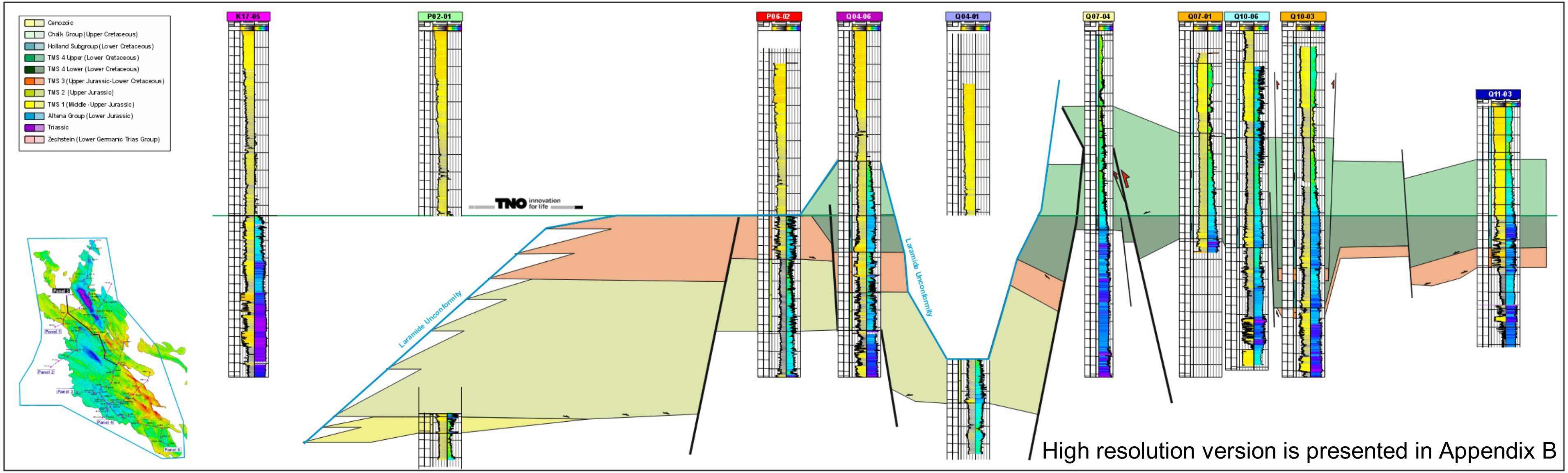
High resolution version is presented in Appendix B

Tectonostratigraphic Results – Seismic/Well Regional Panels

Panel 5

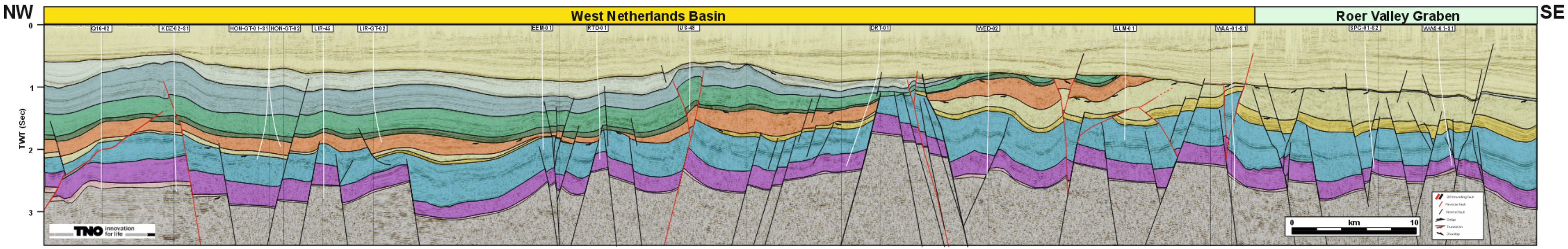
High resolution version of the panels are presented in Appendix B.

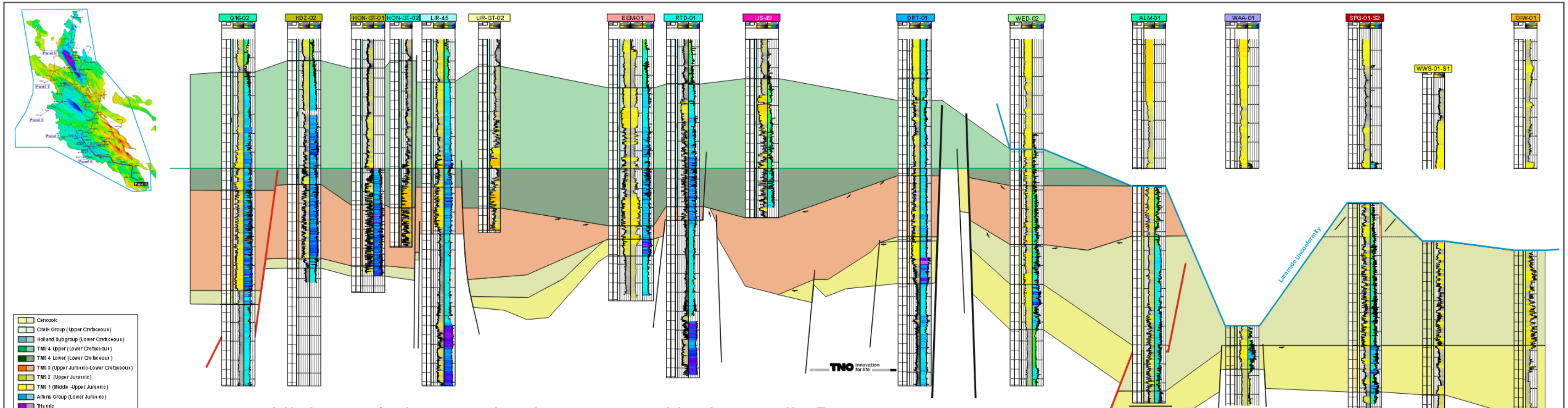




High resolution version of the panels are presented in Appendix B.

Panel 6



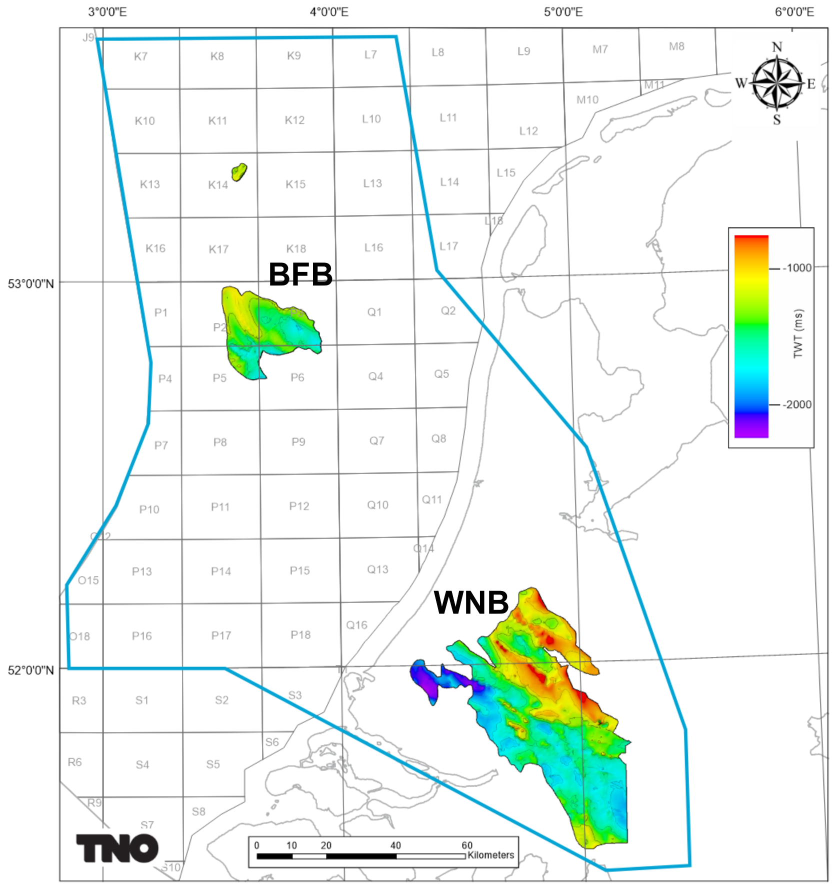


High resolution version is presented in Appendix B

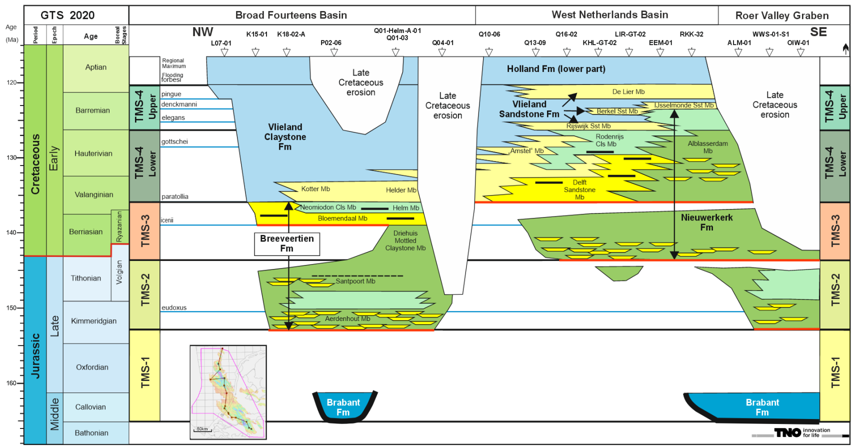
4 Tectonostratigraphic Results – Time Structure Maps

High resolution version of the maps are presented in Appendix A

Tectonostratigraphic Results – Time Structure Maps – Base TMS-1

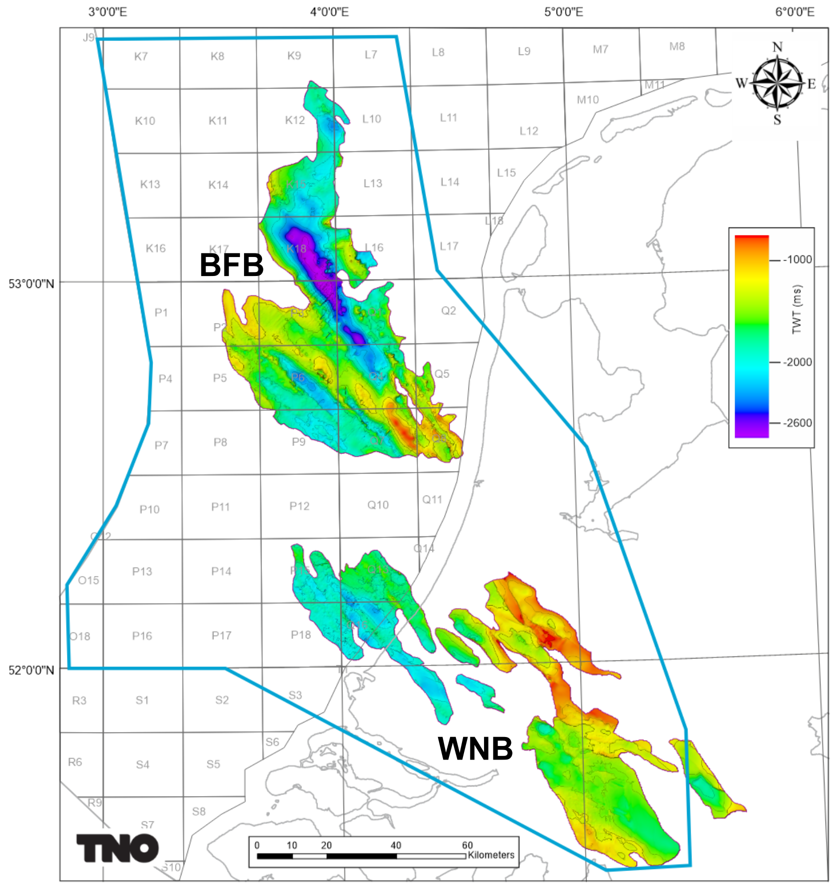


- Base TMS-1 (base of Brabant Formation) is present in three locations, a large area in the eastern part of the WNB, extending towards the Roer Valley Graben (not entirely mapped in this project, hence the straight termination of the map to the E) and in two smaller areas in the P2/P3/P5/P6 and K14 blocks.
- The base TMS-1 locally erode into the older Altena Group intervals (See Appendix B, Panel 1).
- Based on seismic reflection pattern (high amplitude reflective intervals), we believe that some TMS-1 age sediments may also present in the offshore extension of the WNB, within the deeper part of half grabens, around Q16, Q13, P15, P18. Since no well penetrate this area no TMS-1 was mapped there in this project.

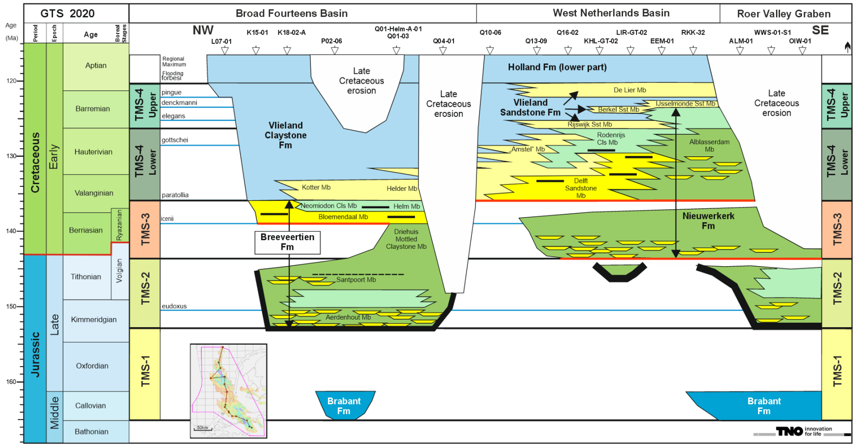


4 Tectonostratigraphic Results – Time Structure Maps – Base TMS-2

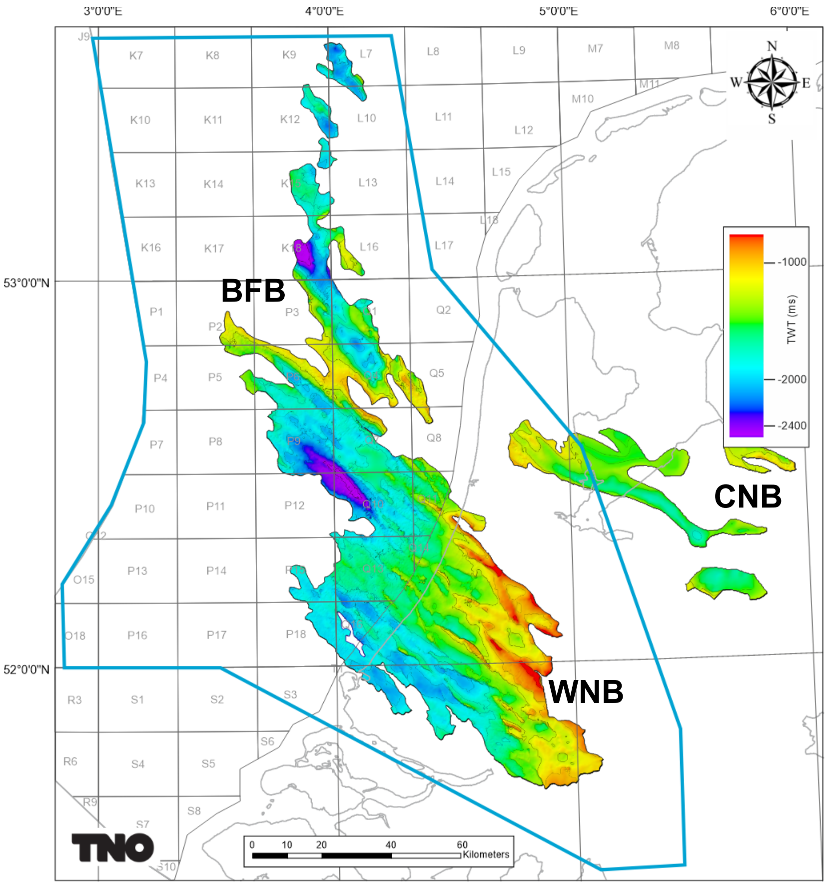
TNO innovation for life



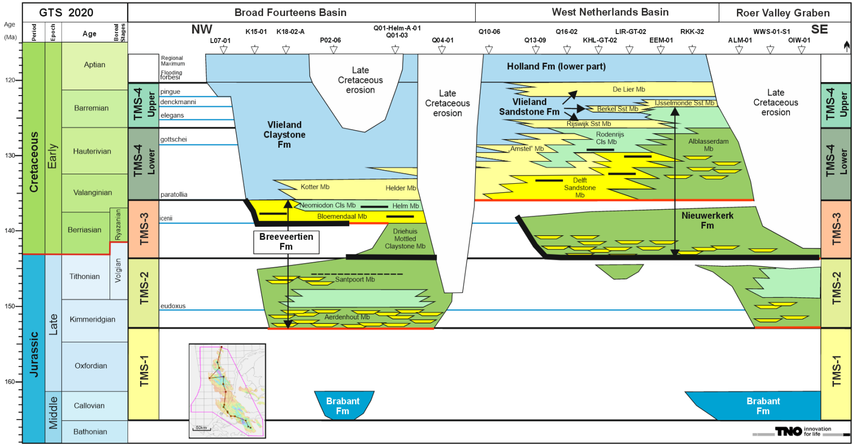
- Base TMS-2 is present in the BFB as a large zone spanning Quadrants K, L, P and Q as well as several disconnected zones in the WNB. Some of the smaller sub-areas are half-grabens within the rift basin.
- Note that in some areas between the BFB and the WNB (Q10, Q11 and Q14) the thin TMS-2 unit makes it difficult to distinguish between base of TMS-2 and the base of TMS-3. Therefore, it is possible that more TMS-2 may be present locally in this transitional area between the two basins.



Tectonostratigraphic Results – Time Structure Maps – Base TMS-3

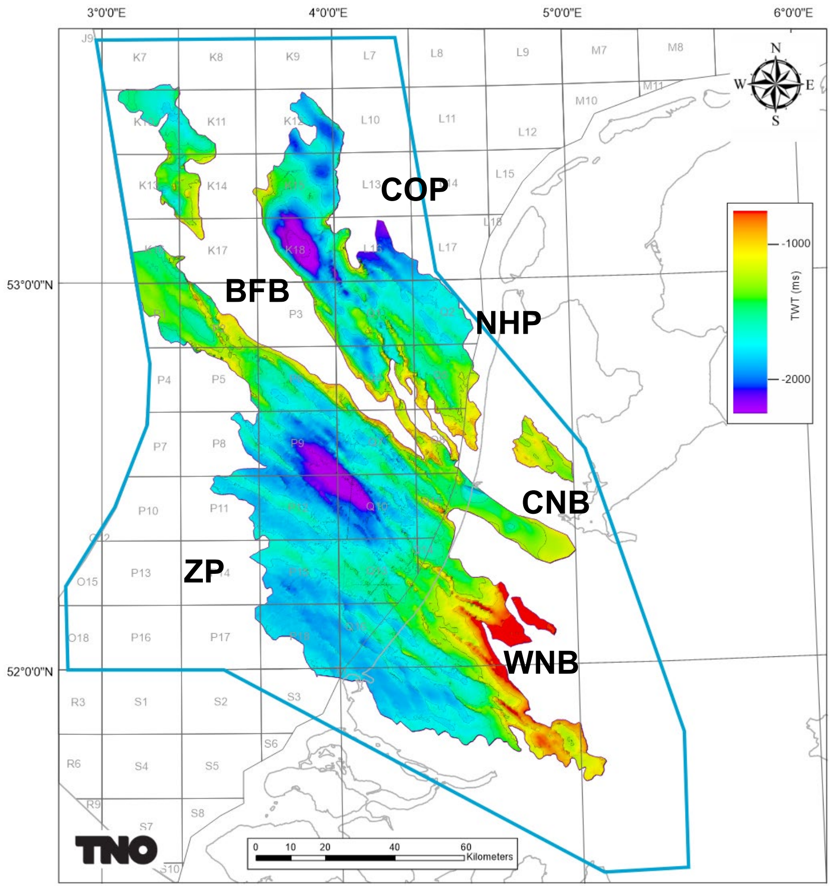


- Base TMS-3 is present in the both basins as the oldest interconnected Upper Jurassic surface.
- In the WNB, the base TMS-3 is deepest on the SW side, reflecting the asymmetric geometry of the basin (more uplift on the NE side of the basin).
- In the BFB, the base TMS-3 is deepest on each side of the uplifted paleo-rift axis P03-Q08.
- Base TMS-3 is also present in the Central Netherlands Basin (CNB) in a few isolated zones.



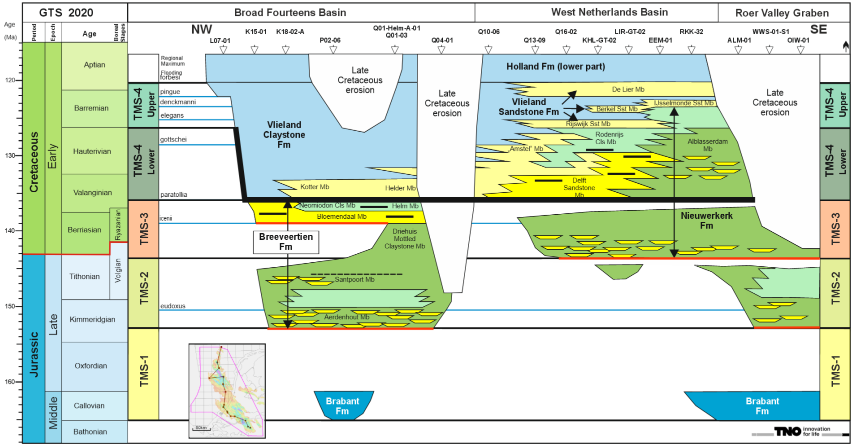
Tectonostratigraphic Results – Time Structure Maps – Base TMS-4 Lower

TNO innovation for life

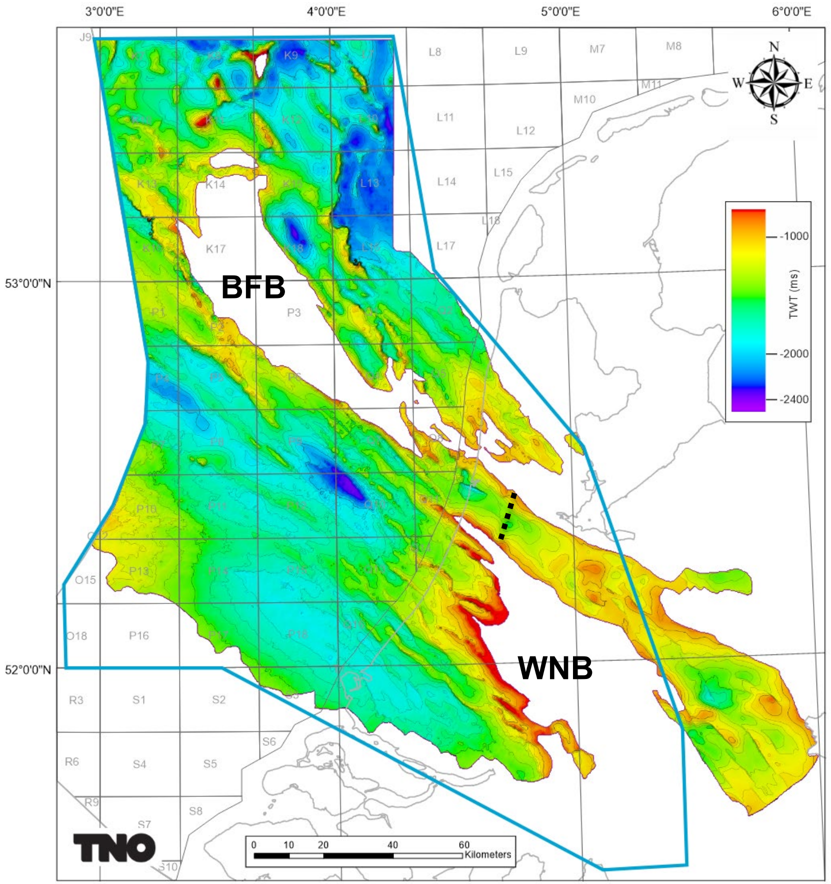


Base TMS-4 Lower covers a large area, reflecting a widening of the depositional area outside of the paleo-rift basins. Valanginian strata are deposited as far as:

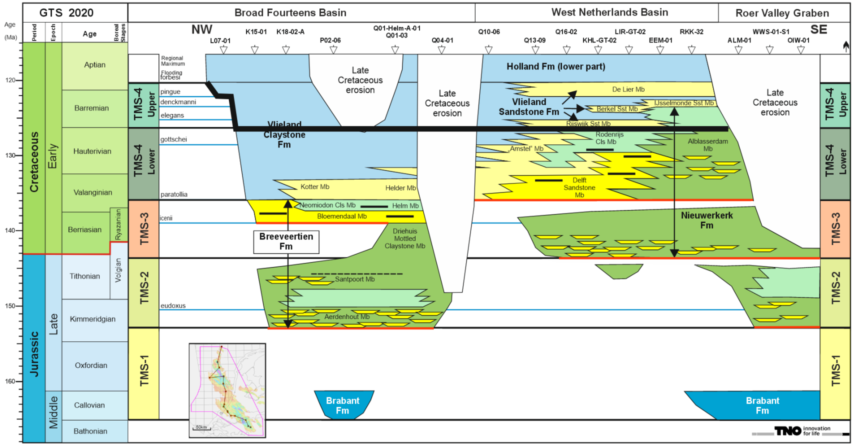
- blocks P17, P11, P08 (Zeeland Platform) and blocks P01, Q16 (north of the Winterton High) to the west of the BFB.
- blocks Q02 (Noord Holland Platform), L17 (Central Offshore Platform) to the east of the BFB.
- the Central Netherlands Basin to the east.



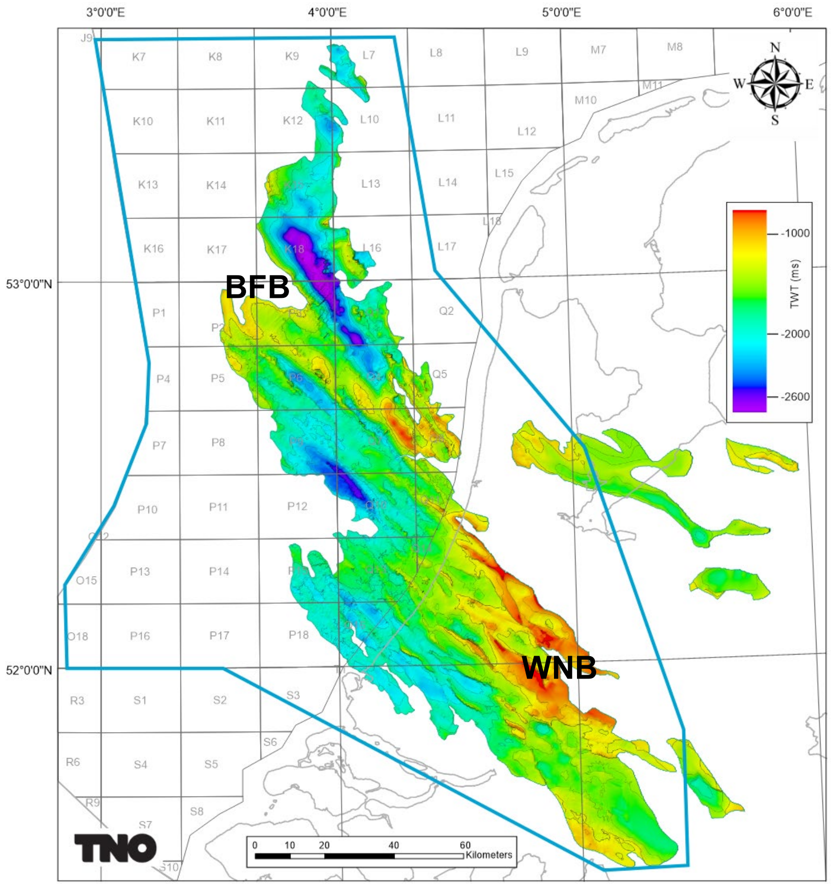
Tectonostratigraphic Results – Time Structure Maps – Base TMS-4 Upper



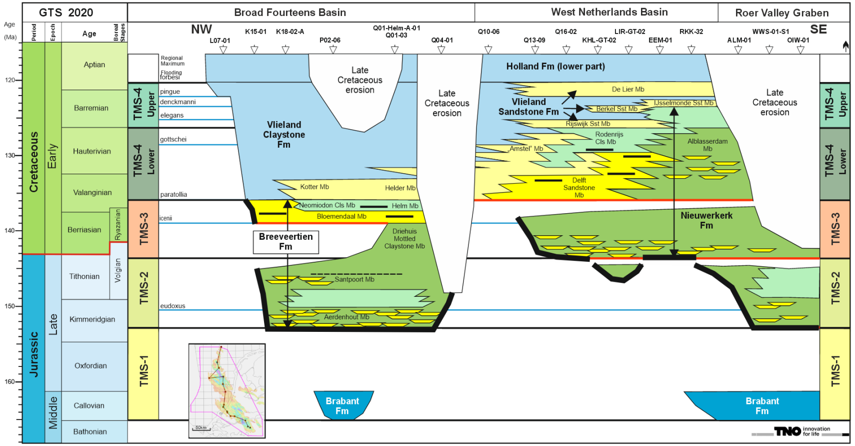
- Base TMS-4 Upper is present in a large part of the study area except in the SW corner (P16 and O18), onlapping further to the NW.
- Note that the Base TMS-4 Upper in the south-eastern part of the map (Central Netherlands Basin; zone east of the dashed black line) is based on the Base Rijnland Group from TNO's DGM 5.0.



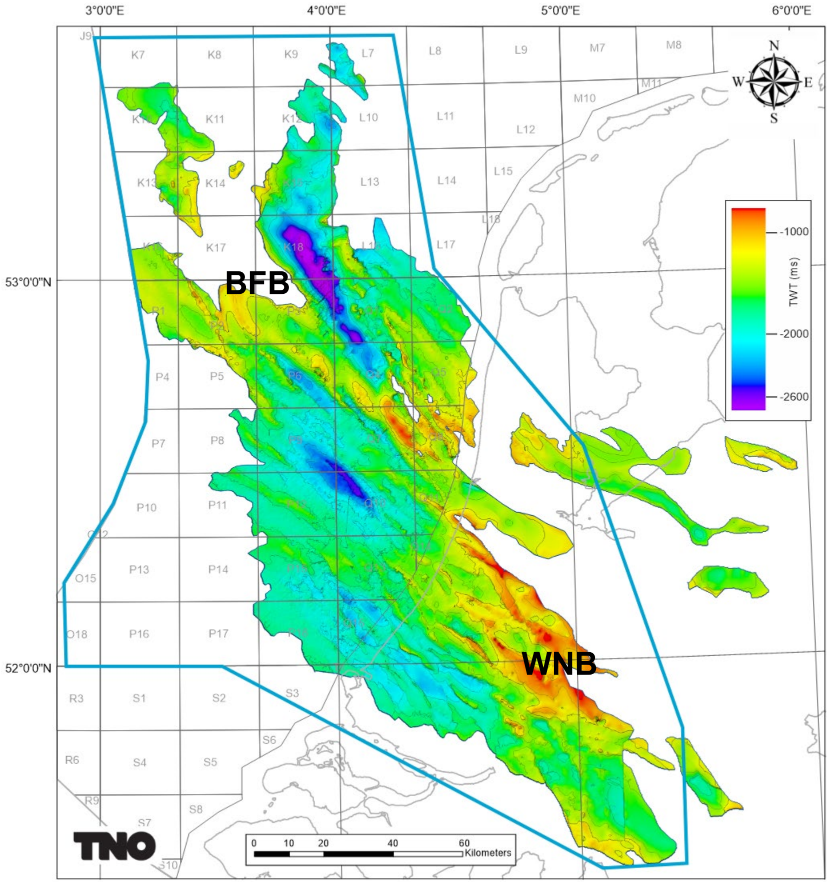
Tectonostratigraphic Results – Time Structure Maps – Base TMS-2 and TMS-3



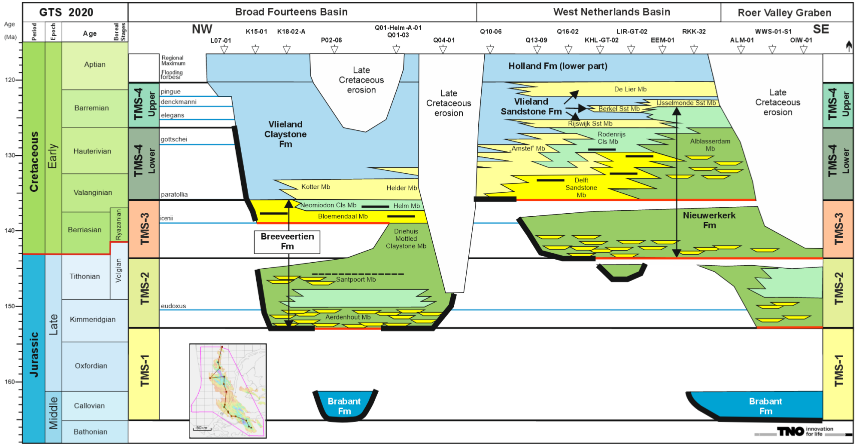
This composite time structure map reflects the Base Delfland Group by combining the bases of TMS-2 and TMS-3



Tectonostratigraphic Results – Time Structure Maps – Base TMS-1 to -4 Lower



This composite time structure map provides the best possible map of the depth of the oldest Middle Jurassic to Lower Cretaceous sediments in the study area because the bases of the Delfland and Vlieland sub-groups are unconformities that merge on the sides of the rift basin to become a composite unconformity.



4 Tectonostratigraphic Results – Time Thickness Maps

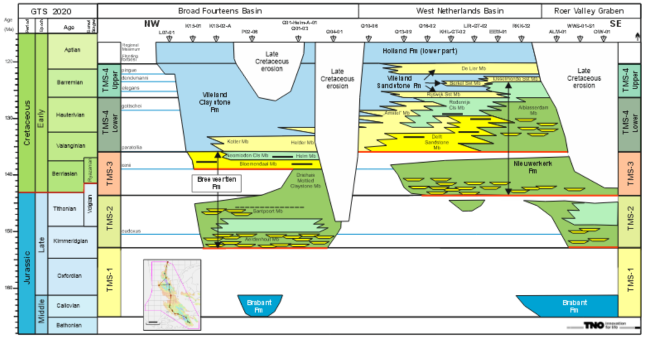
High resolution version of the maps are presented in Appendix A

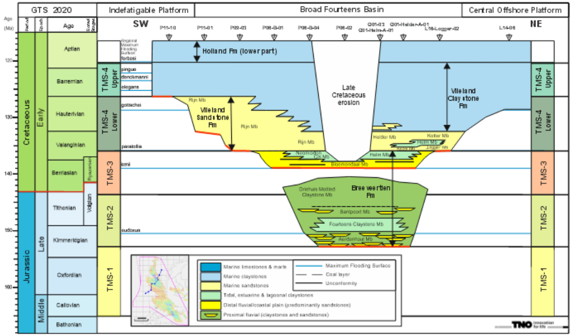
4 Tectonostratigraphic Results – Time Thickness Maps

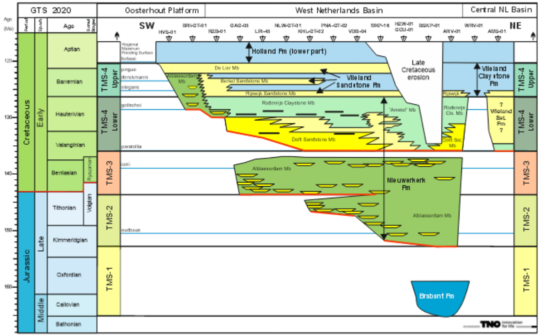
- The following pages show the time thickness maps for TMSs and some composite sequences.
  - TMS-1
  - TMS-2
  - TMS-3
  - TMS-2 + 3
  - TMS-1 to 3
  - TMS-4 Lower
  - TMS-1 to 4 Lower
  - TMS-5
  - TMS-4 Upper + 5

- The maps displayed on the right-side on the following pages, show the partial erosion of the particular intervals. Light grey polygons relate to Upper Cretaceous/Laramide unconformities, dark grey polygons to intra-Upper Jurassic or intra-Lower Cretaceous unconformities.

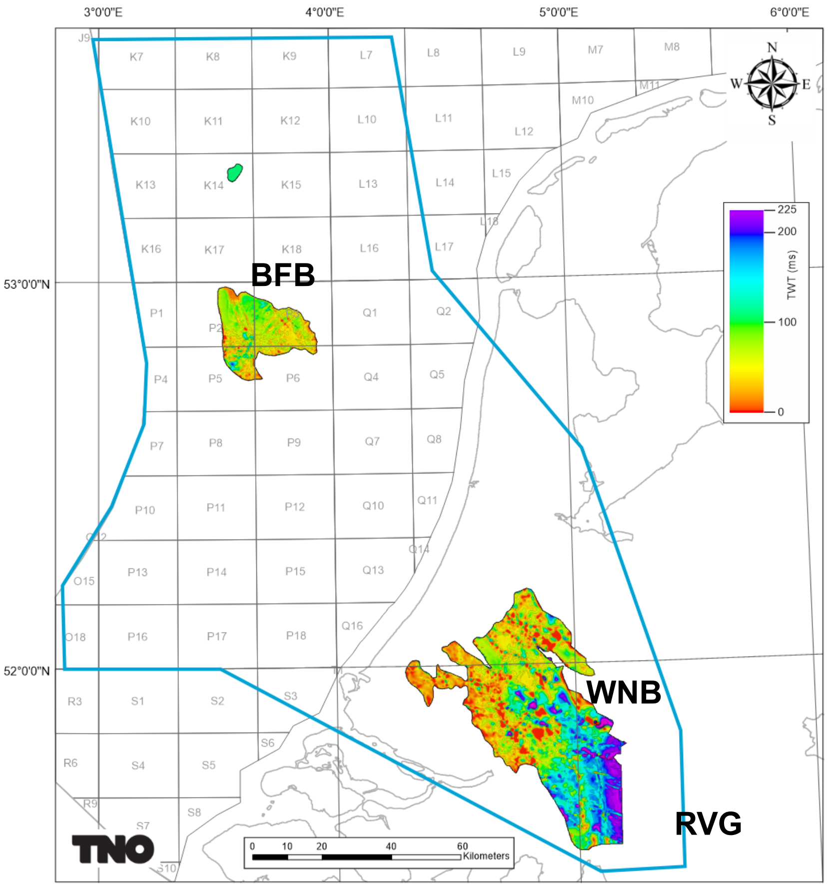
- The time thickness maps are showing the true stratigraphic time thickness, the maps are corrected from stratal tilt. Note that the thickness scale is different in different maps.





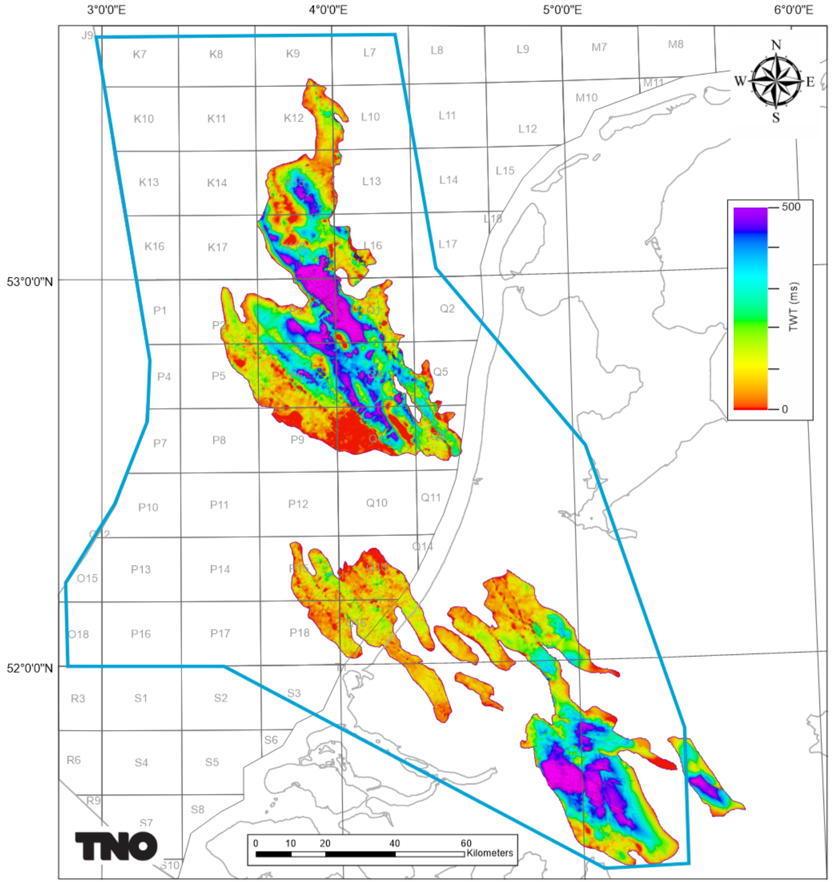


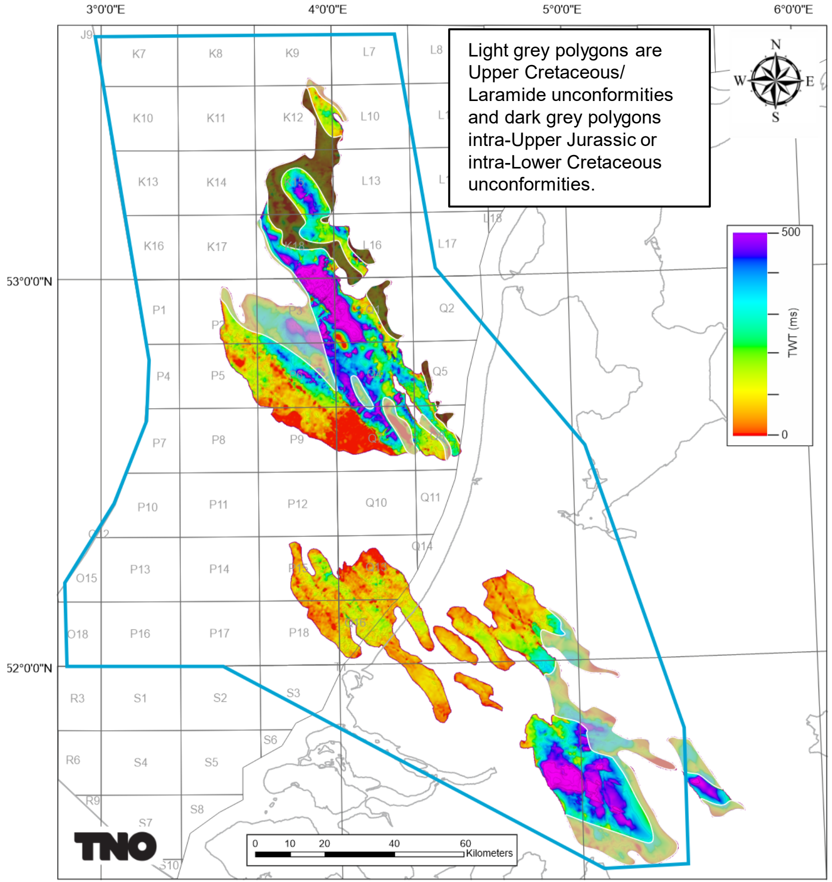
Tectonostratigraphic Results – Time Thickness Maps – TMS-1



- TMS-1 is thickest in the western part of the WNB, in the transitional area toward the RVG.
- Most areas show little evidence of syn-depositional faulting, nor major erosion at the top of the Brabant Formation, beside some local erosions on the outer rims of the basins (base of TMS-2 or TMS-3), offshore (see Appendix B, Panel 1) and onshore (see Appendix B, Panel 6).

Tectonostratigraphic Results – Time Thickness Maps – TMS-2

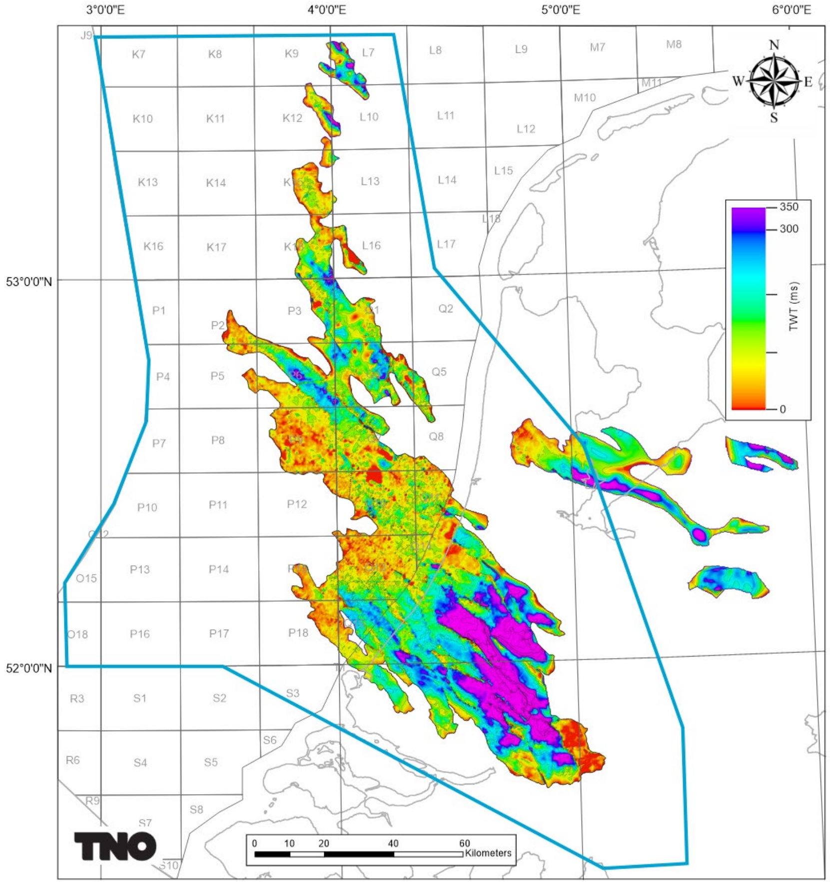


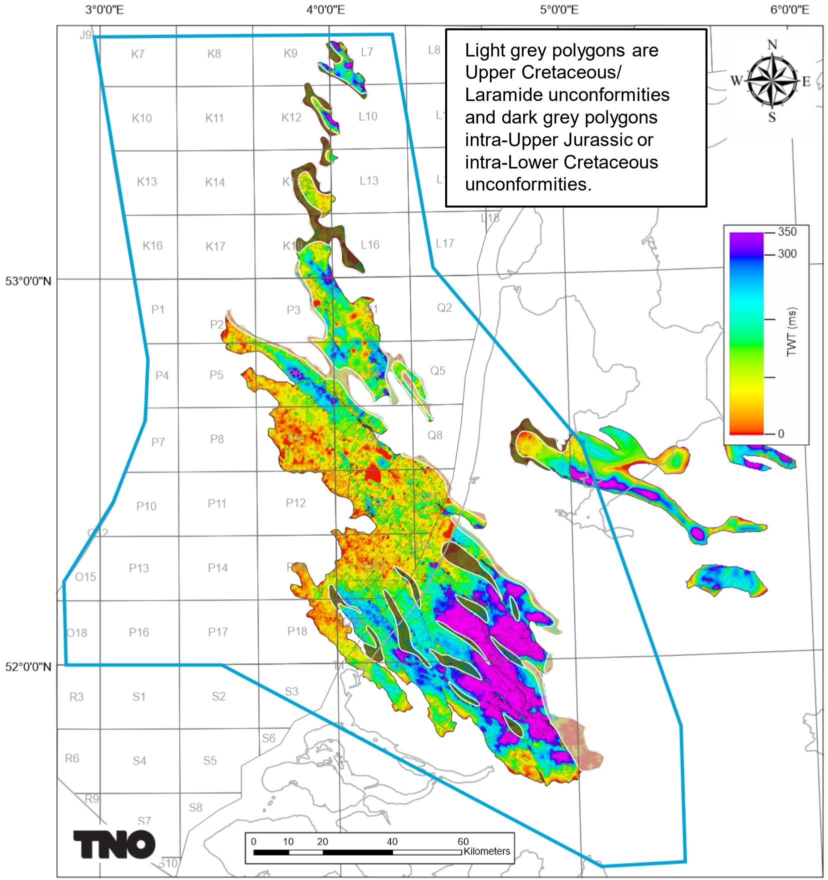


Light grey polygons are Upper Cretaceous/ Laramide unconformities and dark grey polygons intra-Upper Jurassic or intra-Lower Cretaceous unconformities.

Tectonostratigraphic Results – Time Thickness Maps – TMS-3

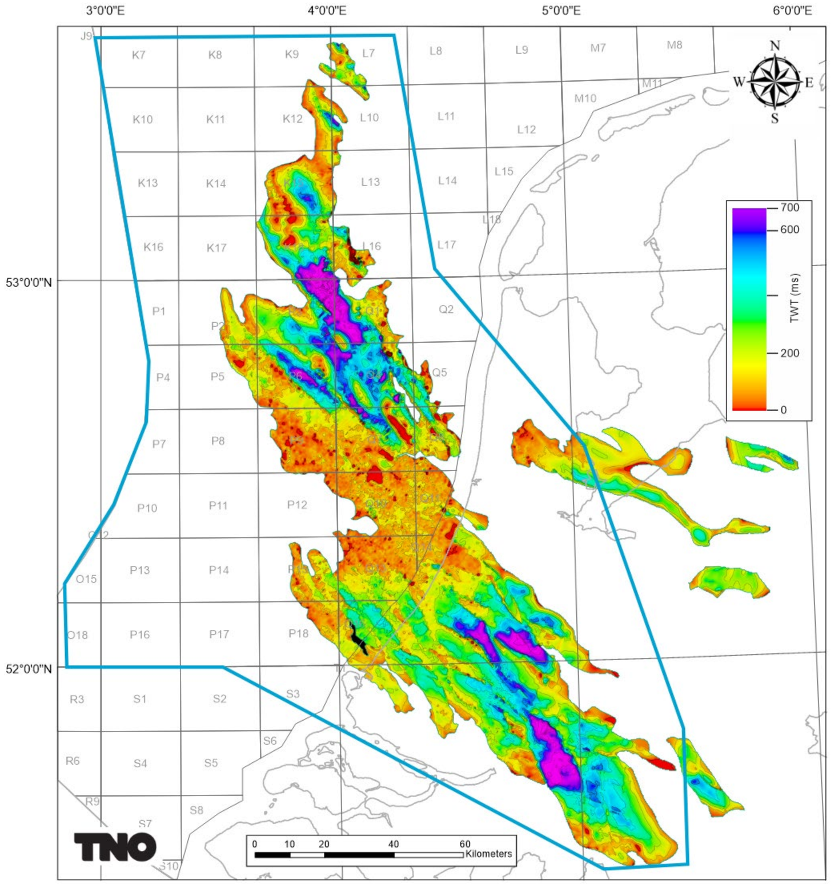
TNO innovation for life

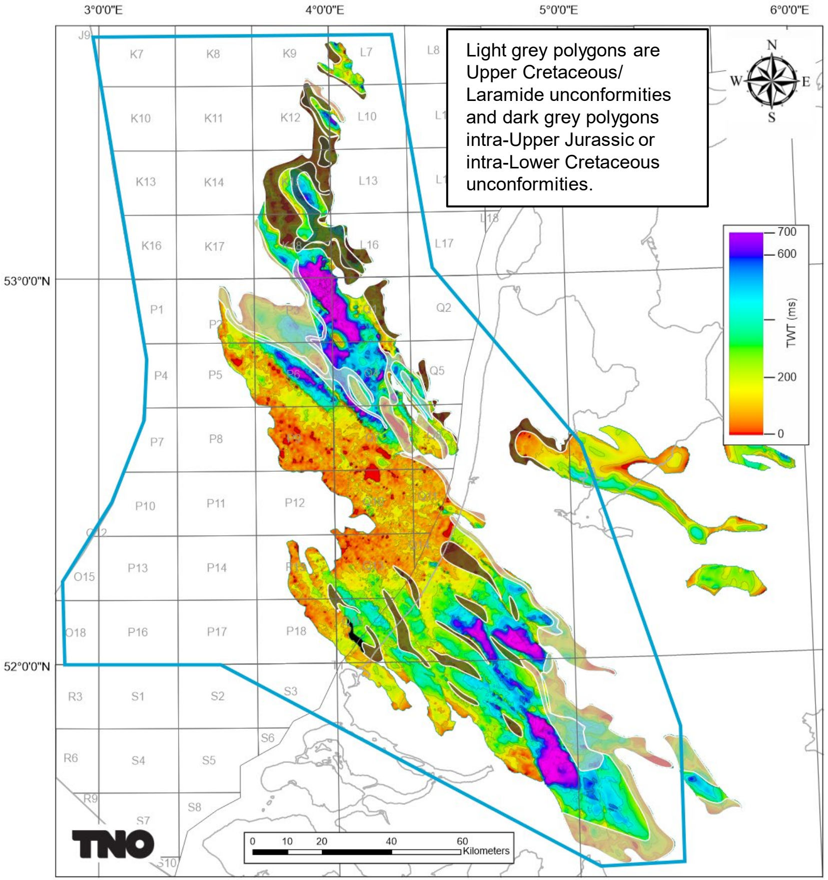




4

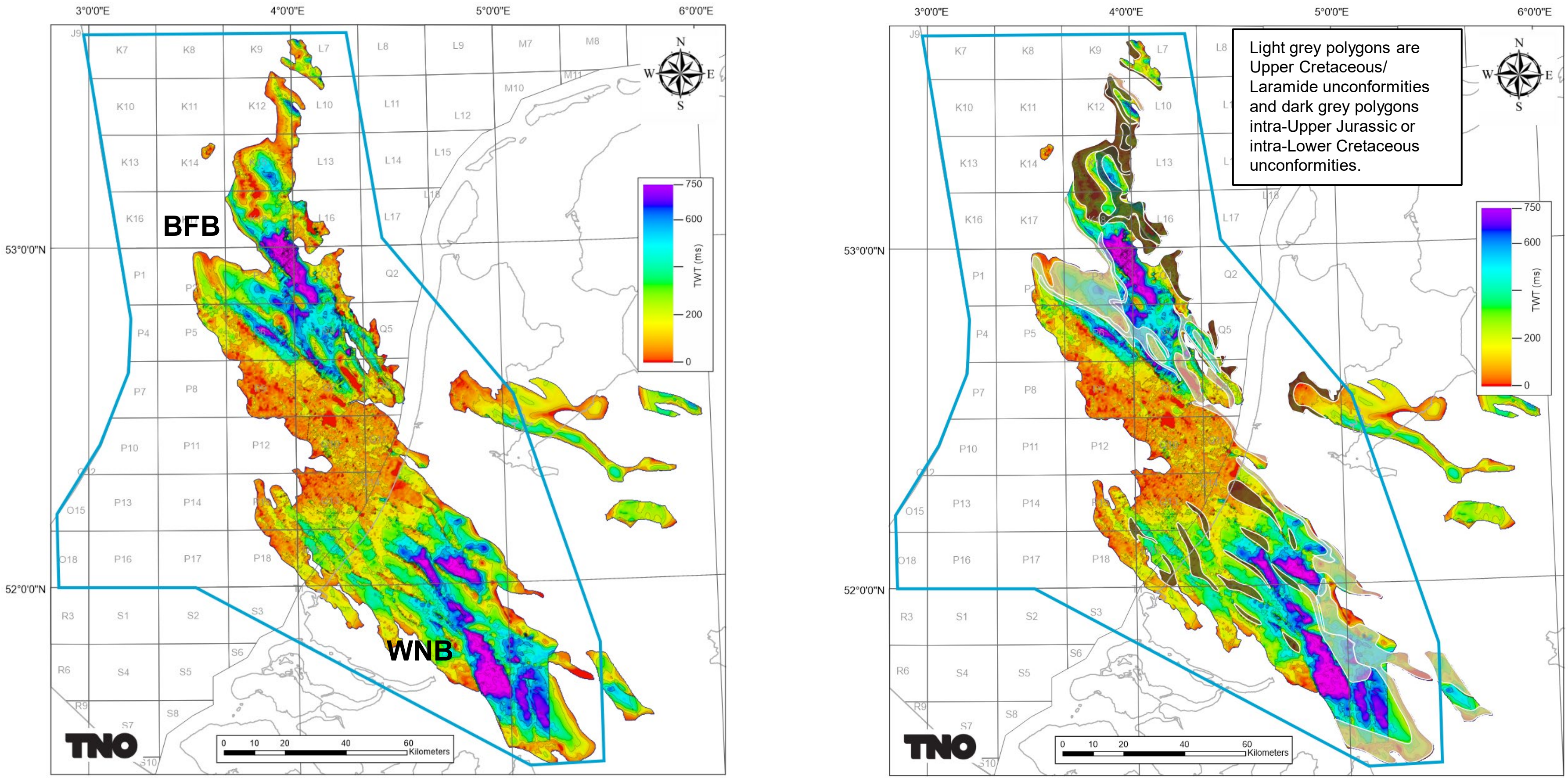
Tectonostratigraphic Results – Time Thickness Maps – TMS-2+3



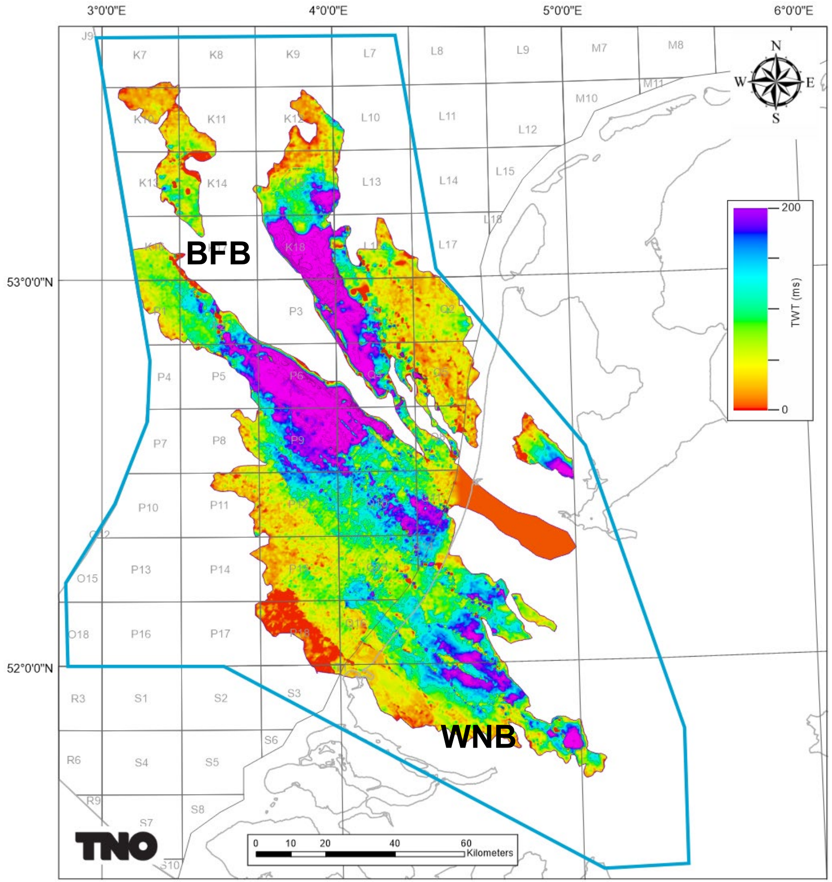


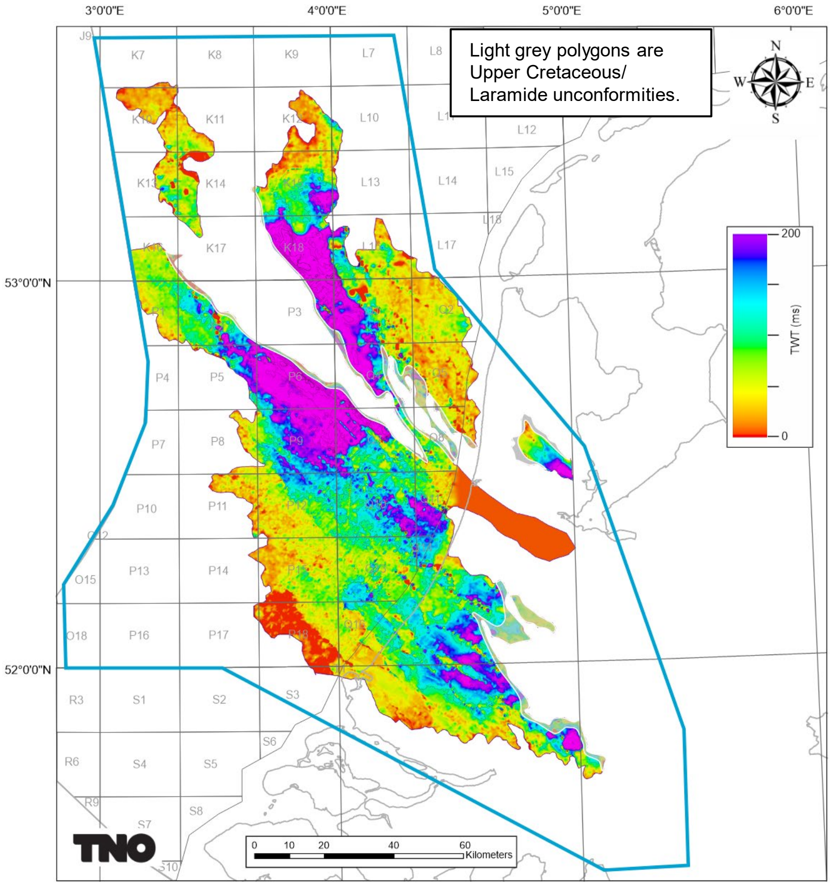
Light grey polygons are Upper Cretaceous/ Laramide unconformities and dark grey polygons intra-Upper Jurassic or intra-Lower Cretaceous unconformities.

Tectonostratigraphic Results – Time Thickness Maps – TMS-1 to 3

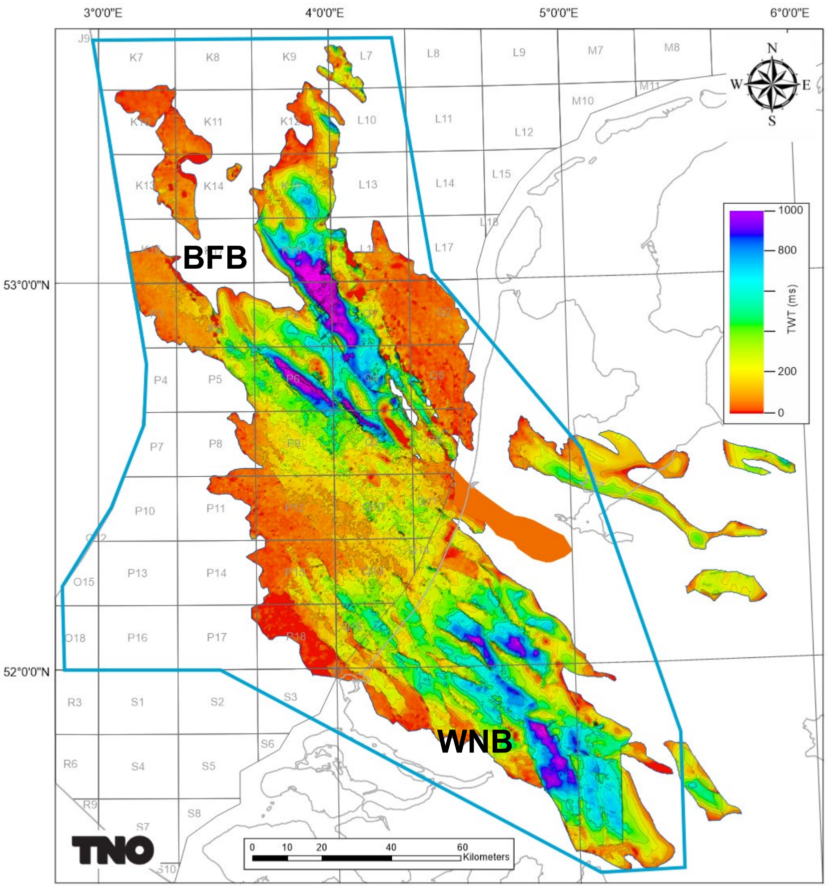


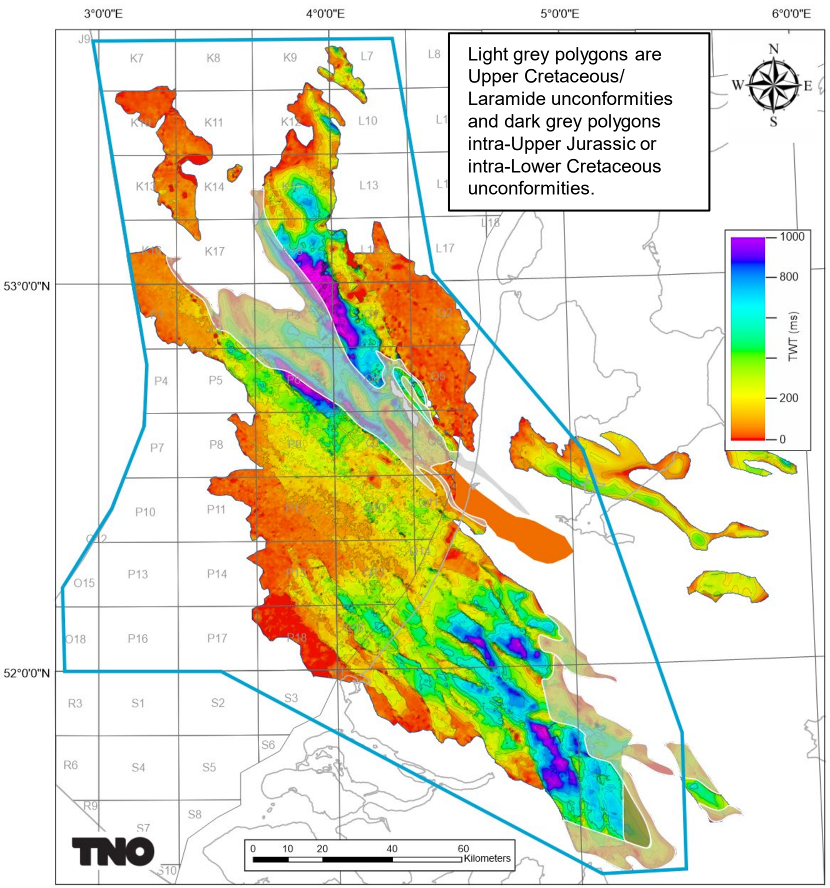
Tectonostratigraphic Results – Time Thickness Maps – TMS-4 Lower



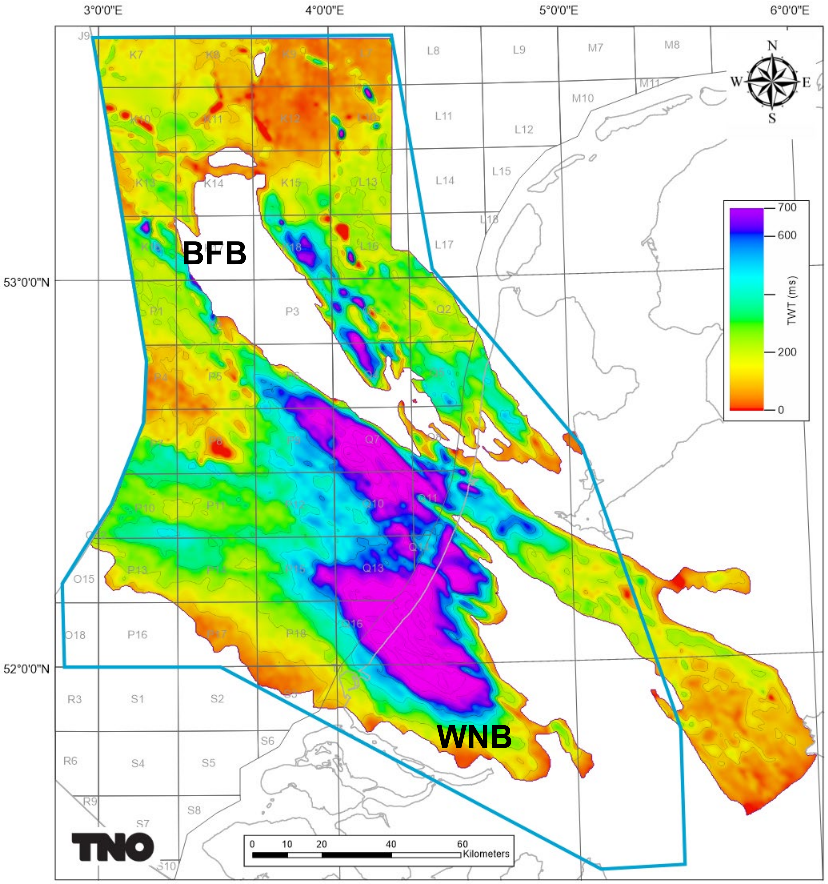


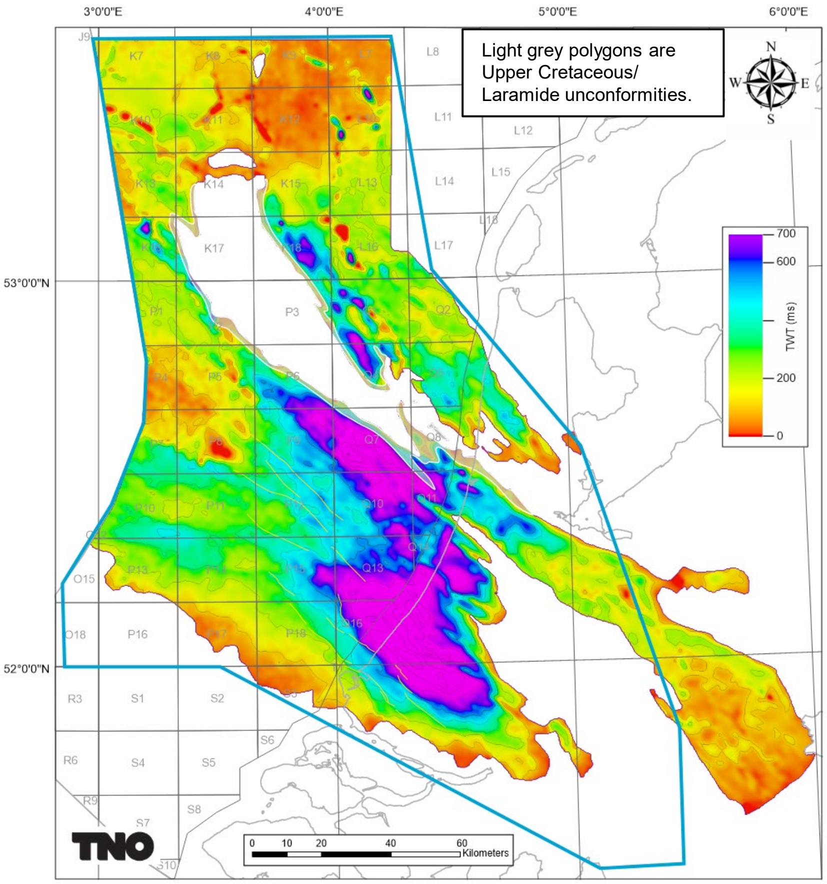
Tectonostratigraphic Results – Time Thickness Maps – TMS-1 to 4 Lower



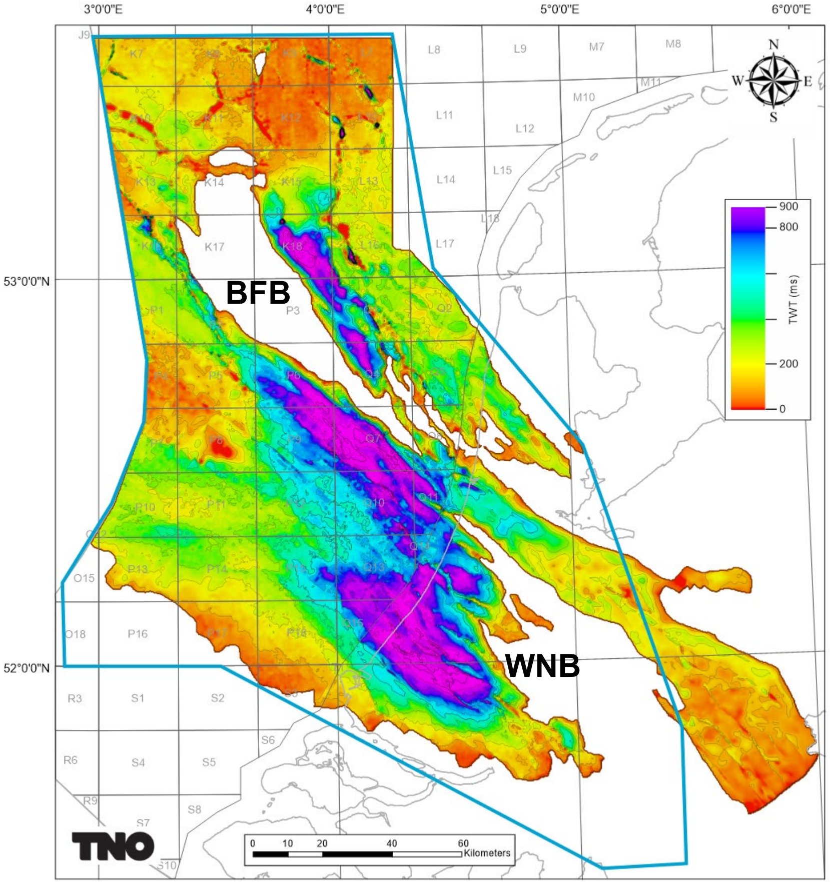


Tectonostratigraphic Results – Time Thickness Maps – TMS-4 Upper + 5





Tectonostratigraphic Results – Time Thickness Maps – TMS-4 + TMS-5

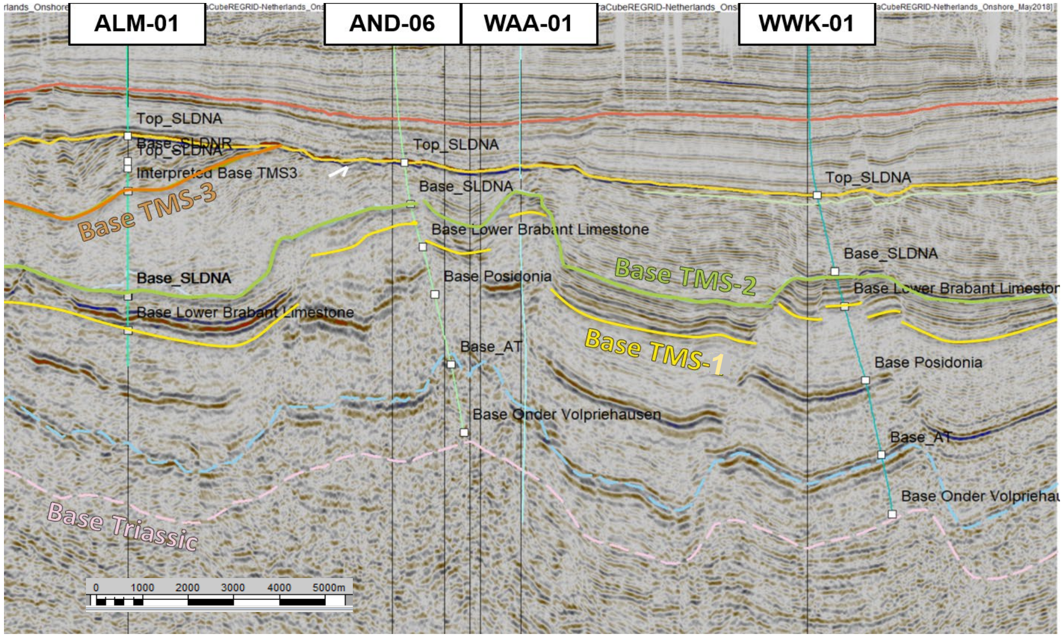


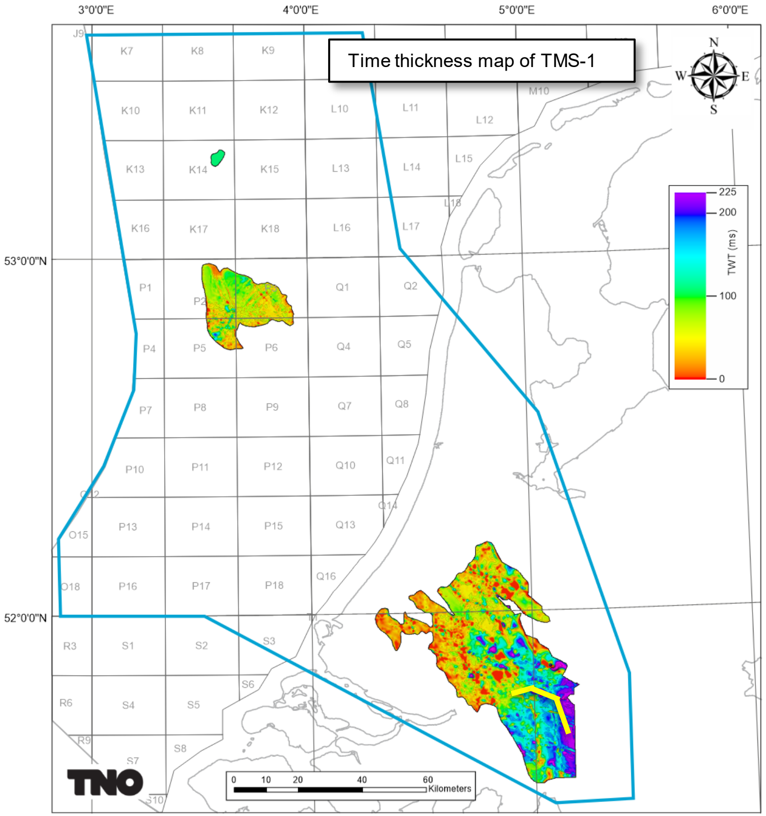
4 Tectonostratigraphic Evolution

4 Tectonostratigraphic Evolution – TMS-1 (Callovian - Early Kimmeridgian)

TNO innovation for life

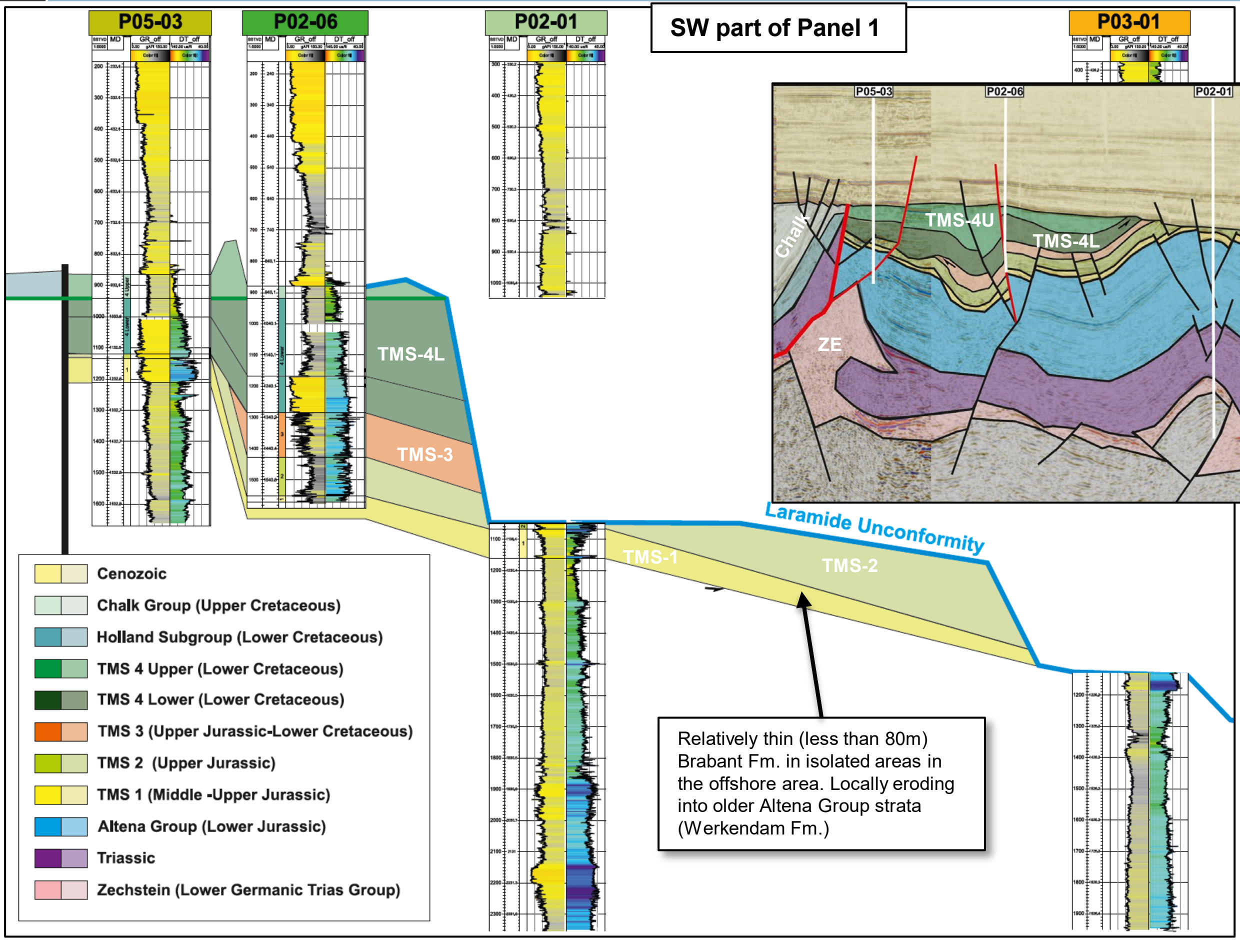
- TMS-1 is seismically the clearest interval to identify thanks to the continuous high amplitude pattern it displays. It is locally eroded at the base of TMS-2 or -3 but angular unconformities are often only observed on the edges of the main accumulations. Either the top surface is a stratigraphically concordant unconformity or more likely a hiatus surface with no proven sedimentation during most of the Oxfordian in this part of the Dutch sector.
- TMS-1 is conformably overlying the older Jurassic Werkendam Fm. as its lateral equivalent, the Corallian Limestone in England.
- Note that this interval corresponds to the Lower Graben Formation in the Dutch Central Graben, which also terminates with evidence of low relief highlighted by three thick and continuous coal beds observed in wells and seismic for more than 80 km in the DCG.

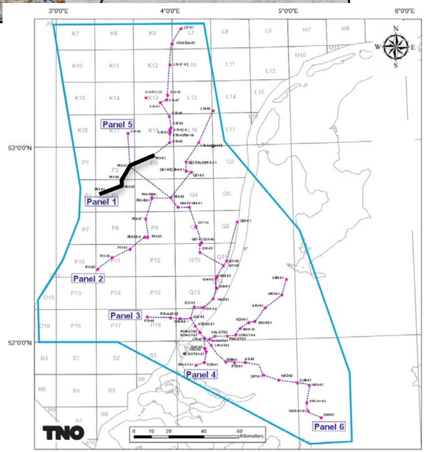




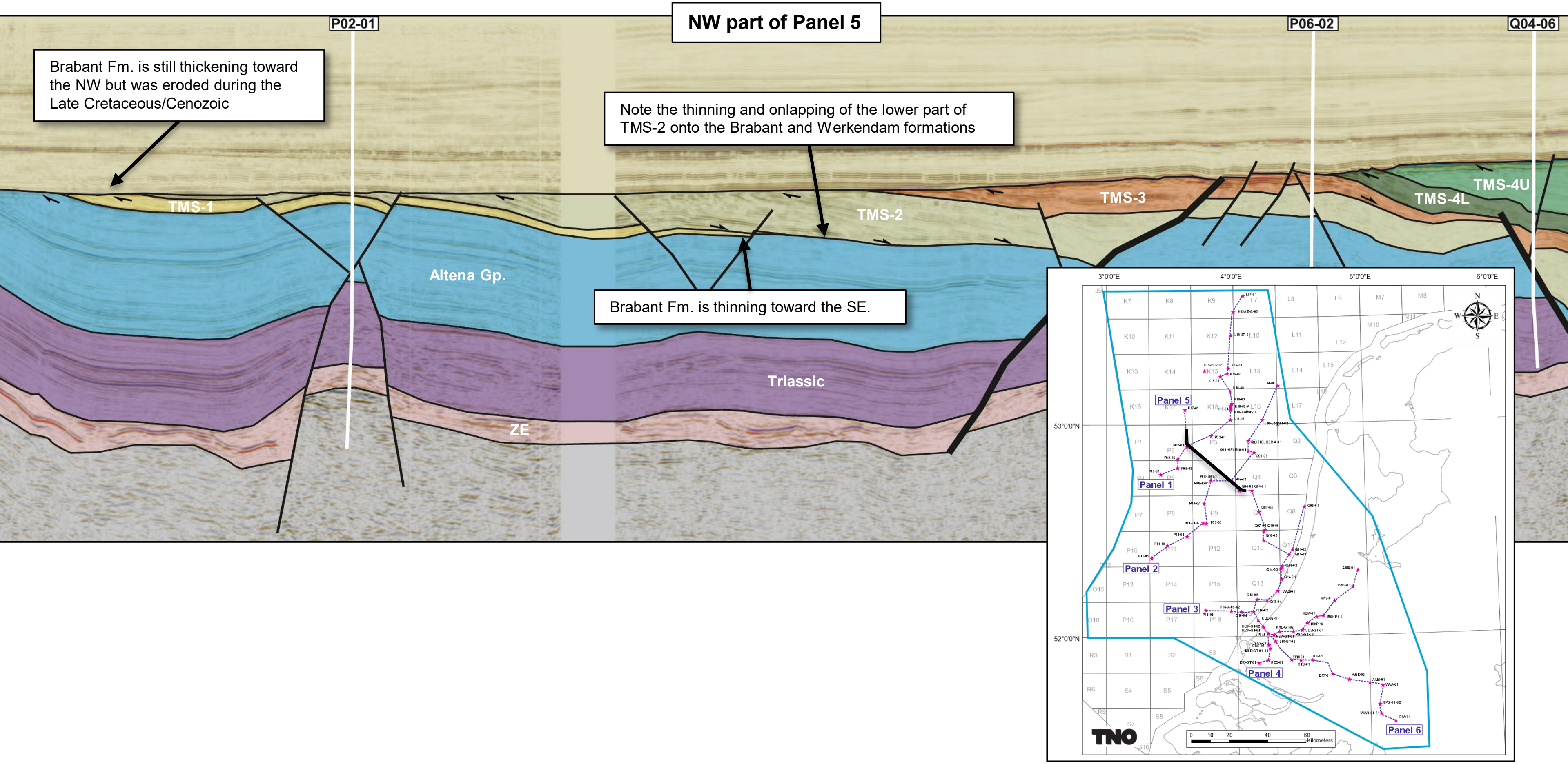
Tectonostratigraphic Evolution – TMS-1 (Callovian - Early Kimmeridgian)

TNO innovation for life

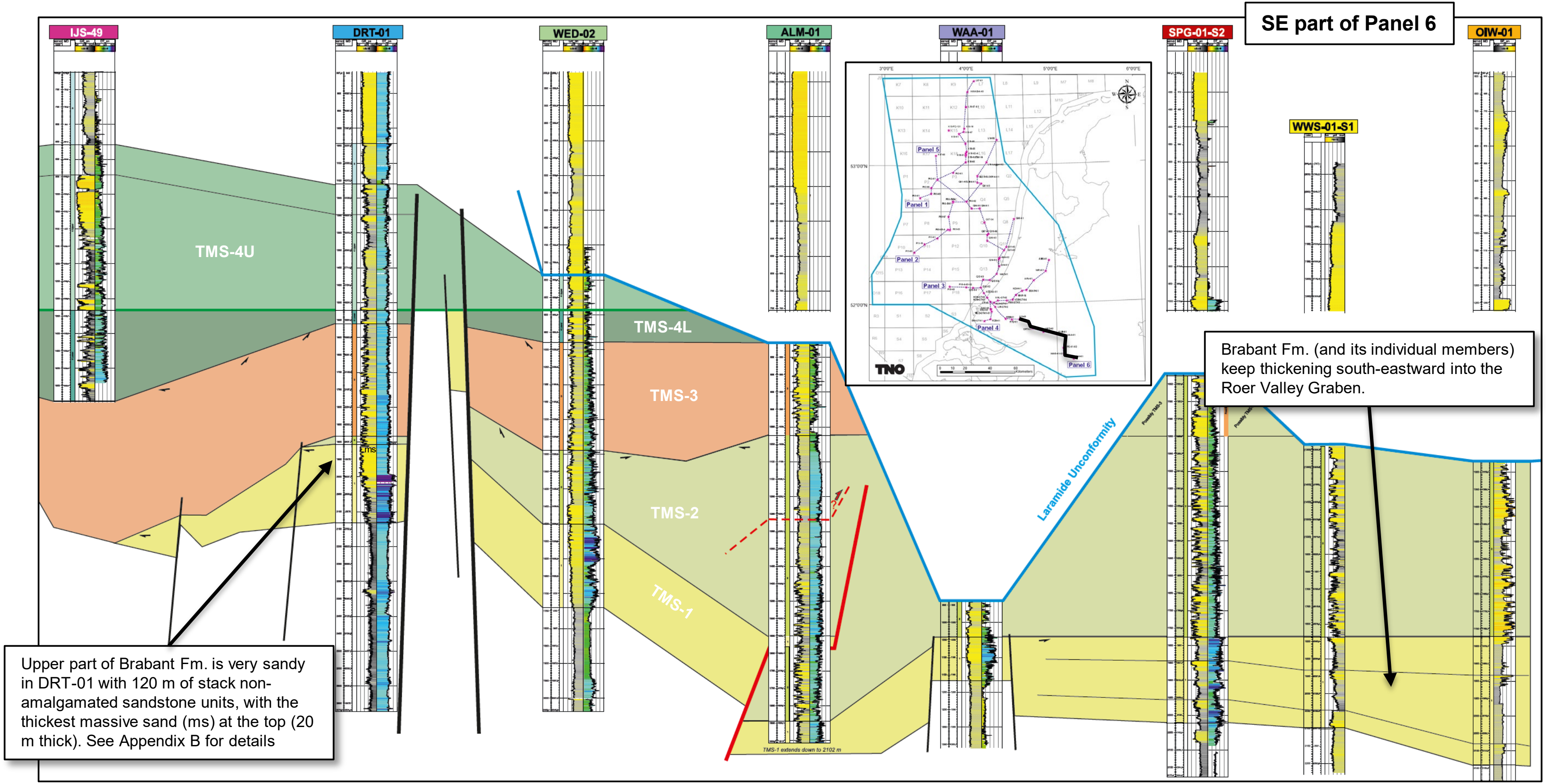




4 Tectonostratigraphic Evolution – TMS-1 (Callovian - Early Kimmeridgian)



Tectonostratigraphic Evolution – TMS-1 (Callovian - Early Kimmeridgian)

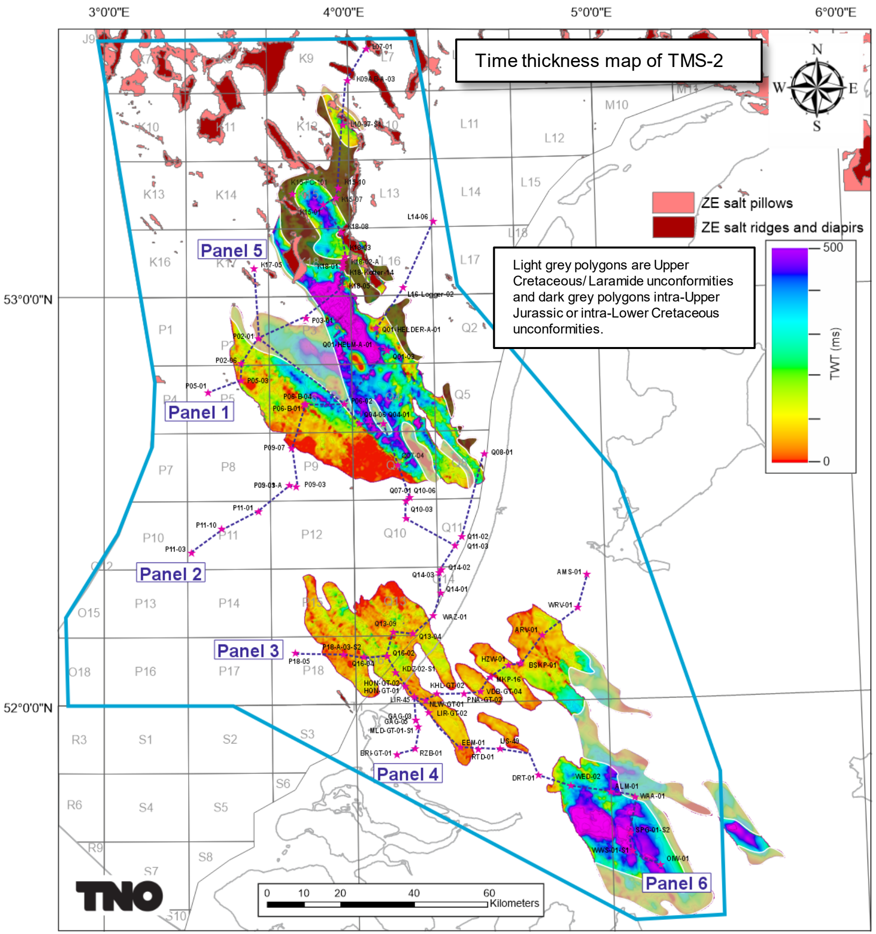


Tectonostratigraphic Evolution – TMS-2 (Late Kimmeridgian - Middle Volgian)

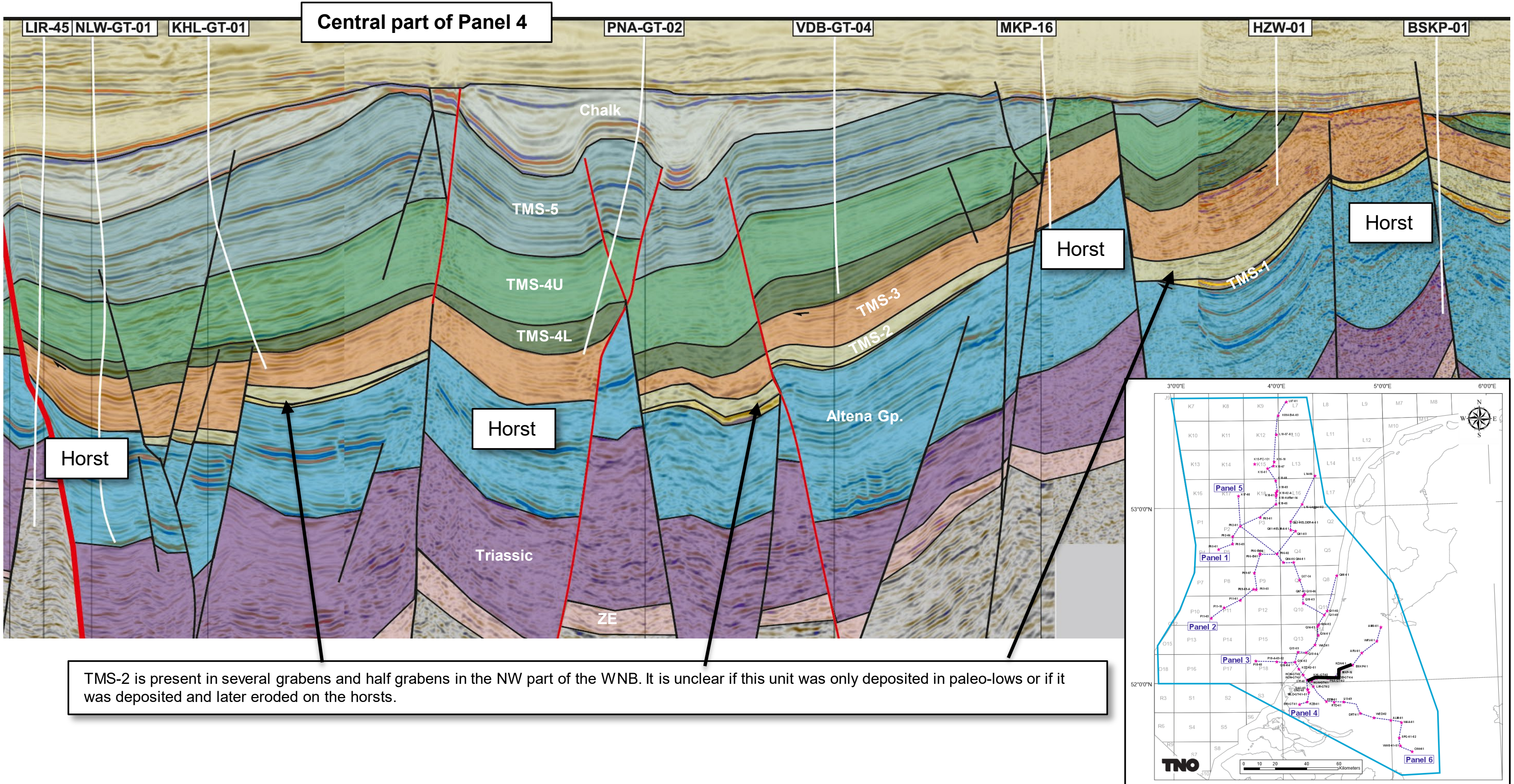
- TMS-2 is present in both the WNB and BFB but no clear evidence of interconnection was observed. However, the very thin TMS-3 sequence in the Q10-Q11-Q14 area may also hold some TMS-2-age sediments, especially in the more preserved from subsequent erosion (e.g. small grabens, hanging walls of syn-depositional faults) but no age dating nor seismically clear evidence in this area support this model.

- The thickest accumulations are in the central part of the BFB and in the south-eastern part of the BFB. The western part of the WNB is much thinner and consists of NW-SE elongated grabens and half-grabens, with average width of less than 10 km (see next page).

- Some other thinner accumulations of TMS-2-age strata (likely Fourteens Claystone Mb., based on stacking pattern) are mapped outside of the main Broad Fourteens rift basin, in the blocks P02, P06-P06, P09, Q07, indicating that the BFB was overfilled due to high sedimentation rate during the Mid-Kimmeridgian Late Volgian.

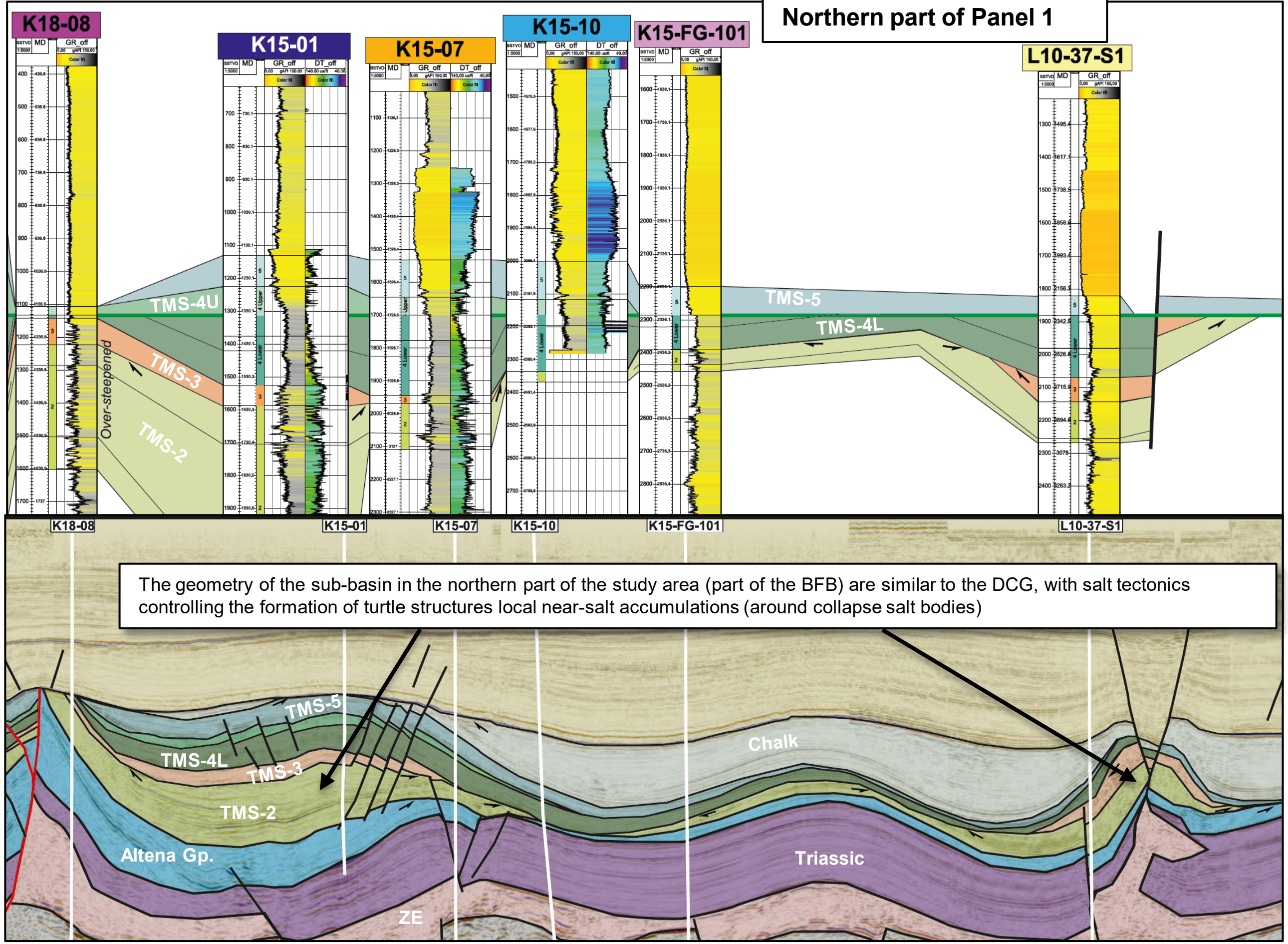


4 Tectonostratigraphic Evolution – TMS-2 (Late Kimmeridgian - Middle Volgian)

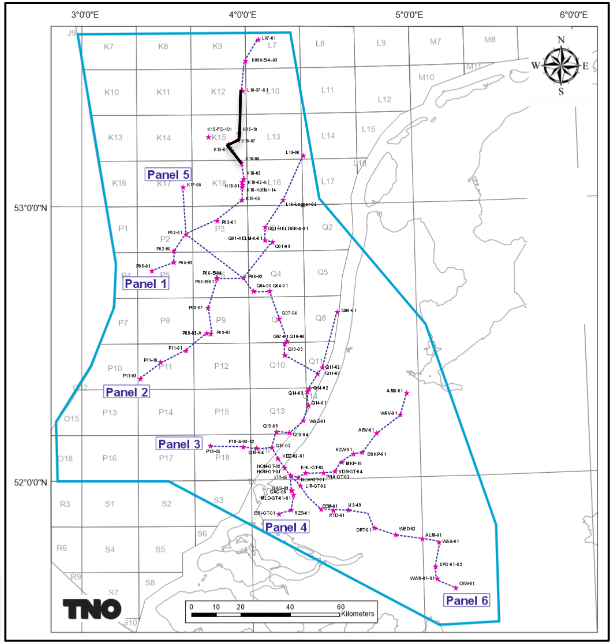


TMS-2 is present in several grabens and half grabens in the NW part of the WNB. It is unclear if this unit was only deposited in paleo-lows or if it was deposited and later eroded on the horsts.

4 Tectonostratigraphic Evolution – TMS-2 (Late Kimmeridgian - Middle Volgian)



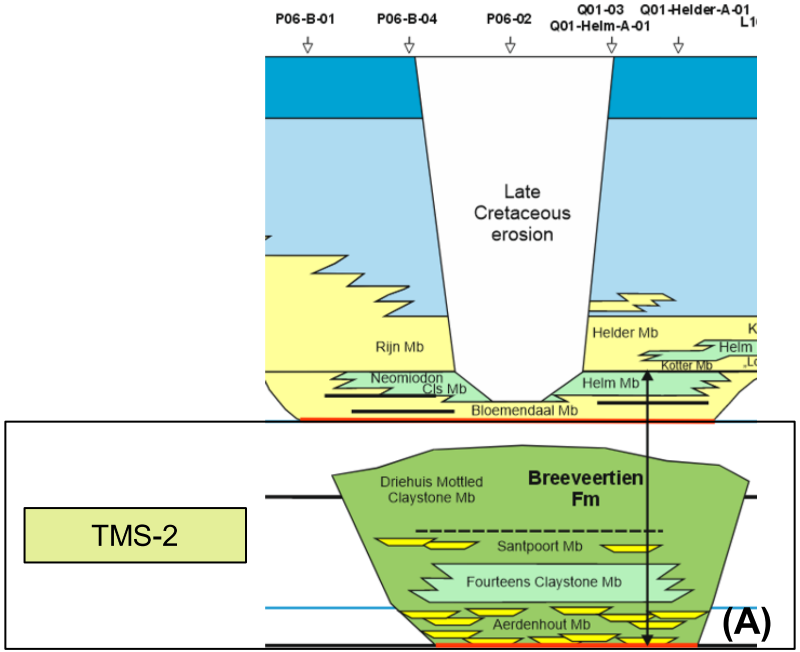
The geometry of the sub-basin in the northern part of the study area (part of the BFB) are similar to the DCG, with salt tectonics controlling the formation of turtle structures local near-salt accumulations (around collapse salt bodies)



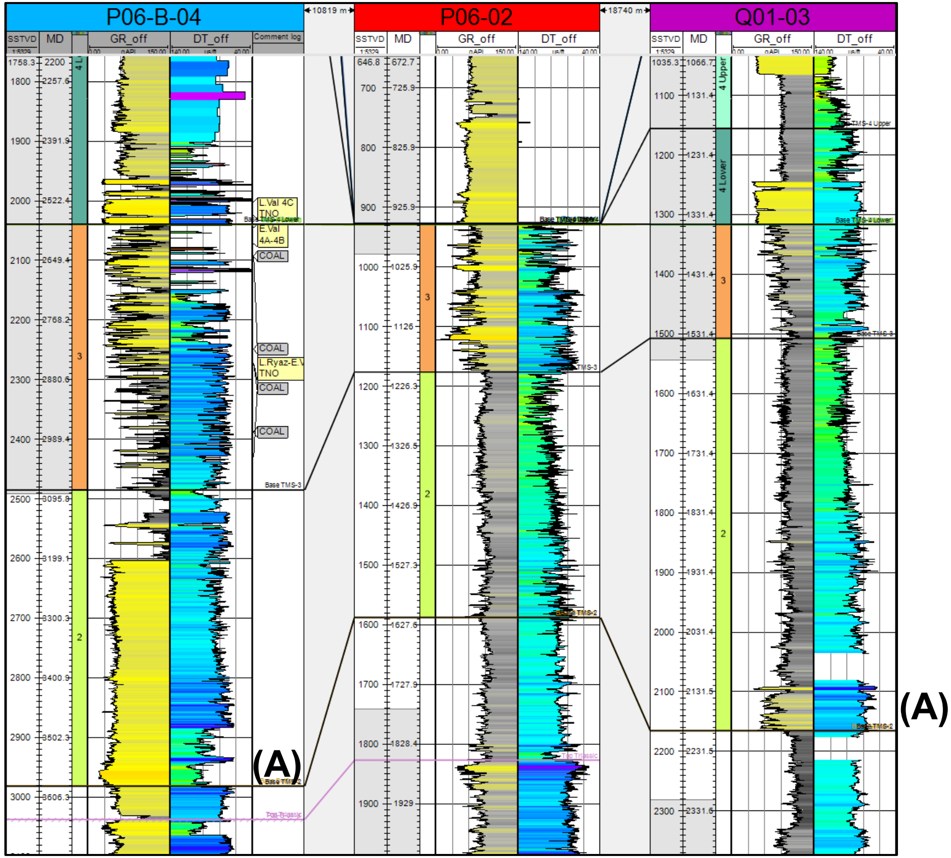
Tectonostratigraphic Evolution – TMS-2 (Late Kimmeridgian - Middle Volgian)

TNO innovation for life

The sandstones of the Aerdenhout Mb. (A) are almost always present at the base of the Breeveertien Fm.



BFB-across

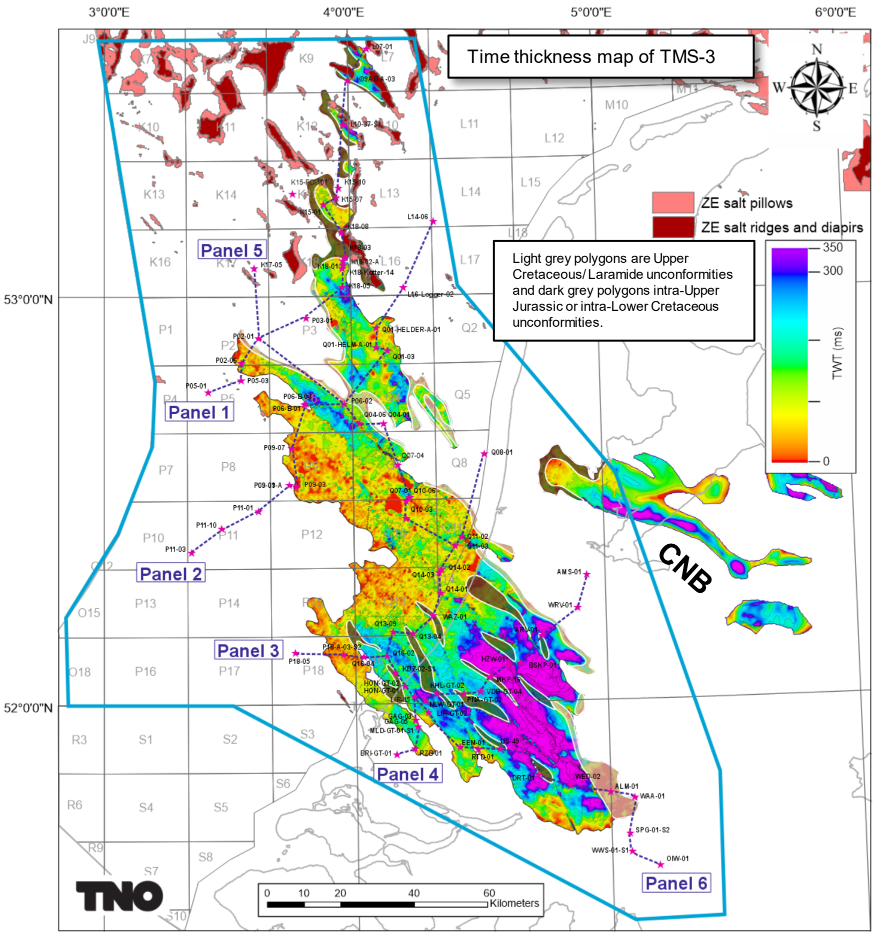


Tectonostratigraphic Evolution – TMS-3 (Late Volgian - earliest Valanginian)

- TMS-3 is present within the two basins and in the area between (Q14, Q10, Q11 and P09). It is also present in the Central Netherlands Basin (CNB) in a few isolated (likely related to differential erosion) zones.

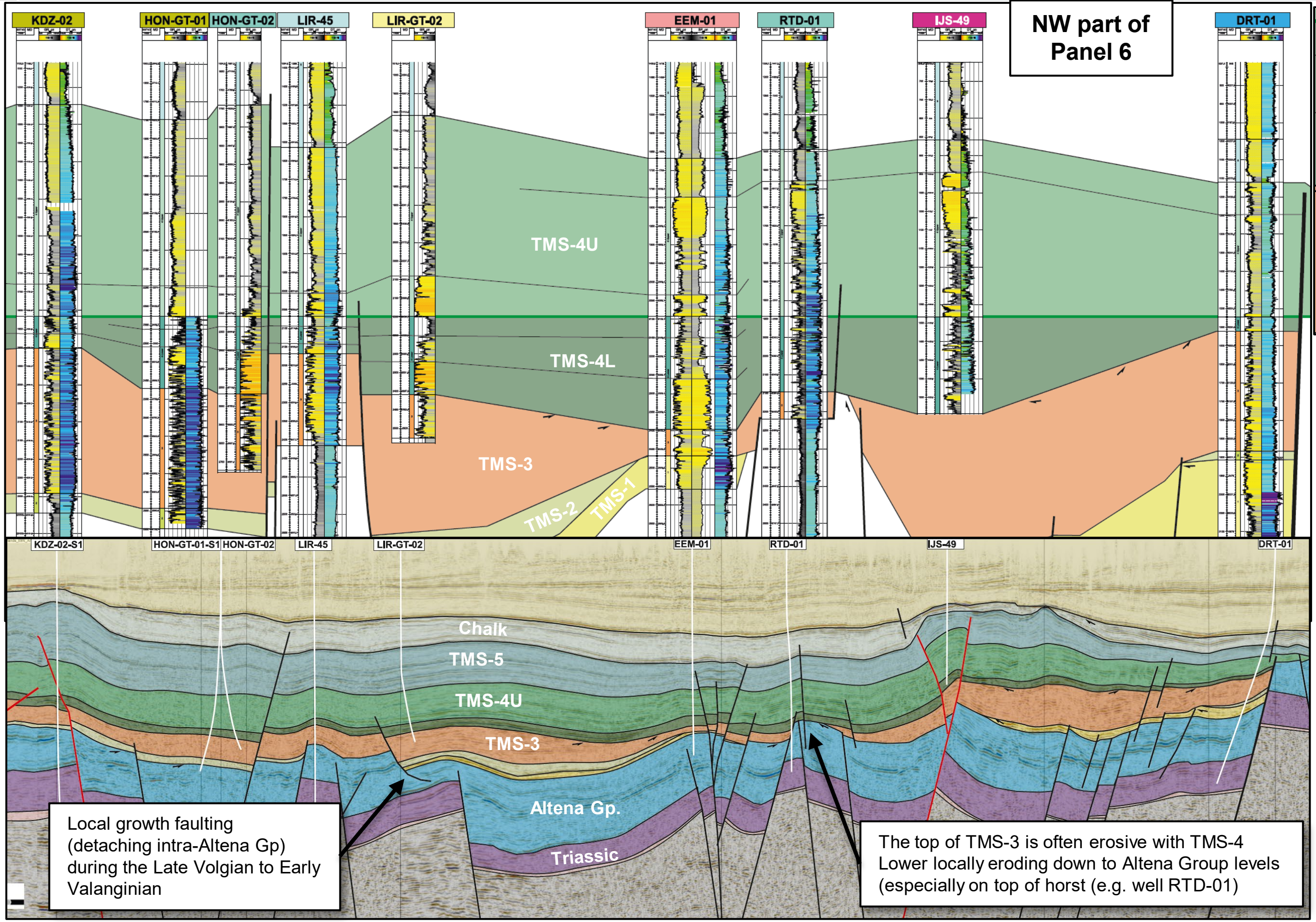
- The thickest part of this interval is in the central part of the WNB, within grabens separated by horsts. TMS-3 is often only partially eroded (see dark grey transparent polygons with white outlines on the map to the right) on these horsts indicating that those intra-rift highs did not fully compartimentalized the WNB during the Late Volgian to Early Valanginian (see seismic example three pages above).

- In the BFB, TMS-3 is present in the SE part of the basin as a broadly thickening units around blocks P06, Q04, Q01, but is only present in the northern part of the BFB as isolated sub-basins, primarily affected by salt tectonics in a similar fashion as in the northern part of the Dutch offshore (asymmetric turtle structures, growth faults and collapse salt bodies/ grabens; see Bouroullec and ten Veen, in press).



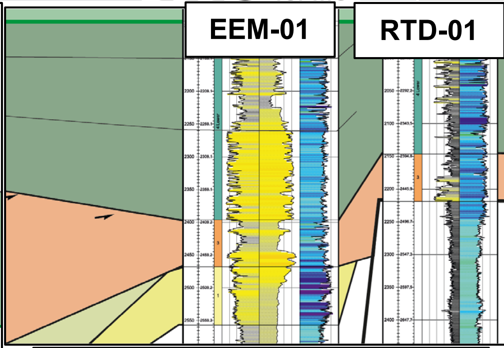
4 Tectonostratigraphic Evolution – TMS-3 (Late Volgian - earliest Valanginian)

TNO innovation for life

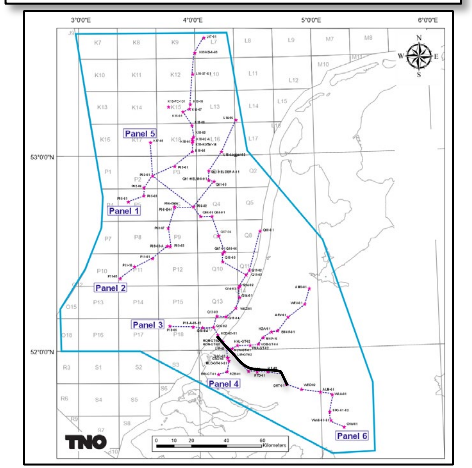


Local growth faulting (detaching intra-Altena Gp) during the Late Volgian to Early Valanginian

The top of TMS-3 is often erosive with TMS-4 Lower locally eroding down to Altena Group levels (especially on top of horst (e.g. well RTD-01)



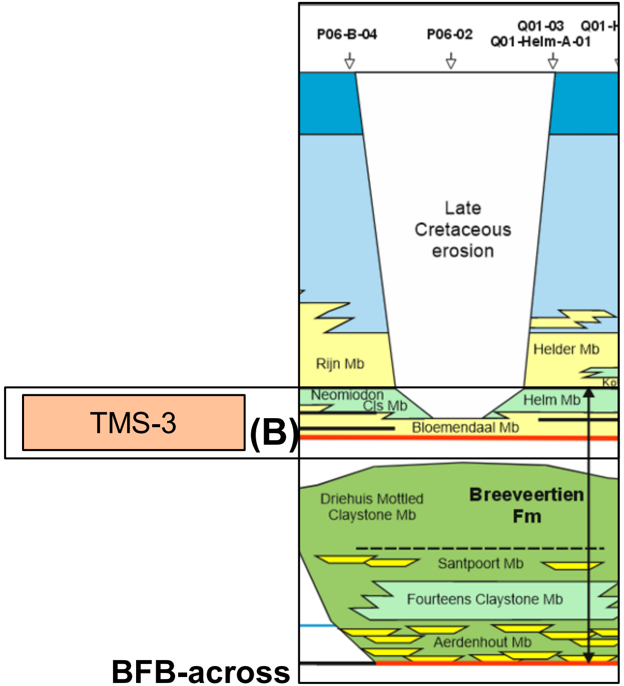
Note that the Delft Sandstone Mb. is very thick (140m) in well EEM-01, eroding down into a large part of TMS-3 at this location. This may indicate that Delft Sandstone Mb. sediment sources may be here very local (alluvial fans ?).



Tectonostratigraphic Evolution – TMS-3 (Late Volgian - earliest Valanginian)

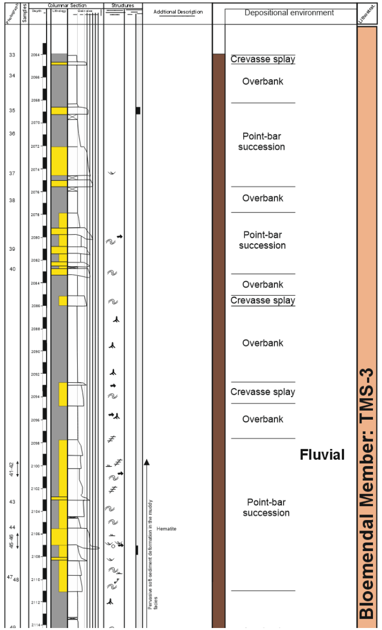
TNO innovation for life

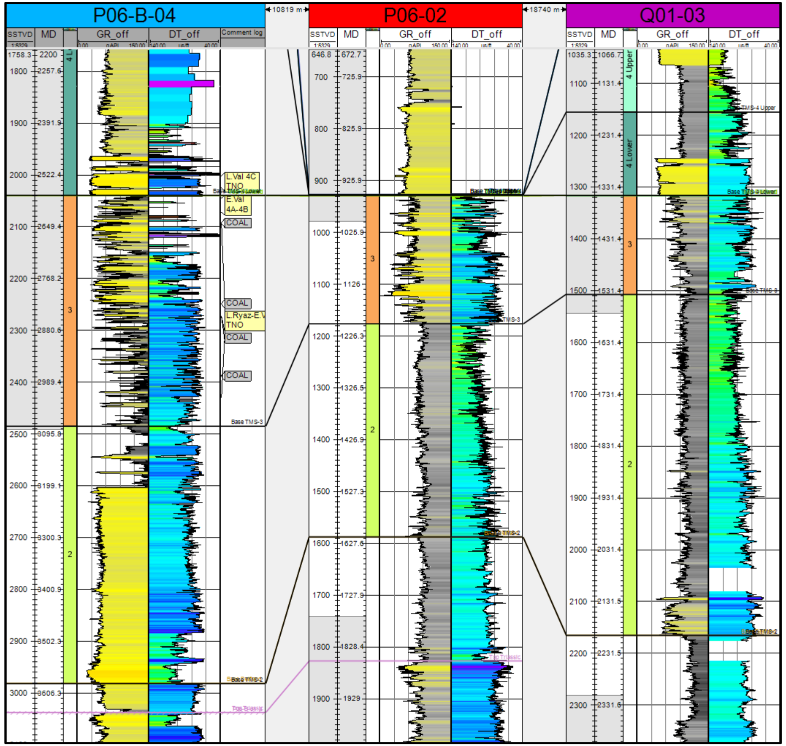
- The Late Ryazanian Bloemendaal Mb. (B) of the Breeveertien Fm. contain coal layers and grade into lagoonal claystones of the Neomiodion Claystone Mb. at the top
- The base of the Bloemendaal Mb. is erosive.



K18-02-A core 1

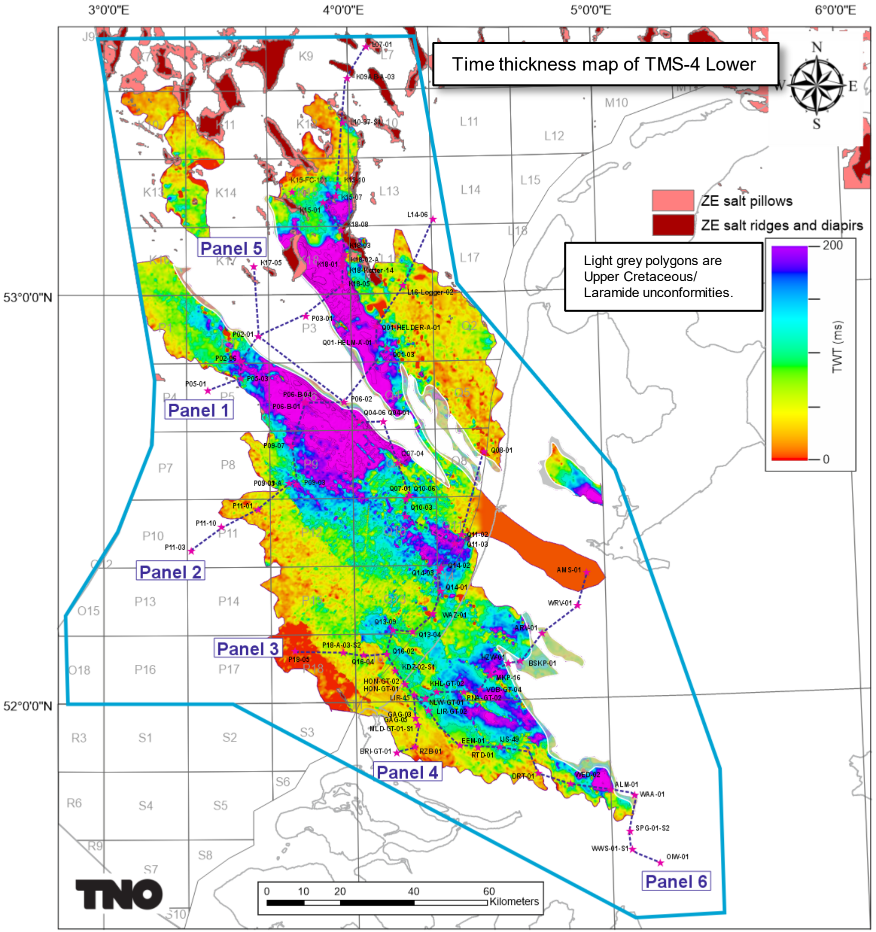
See Appendix C for full core description



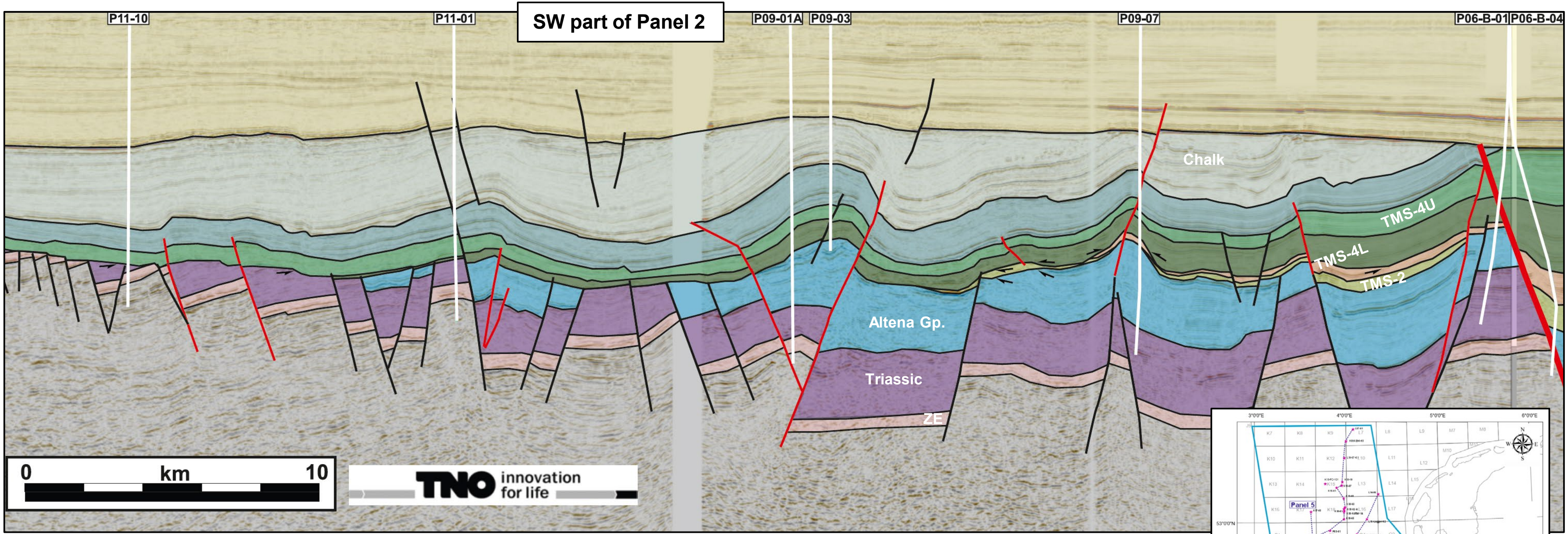


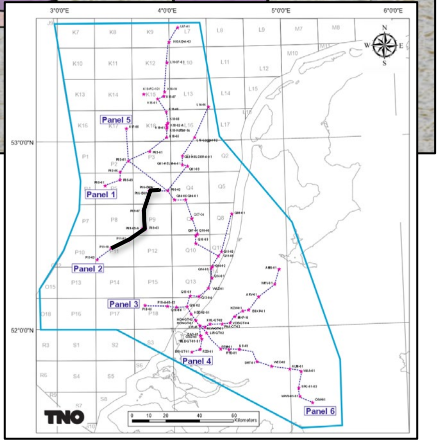
Tectonostratigraphic Evolution – **TMS-4 Lower** (Valanginian - Hauterivian)

- TMS-4 Lower reflect a major change in the basin evolution with a widening of the depositional area onto the rift shoulders. The base of TMS-4 is highly erosive and constitute one of the clearest unconformity in the study area. This unconformity is a part of a composite unconformity that extends to the base of TMS-4 Upper farther toward the outer edges of the Lower Cretaceous basins (e,g. toward the SW, blocks P14, P10). See next page for seismic example.
- This interval also is of great economic importance since the Delft Sandstone Mb., and the Rijn/Kotter/Logger/Helm members complex are located in its lower section, sitting onto the basal unconformity. These sandstone units are important onshore as geothermal targets, while their onshore equivalents may be CCS targets.
- The stacking pattern and reservoir architecture of these sandstone units are not discussed in this study since this project is primarily regional. Local onlaps onto the basal unconformity, as well as deposition along pre-existing fault scarps and shaling-out trends toward the central part of the basins are discuss in this section.
- Offshore, in the SW part of the study area, the basal sands are part of the Rijn Member (its lower section). This system shales-out toward the NW and is time-equivalent on the NE part of the study area of another sandy system, referred to as the "Kotter Complex" which is composed of sandstone units of the Kotter, Helm, Helder and Logger members, named after respective oil fields where these are the main reservoir



4 Tectonostratigraphic Evolution – TMS-4 Lower (Valanginian - Hauterivian)



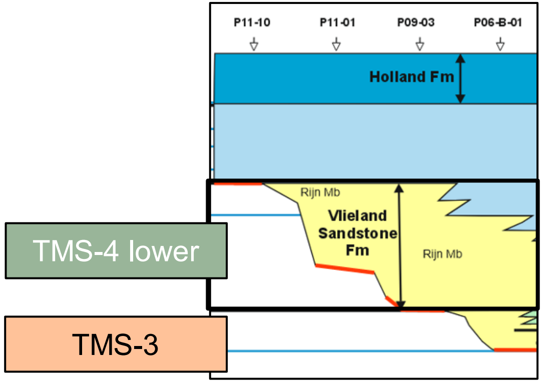


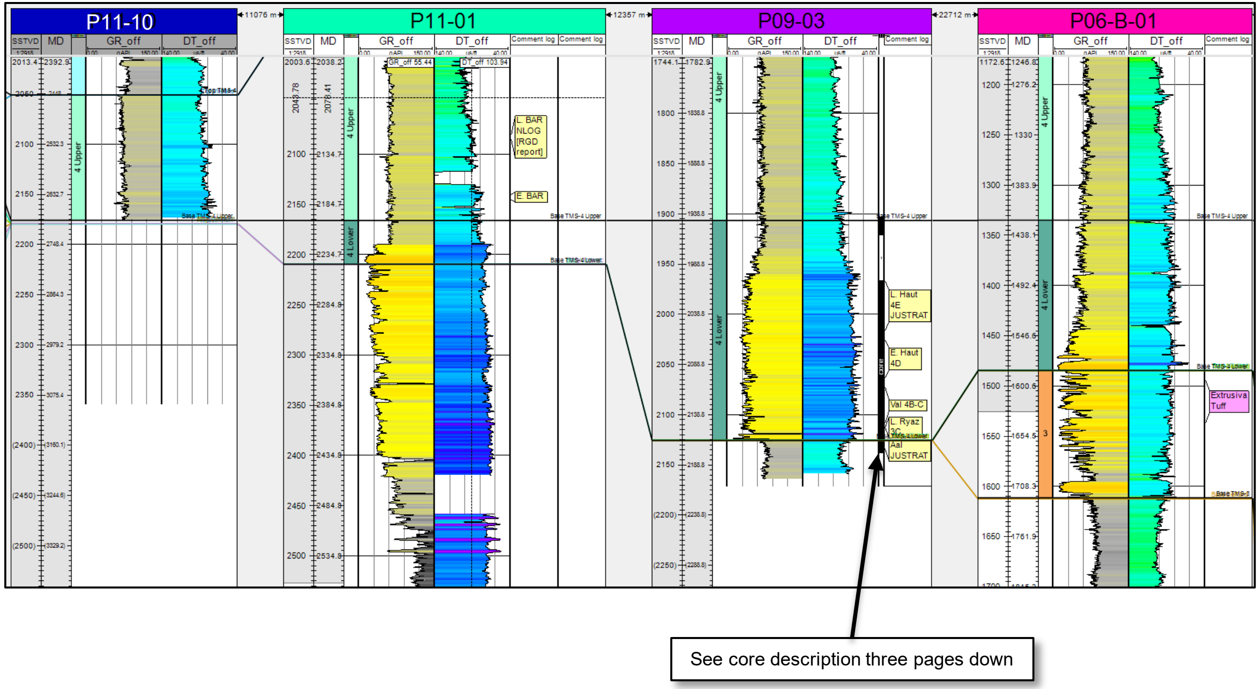
TMS-4 is onlapping on previous Jurassic or older interval toward the basin margin. The basal unconformity locally erode Triassic (on horst blocks). The western limit of TMS-4 Lower is often a paleotopographic feature (fault scarp) at the top of pre-existing faults.

TNO innovation for life

Transition from platform to basin

- Vlieland Claystone Fm. (TMS-4 upper) transgresses over the Zeeland Platform [P11-10].
- Thick stacks of amalgamated sandstone units of the Valanginian and Hauterivian Rijn Mb. accumulate along the paleo- basin margin (P09-03).
- Pinch-out of Bloemendaal Mb. (TMS-3) towards basin margin (P06-B-01).
- Presence of extrusives volcanics in the Bloemendaal Mb. (P06-B-01).

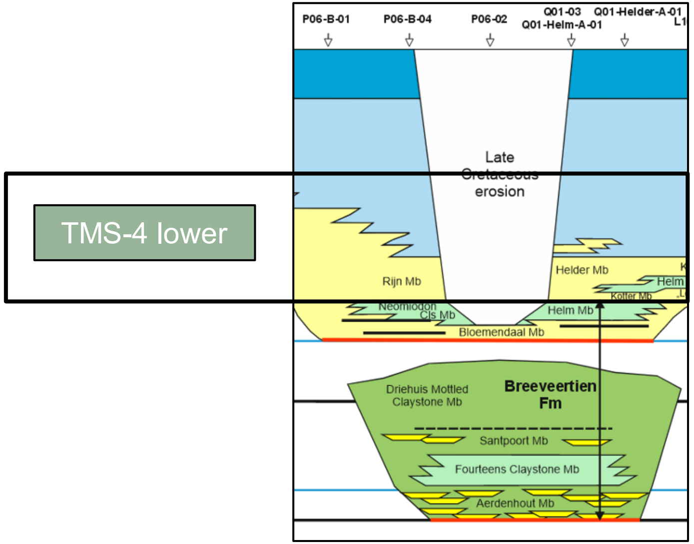




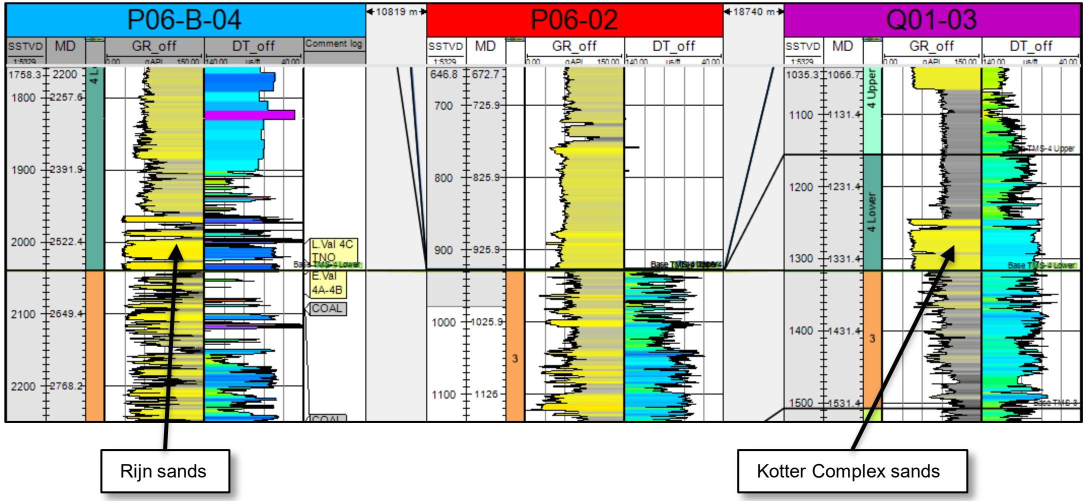
Tectonostratigraphic Evolution – TMS-4 Lower (earliest Valanginian - Hauterivian)

TNO innovation for life

- The clean sandstones of the Rijn Mb. (TMS-4 lower) on the SW side of the inverted basin are a mirror image of the Kotter, Helder and Logger members sandstones on the NE side of the basin.
- The two sandy systems ("Rijn" to the west and "Kotter Complex" to the east) have the same age and log expressions but their sourcing was likely different. No provenance work has been carried out yet and the comments below are speculative.
- Beside the regional SE to NW sediment input (basin axis) some lateral sediment sources were also likely:
  - eroded Triassic and older strata from the Zeeland Platform and beyond for the western sand-rich accumulations
  - eroded Zechstein, Triassic and older strata from the Central Netherlands Basin, Noord Holland and areas beyond for the eastern sand-rich accumulations.

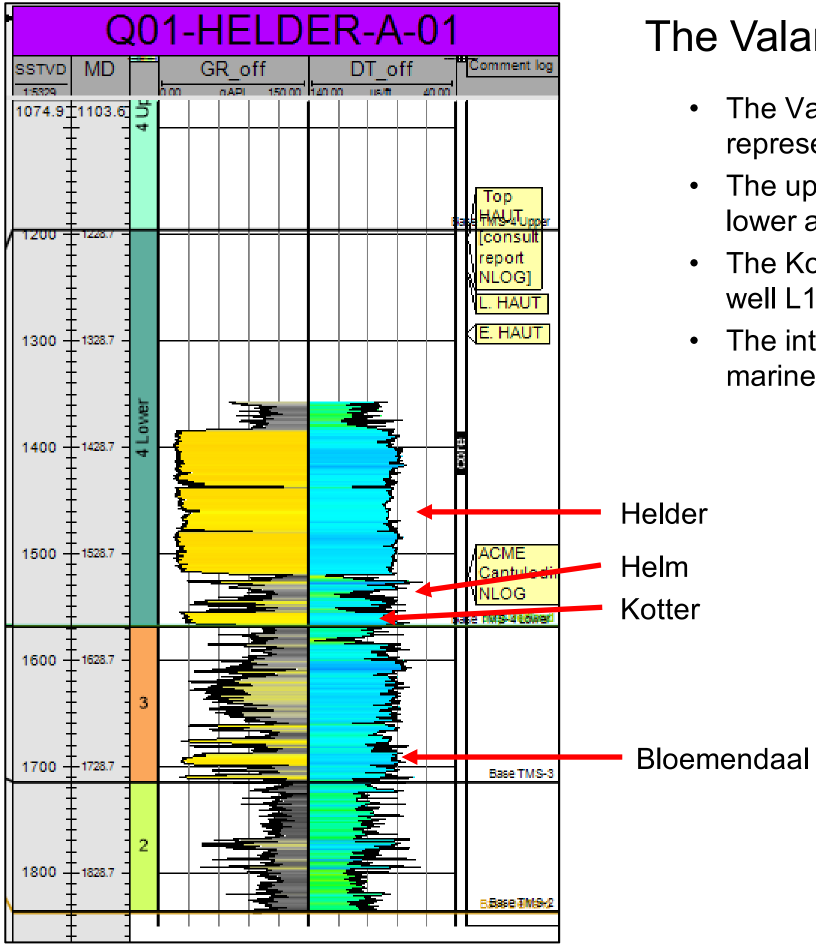


BFB-across



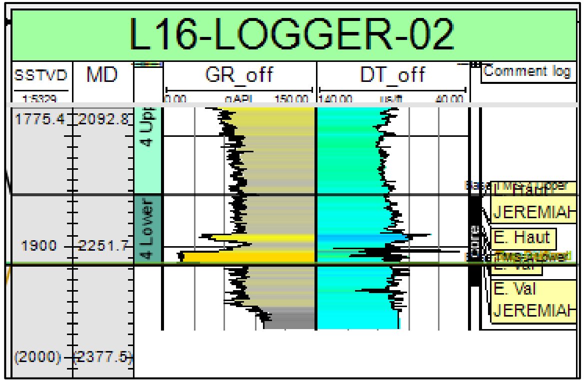
Tectonostratigraphic Evolution – **TMS-4 Lower** (earliest Valanginian - Hauterivian)

TNO innovation for life



The Valanginian "Kotter complex" (TMS-4 lower)

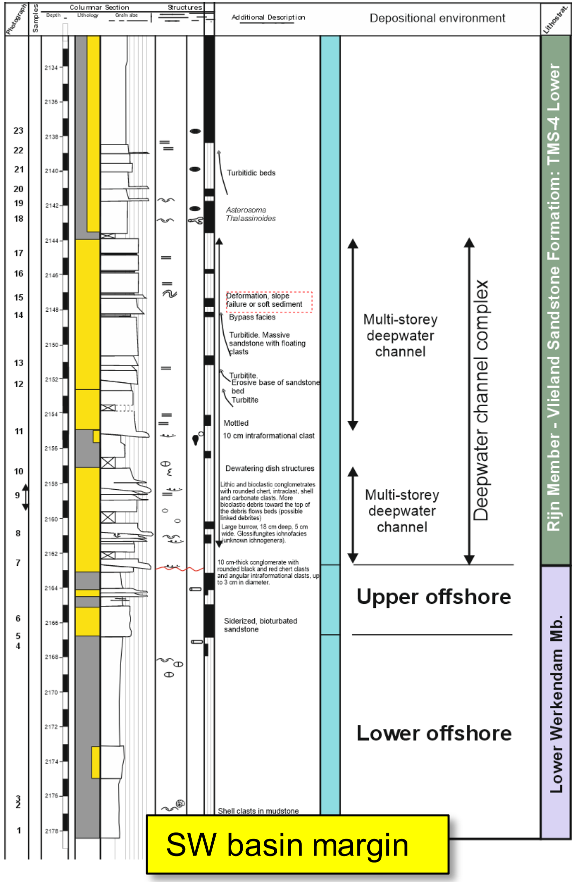
- The Valanginian (TMS-4 lower) in the central part of the Broad Fourteens Basin is represented by an alternation of massive sandstones and shales
- The upper sandstone is referred to as the Helder Mb. (Vlieland Sandstone Fm), the lower as the Kotter Mb. (Vlieland Sandstone Fm.) in well Q01-Helder-A-01
- The Kotter complex thins out towards the NE into the informal "Logger Mb" (see well L16-LOGGER-02 below).
- The interbedded shales of the Helm Mb. (Breeveertien Fm.) reflect a restricted marine, lagoonal depositional environment.



TNO innovation for life

P09-03

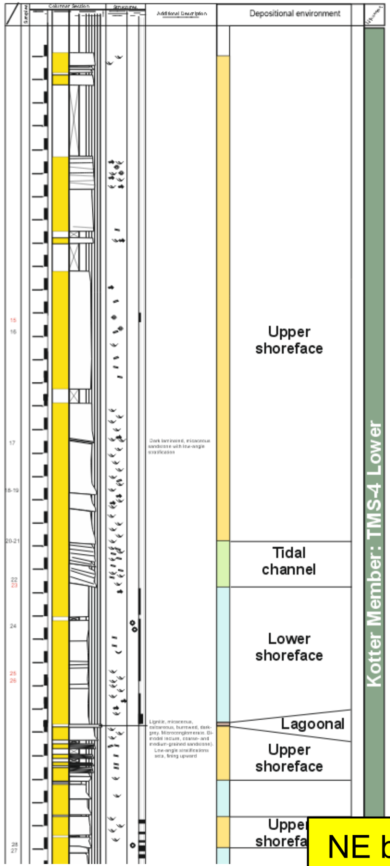
See Appendix C for full core description



Within the Vlieland Sandstone Formation, the lower part of the Rijn Mb. in the SW of the study area corresponds to the “Kotter Complex” in the NE of the study area.

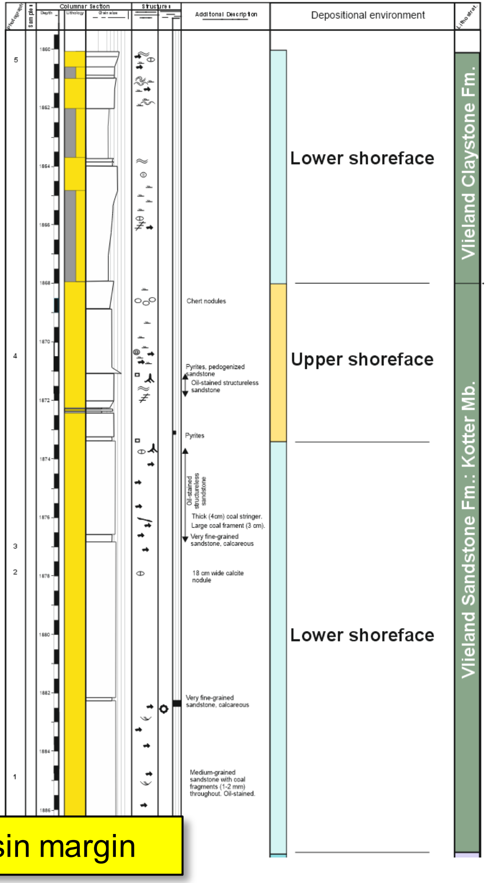
K18-02-A core 2

See Appendix C for full core description



L16-06

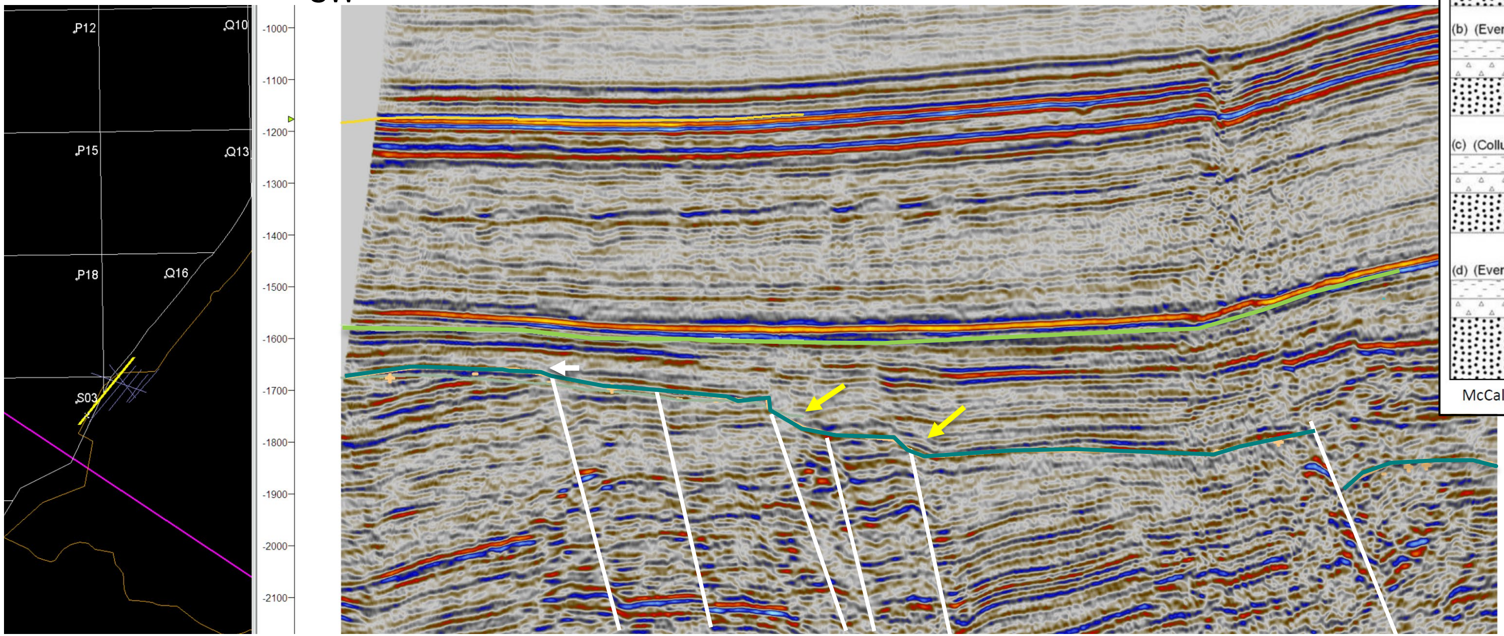
See Appendix C for full core description

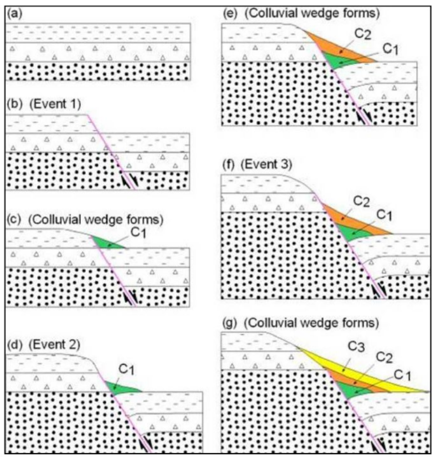


BaseTMS-4 (Rijnland Gp) topography: Successively eroded fault scarps

Pre-existing faults (likely Jurassic in age but cutting into the Triassic) formed scarps (underwater cliffs, yellow arrows) that controlled the southwest basin margin evolution. These features controlled the depositional areas of the successive marginal sandstone units (Rijn Mb., Kotter complex) but were successively smoothed out (see diagram above) or buried, correcting the paleotopography and widening the basin. This occurred several times, from one fault scarp to the next or by onlaps (white arrow) onto the Triassic substrates. The positions of these fault scarps are shown on the map in next page. These features are clear in the SW part of the basin, but are more difficult to identify to the NE due to more deformation of the basin margin during the Late Cretaceous.

SW NE

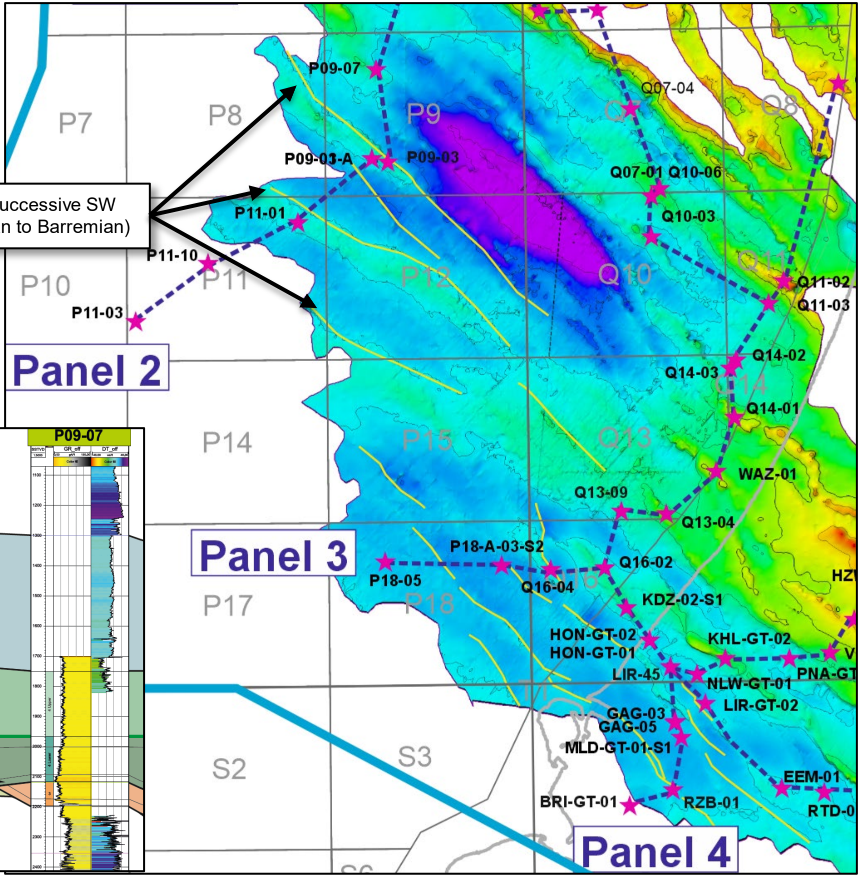




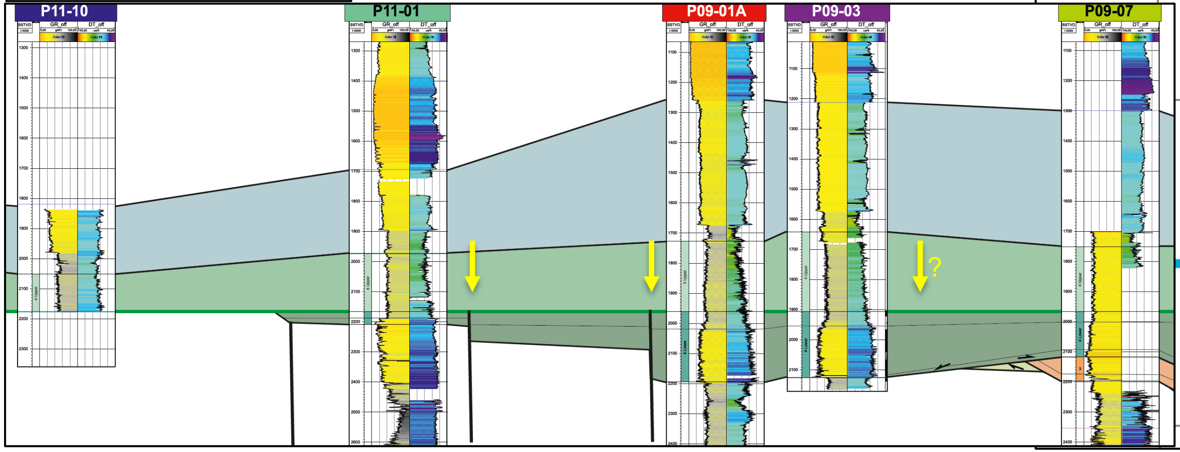
McCalpin, 1987

TNO innovation for life

BaseTMS-4 (Rijnland Gp) topography: Successively eroded fault scarps



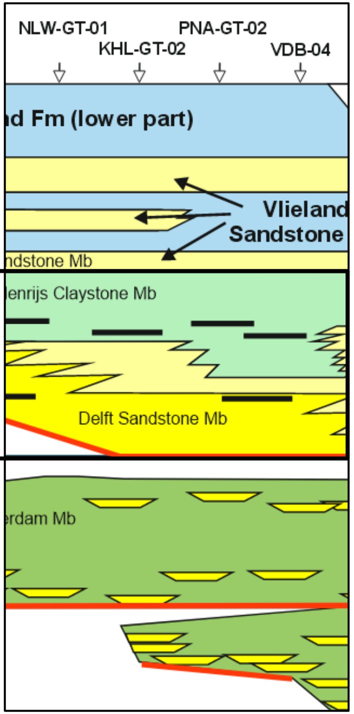
Northern part of Panel 2

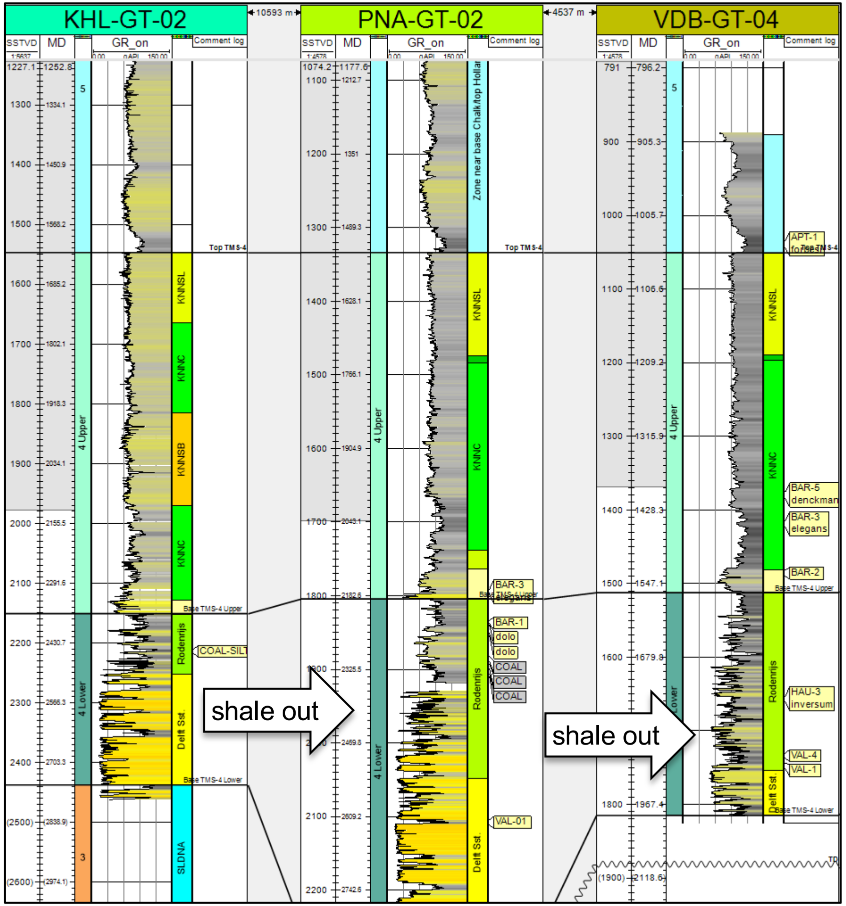


Shale out of the top of the Delft Sandstone Mb. towards the NNE

- The top of the Delft Sandstone Mb. shales out towards the center of the WNB, toward the NE.
- Local highs (horsts) may have also affected the distribution of the Delft Sst. Mb. depositonal systems (e.g. position of alluvial fans or fluvial channels). More detail seismic interpretation and of the sub-basins (horsts and grabens) is needed.

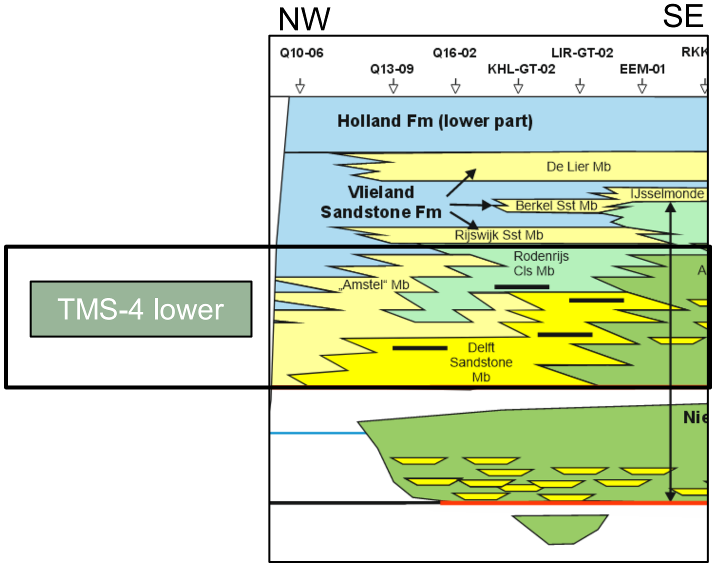
TMS-4 lower

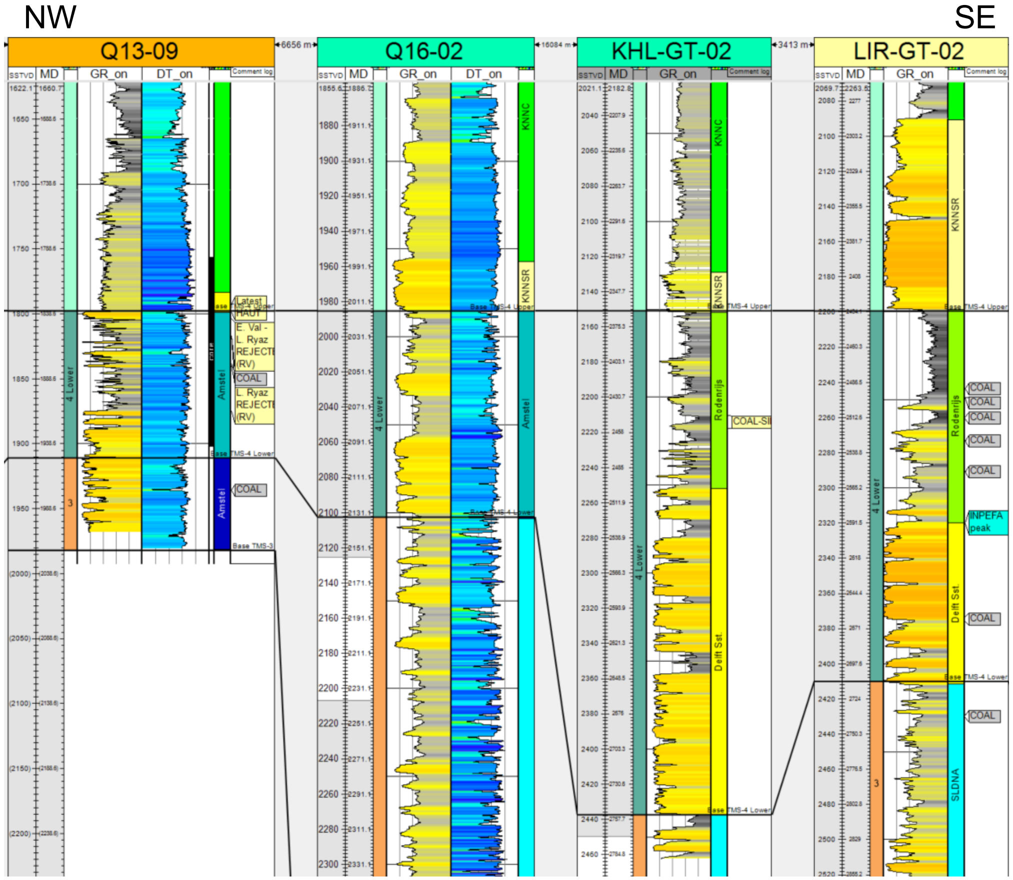




Tectonostratigraphic Evolution – TMS-4 Lower (Valanginian - Hauterivian)

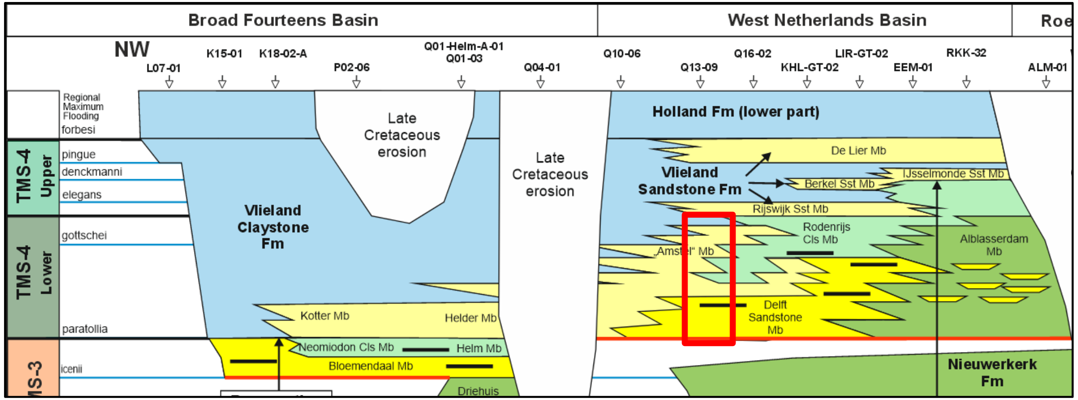
The relatively proximal "Delft-Rodenrijs" depositional system in the central part of the WNB transitioned towards the NW into the informal "Amstel" Mb., which consists of more marine-influenced depositional systems (estuarine, lagoonal, shoreface) and reflects less accommodation, as demonstrated in Core Q13-09 (see next pages and Appendix D).

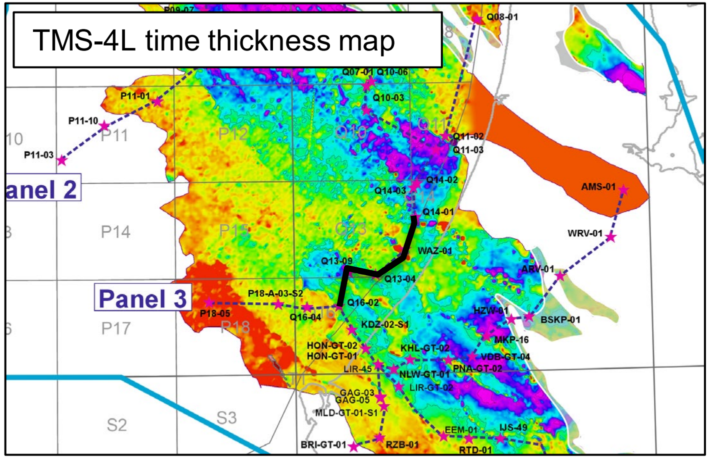


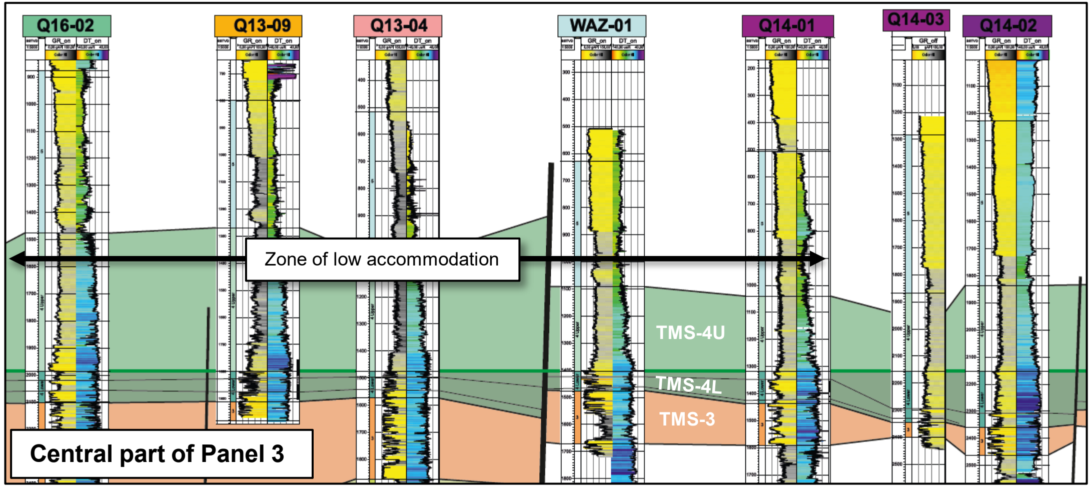


The informal "Amstel" Member

Around the Q13/Q14 and neighboring blocks, the "Amstel" Mb. is relatively thin (TMS-4 Lower around 60-80 m thick). This transitional area between the WNB and the BFB represents an area of low accommodation with prevalence of rapidly transitioning depositional systems and paleo-water depth (as seen in Q13-09 core).







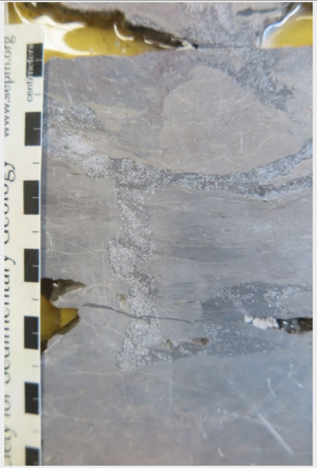
The informal “Amstel” Member

Q13-09

Nieuwerkerk Fm. Core of well Q13-09 shows a good example of the “Amstel” depositional system where rapid vertical shifts of depositional systems and paleo-water depths are observed. The lack of accommodation is also evidenced by the frequency of sequence boundaries and regressive surfaces observed. *Glossifungites* ichnofacies are recurrent, indicating frequent episodic erosions.

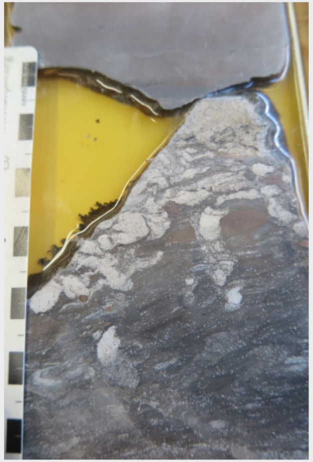
Glossifungites ichnofacies

90



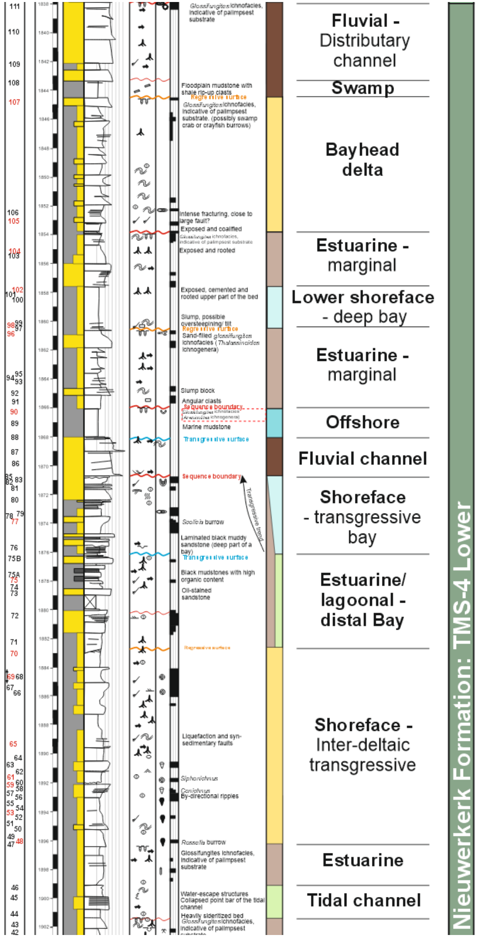
Glossifungites ichnofacies (*Arenicolites* ichnogenera)

96



Sand-filled *glossifungites* ichnofacies (*Thalassinoides* ichnogenera)

Burrows in firm, not lithified, substrate after the unconsolidated layers were removed by erosion, hence indicative of regressive surfaces and sediment bypass. See Appendix C for more entire core description.

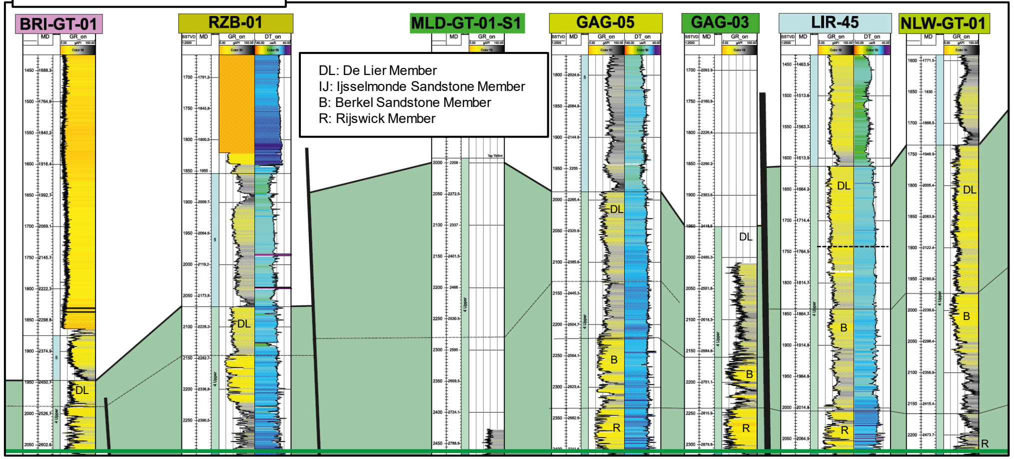


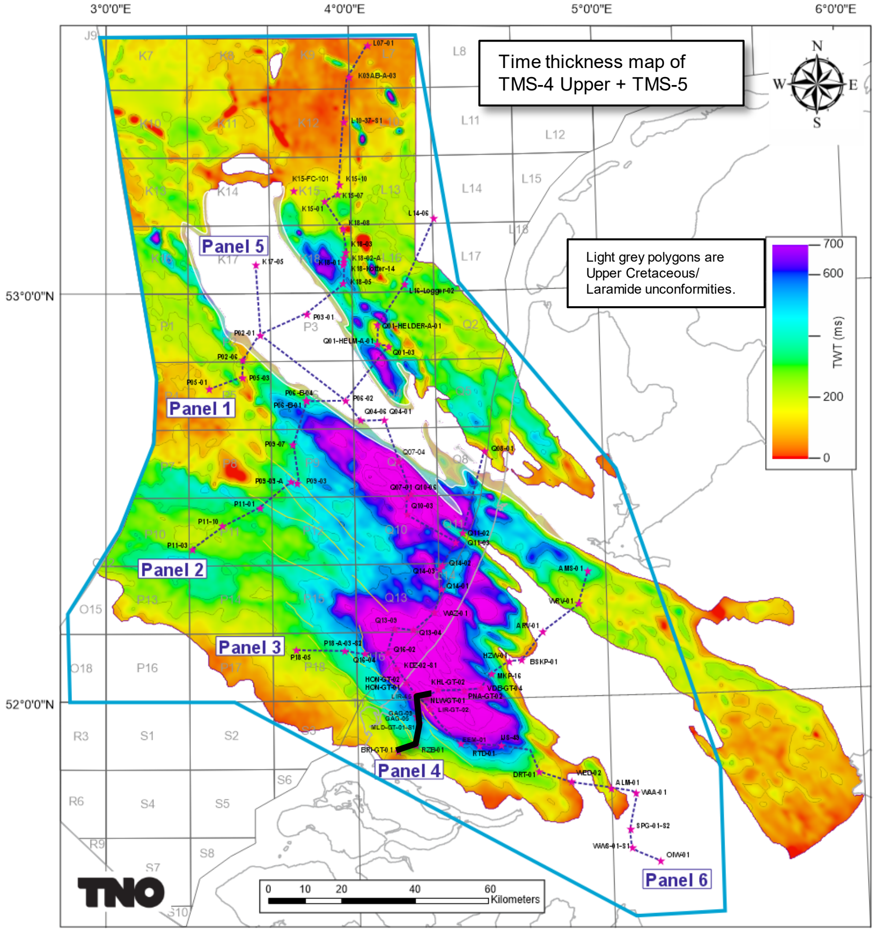
Tectonostratigraphic Evolution – TMS-4 Upper (Barremian - earliest Aptian)

TNO innovation for life

To the SW TMS-4 Upper consists of continental deposits of the upper part of the Ablasserdam Fm.. This rapidly transitions to a prevalence of marine sandy depositional systems of the Rijswick, Berkel Sandstone, IJsselmonde and De Lier members. These sand-rich depositional systems consist of the younger part of the Vlieland Sandstone Formation, which transition laterally to the more distal shale-rich Vlieland Claystone Formation to the NW.

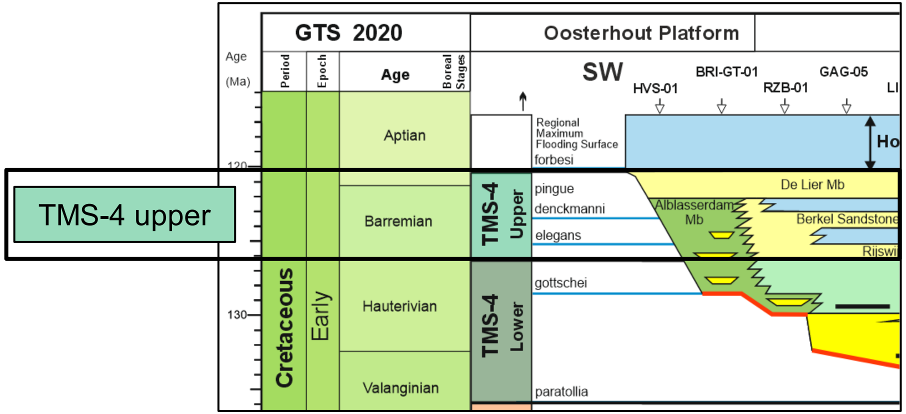
SW part of Panel 4

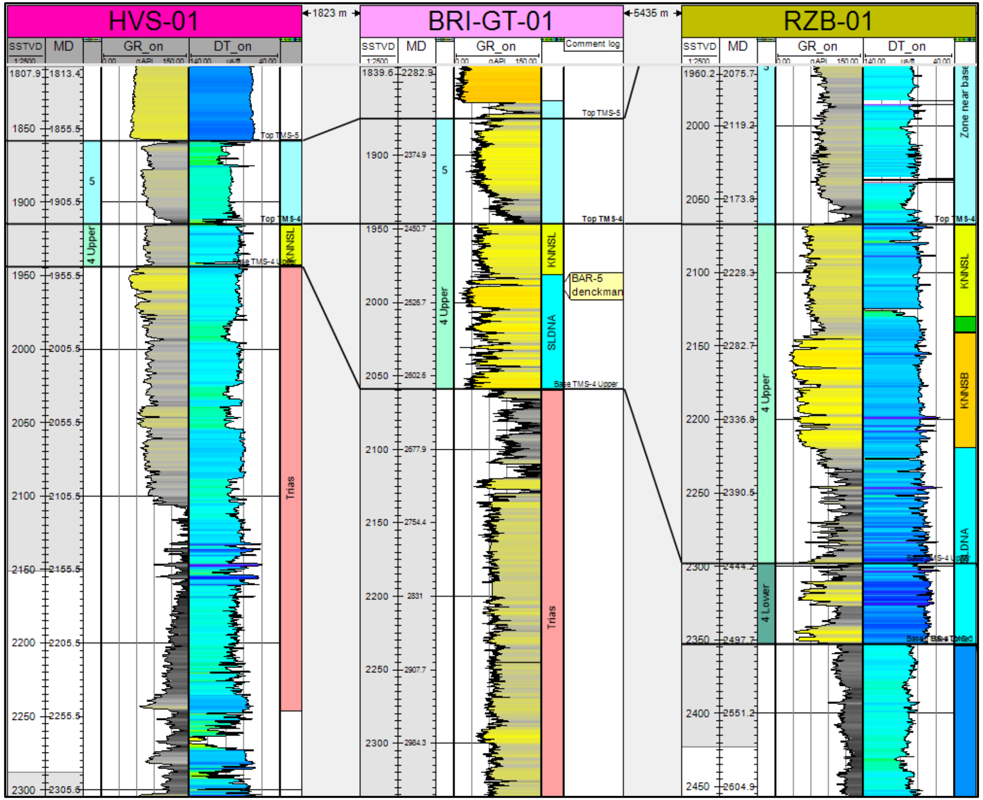




Transition from Oosterhout Platform to basin

- The latest Barremian De Lier Mb. (Vlieland Sandstone Fm.) steps out over the basin margin onto the Oosterhout Platform to the SW.
- The mainly non-marine Alblasserdam Mb. (Nieuwerkerk Fm.) in well BRI-GT-01 is of Barremian age (TMS-4 upper).
- The marine Berkel Sandstone Mb. (Vlieland Sandstone Fm.) pops up under the De Lier Mb. close the margin of the basin.

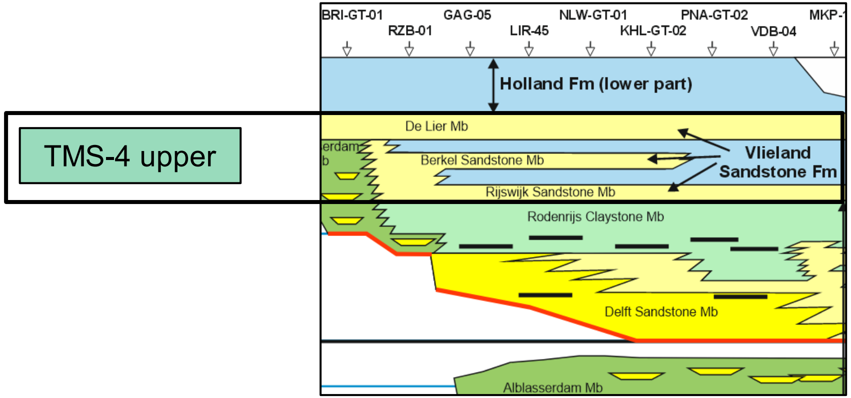


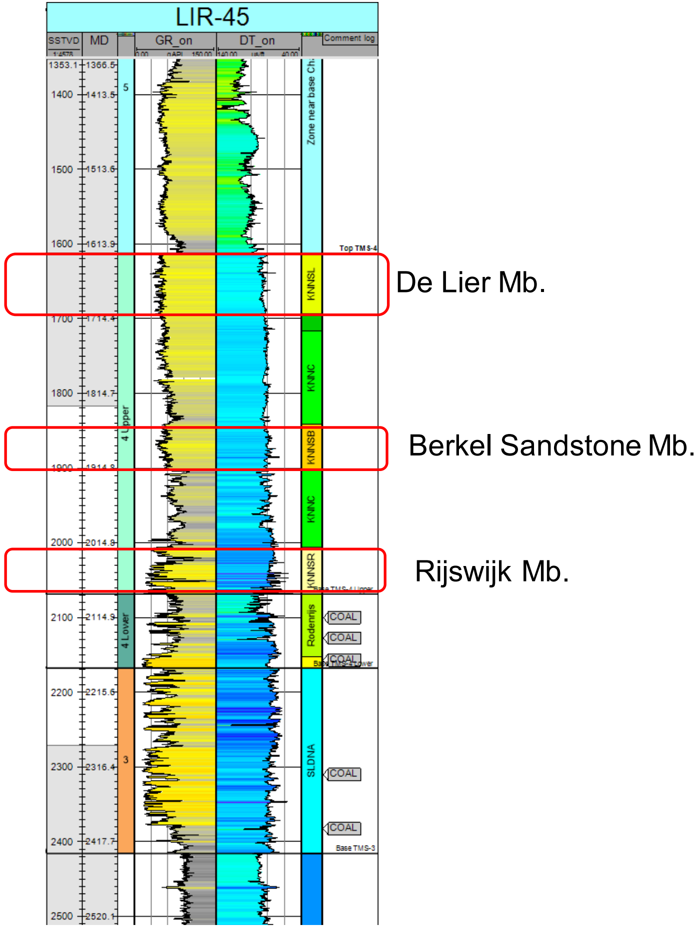


The southwestern part of the West Netherlands Basin

TMS-4 Upper in the southwestern part of the West Netherlands Basin (WNB) is characterized by three successive sandstone members in the Vlieland Subgroup:

- The Rijswijk Mb. at the base.
- The Berkel Sandstone Mb. in the middle
- The De Lier Mb. at the top.

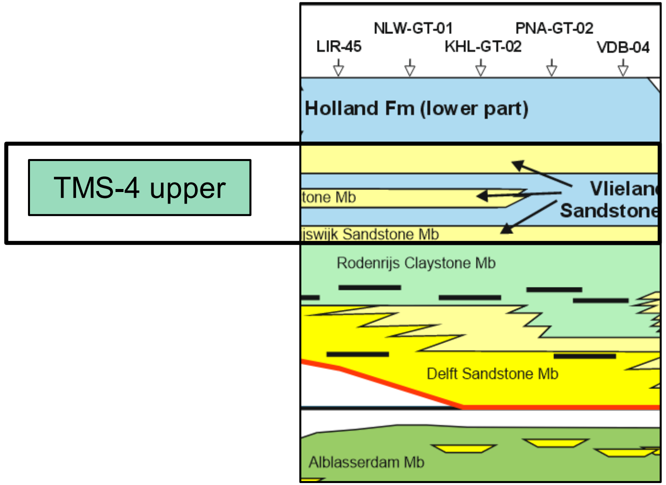




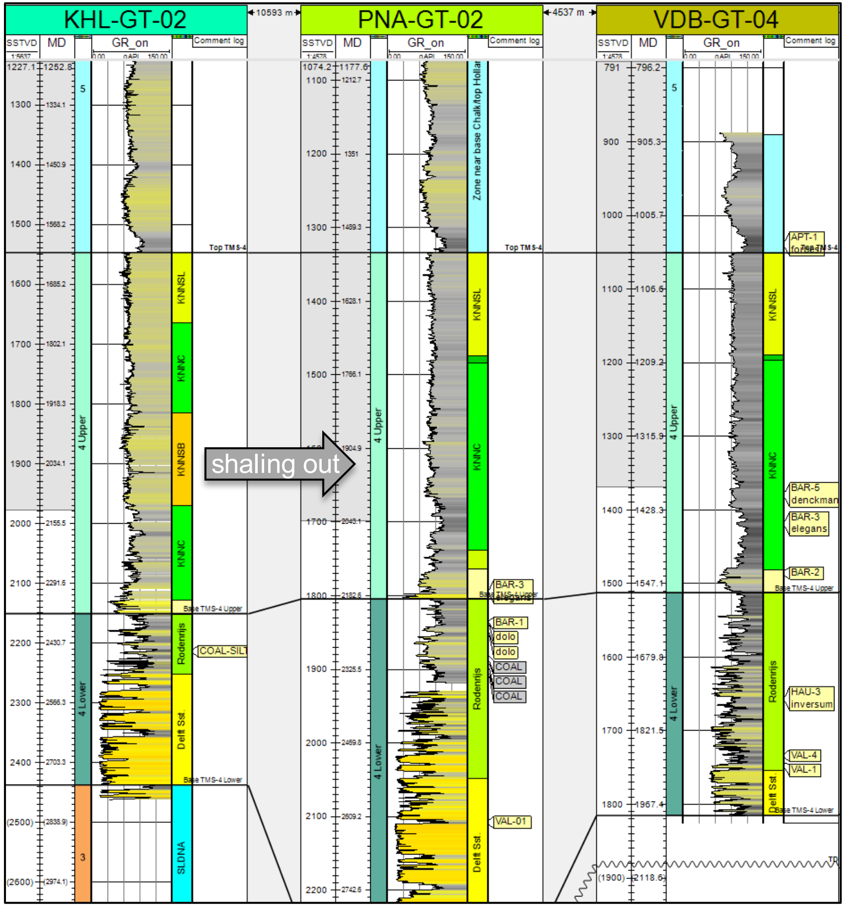
TNO innovation for life

Shale out of Berkel Sandstone Mb. to the NE

The Berkel Sandstone Mb shales out towards the centre of the basin in the NE



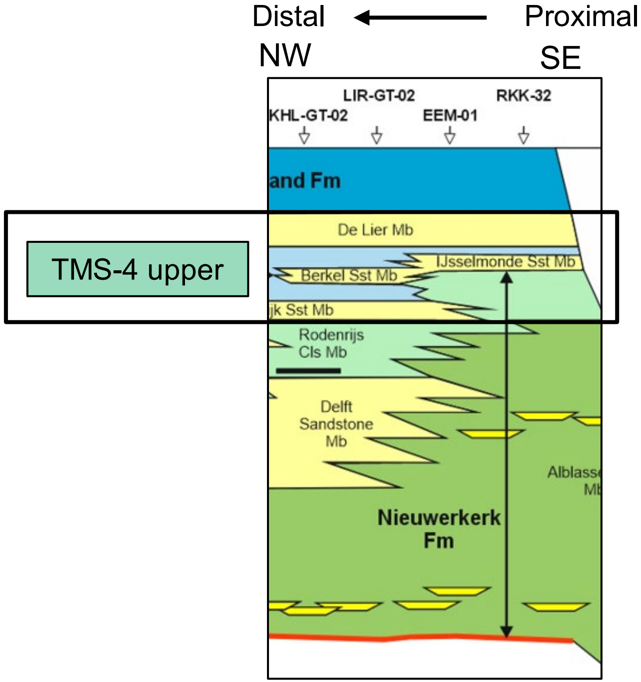
WNB-across

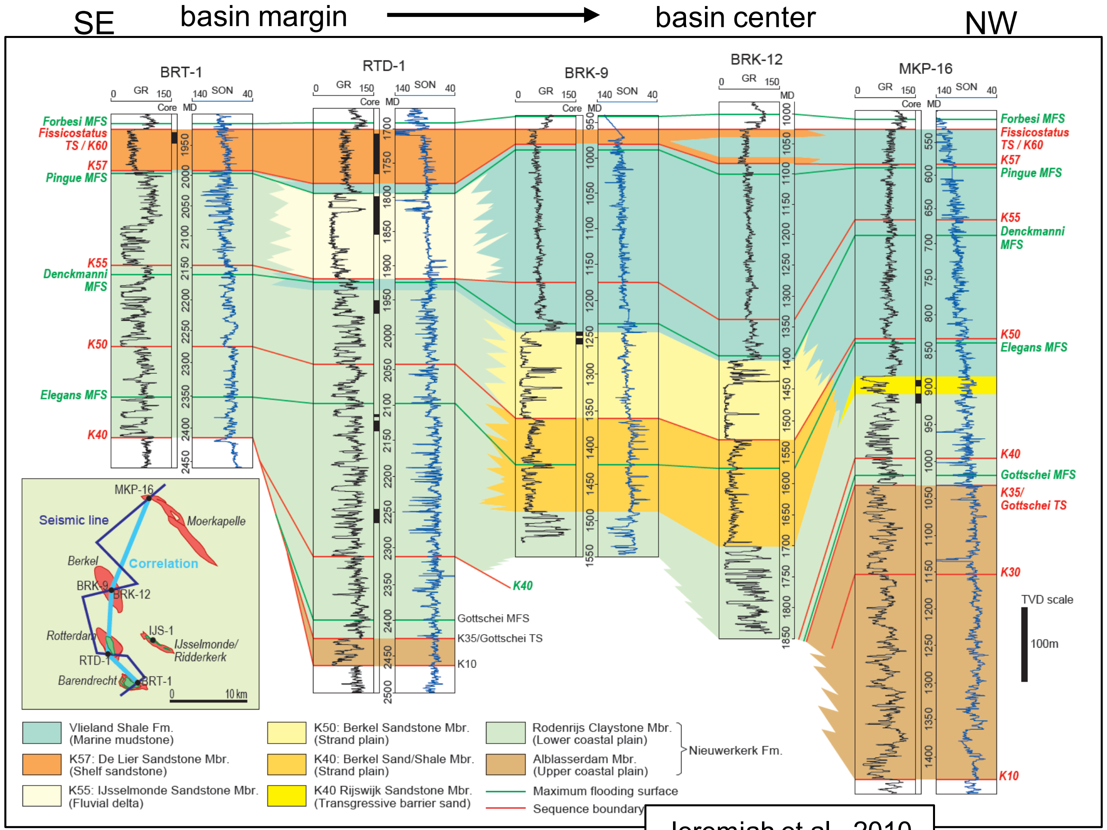


Tectonostratigraphic Evolution – TMS-4 Upper (Barremian - earliest Aptian)

innovation for life

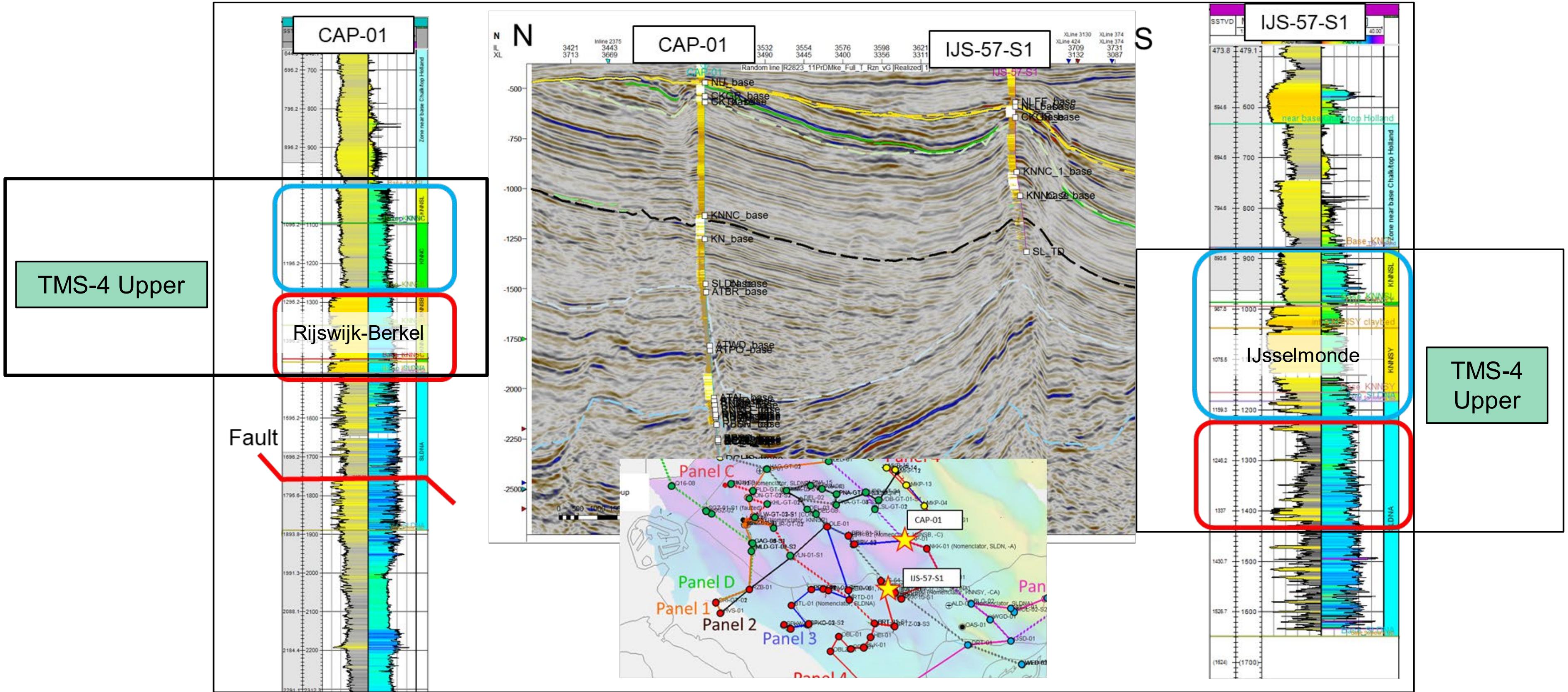
The retrograding Berkel-IJsselmonde beach-barrier system



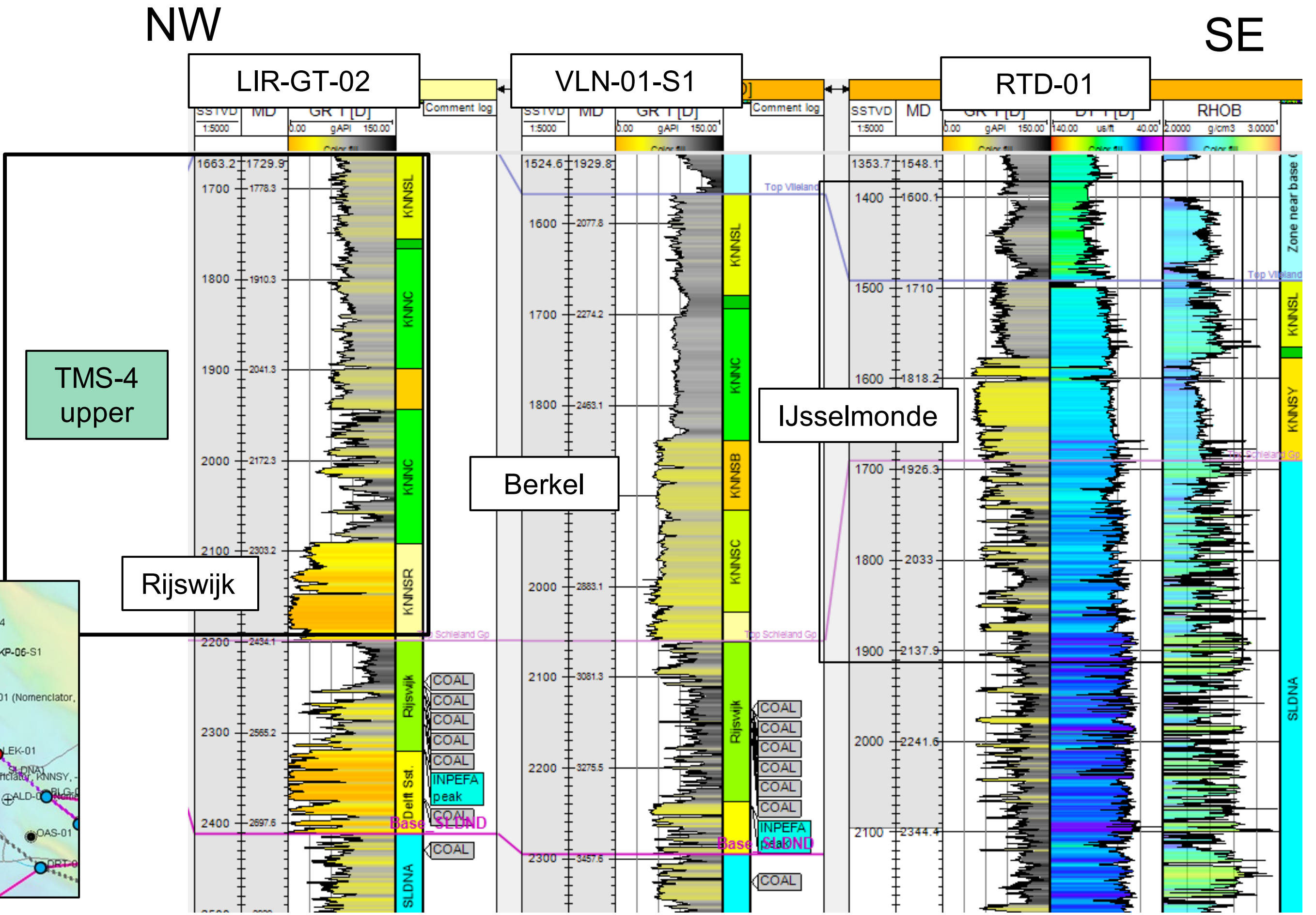


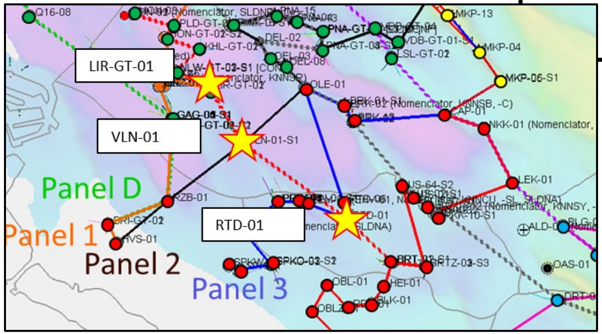
Jeremiah et al., 2010

Beach-barrier system retrograding towards the South



Retrograding shoreface systems from NW to SE





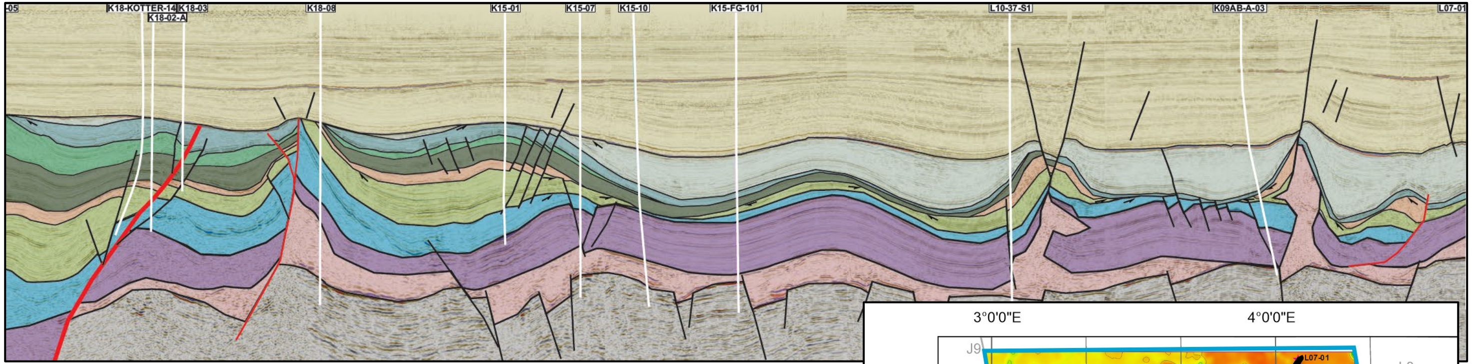
5 Discussion – Basin Configuration

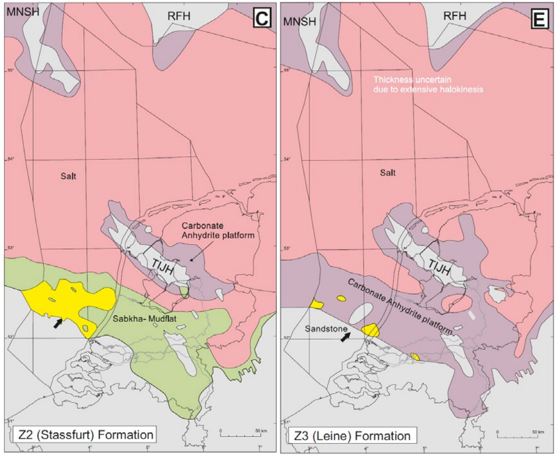
The northern salt-controlled area

- Salt tectonics is limited primarily to the northern part of the study area due to the absence of thick Z2 and Z3 Zechstein halite in most of the study area.

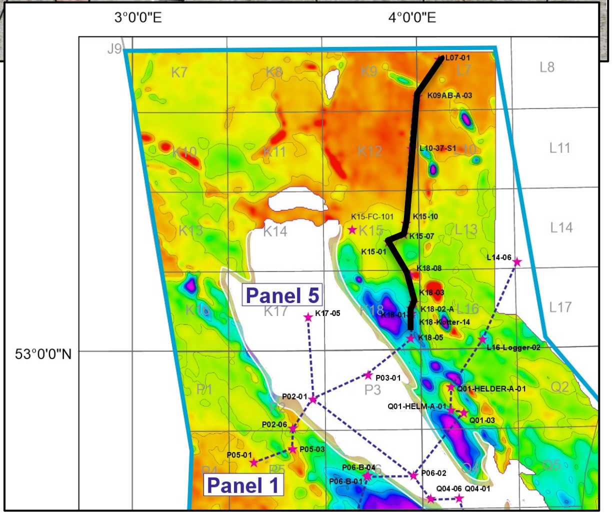
- In the northern part of the study area salt tectonics start to play a role in the configuration of the Upper Jurassic to Lower Cretaceous. Turtle structures, squeezed diapirs, rim synclines and growth faults are observed and are developing in a similar fashion as in the northern Dutch offshore (see Bouroullec and ten Veen, in press).

Northern part of Panel 1



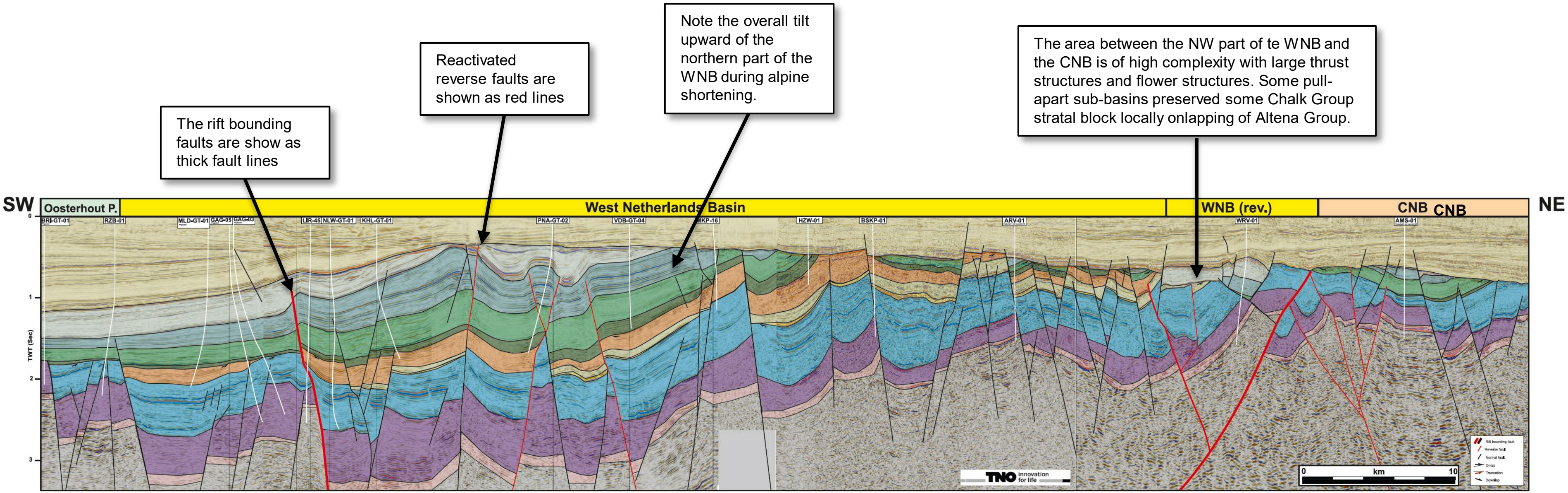


Paleogeographic and facies maps of the Zechstein Z2 and Z3 members. From Bouroullec and ten Veen (in press), modified from Geluk (2007).



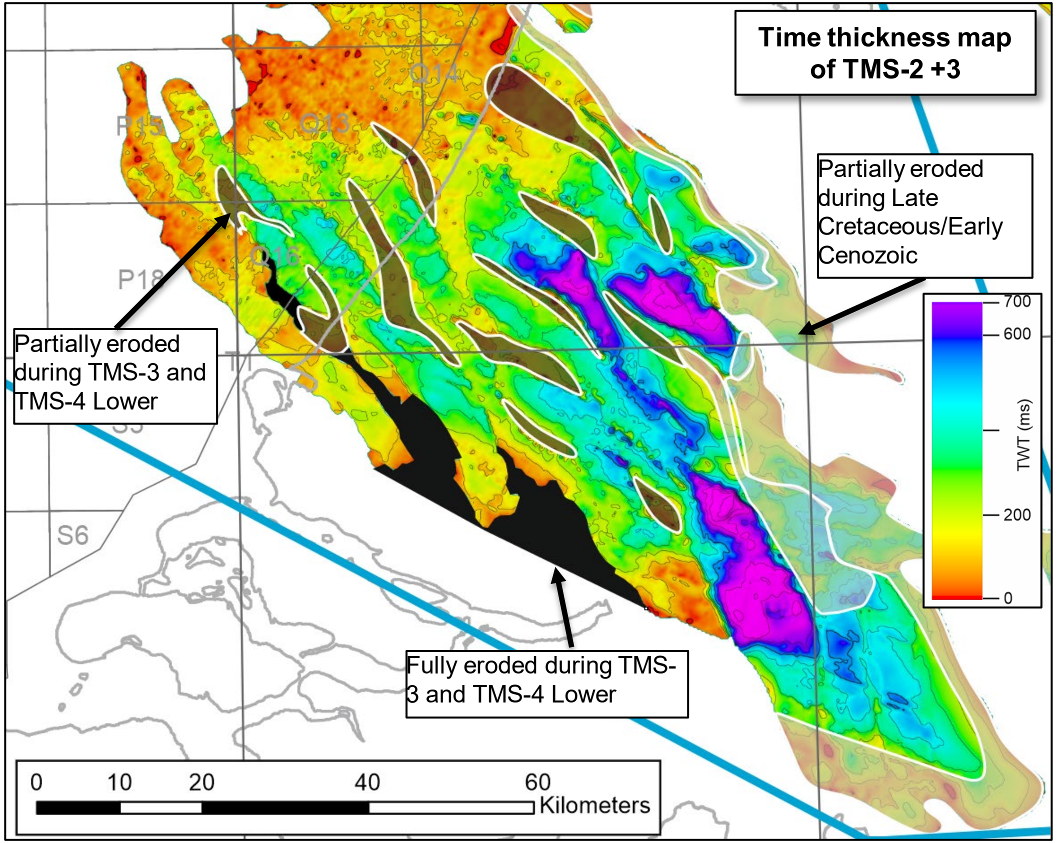
Discussion – Fault geometry and kinematics

- Faults and fault offsets were taken into account in this study, but fault planes were only mapped to clarify complex zones and to facilitate stratigraphic correlations.
- The majority of faults show evidence of growth stratigraphy during the deposition of TMS-2 to TMS-4 Upper (see regional panels in Appendix B).
- Some of those faults were also active during TMS-5 (Holland Formation) but an overall decrease of syn-depositional faulting is observed.
- Many of the Mid-Jurassic to Lower Cretaceous syn-depositional normal faults were reactivated as reverse faults during the Late Cretaceous.
- Evidence of strike-slip deformation during the deposition of TMS-2 to TMS-4 Lower (Mid-Kimmeridgian to end of Hauterivian) is also proposed (see last discussion topic of this report).



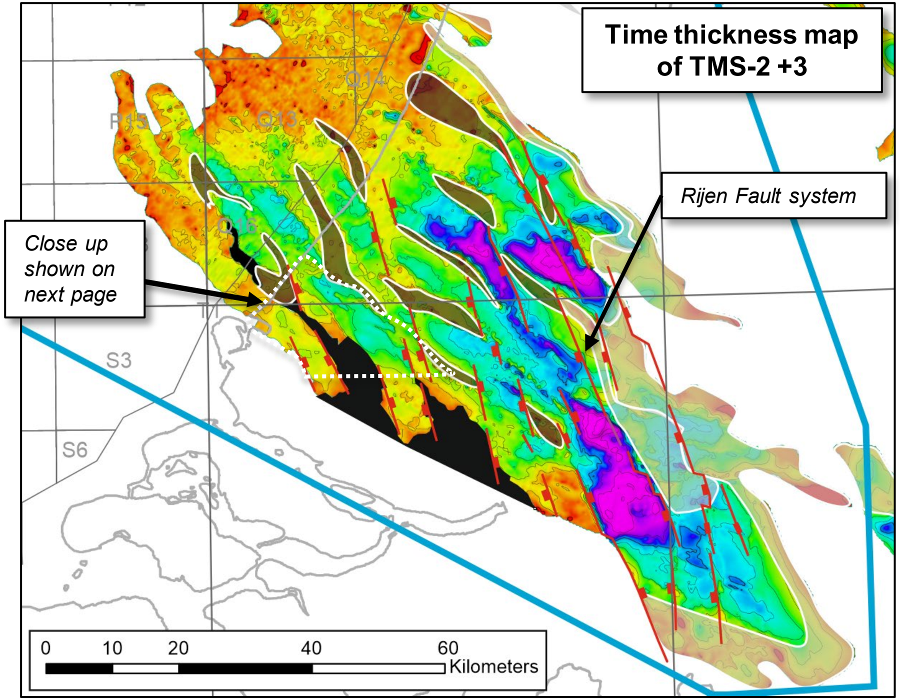
Relative erosion of intra-basinal paleo-structural highs

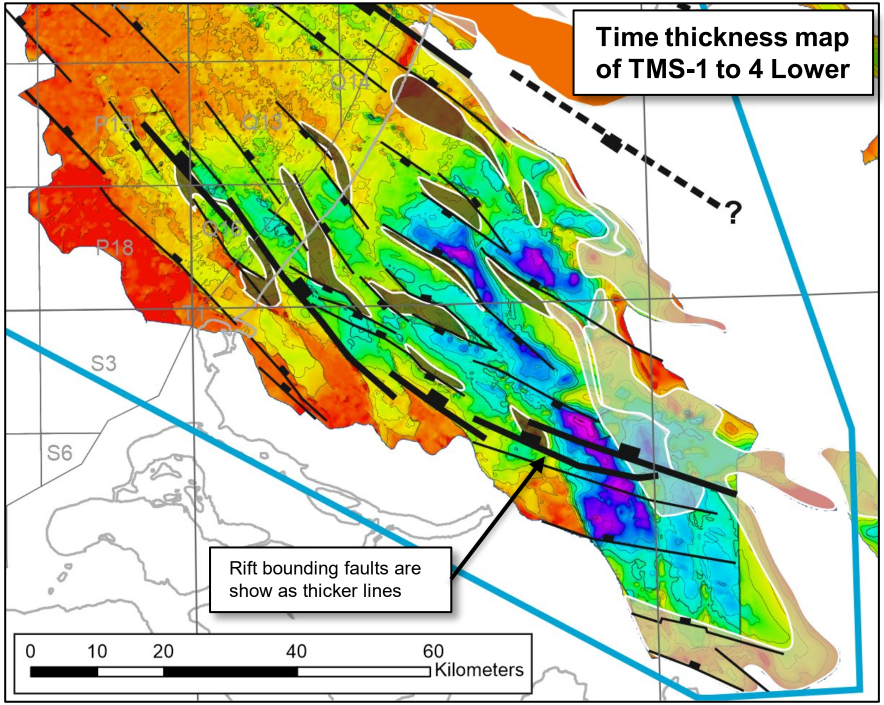
- This section of the report discusses fault kinematics and basin-scale fault dynamics, based on this study and on recent work by TNO Deep Subsurface Modelling Team on the western part of the WNB (see next pages).
- The central and western part of the WNB gives a good idea of the overall fault trends and their temporal changes by integrating seismically identified faults and using the new integrated Devli Project thickness maps.
- These observation were foundational to extrapolate the fault and basin dynamics further North into the offshore, including the BFB and its surrounding platforms.



Relative erosion of intra-basinal paleo-structural highs

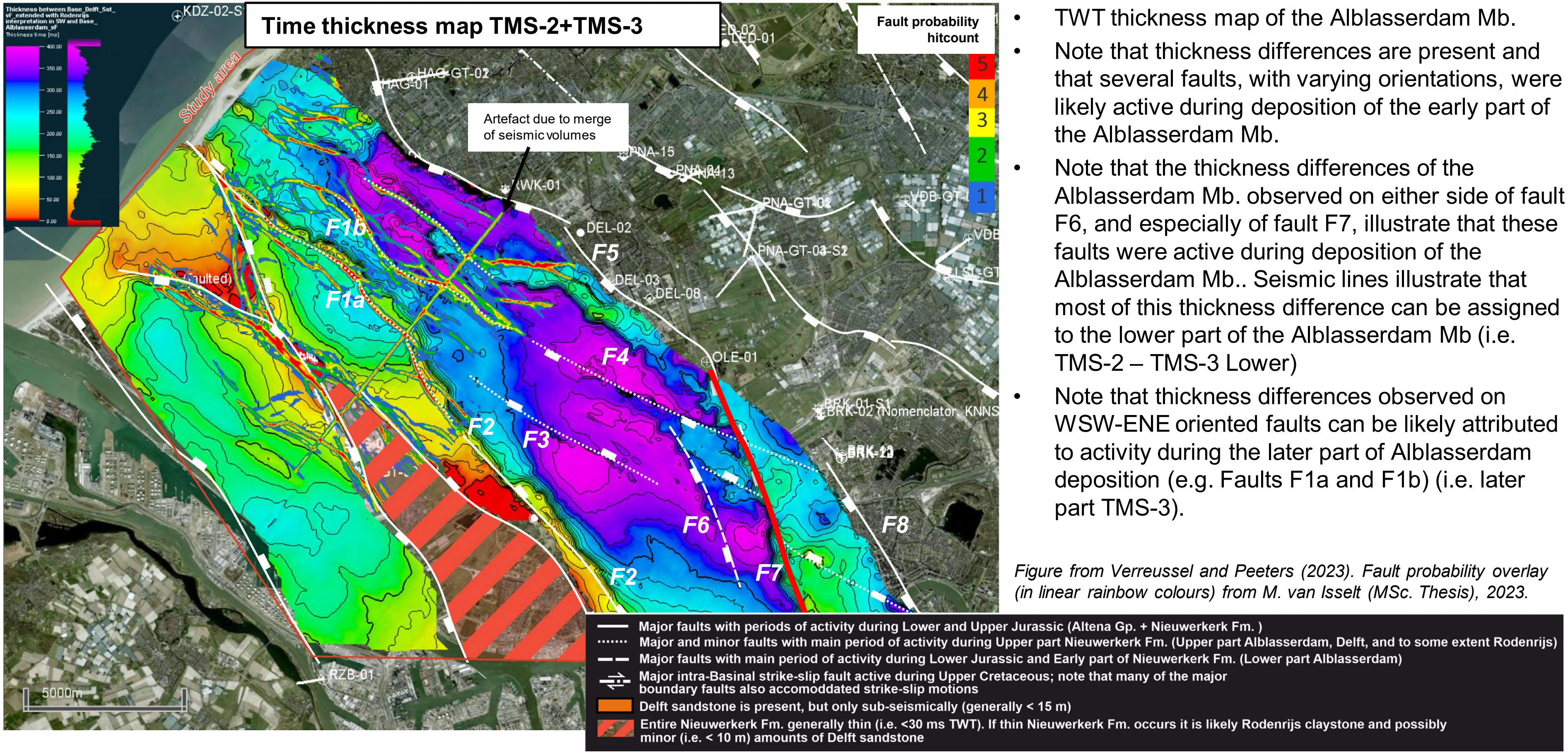
- Faults active during the depositional time of TMS-2 and early part of TMS-3 (Mid-Kimmeridgian to Late Volgian) are oriented NNW-SSE (red faults below) while faults active during the depositional time of TMS-3 and TMS-4 Lower (Late Volgian to Hauterivian) are oriented NW-SE (black faults below).
- These two trends explain the sigmoidal to rhomboidal geometries of the intrabasinal high (horsts) and lows (graben).





Discussion – Fault geometry and kinematics – Previous work

TNO innovation for life

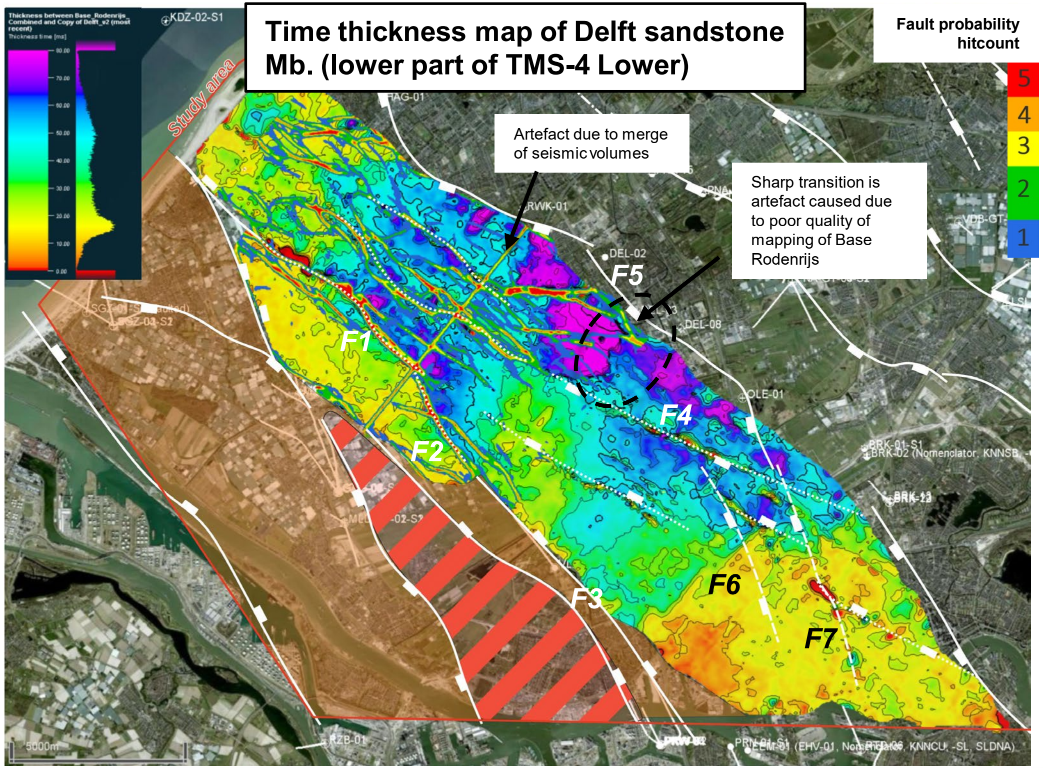


- TWT thickness map of the Alblasserdam Mb.
- Note that thickness differences are present and that several faults, with varying orientations, were likely active during deposition of the early part of the Alblasserdam Mb.
- Note that the thickness differences of the Alblasserdam Mb. observed on either side of fault F6, and especially of fault F7, illustrate that these faults were active during deposition of the Alblasserdam Mb.. Seismic lines illustrate that most of this thickness difference can be assigned to the lower part of the Alblasserdam Mb (i.e. TMS-2 – TMS-3 Lower)
- Note that thickness differences observed on WSW-ENE oriented faults can be likely attributed to activity during the later part of Alblasserdam deposition (e.g. Faults F1a and F1b) (i.e. later part TMS-3).

Figure from Verreussel and Peeters (2023). Fault probability overlay (in linear rainbow colours) from M. van Isselt (MSc. Thesis), 2023.

Discussion – Fault geometry and kinematics – Previous work

TNO innovation for life



- TWT thickness map of the Delft Sandstone Mb. (Peeters and Verreussel, 2023).
- Note that thickness differences are present and that some faults, which are trending approximately WNW-ESE were likely active during deposition of the Delft Sandstone Mb. The clearest examples include faults F1 and F2. But also fault F3 was likely active. Same holds for the main bounding faults north of the Honselersdijk block (including e.g. fault F5).
- Note that Faults F6 and F7 don't indicate any signs of syn-depositional activity.

Figure from Verreussel and Peeters (2023). Fault probability overlay (in linear rainbow colours) from M. van Isselt (Msc. Thesis), 2023.

- Major faults with periods of activity during Lower and Upper Jurassic (Altena Gp. + Nieuwerkerk Fm.)
- Major and minor faults with main period of activity during Upper part Nieuwerkerk Fm. (Upper part Alblasserdam, Delft, and to some extent Rodenrijs)
- Major faults with main period of activity during Lower Jurassic and Early part of Nieuwerkerk Fm. (Lower part Alblasserdam)
- Major intra-Basinal strike-slip fault active during Upper Cretaceous; note that many of the major boundary faults also accomodadted strike-slip motions
- Delft sandstone is present, but only sub-seismically (generally < 15 m)
- Entire Nieuwerkerk Fm. generally thin (i.e. <30 ms TWT). If thin Nieuwerkerk Fm. occurs it is likely Rodenrijs claystone and possibly minor (i.e. < 10 m) amounts of Delft sandstone

5 Discussion – Fault geometry and kinematics – Previous work

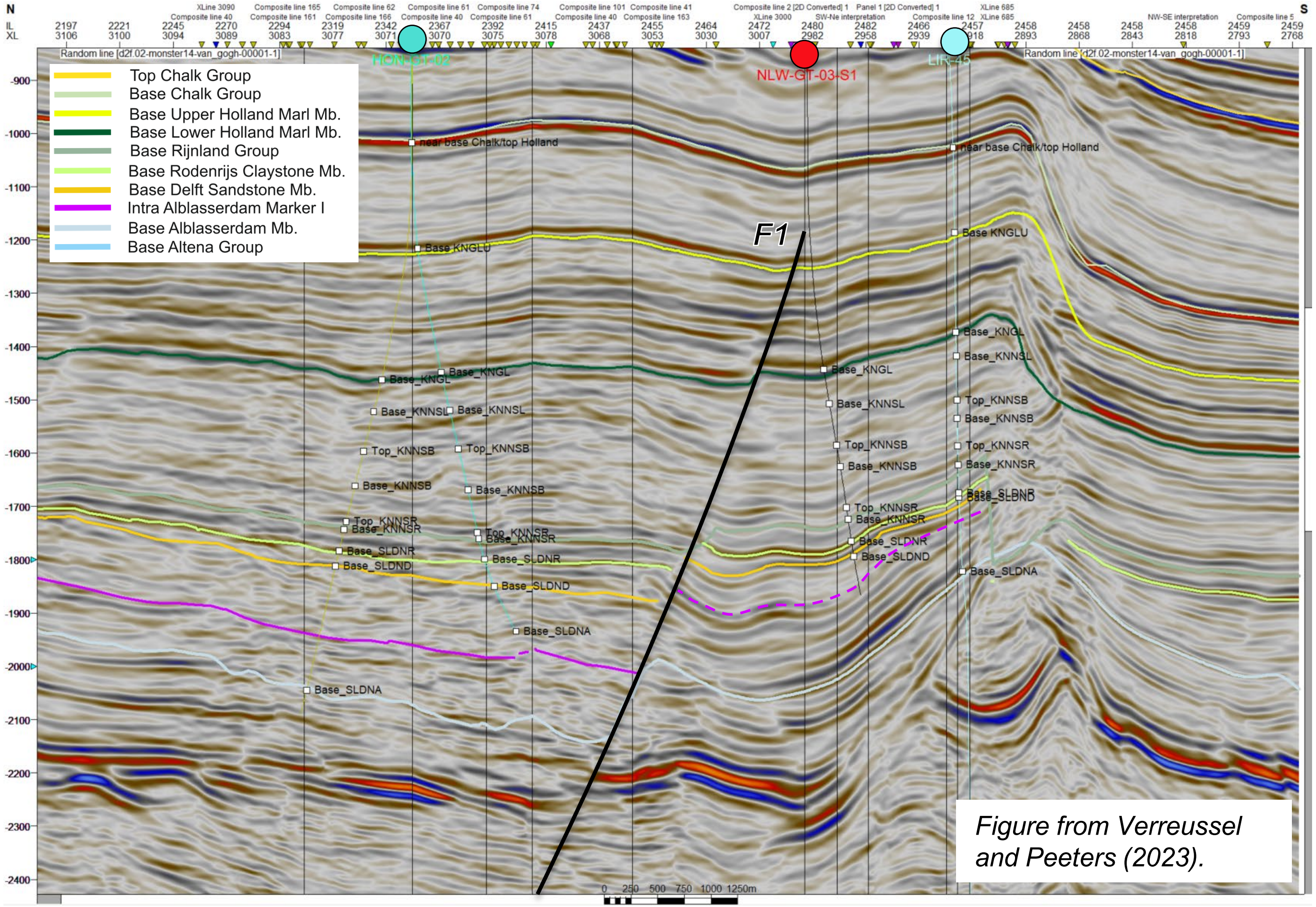
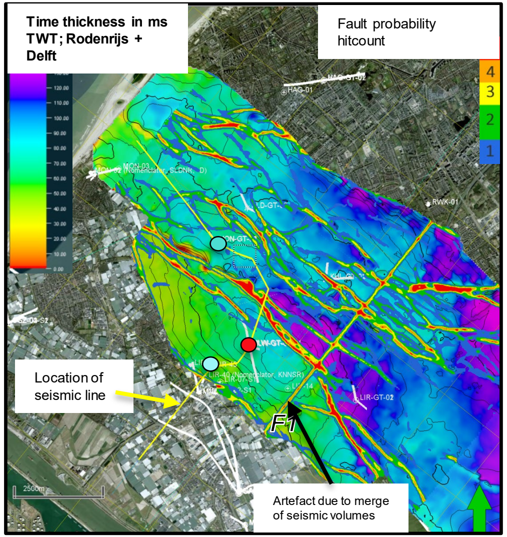


Figure from Verreussel and Peeters (2023).

The interval composed of the Delft Sandstone and Rodenrijs members is significantly thicker in the hanging wall of fault F1 than in the footwall. This is also the case for the Alblasserdam interval and to a lesser extent for the Holland Fm (see also next page for the relevant well panel).

Figure from Verreussel and Peeters, (2023). Fault probability overlay (in linear rainbow colours) from M. van Isselt (Msc. Thesis), 2023.



Discussion – Fault geometry and kinematics – Previous work

innovation for life

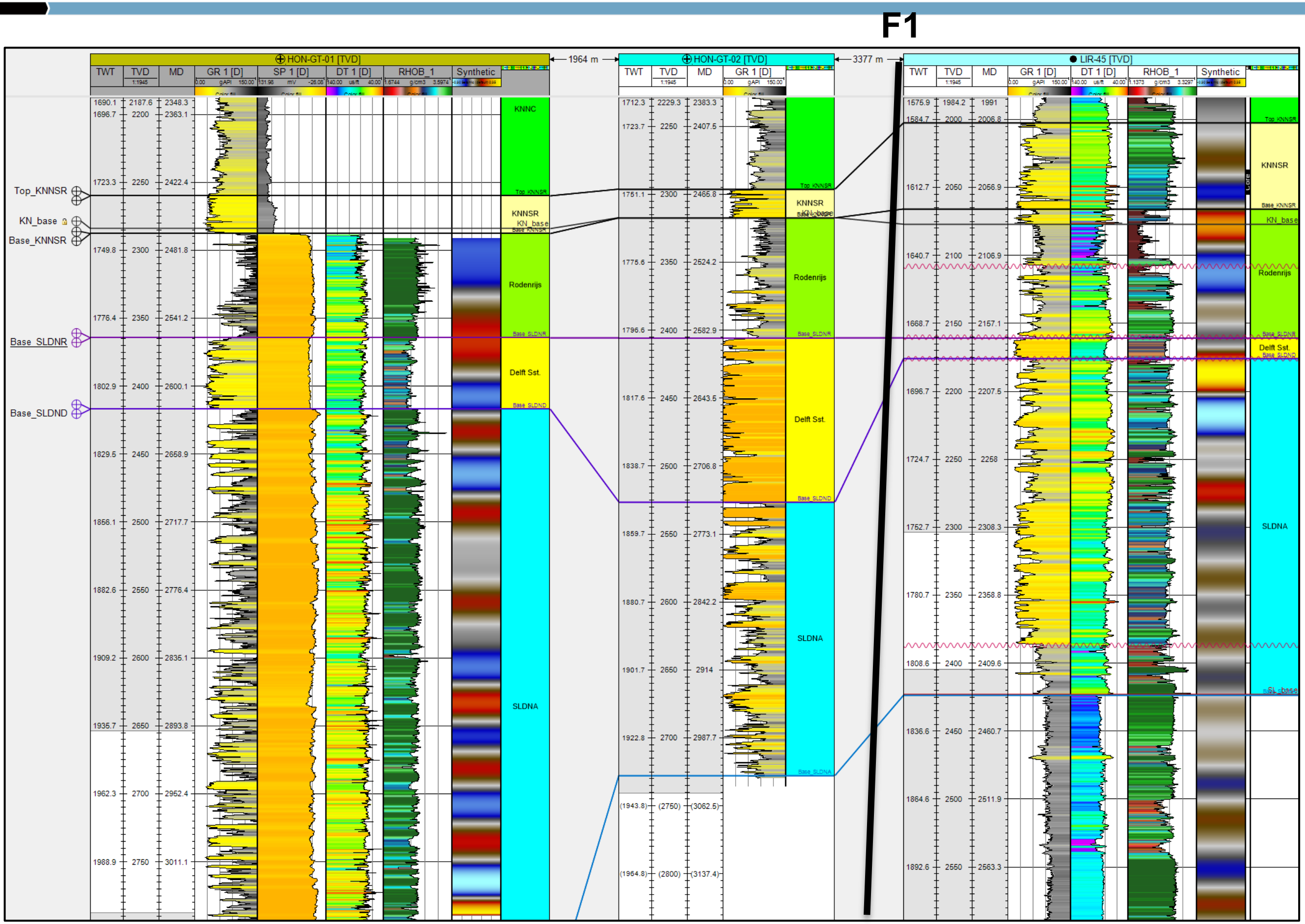
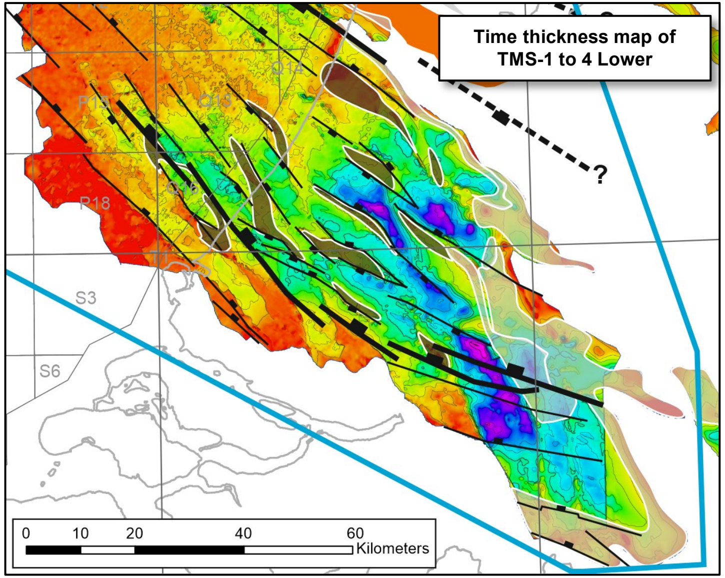
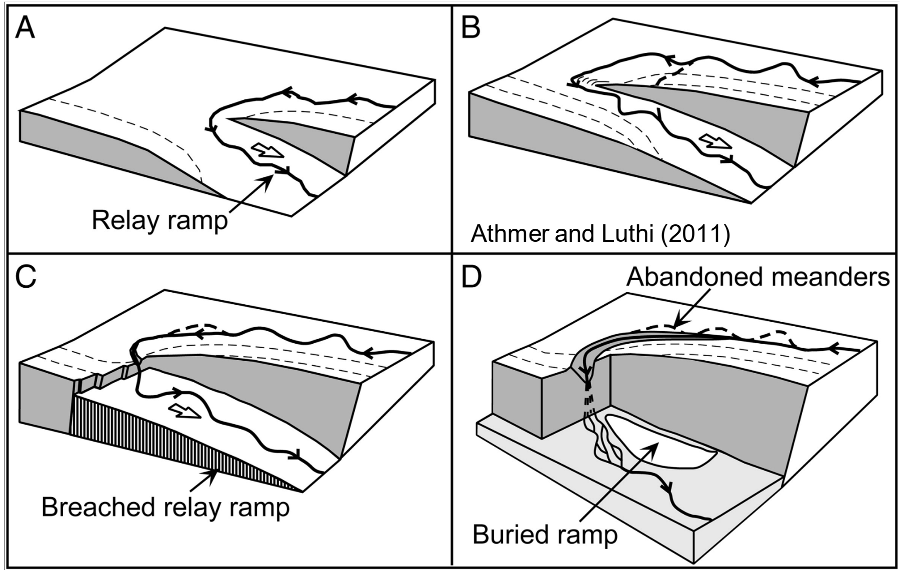


Figure from Verreussel and Peeters (2023).

Discussion – Rift dynamics – Relay ramp and sediment pathways

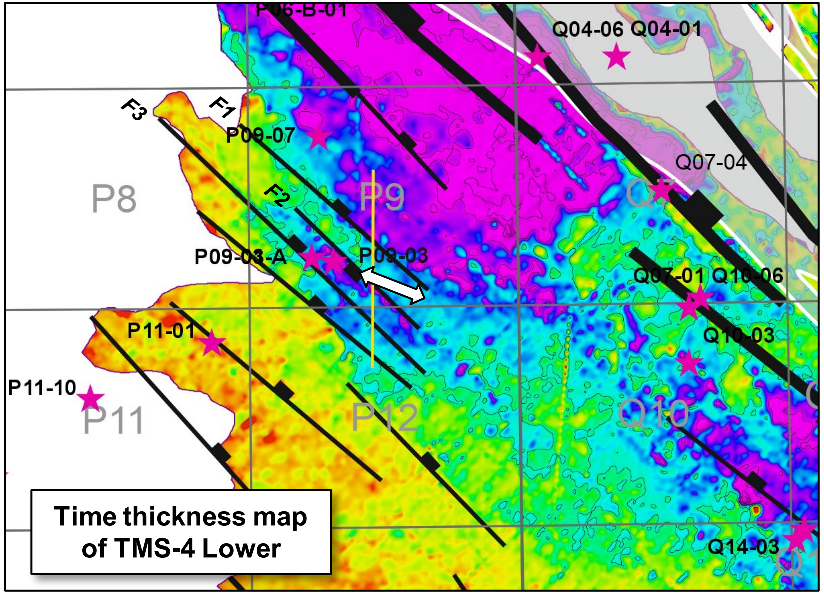
- The **relay ramp geometries** are prevalent in most rift basins around the globe. The en-echelon configuration of the basin-bounding faults as well as faults on the rift's platforms (see map below), suggest that relay ramps were likely present between faults. This may have possibly occurred within individual faults that were initially composed of individual segments, later linked due to lateral fault growth (lateral fault linkage).
- Such relay ramps are preferential sediment pathways between the rift platforms (shoulders) and the basin, as well as between individual platform fault blocks.
- A few candidates for marginal incisions (e.g. sub-aerial canyon, incised valleys or deep-marine channel/canyon) have been identified during seismic interpretation, but systematic mapping of those conduits is yet to be undertaken. One example, however, is discussed in next pages.



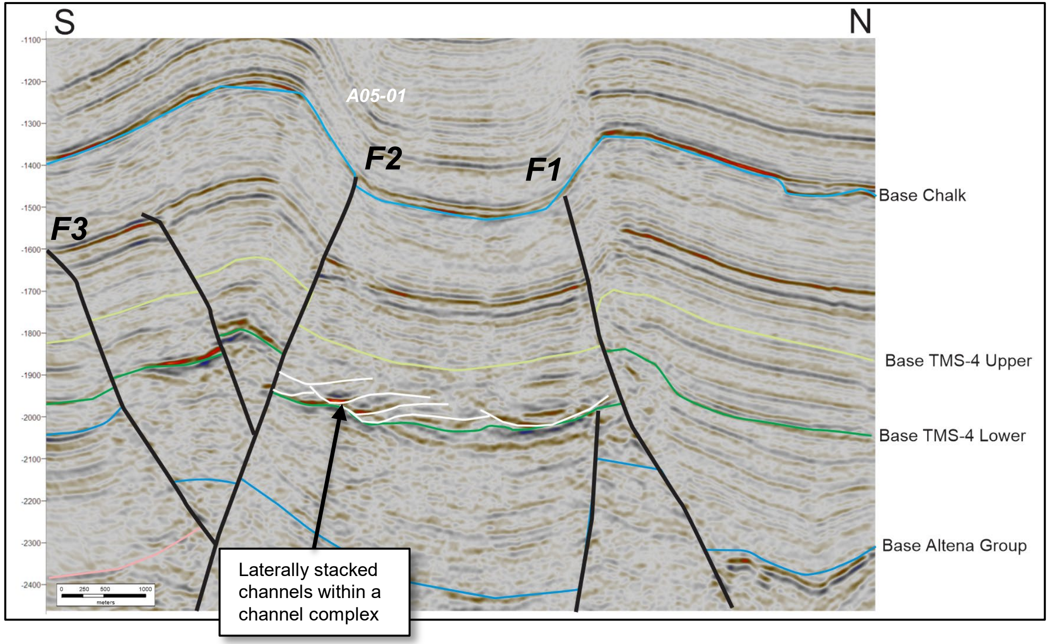


Discussion – Rift dynamics – Relay ramp and sediment pathways

- Several stacked channels are observed in the area located between the two reverse faults (see seismic line and map)
- These faults were originally active as normal faults on the SW shoulder of the BFB (Zeeland Platform).
- No detail mapping of these channels was undertaken, but basic mapping indicates that they are oriented NW-SE (see white arrow on the map below).



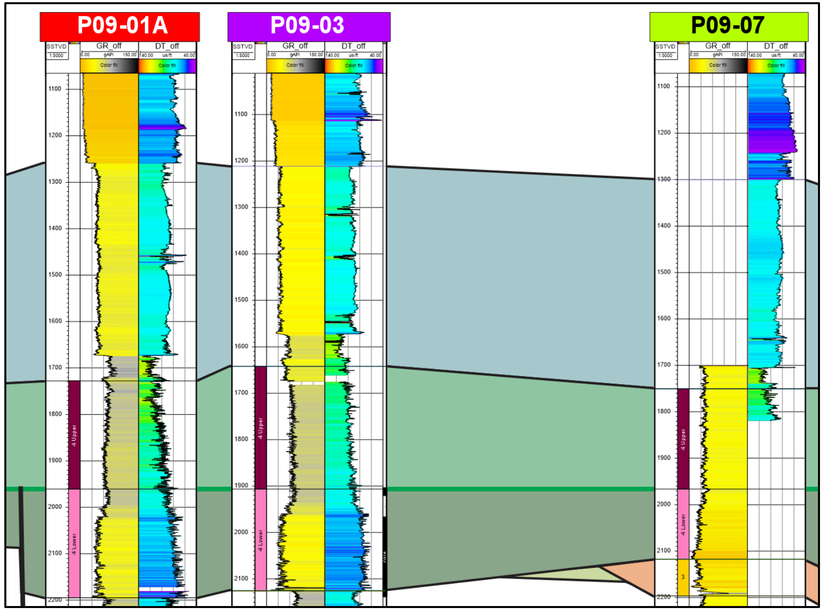
Time thickness map of TMS-4 Lower

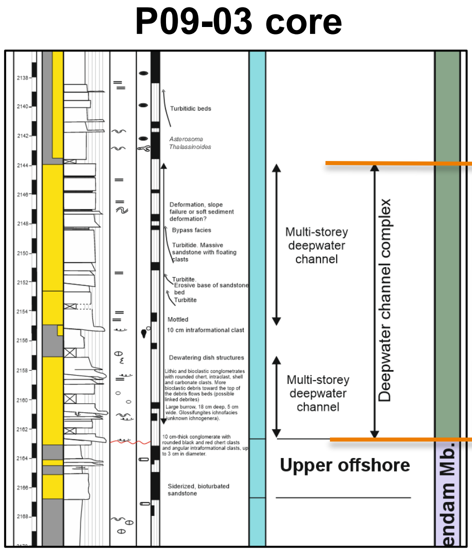


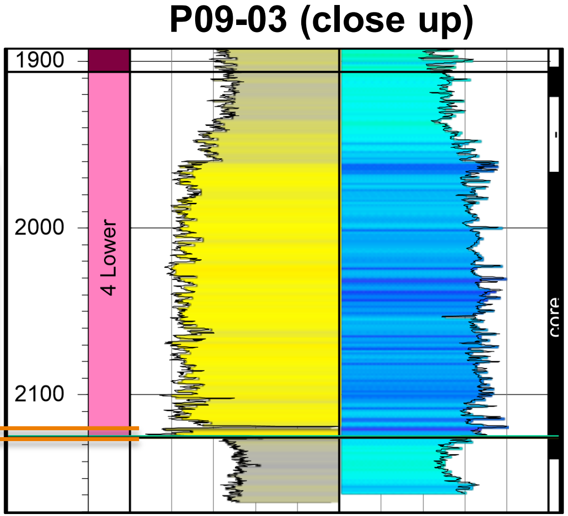
- Since well P09-03 is located NW of the mapped incisions it could provide valuable information if this channelized depositional system extended to that location (see next page).

Discussion – Rift dynamics – Relay ramp and sediment pathways

- Well P09-03 is located 2km to the NW of the identified channels and in line with their overall trends. This well has a core at the same stratigraphic level than observed channels.
- The core (Appendix C) shows that the lower part of the TMS-4 Lower (lower part of the Rijn Member) erodes down to the Werkendam Fm (Altena Group). The lowest 19 m are composed of a deepwater channel complex with gravel-rich lags, turbidites and linked debrites. This interval is likely the same channelized system observed on seismic to the southeast of that location.
- Such deepwater channels can carry large amounts of sediment further down into the deepest part of the basin, where lobes and weakly confined lobe/channel complexes could be deposited. These sediment gravity flow deposits may be of economic value for future exploration.

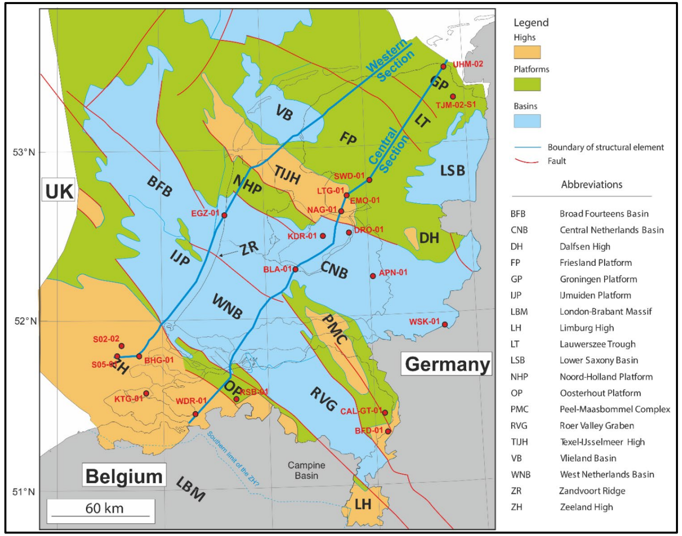




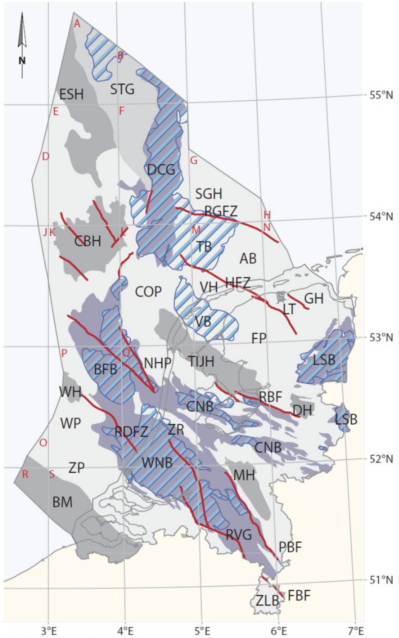


Discussion – Rift dynamics – New structural model

- A new Mid-Jurassic to Early Cretaceous structural model is proposed for the southern Dutch rift system based on its tectono-stratigraphic evolution.
- The system includes the Broad Fourteen Basin, the West Netherlands Basin, the western part of the Roer Valley Graben and their platforms (Central Netherlands Basin, Noord Holland Platform, Central Offshore Platform, Winterton Platform, Zeeland Platform, Oosterhout Platform.



Late Jurassic - Early Cretaceous structural elements of the Netherlands. From Bouroullec et al. (2019), redrafted from Kombrink et al., 2012)



d. Late Jurassic - Early Cretaceous structural elements (Late Kimmerian phases)

Faults and fault zones

Feldbiss Fault	FBF	Southern fault of the Roer Valley Graben trending NW-SE
Gronau Fault Zone	GFZ	Separating Central Netherlands Basin and Lower Saxony Basin
Hantum Fault Zone	HFZ	Separating the Ameland Block from the Vlieland High and the Friesland Platform, active since Carboniferous
Indefatigable Fault Zone	IDFZ	Separating Broad Fourteens Basin and the Winterton Platform
Mid-Netherlands Fault Zone	MNFZ	Separating the Central Netherlands Basin and the West Netherlands Basin and flanks the Zandvoort Ridge
Peel Boundary Fault	PBF	Northern border of Roer Valley Graben, active since Carboniferous and Brabant trending NW-SE
Raalte Boundary Fault	RBF	Separating the Texel-IJsselmeer High and Central Netherlands Basin
Rifgronden Fault Zone	RGFZ	Separating the Terschelling Basin and the Schill Grund High
Rijen Fault	RF	Southwestern limit of the northwestern part of the Roer Valley Graben
Rotterdam Fault Zone	RDFZ	Fault zone in the axis of the inversion zone of the West Netherlands Basin
Tegelen Fault	TF	Separating the Peel Block and the Central Netherlands Basin

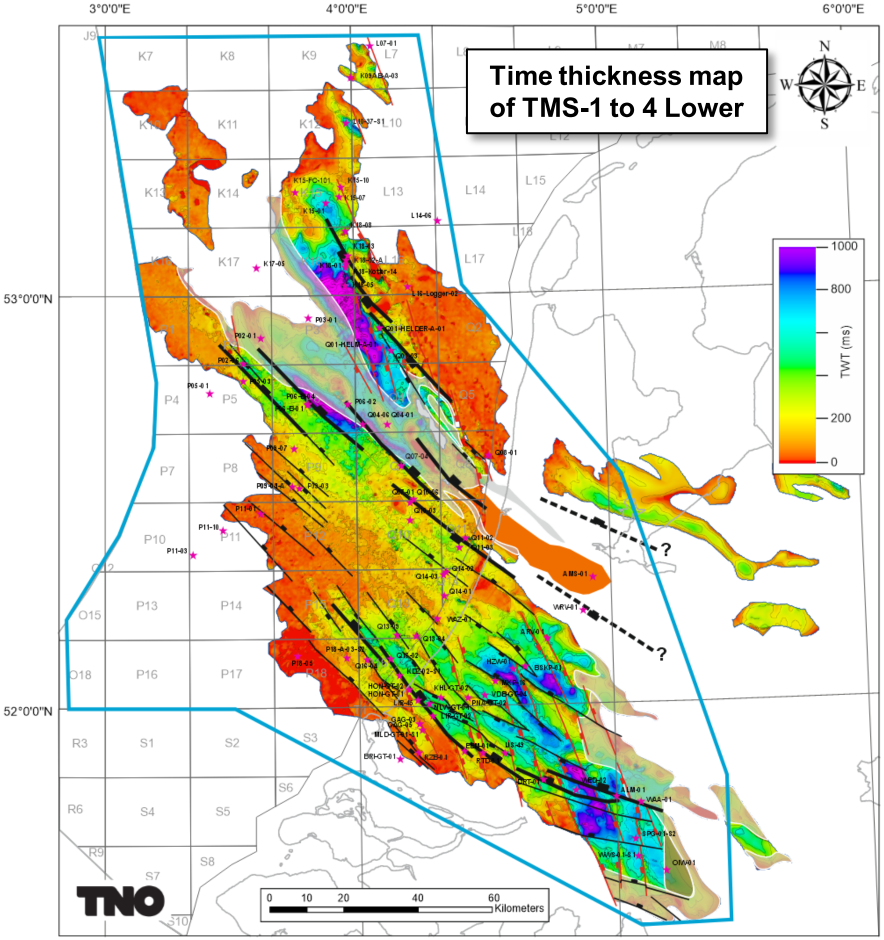
Ameland Block	AB
Brabant Massif	BM
Broad Fourteens Basin	BFB
Campine Basin	CB
Central Netherlands Basin	CNB
Central Offshore Platform	COP
Cleaver Bank High	CBH
Dalfsen High	DH
Dutch Central Graben	DCG
Elbow Spit High	ESH
Ems Low	EL
Friesland Platform	FP
Groningen High	GH
Kijkduin High	KH
Lauwerszee Trough	LT
Lower Saxony Basin	LSB
Maasbommel High	MH
Mid North Sea High	MNSH
Netherlands High	NH
Netherlands Swell	NS
Noord-Holland Platform	NHP
North Sea Basin	NSB
Peel Block	PBL
Rhenish Massif	RM
Roer Valley Graben	RVG
Schill Grund High	SGH
Southern Permian Basin	SPB
Step Graben	STG
Terschelling Basin	TB
Texel-IJsselmeer High	TIJH
Venlo Block	VBL
Vlieland Basin	VB
Vlieland High	VH
Voorne Trough	VT
West Netherlands Basin	WNB
Winterton High	WH
Winterton Platform	WP
Zandvoort Ridge	ZR
Zeeland Platform	ZP
Zuiderzee Low	ZZL
Zuid-Limburg Block	ZLB

Figure from Duin et al. (2006).

5 Discussion – Rift dynamics – New structural model

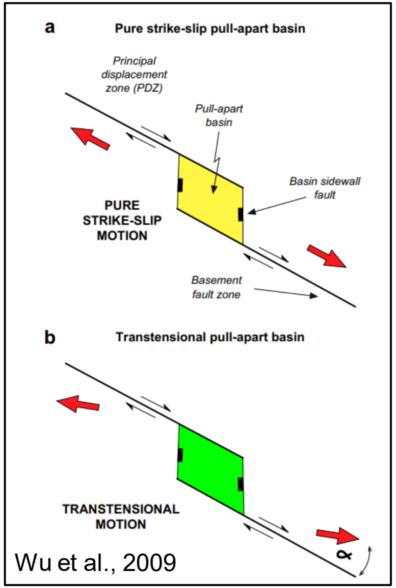
Key facts

- Faults active during the deposition of the Mid- Kimmeridgian to Hauterivian are of two distinct orientations.
- The older fault system (red fault on the map) is oriented NNW-SSE and was active during the Mid-Kimmeridgian and Volgian (TMS 2 to early part of TMS-3).
- The subsequent fault system (thin black fault on the map, active during the Ryazanian to Hauterivian; later part of TMS-3 and TMS-4 Lower) is oriented NW to SE (between 25 to 50 degrees from the previous fault trend), depending on the local geometries).
- These two trends create sigmoidal to rhomboidal horst and graben geometries within the rift basins.
- The West Netherlands Basin itself has an overall sigmoidal geometry. In the case of the BFB it is less clear due to central part and entire NW side of the basin being eroded.
- All rift-bounding faults (thick black lines on the map) are **en-echelon basin sidewall faults**, which indicate **strike slip tectonics with a dextral (right-lateral) motion**.
- Such basins are bounded longitudinally by a transverse system of oblique-extensional faults, termed ‘‘basin sidewall faults’’, that link with the bounding PDZs (e.g. Burchfiel and Stewart, 1966; Crowell, 1974)
- En-echelon geometry indicate **a transtensional rotated pull-apart** basin configuration, rather than a pure strike-slip pull-apart basin configuration (Garfunkel, Z., 1981; ten Brink et al., 1996; Wu et al., 2009).

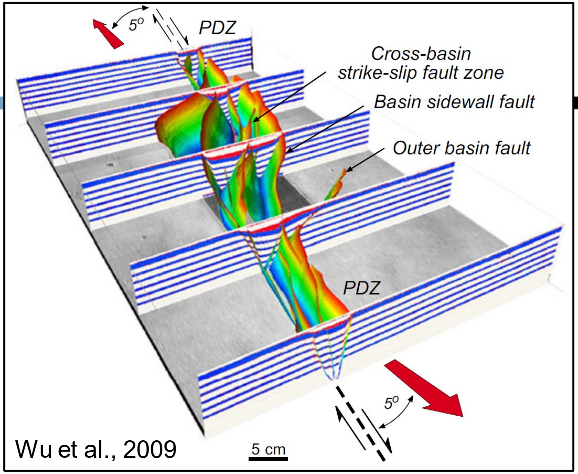


5 Discussion – Rift dynamics – New structural model

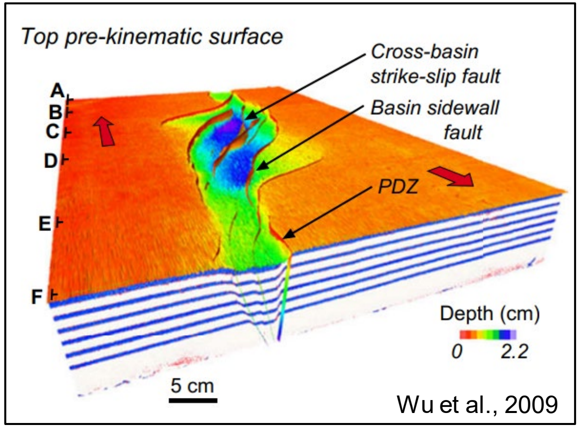
- Scaled analogue modelling of pull-apart basins (Wu et al., 2009) shows that very different basins are developed in transtensional (oblique divergent) slip along the basement master fault zones compared to pure strike-slip.
- In both settings the gross geometry consists of elongate, sigmoidal to rhomboidal, pull-apart basins.
- Sidewall faults merge into one deep fault zone, referred as Principal Displacement Zone (PDZ).
- However, in transtension the pull-apart basin margin is characterized by the development of en-echelon oblique-extensional faults that soft- or hard-link with increasing displacement on the principal displacement zones (PDZs).
- En-echelon faulting is not observed at the basin margins of the pure strike-slip model, which instead develops a basin margin composed of terraced, sub-parallel oblique-extensional faults.
- **Therefore, an en-echelon basin margin system is an important primary indication that a pull-apart basin has likely developed in transtension.**



General characteristics of a pull-apart basin in a dextral side-stepping fault system.



3D visualisation of pull-apart basin model reconstruction in the case of a transtensional model. The top surface is the top of the pre-kinematic sequence.



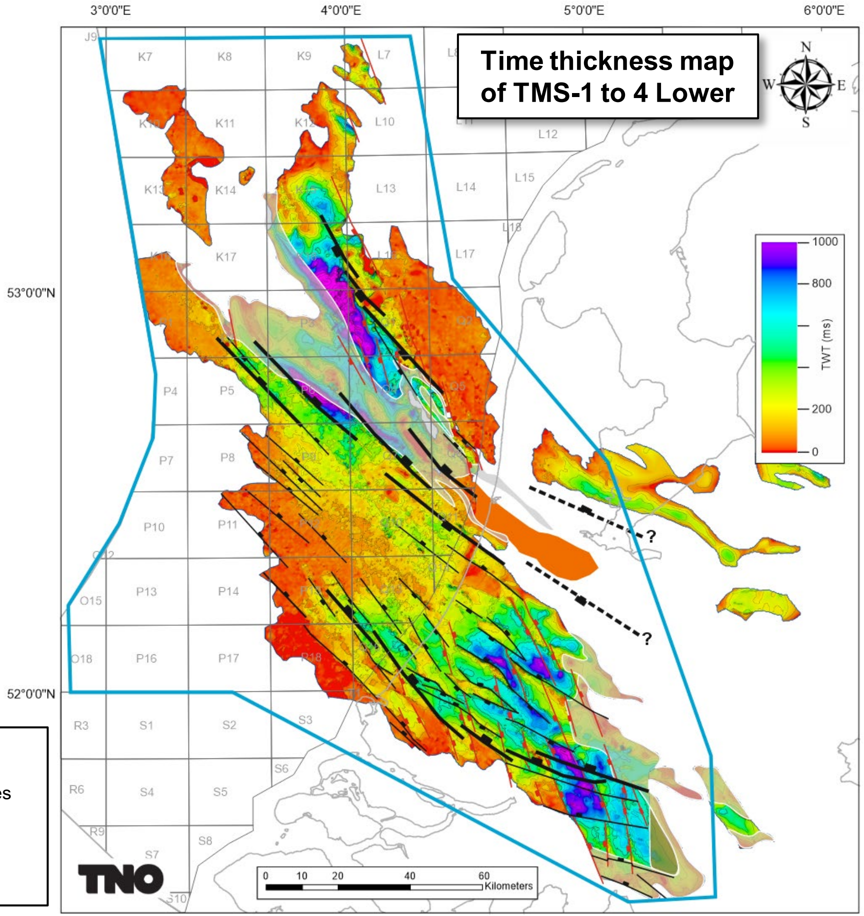
3D visualisation of fault architectures of pull-apart basin models developed in transtension.

5 Discussion – Rift dynamics – New structural model

- The southern Dutch rift system elements (fault geometry, basins and sub-basins geometry and stratigraphic evolution), match the criterion for a transtensional pull-apart system.
  - The WNB is sigmoidal in shape.
  - The rift bounding faults are en-echelon
  - The intra-rift sub-basins and highs (horst and grabens) are sigmoidal or rhomboidal in map view.

- Wu et al. (2009) show that in the case of transtensional pull-apart geometries the basins are wider (2 to 3 times), than in the case of pure strike-slip geometries. This could explain why the WNB has a short aspect ratio (1:2).

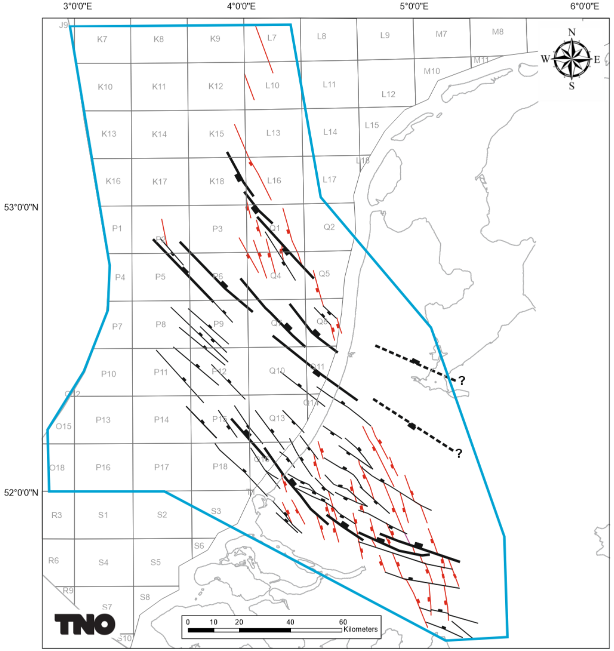
- These analogue physical (sandbox) models also show that fault trends associated with transtensional pull-apart dynamics, have changing trends during the different phase of basin activation (see next page).

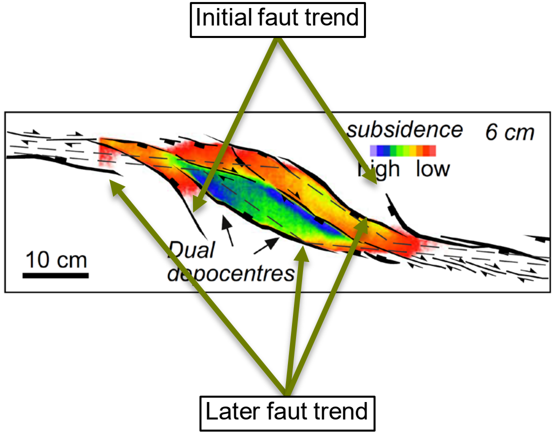


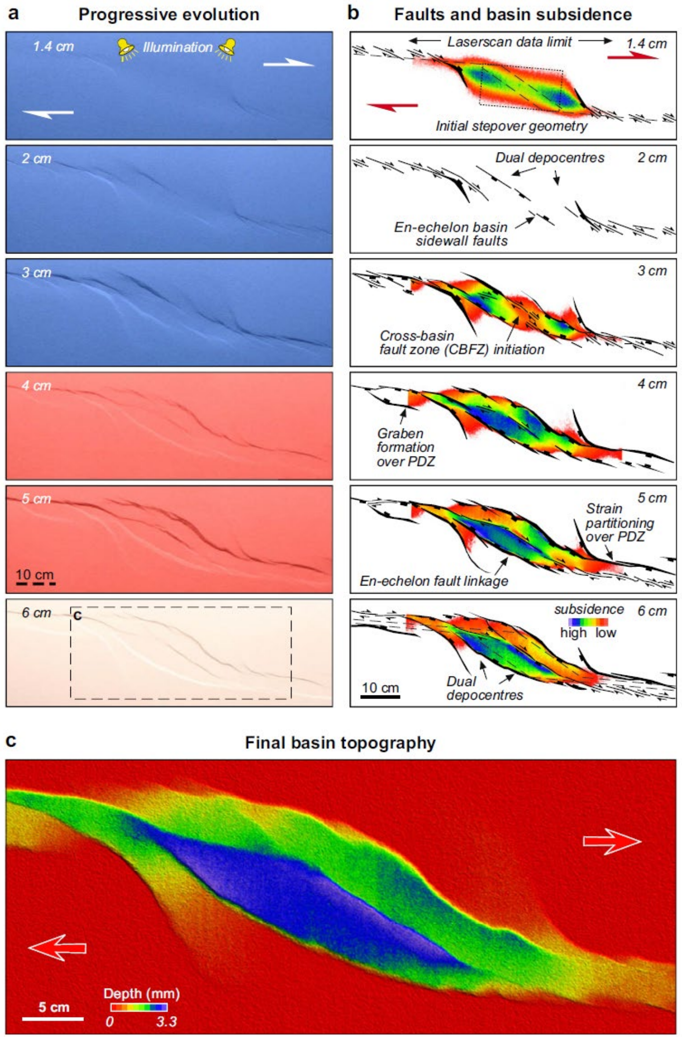
Light grey polygons are Upper Cretaceous/ Laramide unconformities and dark grey polygons intra-Upper Jurassic or intra-Lower Cretaceous unconformities.

5 Discussion – Rift dynamics – New structural model

- The change of fault trends between the Mid-Kimmeridgian to Volgian trend (red NNW-SSE faults) and the Ryazanian to Hauterivian trend (black NW-SE faults), can also be explained without changing the direction of extension and the increased fragmentation (more intrabasinal sub-basins and –highs) in later stages.
- Experimental physical modelling show that the initial faults, when compared to the later faults, are at a higher angle to both the main direction of movement and Principal Displacement Zone (PDZ).



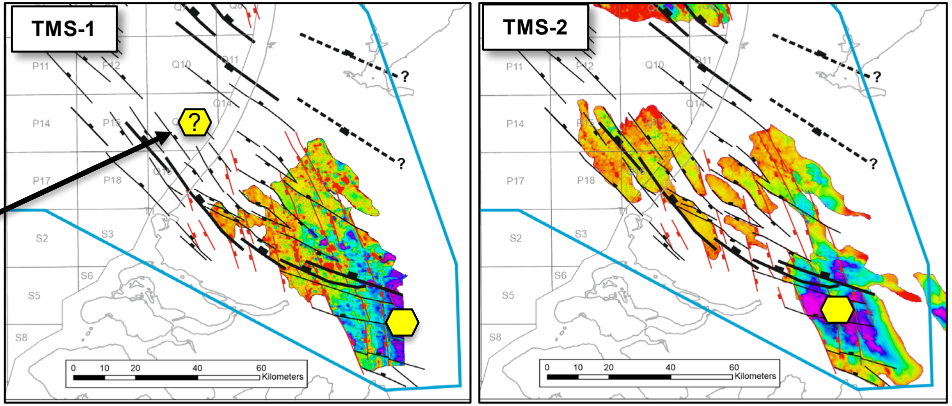


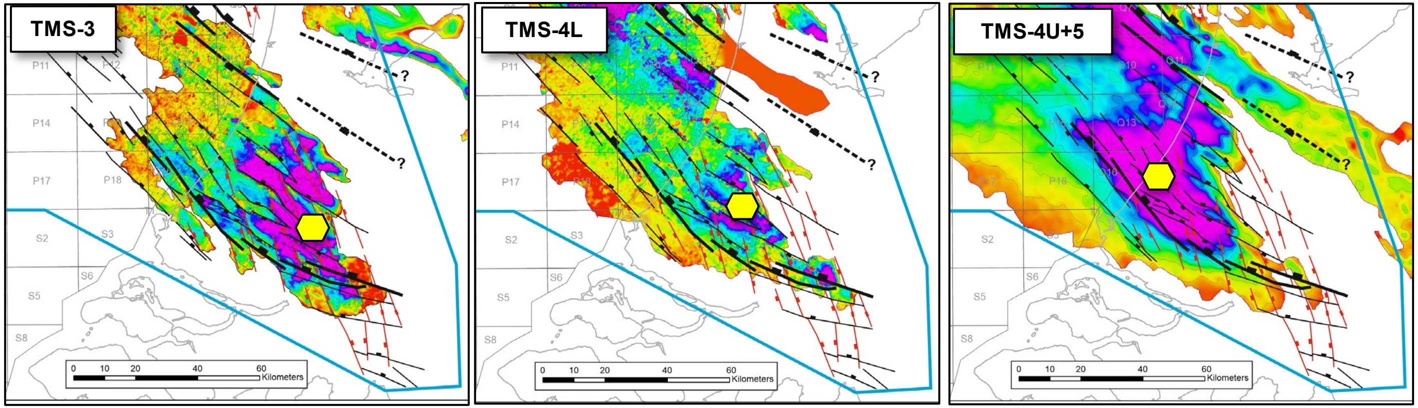


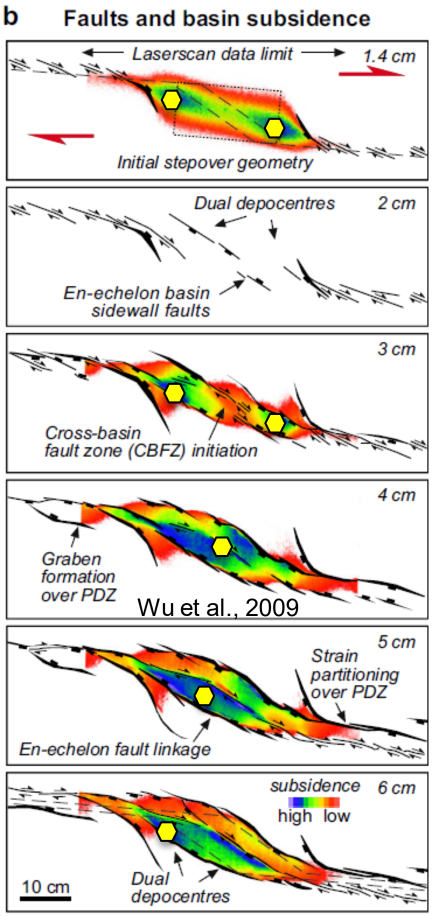
Discussion – Rift dynamics – New structural model

- The shift of successive depocenter locations and presence of intra-basinal highs, can also be explain using a trans-tensional pull-apart model.

A “dual opposing depocentre” geometry develops in the early to middle stages of transtensional basin evolution (see Fig. b, 1st stage), also supports the presence of the Brabant Formation in the Q13/Q14 block, as suggested earlier in this report (based on seismic amplitude pattern).



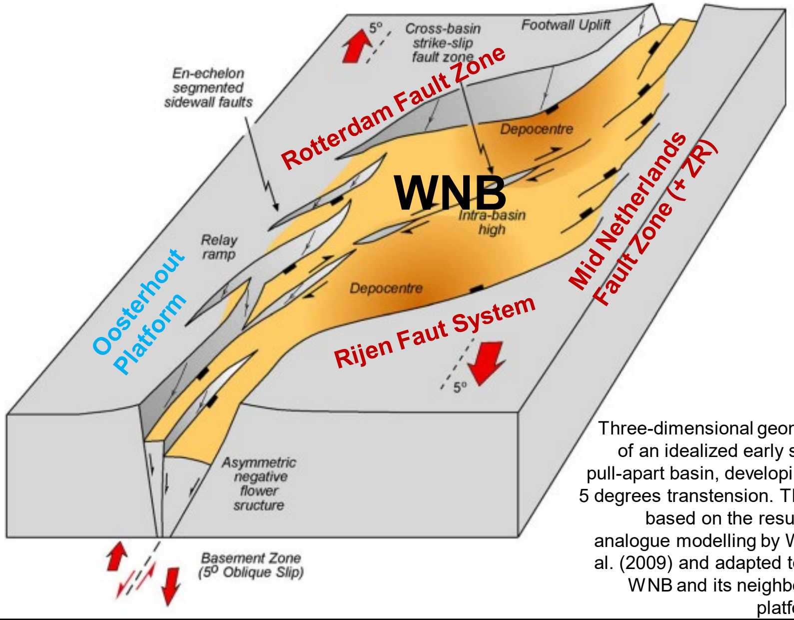




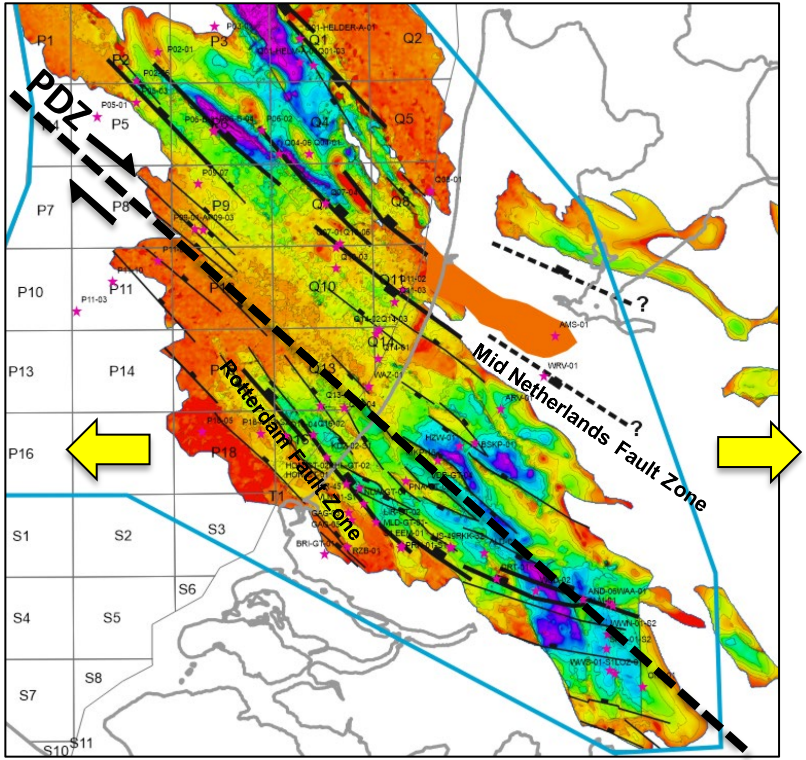
5 Discussion – Rift dynamics – New structural model

- This model explains the complexity of the WNB during the Late Jurassic and Early Cretaceous, whilst using a single direction of extension.

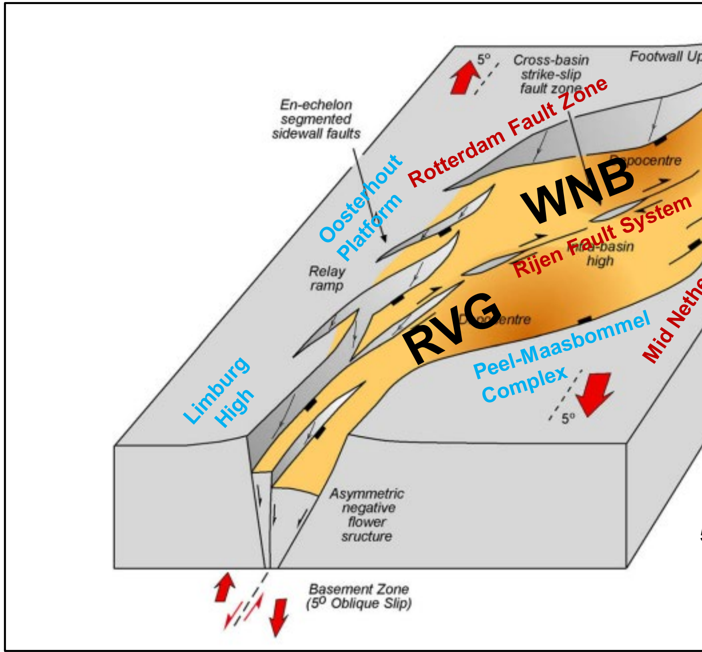
- Below is an attempt to place the main structures observed in the rift, and propose a position of the Principal Displacement Zone (PDZ). This is likely linked to a deep detachment in the upper crust.



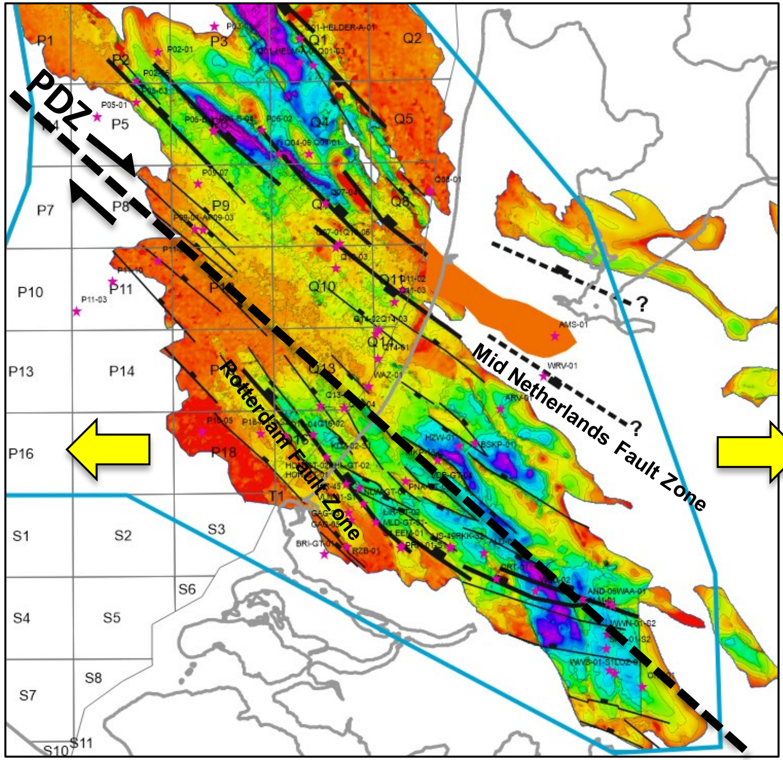
Three-dimensional geometry of an idealized early stage pull-apart basin, developing in 5 degrees transtension. This is based on the results of analogue modelling by Wu et al. (2009) and adapted to the WNB and its neighboring platforms



One may also suggest that the BFB, WNB and RVG are depocenters of a larger transtensional pull-apart rift system with the IJmuiden platform and the Rijen Fault system as intra-basin highs.



Three-dimensional geometry of an idealized early stage pull-apart basin developing in 5 degrees transtension based on the results of analogue modelling by Wu et al. (2009) and adapted to the WNB and its neighboring platforms



6 Conclusions

TNO innovation for life

- A new Middle Jurassic to Early Cretaceous sequence stratigraphic framework is compiled for the Broad Fourteens, West Netherlands Basin and neighboring areas. This framework introduces a sequence stratigraphic approach to the complex and often confusing lithostratigraphy of the area. Based on the results of this study TNO will revise the lithostratigraphic affiliation of a number of wells, and – if required – simplify the lithostratigraphy to better reflect the lateral and vertical stratigraphic trends observed.

- Three Wheeler diagrams - along and across the strike of the basins - were constructed to visualize the lateral and vertical relationships of all lithostratigraphic units. The TNO tectonostratigraphic megasequences subdivisions (TMS-1 to – TMS-5) were applied the study area, using a new and revised biostratigraphic information and age dating.

- Regional seismic interpretation was undertaken using all available 3D and 2D surveys. Seven horizons were mapped: bases of TMS-1, -2, -3, -4 Lower and -4 Upper.

- The overall basin evolution shows an infilling of the rift basins during the Kimmeridgian to Valanginian, with prevalence of proximal depositional environments (TMS-1 to TMS-3). From the Valanginian to Barremian the rift basins become overfilled and sediments start onlapping on the lateral platforms which were subject to erosion since the early phases of rifting. The depositional systems become increasingly marine during that later part of the basin evolution. The resulting geometry is a composite unconformity with sediments onlapping onto the lateral platforms, widening the size of the basin toward the SE and NW.

- On the western platforms, fault scarps inherited from earlier phase of rifting created topographic features onto which Lower Cretaceous sediment onlapped, then buried, stepping over those paleo-topographic features and allowing for sediment to reach further toward the W and SE.

- Structural analysis shows that many faults affecting the geometry of the rift basins and platforms, were syn-depositional faults. Many of these faults were reactivated as reverse faults during the Late Cretaceous and Cenozoic.

- The integration of time structure and time thickness maps, in association with fault mapping, show that the basins were affected by strike-slip tectonics. These basins may be classified as transtensional pull-apart basins, with en-echelon bounding faults and changing fault trends. Most of the intra-basinal highs and lows (horsts and grabens) were also present during the Late Jurassic and Early Cretaceous. These were formed as part of the transtensional pull-apart rift systems, forming sigmoidal to rhomboidal-shaped sub-basins and highs.

- Significant stratal thickness differences can be observed across some faults. For example, during deposition of the upper part of the Nieuwerkerk Fm. (upper part of the Alblasserdam Mb., Delft Sandstone Mb. and to some extent the Rodenrijs Claystone Mb.), movement occurred along newly formed WNW-ESE oriented faults (likely Valanginian - Early Hauterivian). This led to a notable across-fault thickness difference in the Delft Sandstone Member.

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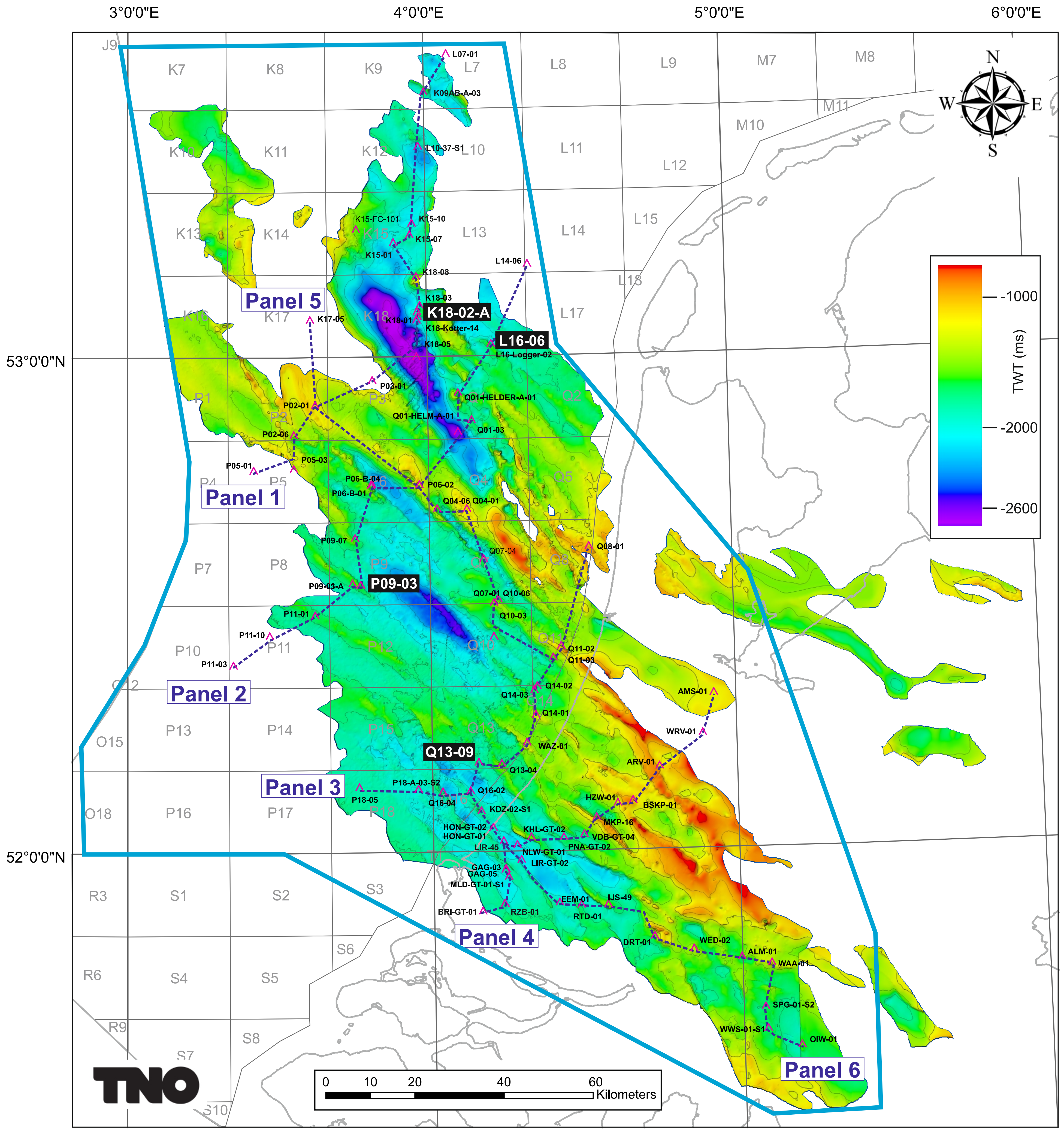
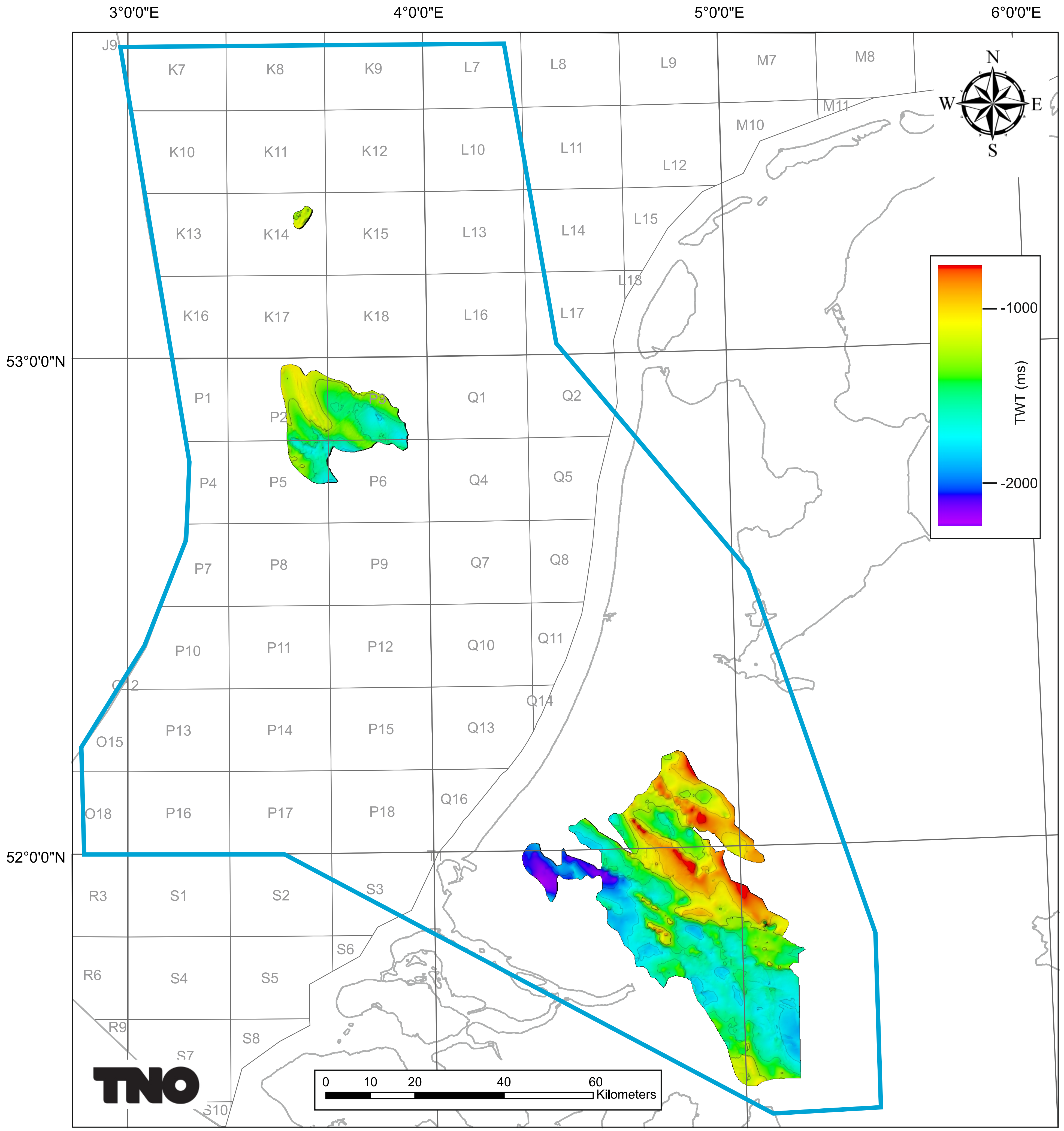
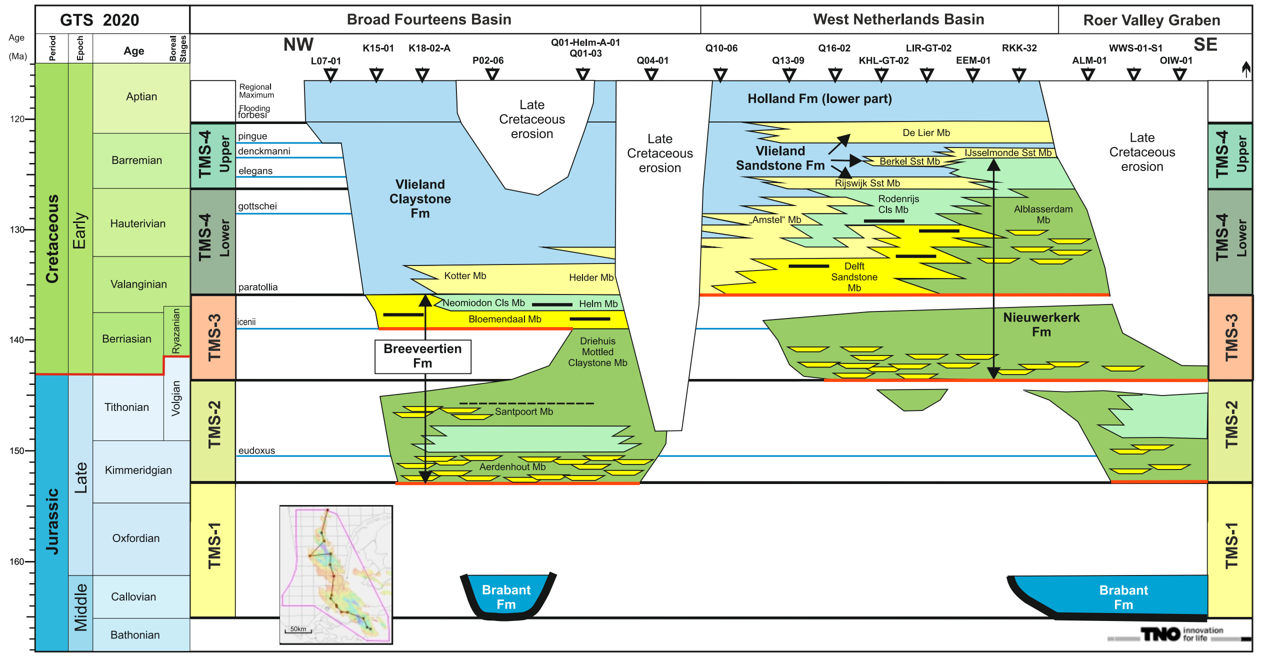
8 Appendices – HR Atlas

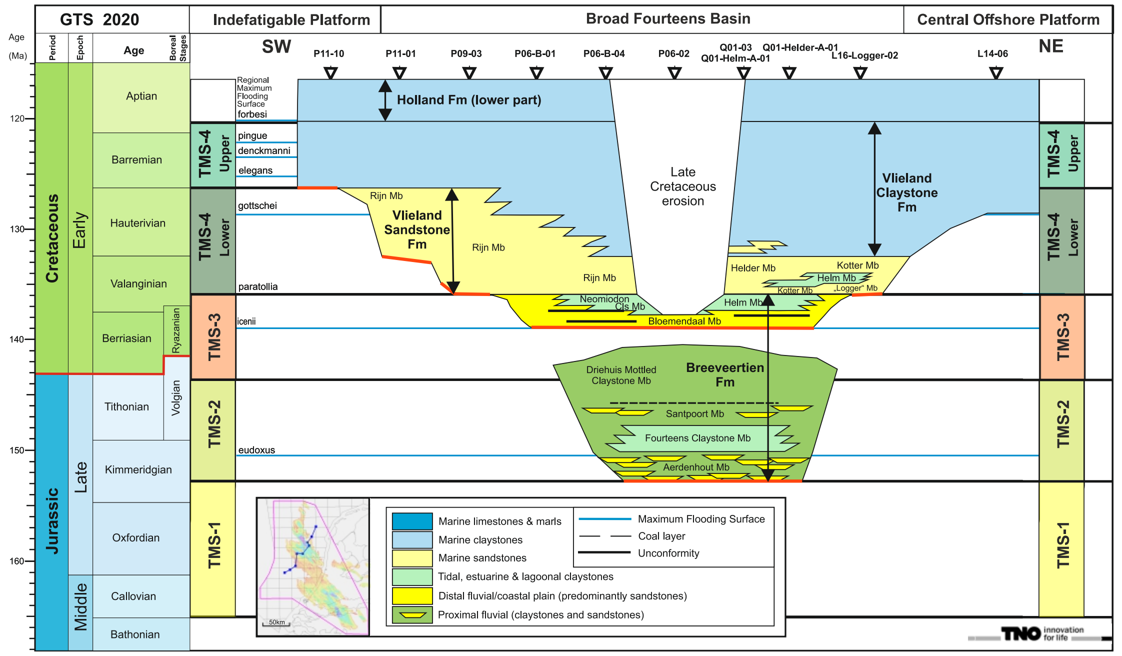


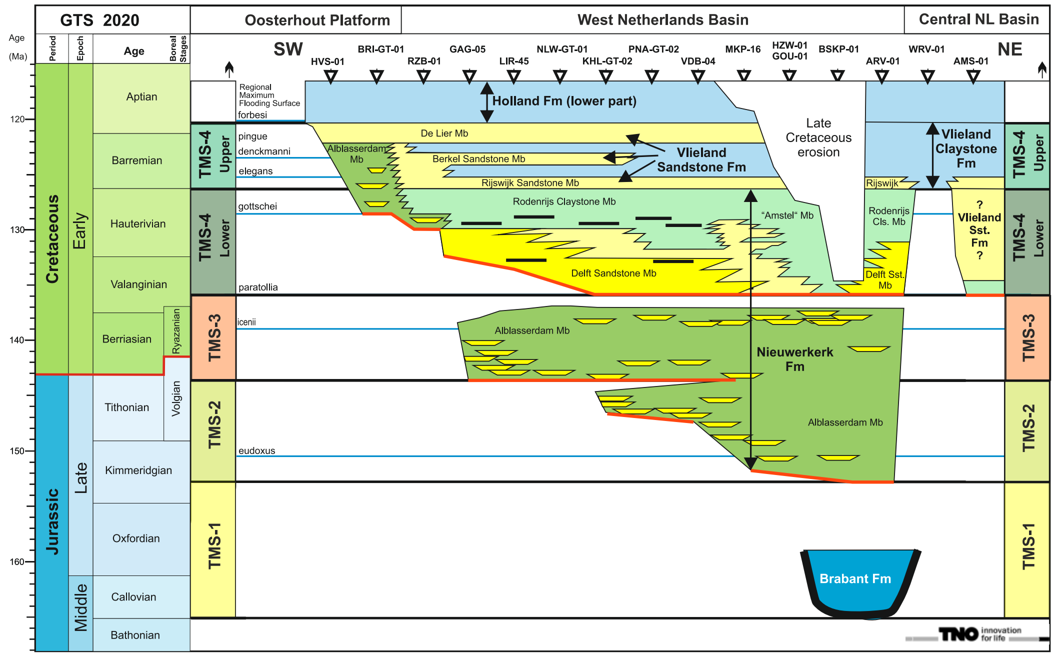
Location map of the Appendix B (regional well/seismic panels 1 to 6) and Appendix C (5 cores from 4 wells). Background map is the time structure map of TMS1-2-3 and 4 Lower combined.

Base TMS-1



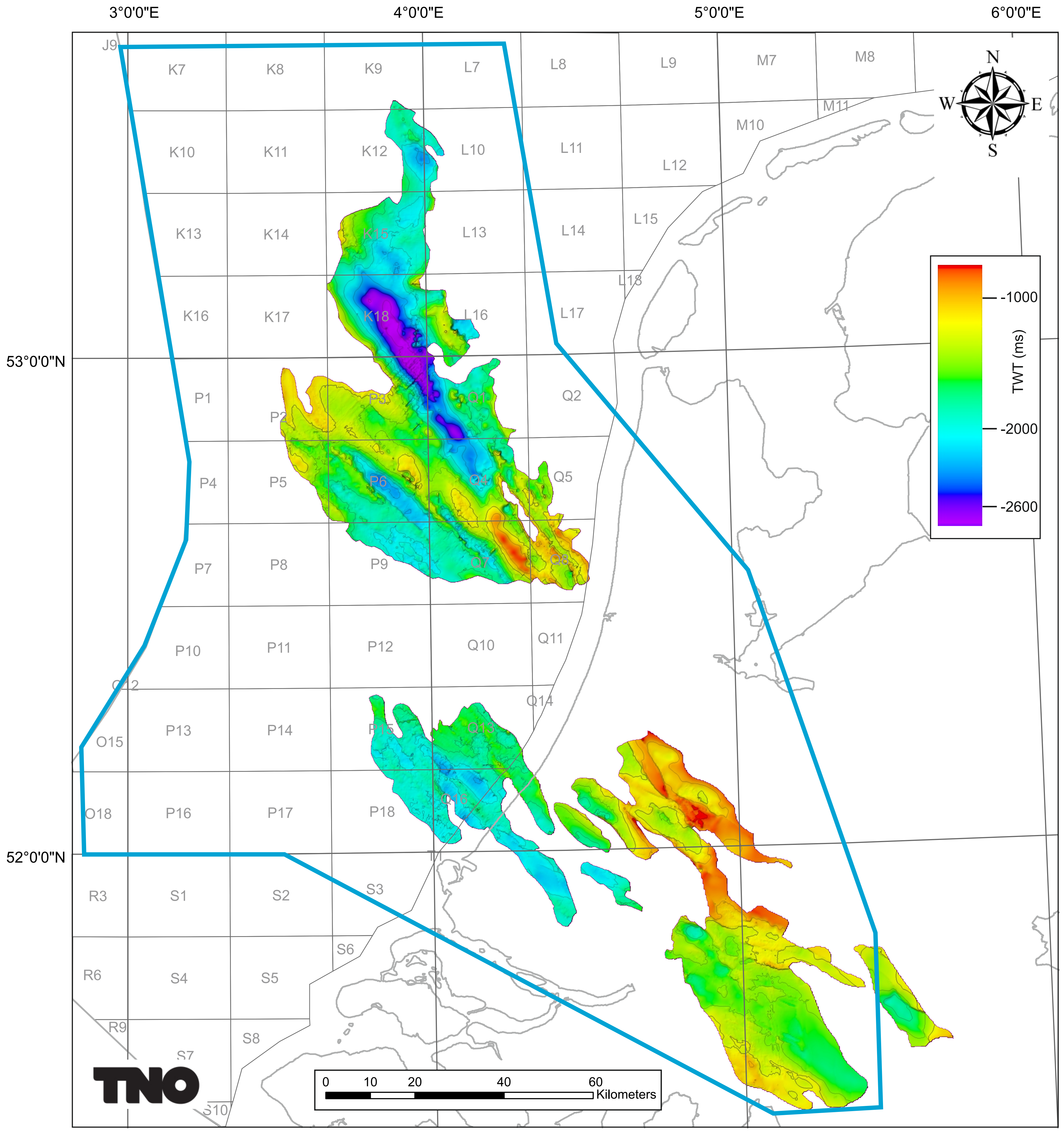


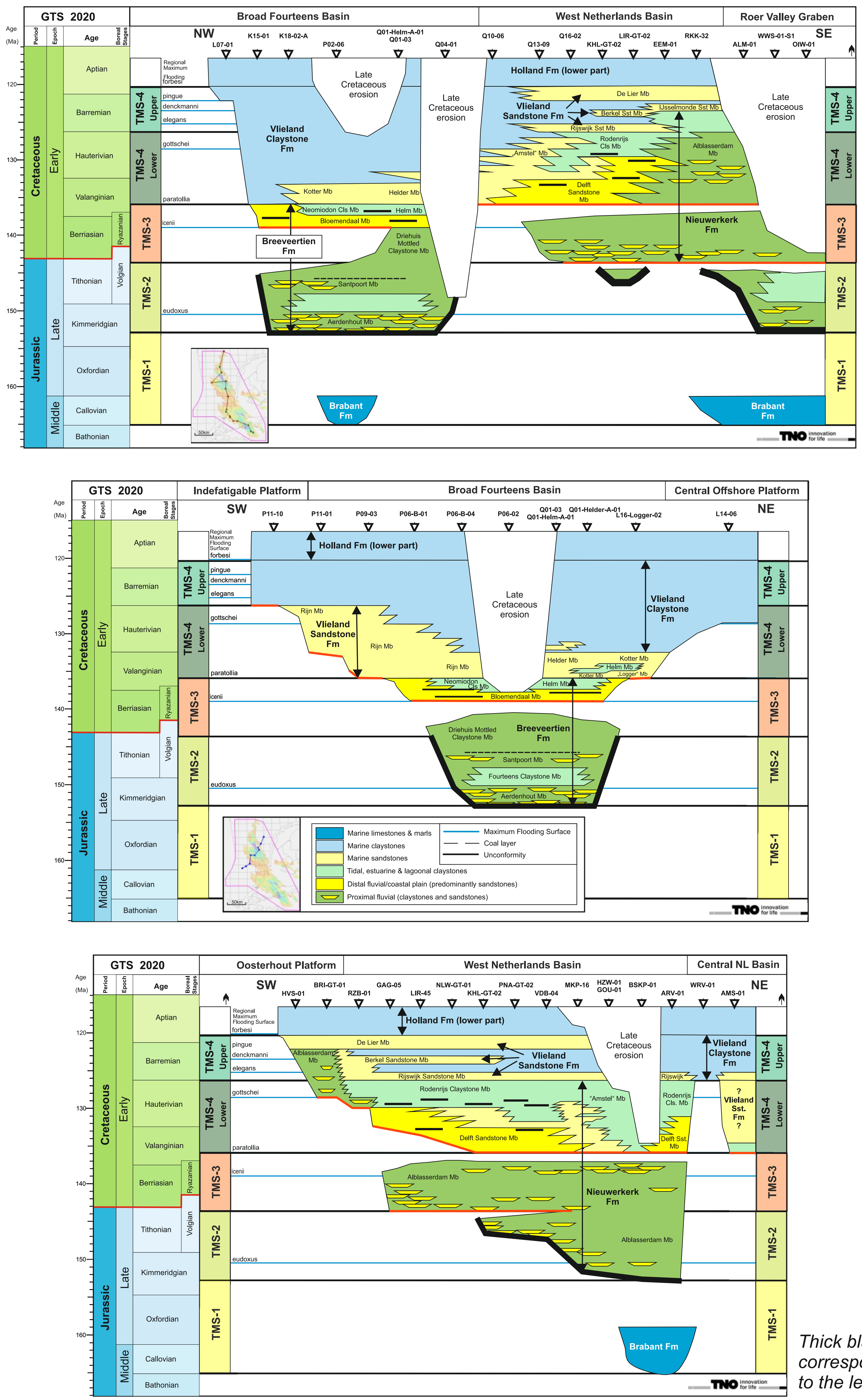




Thick black lines correspond to the map to the left.

Base TMS-2

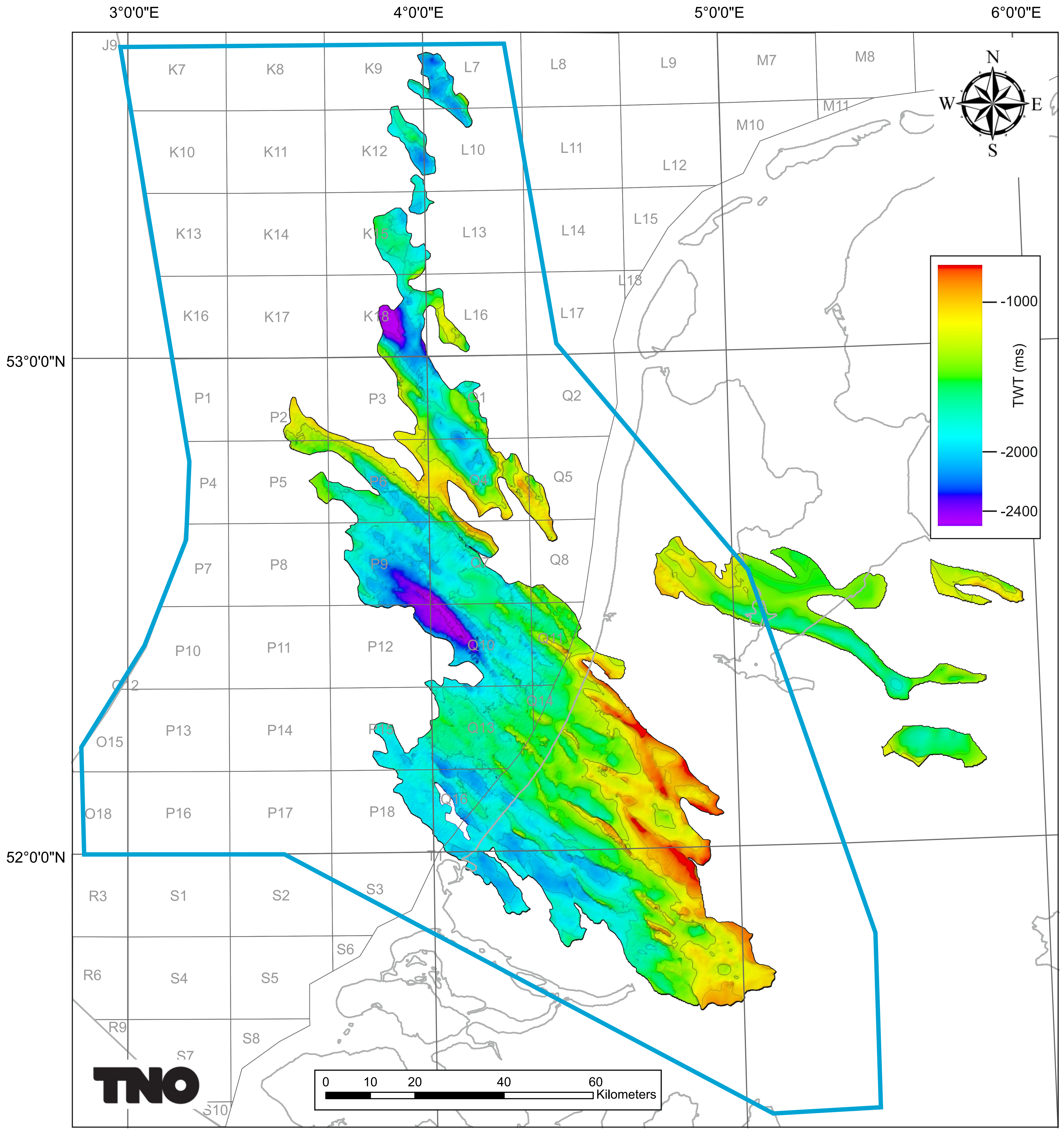


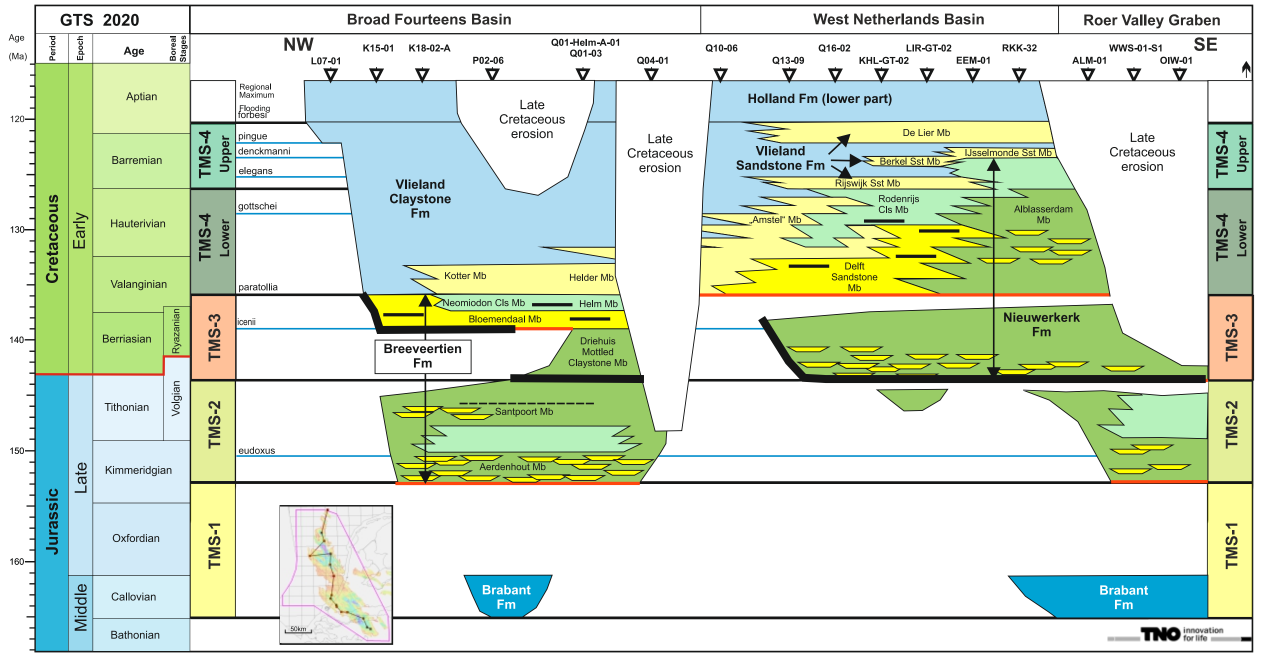


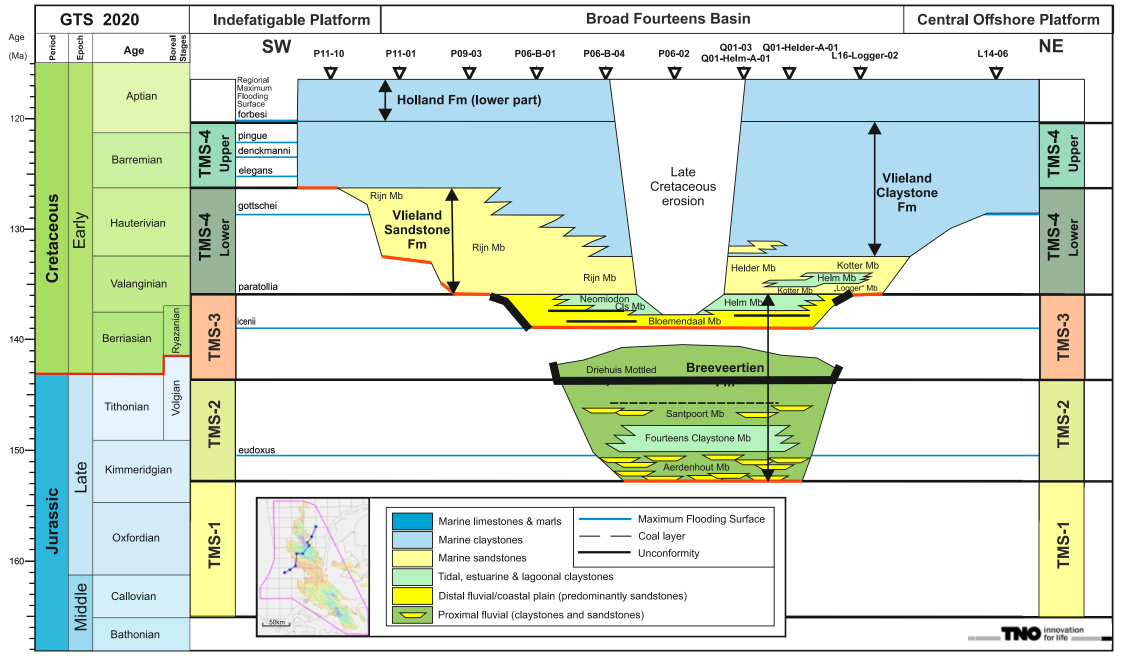
Thick black lines correspond to the map to the left.

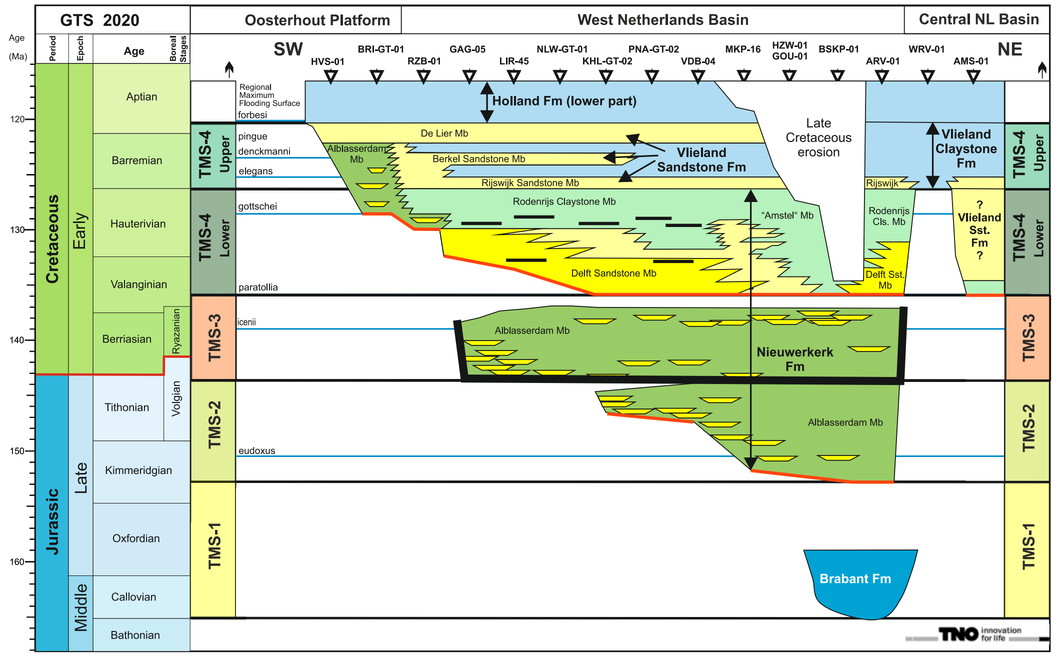
Appendix A: Time Structure Maps

Base TMS-3



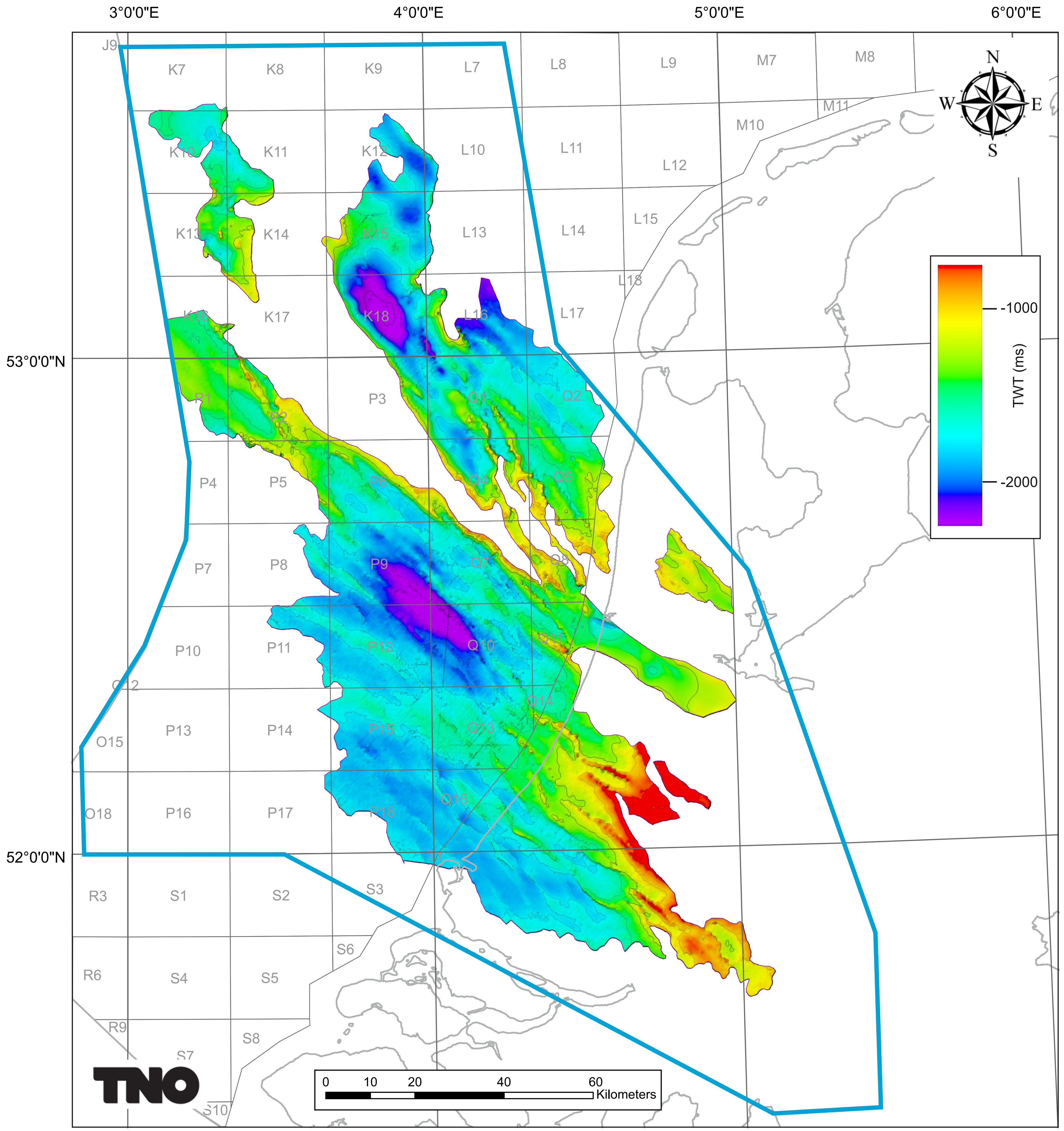


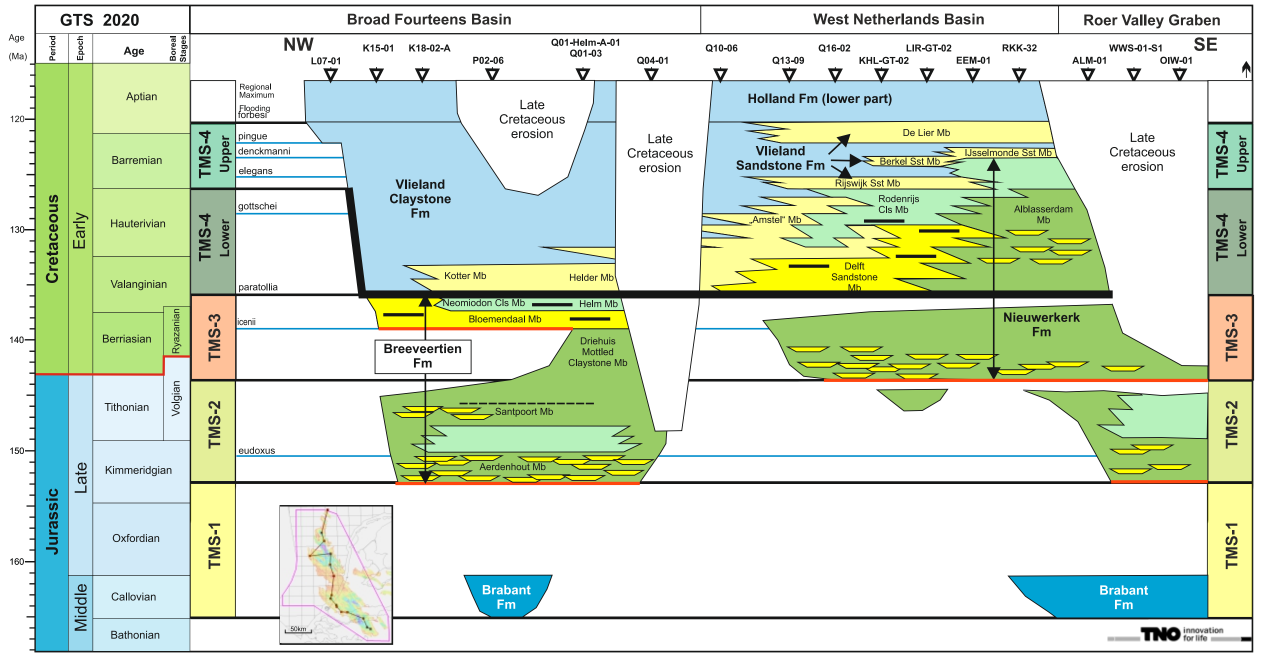


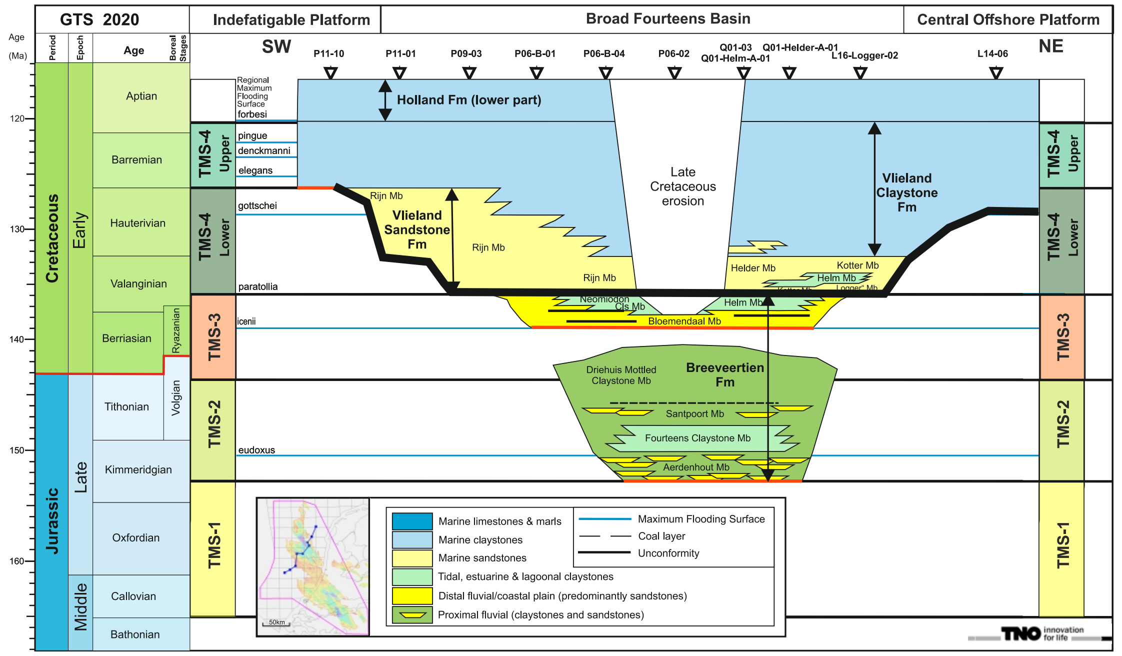


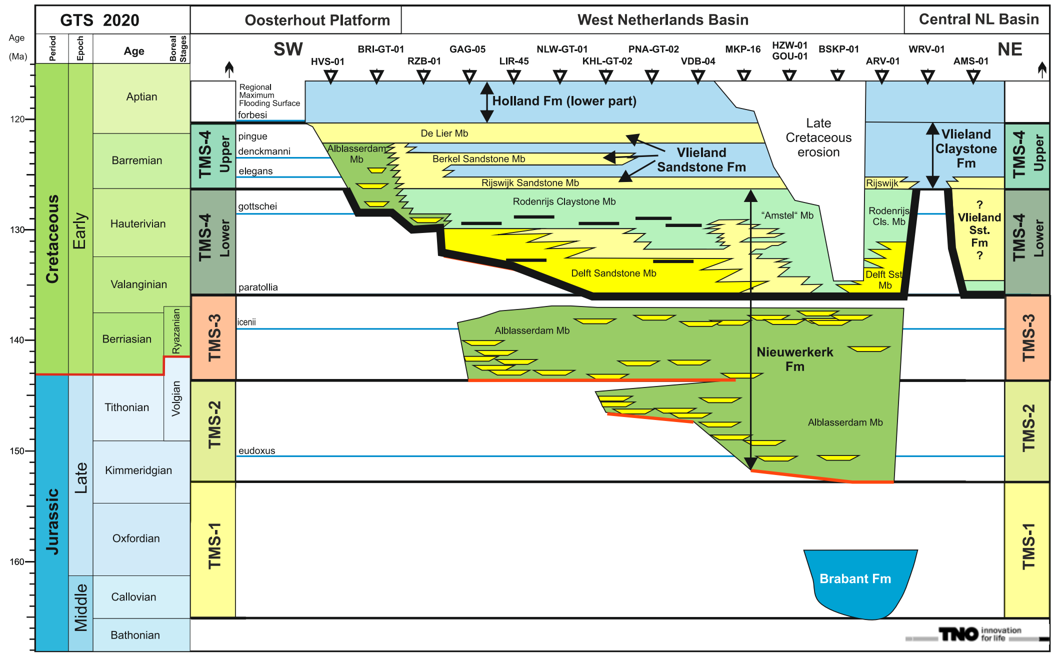
Thick black lines correspond to the map to the left.

Base TMS-4 Lower



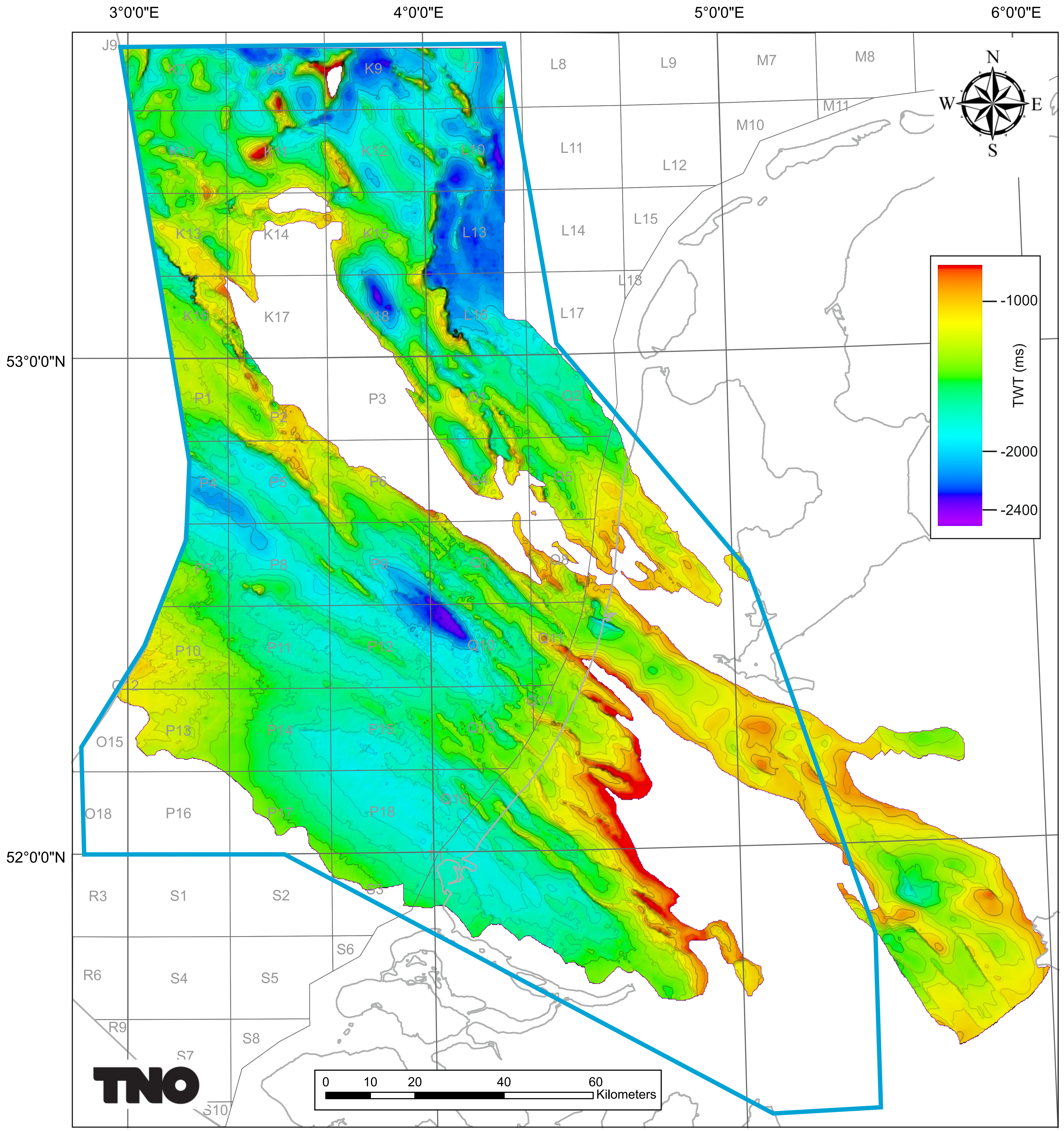


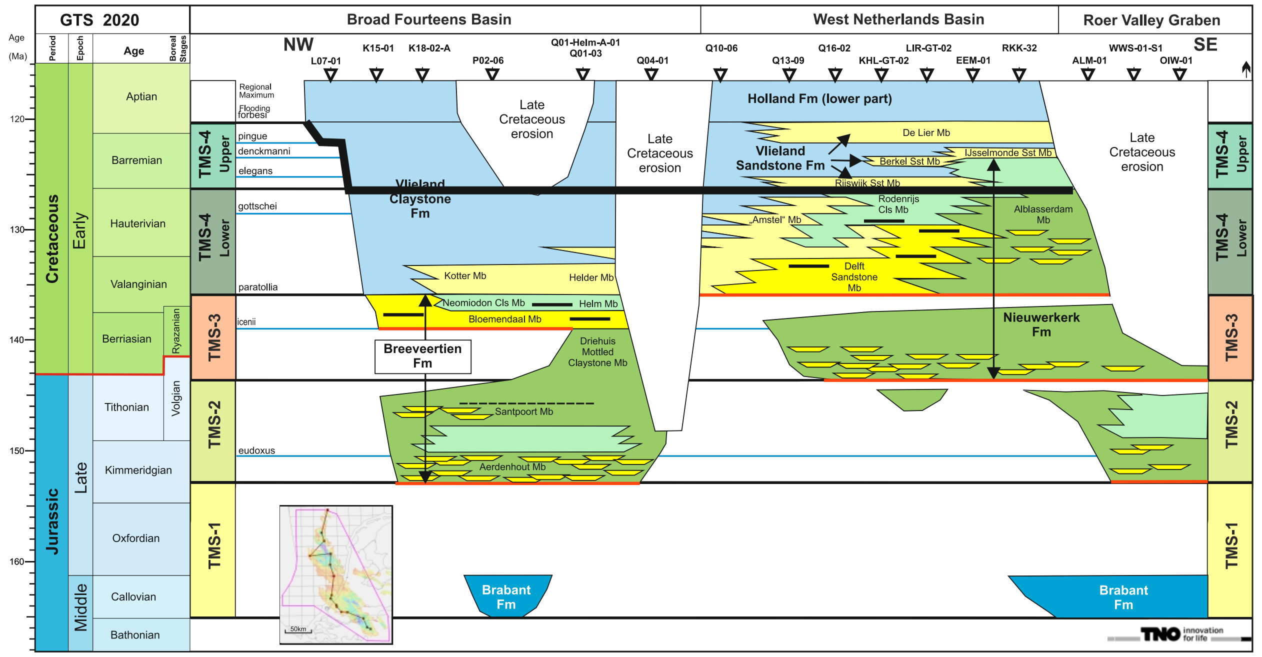


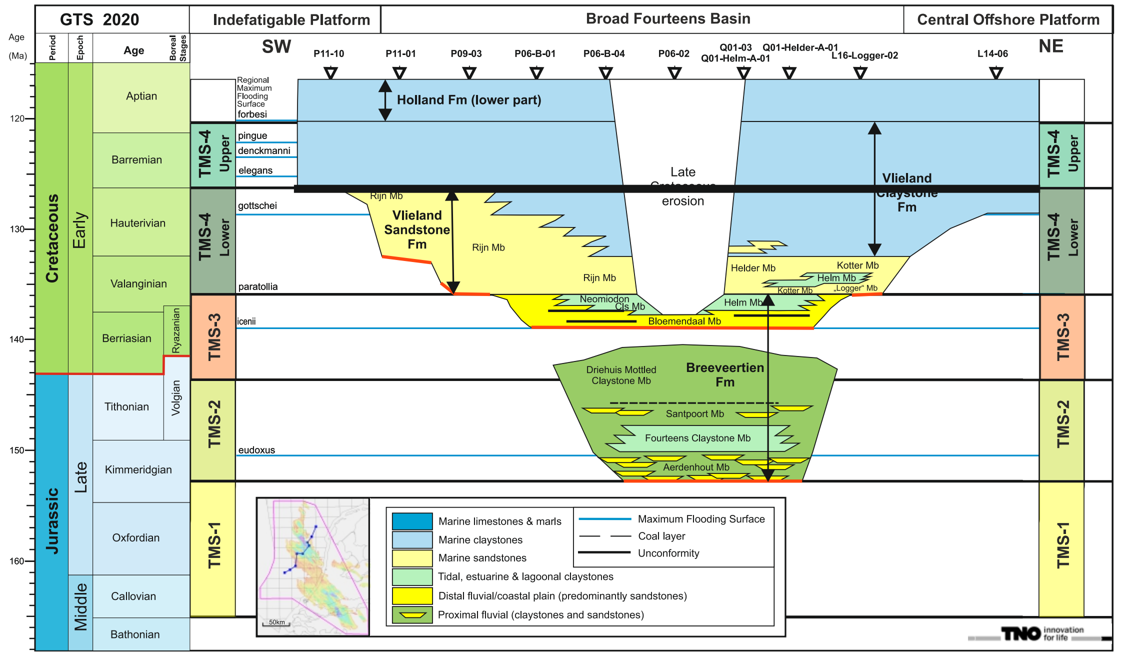


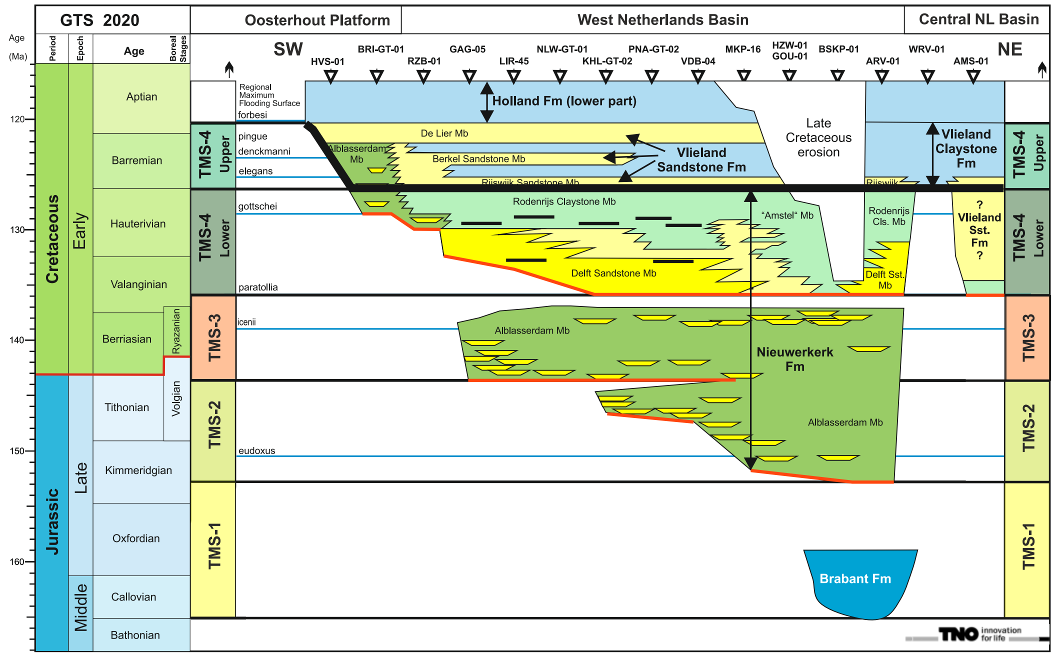
Thick black lines correspond to the map to the left.

Base TMS-4 Upper









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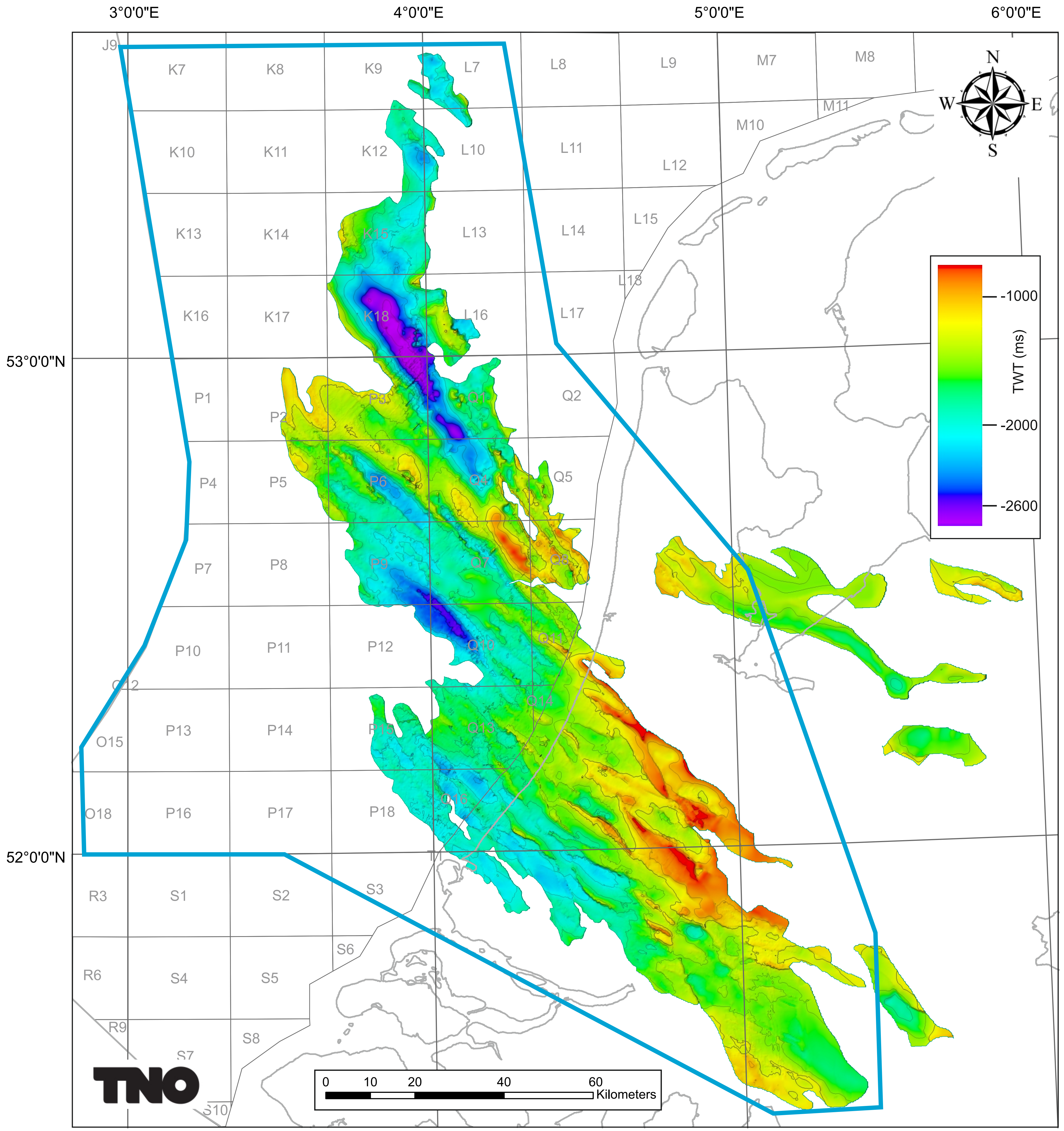
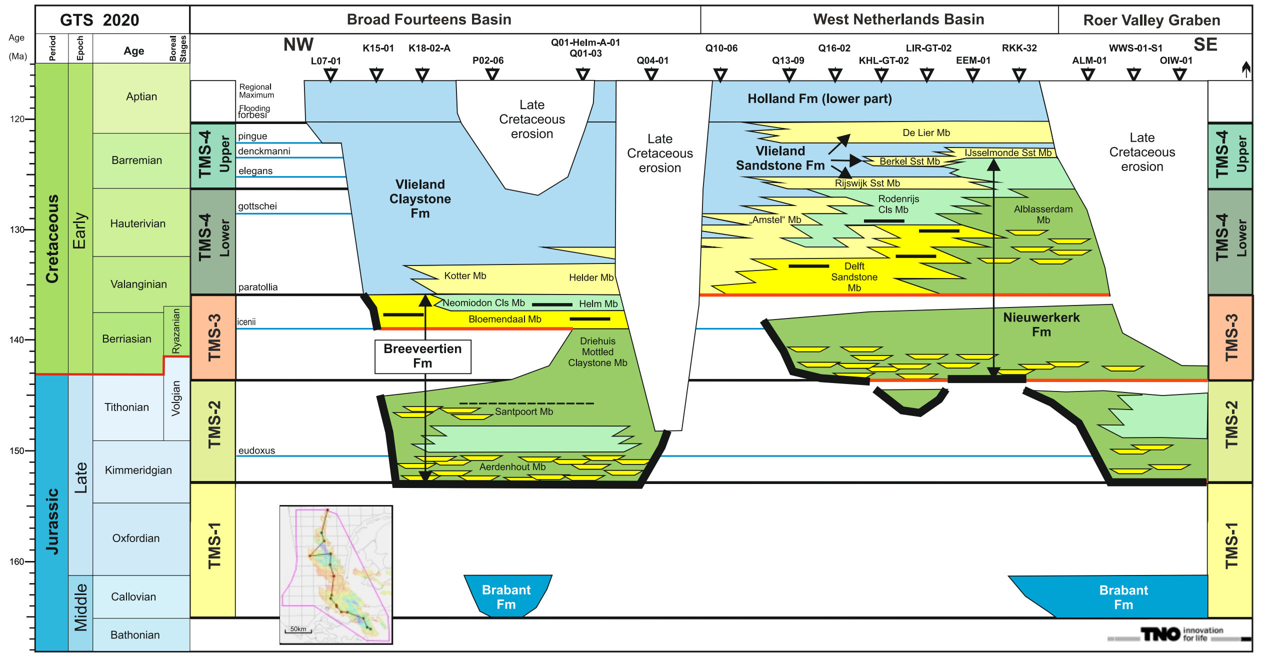
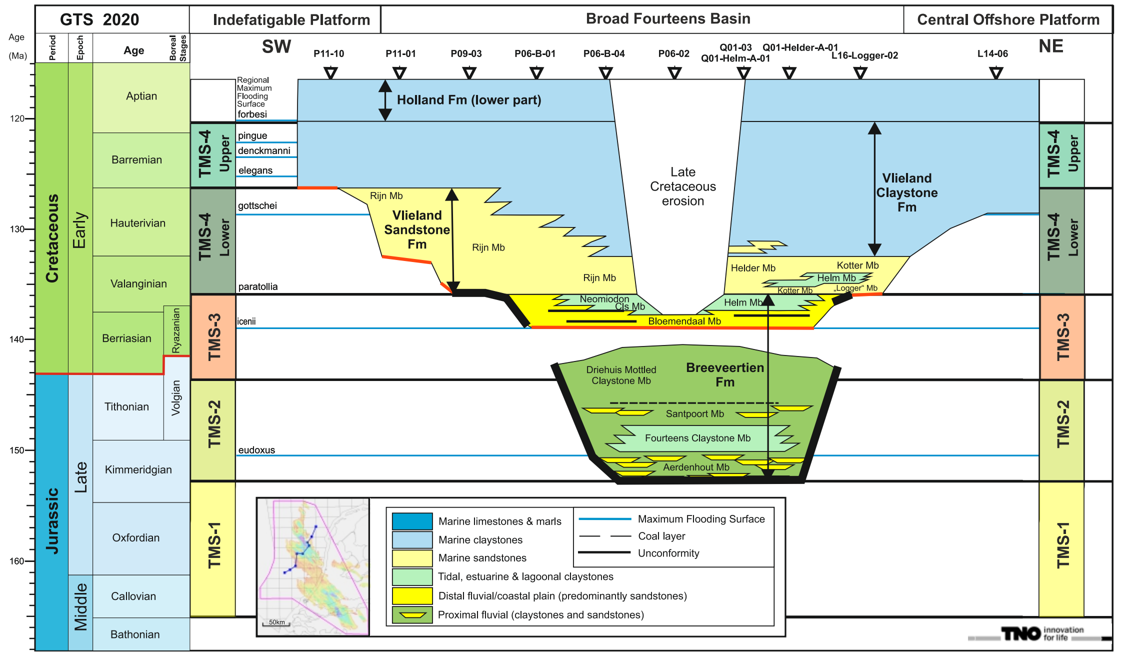
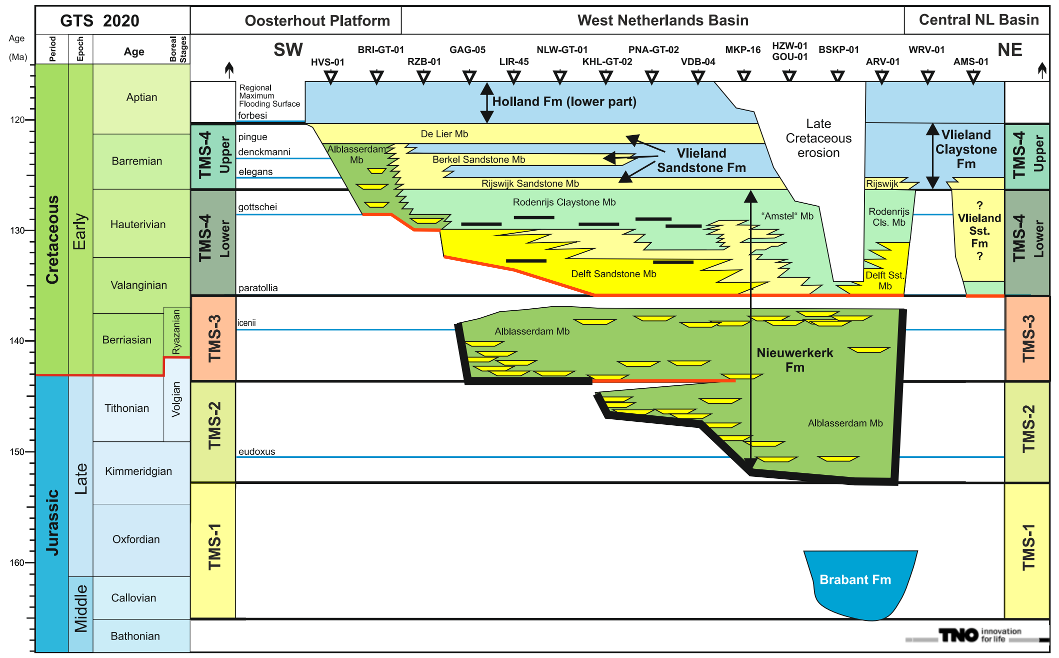
Combined bases TMS-2 and TMS-3









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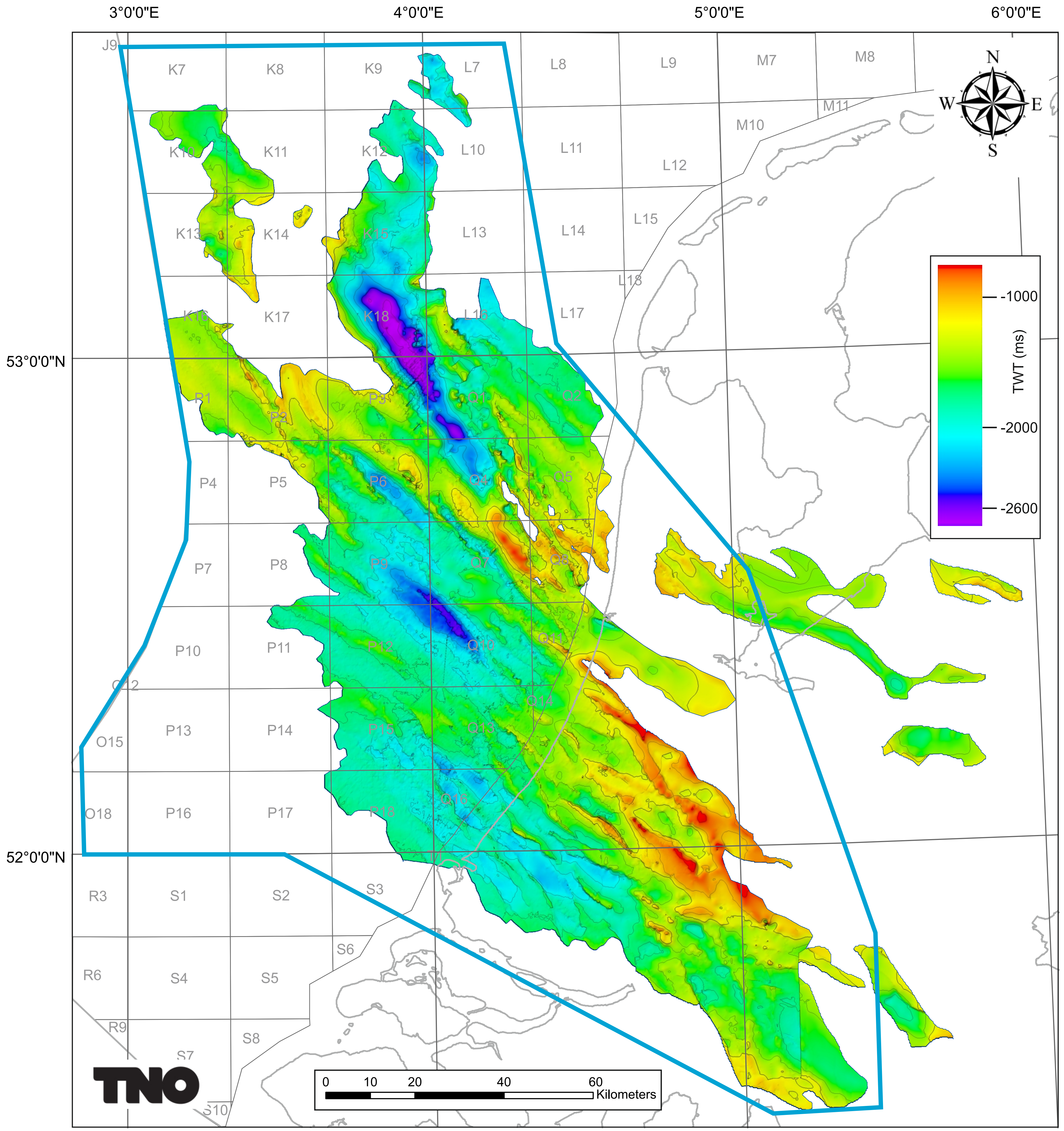
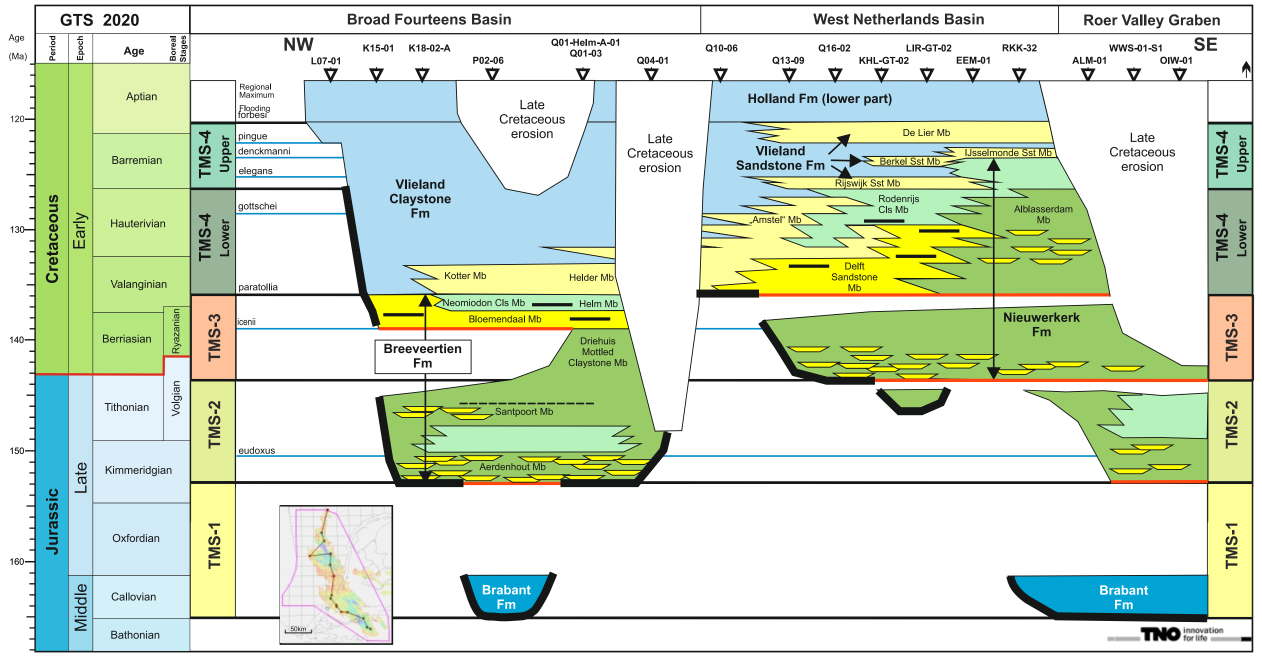
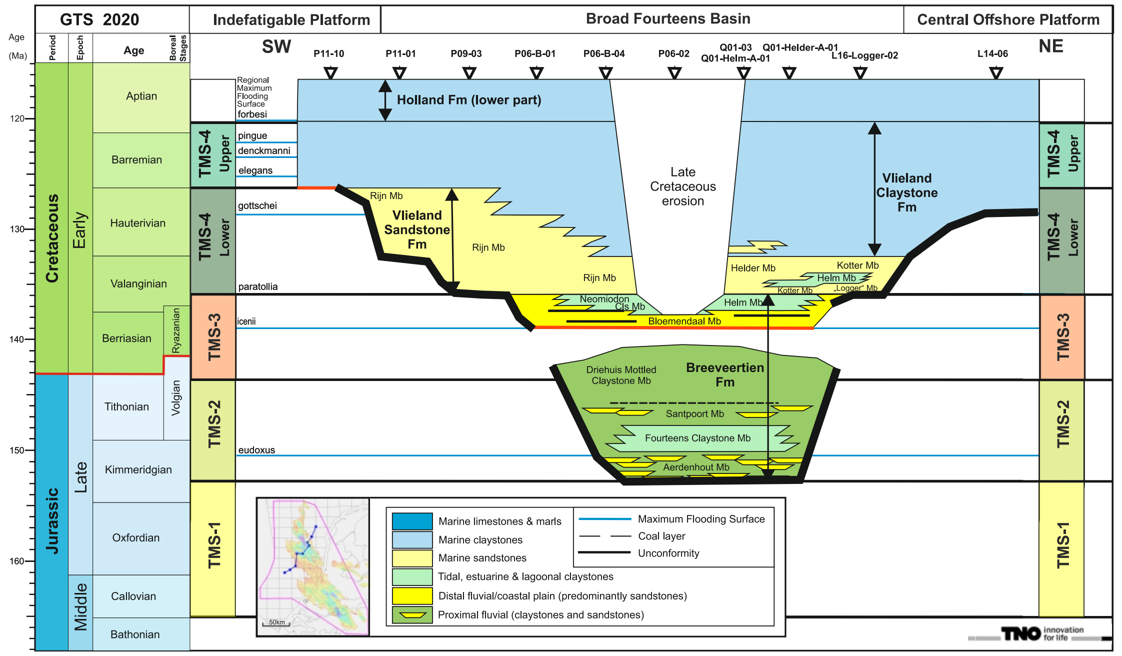
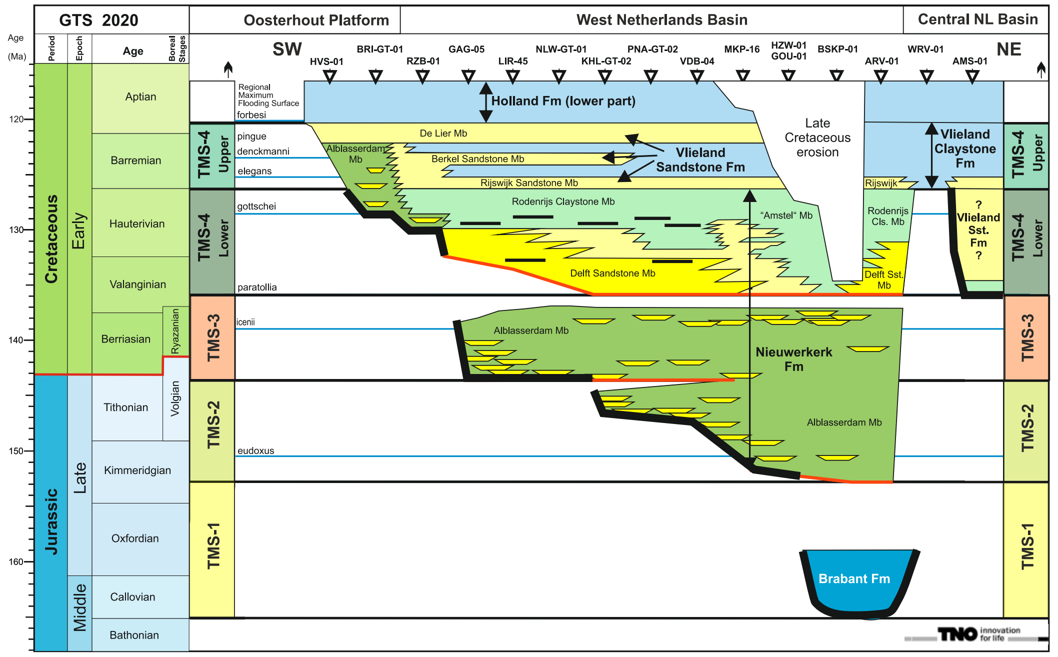
Combined bases TMS-1 to TMS-4 Lower









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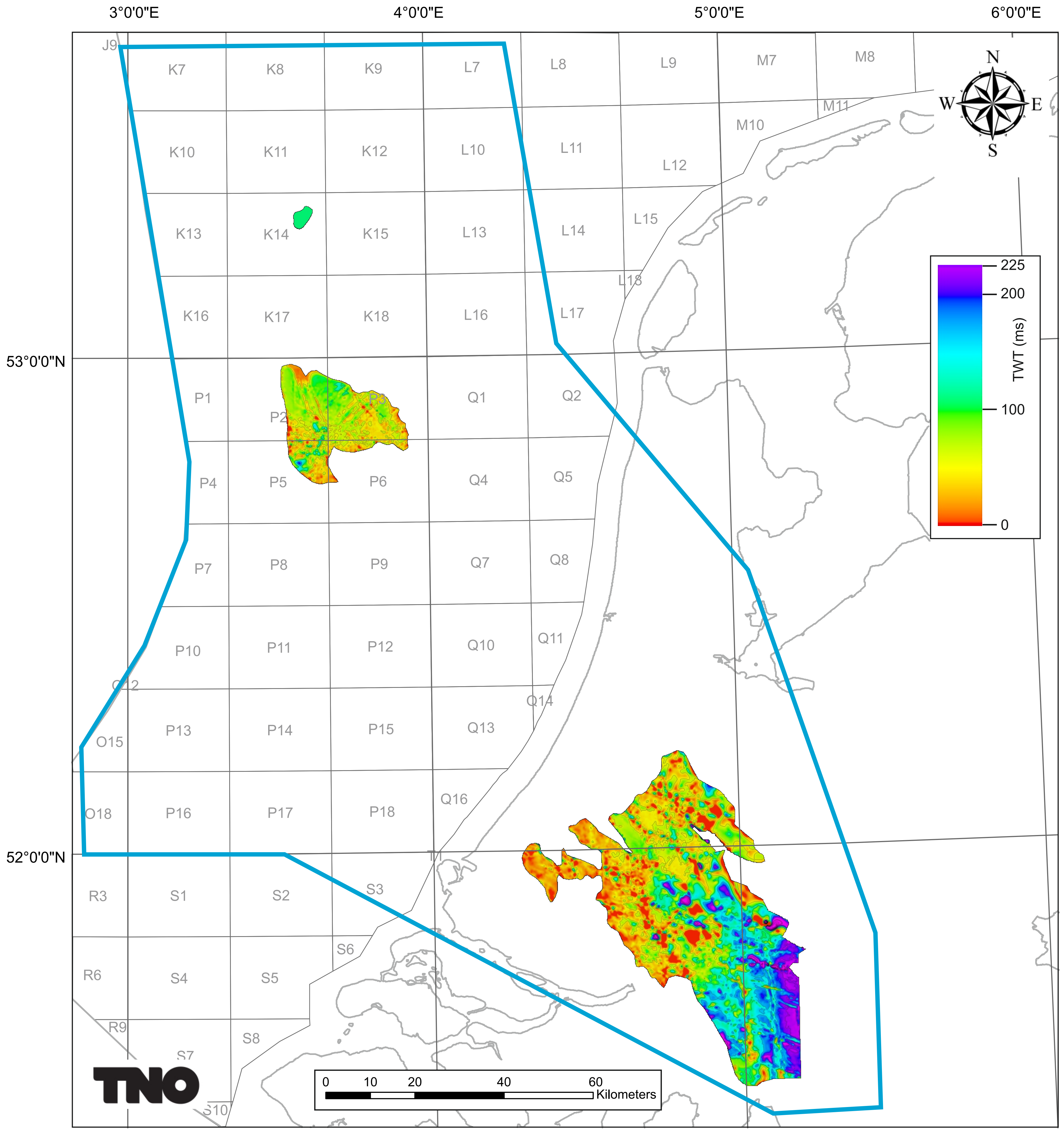
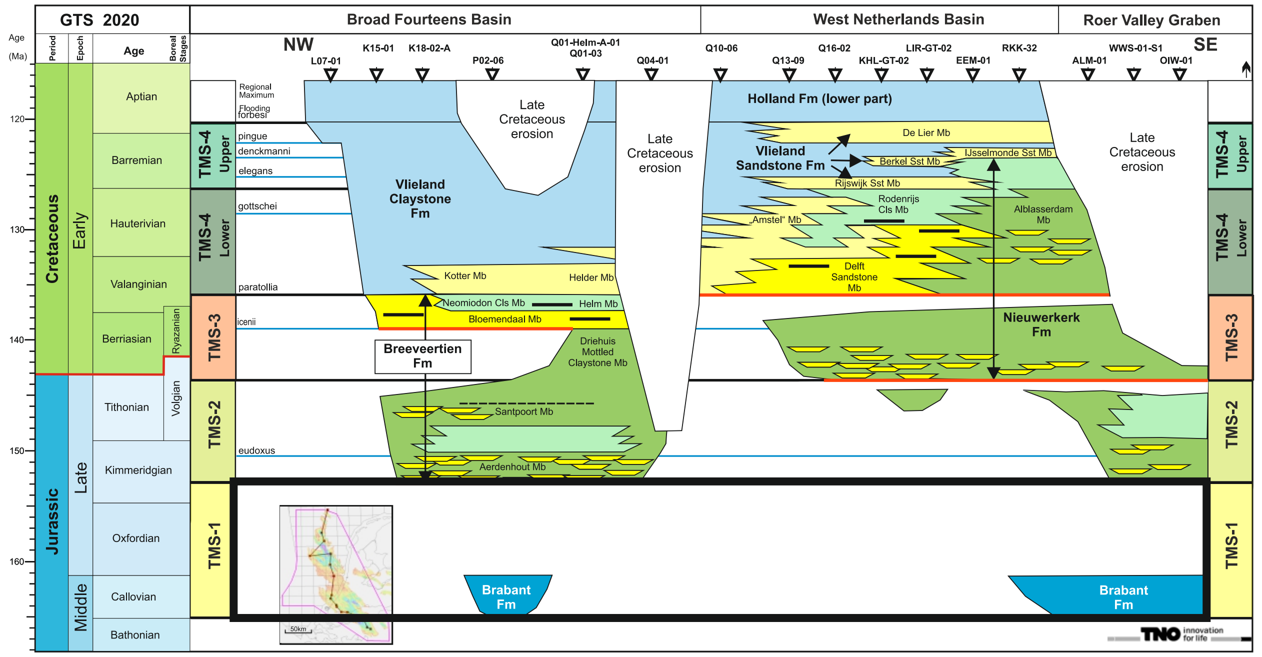
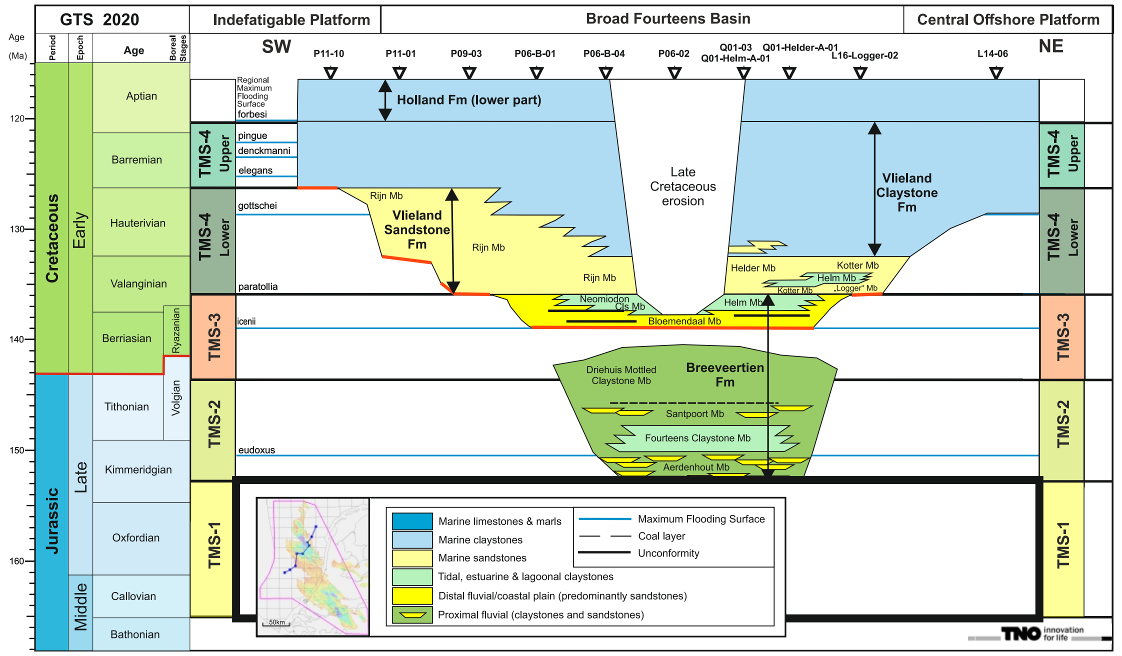
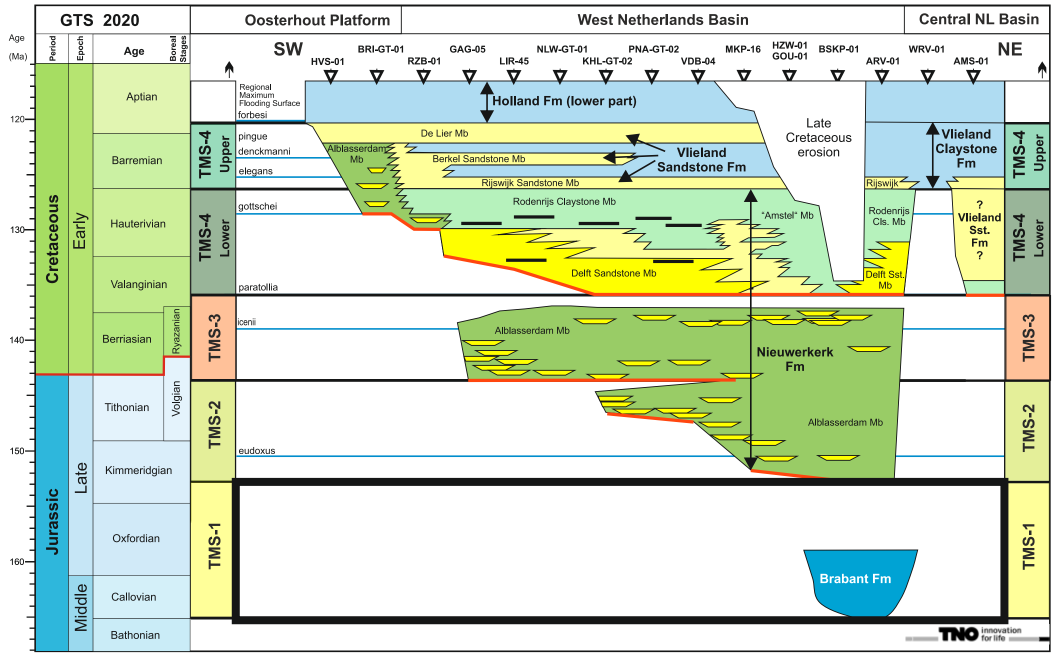
TMS-1 (Callovian - Early Kimmeridgian)









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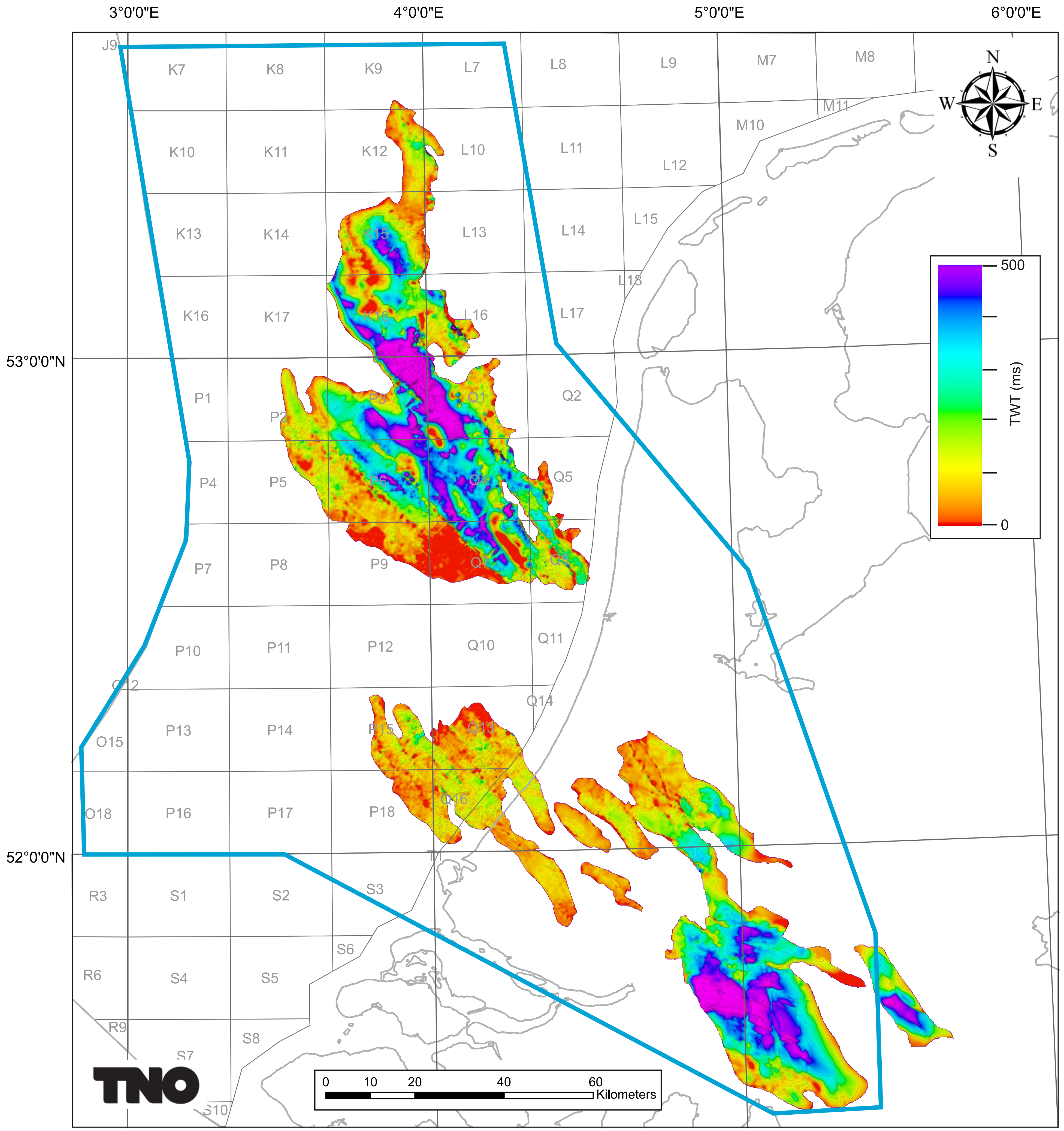
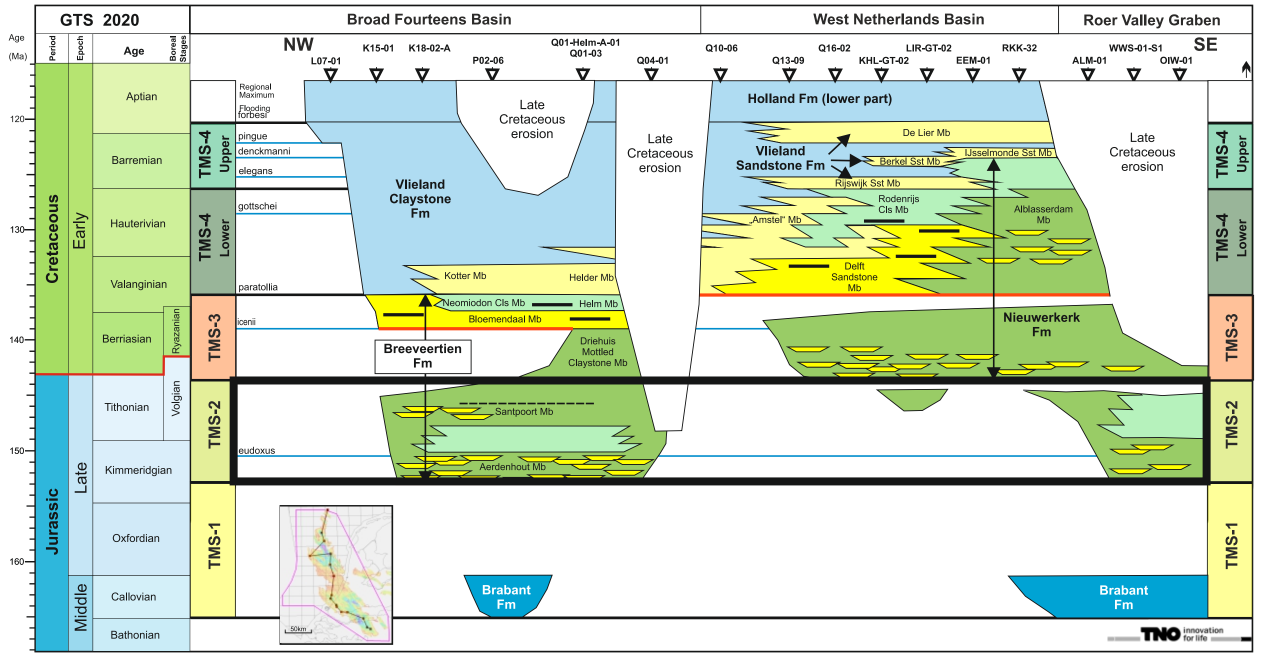
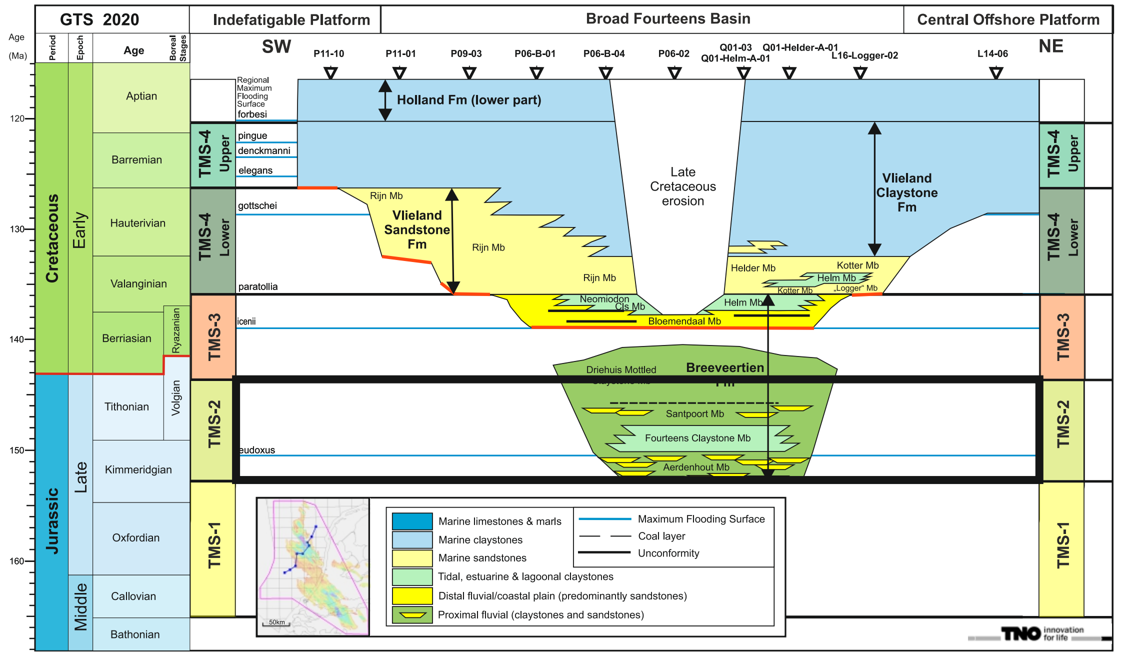
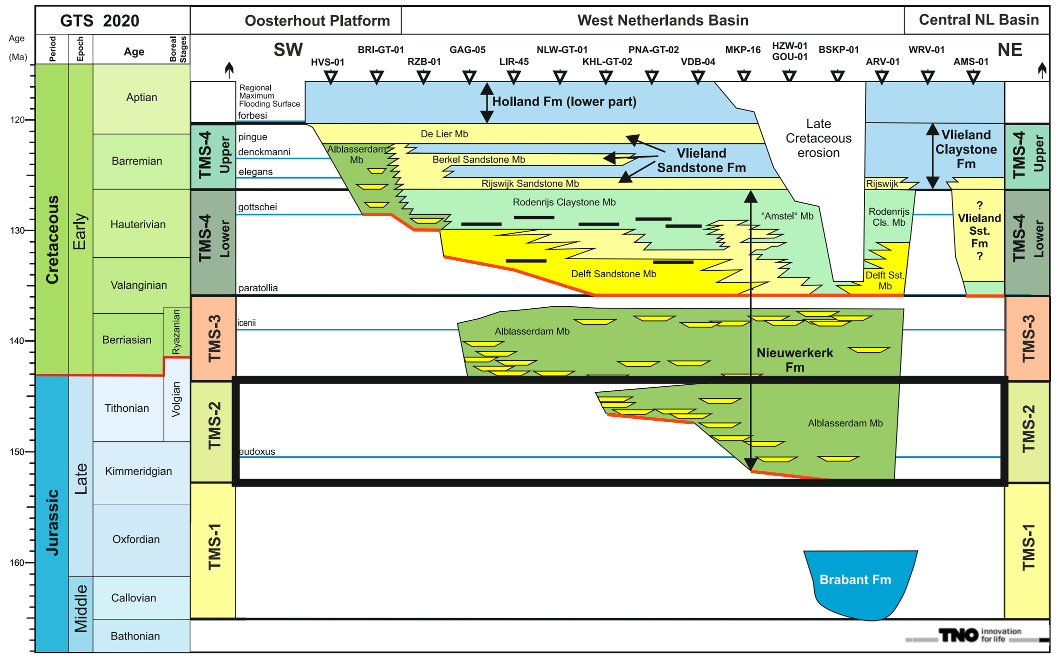
TMS-2 (Late Kimmeridgian - Middle Volgian)









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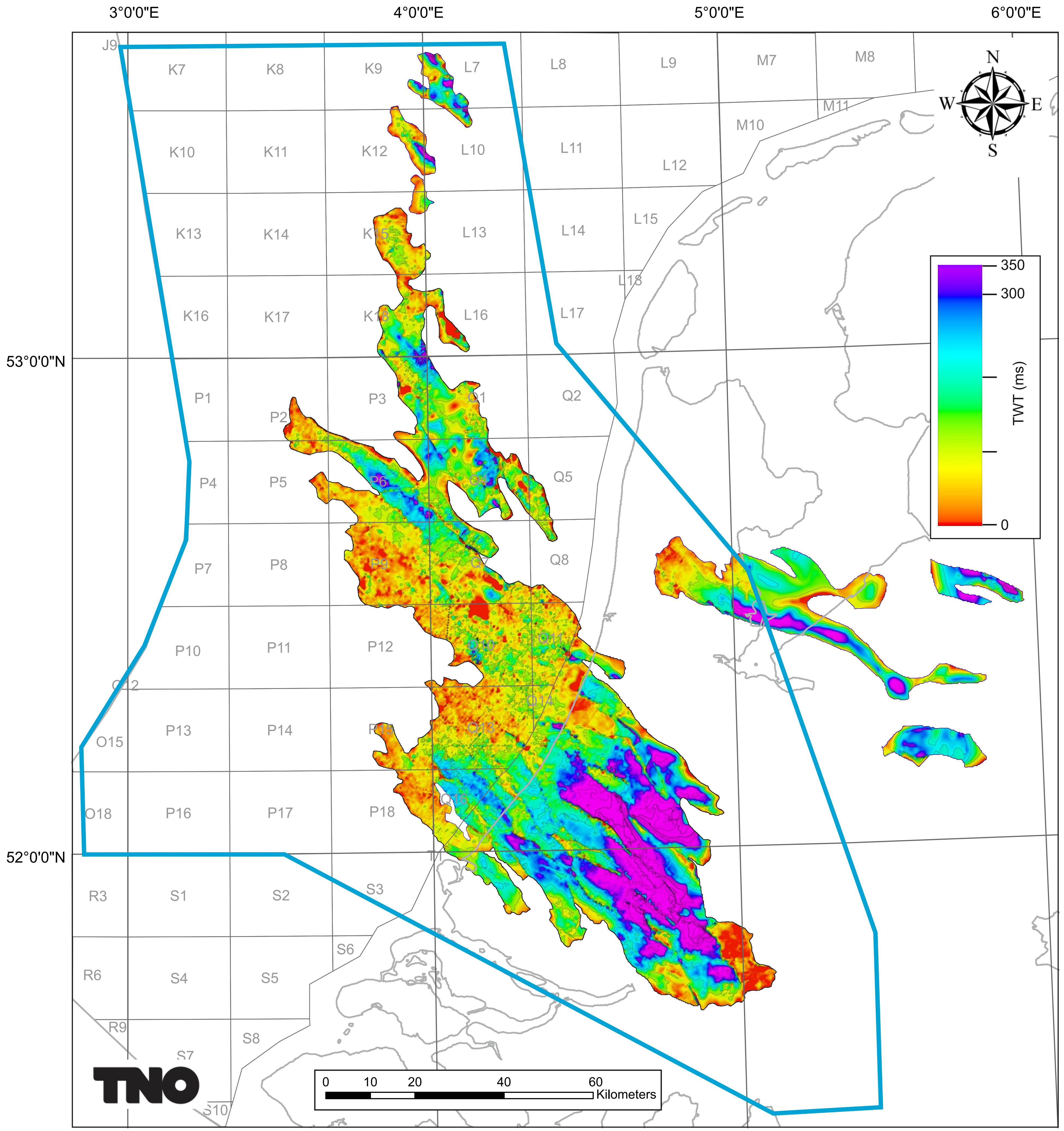
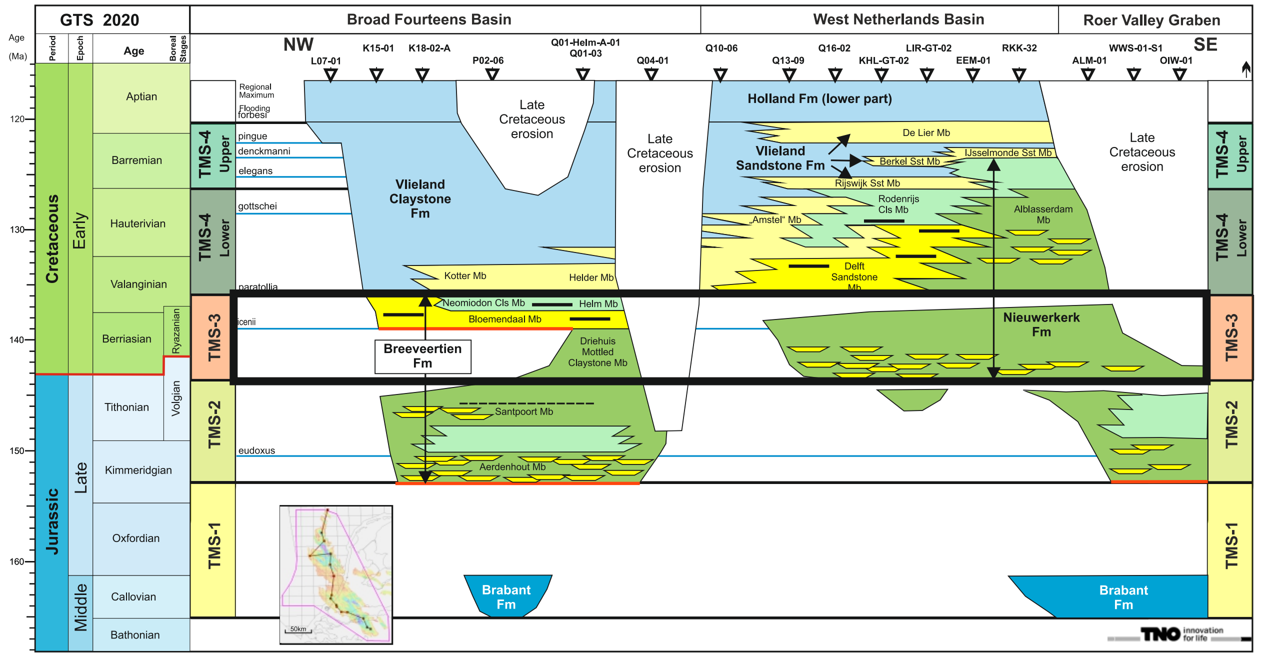
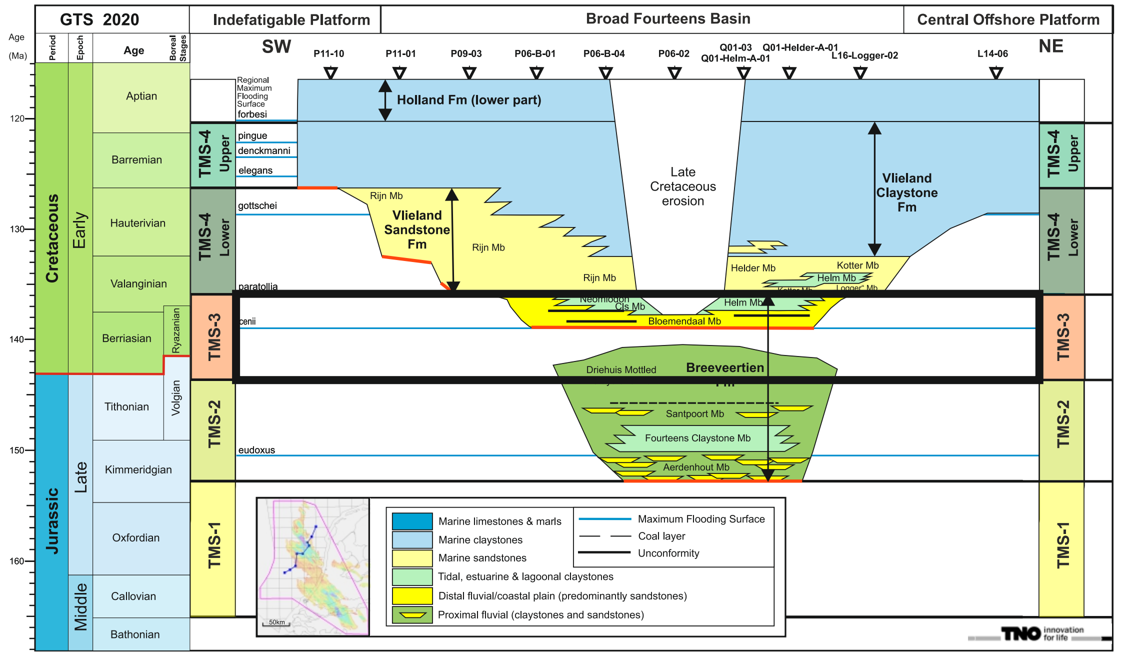
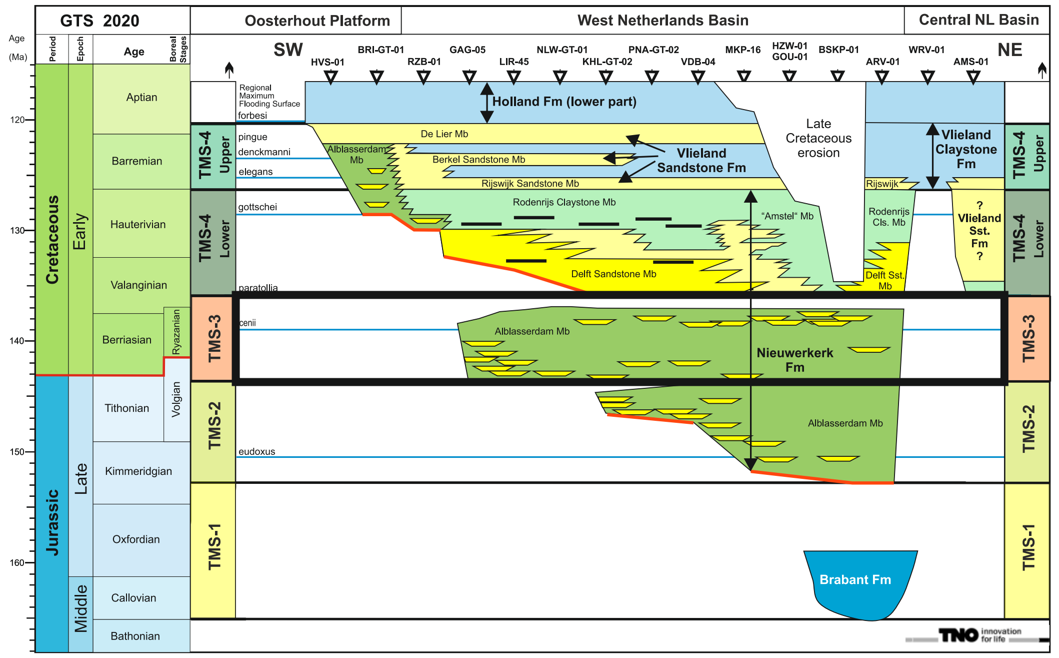
TMS-3 (Late Volgian - earliest Valanginian)









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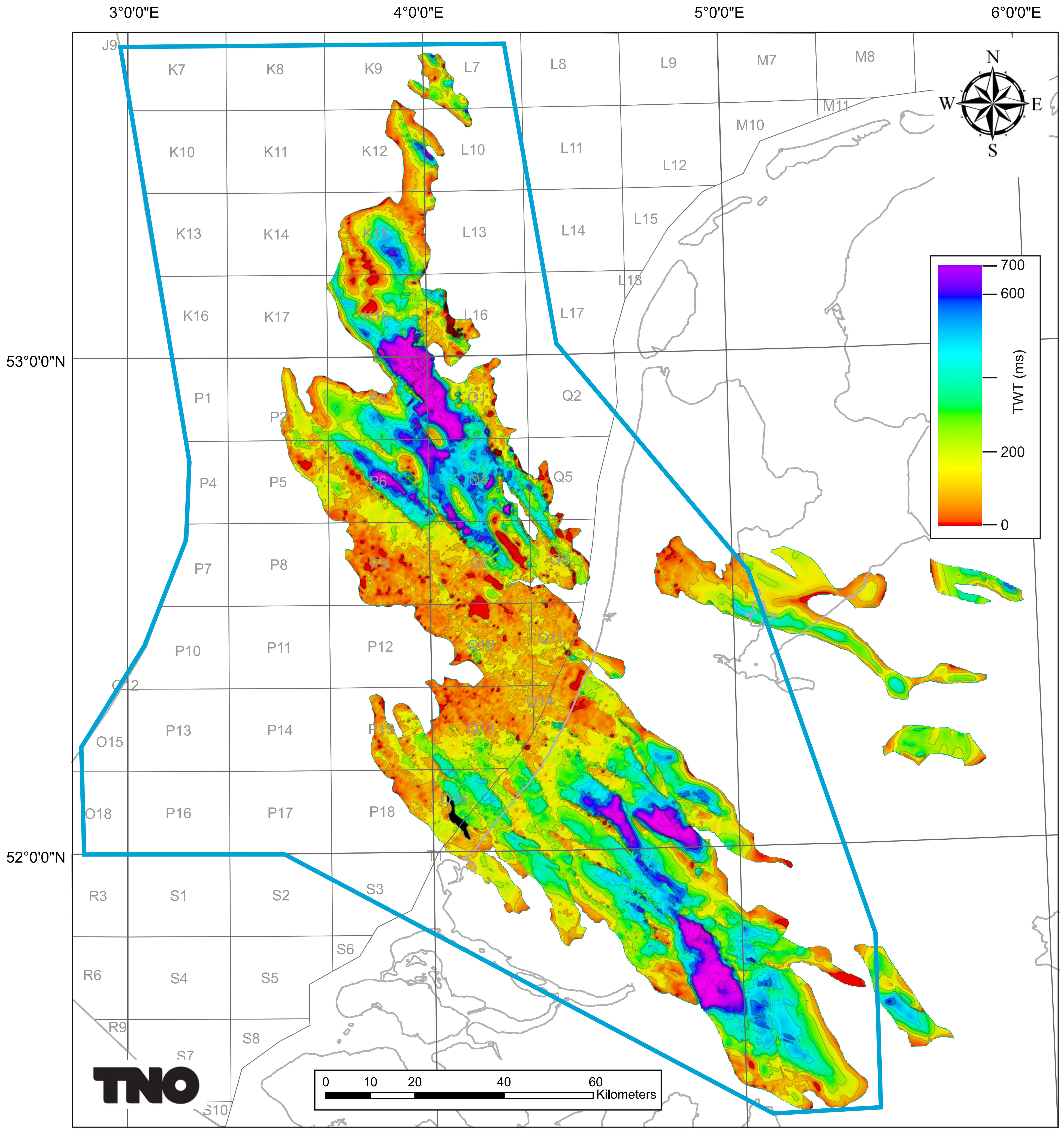
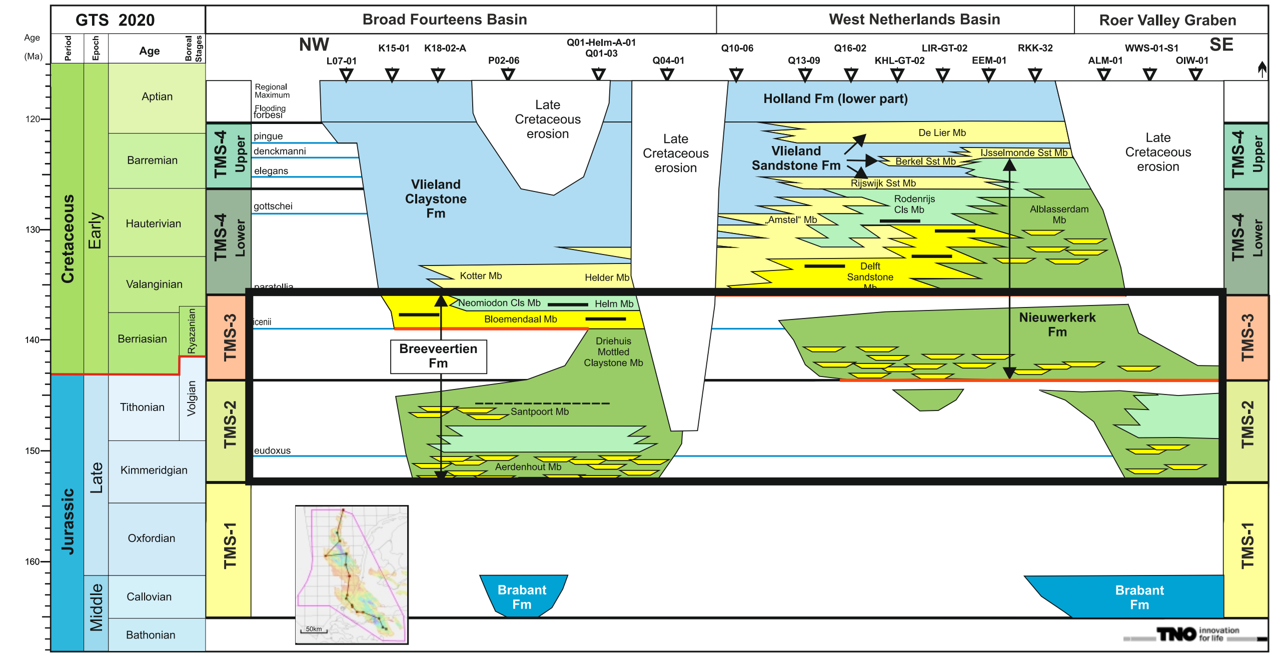
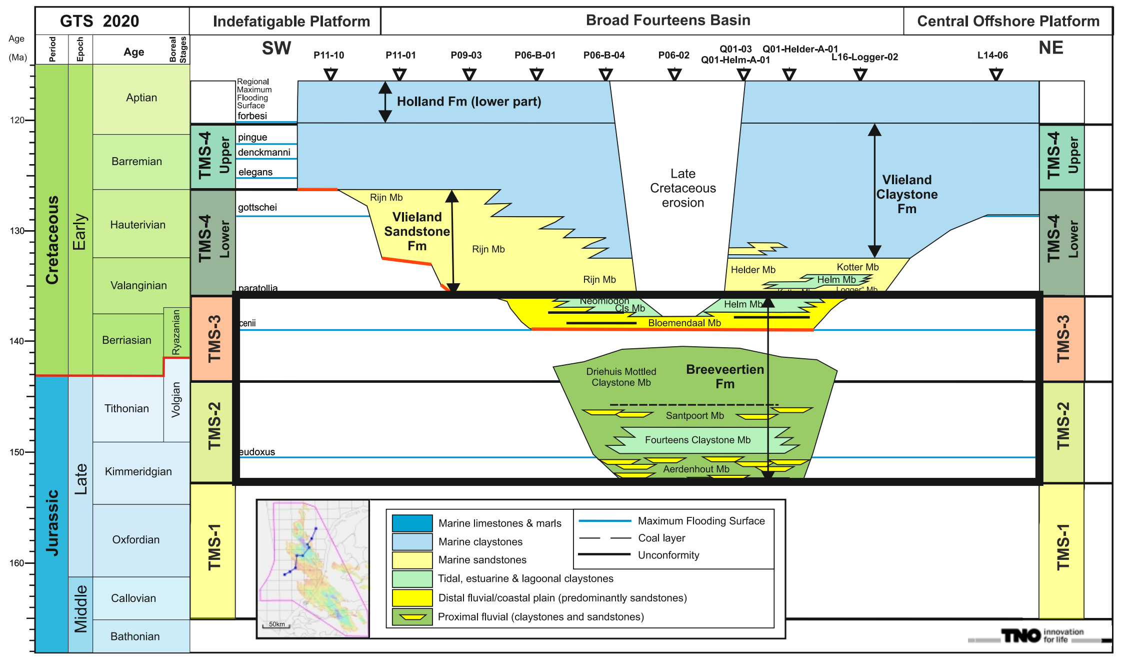
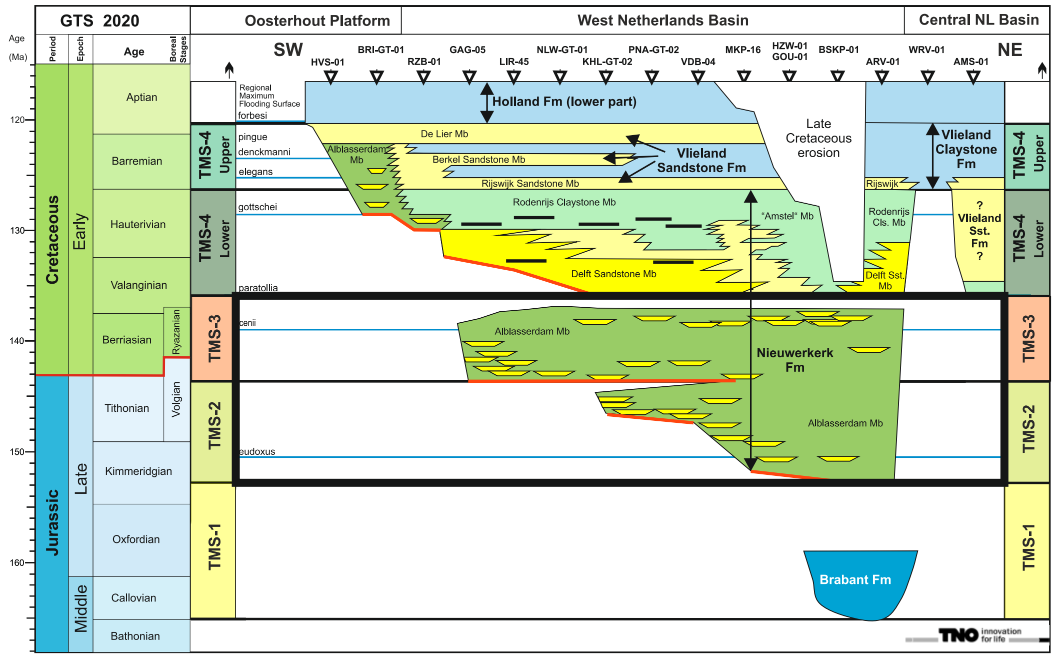
TMS-2 and TMS-3 combined (Late Kimmeridgian - earliest Valanginian)









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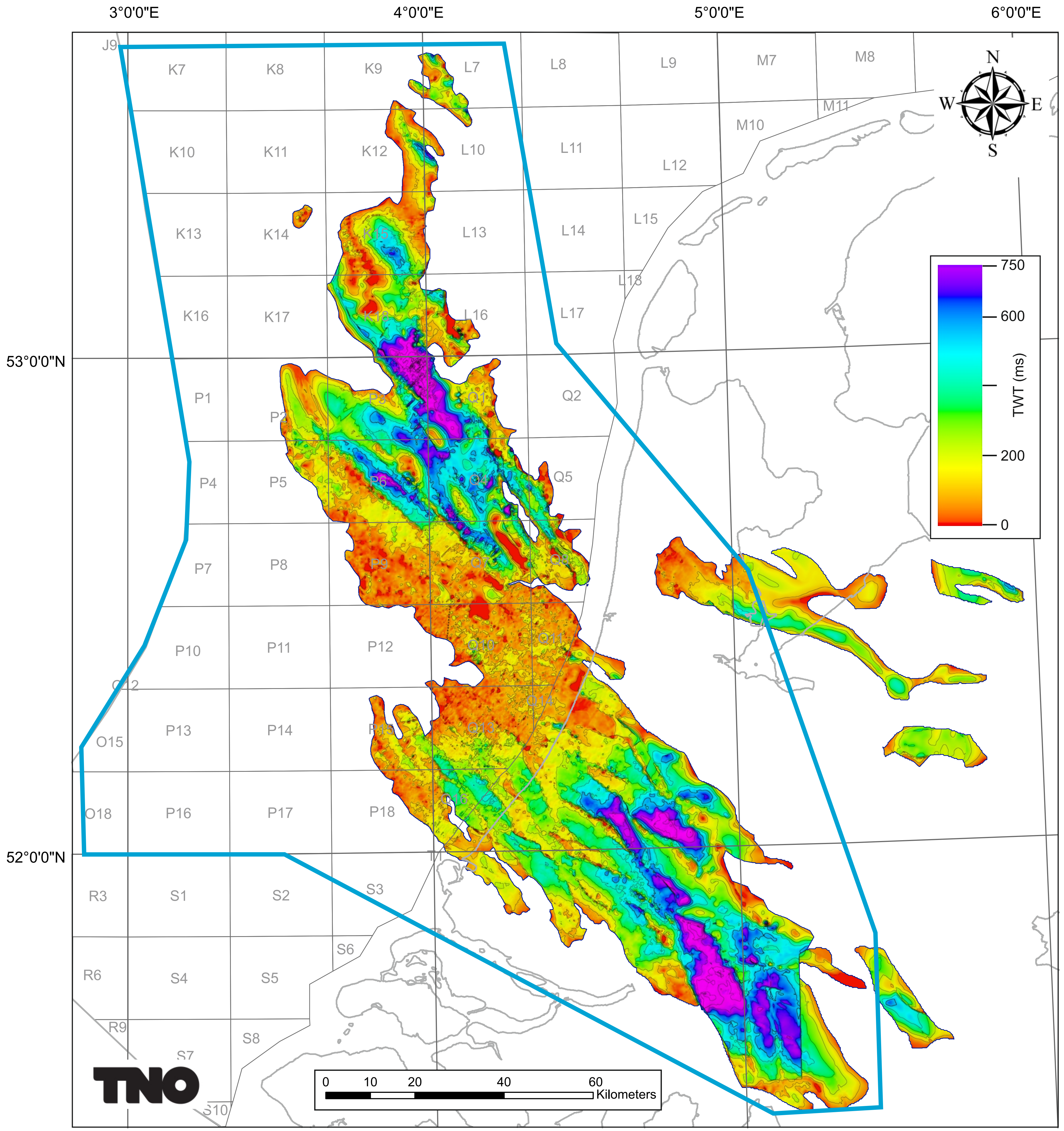
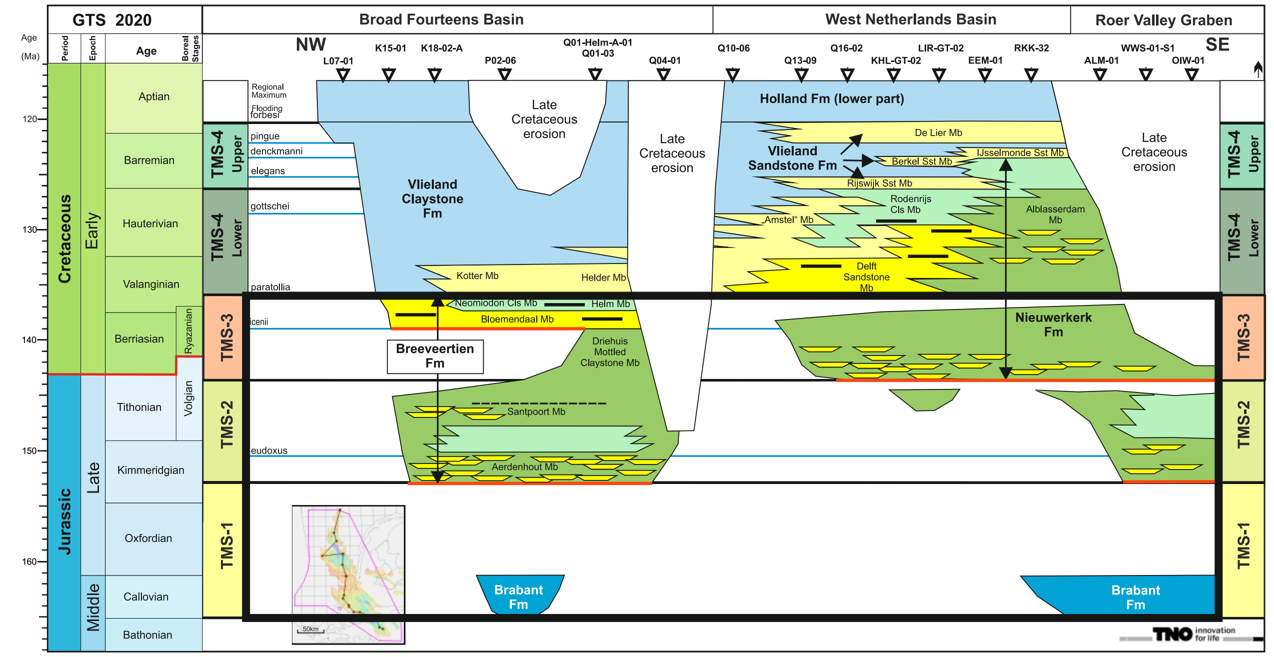
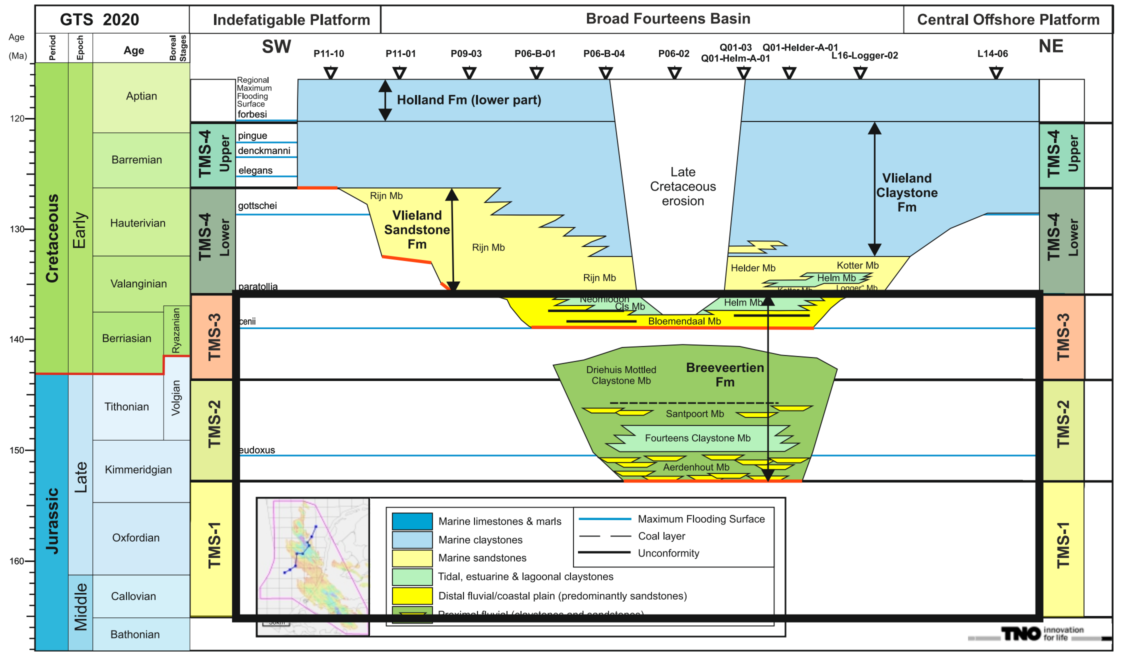
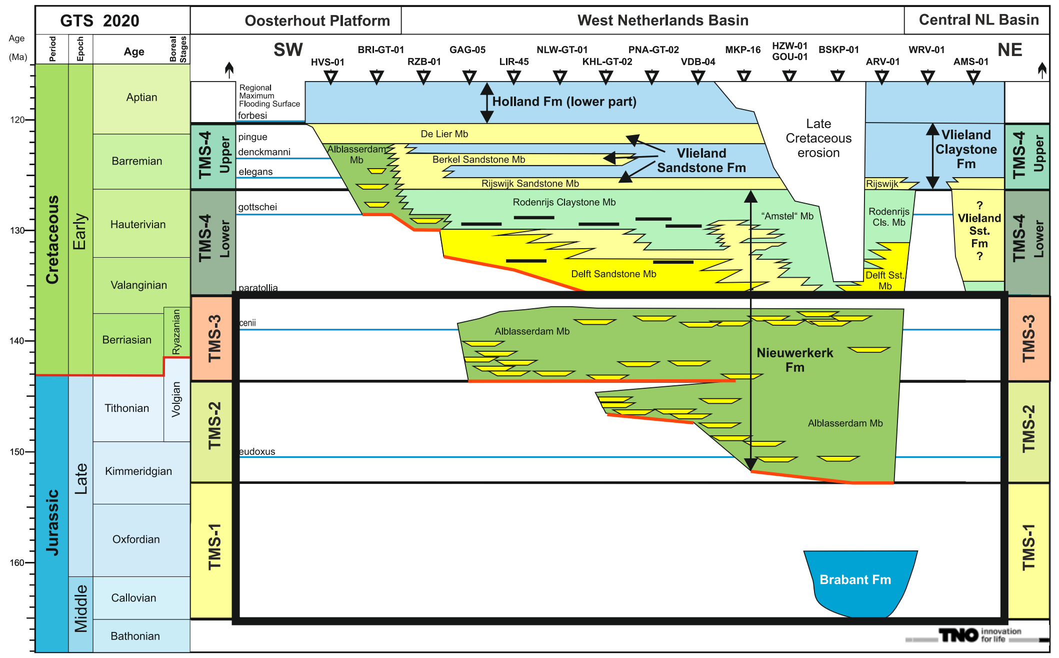
TMS-1, TMS-2 and TMS-3 combined (Callovian - earliest Valanginian)









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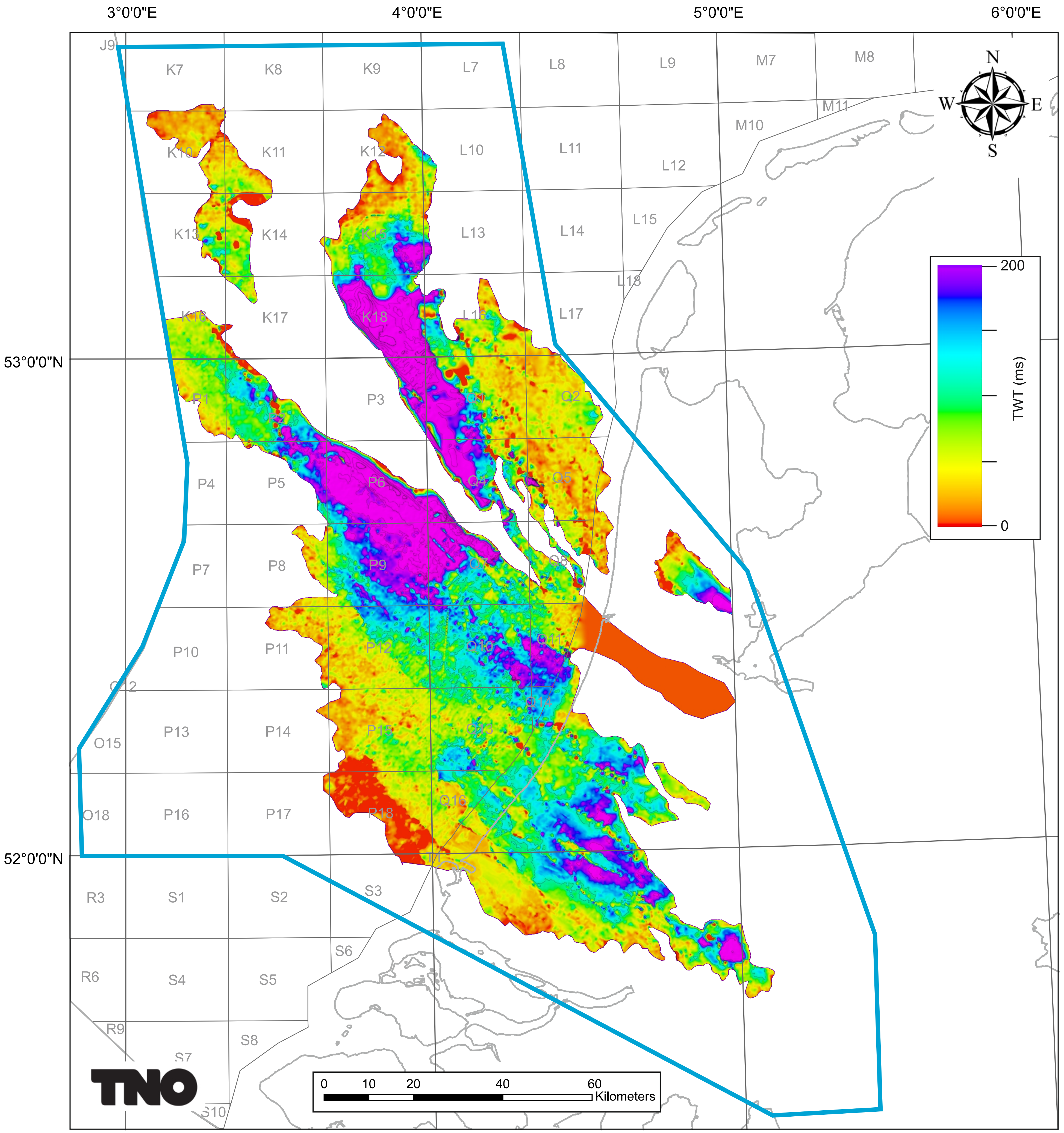
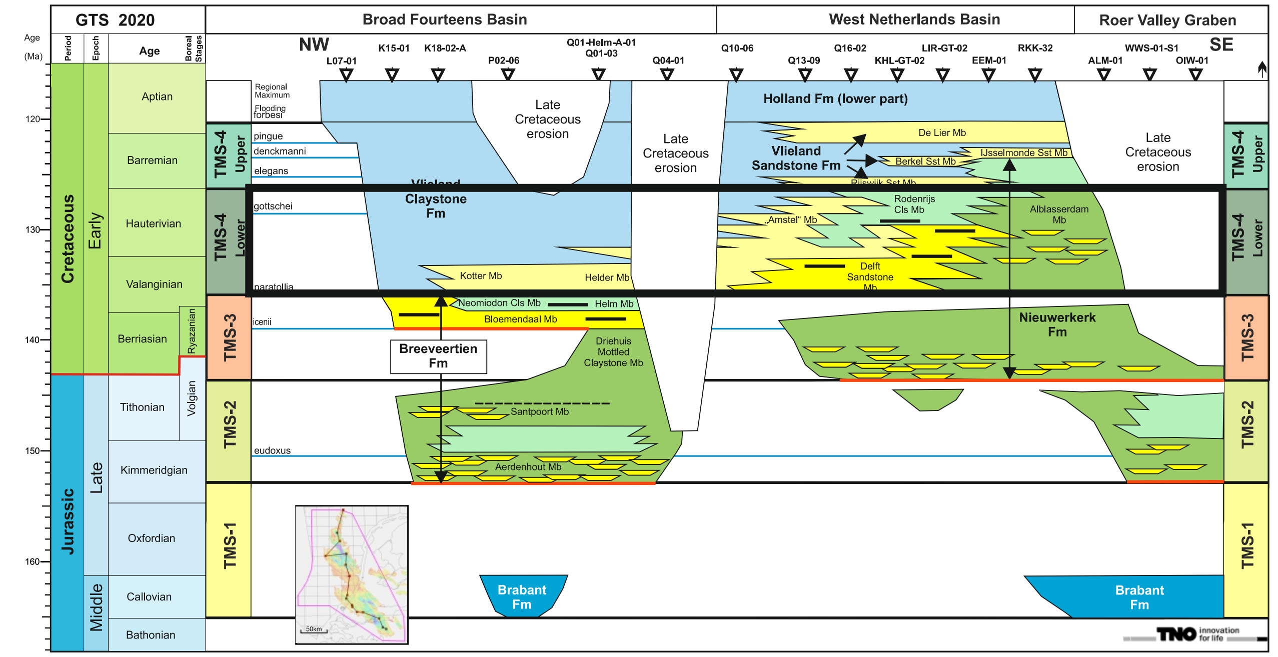
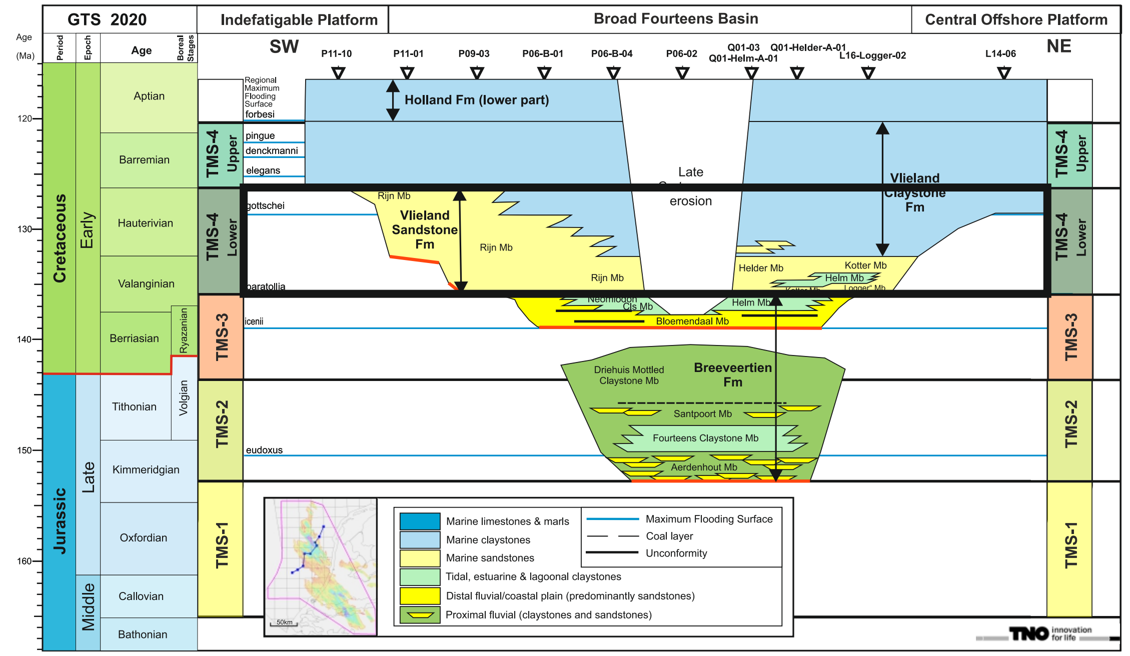
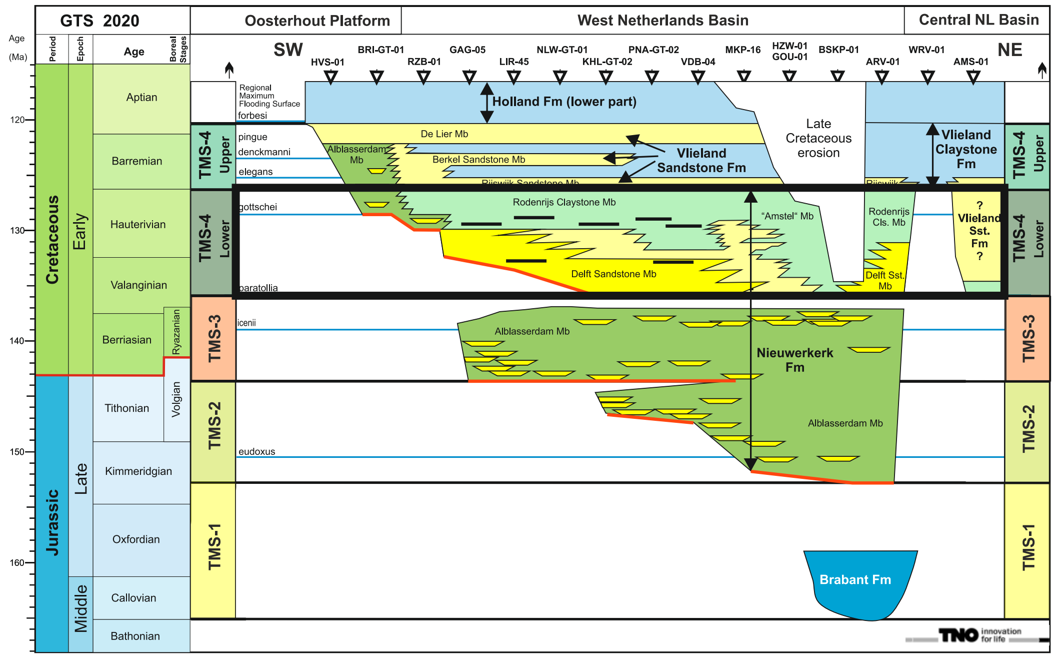
TMS-4 Lower (earliest Valanginian - Hauterivian)









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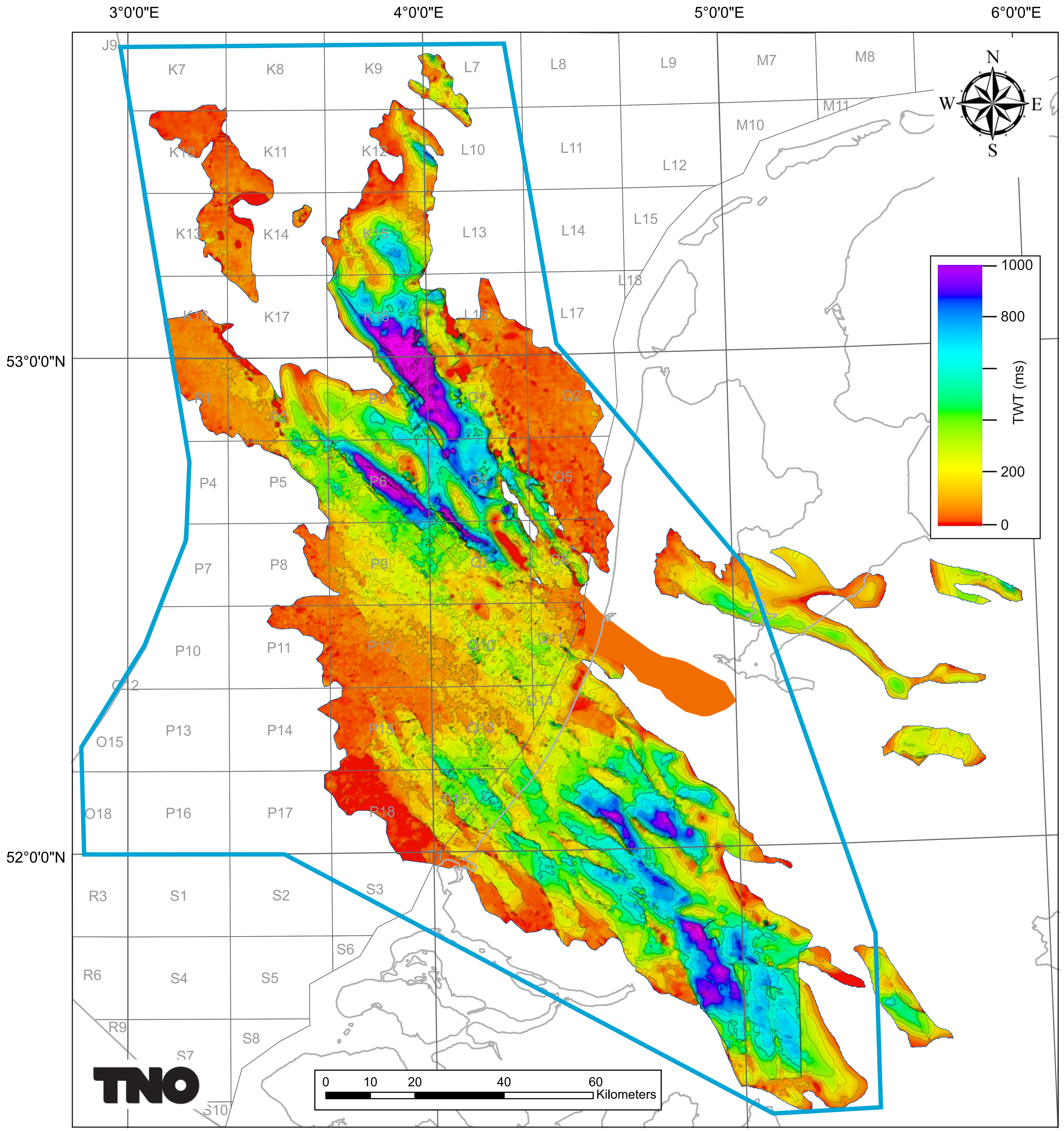
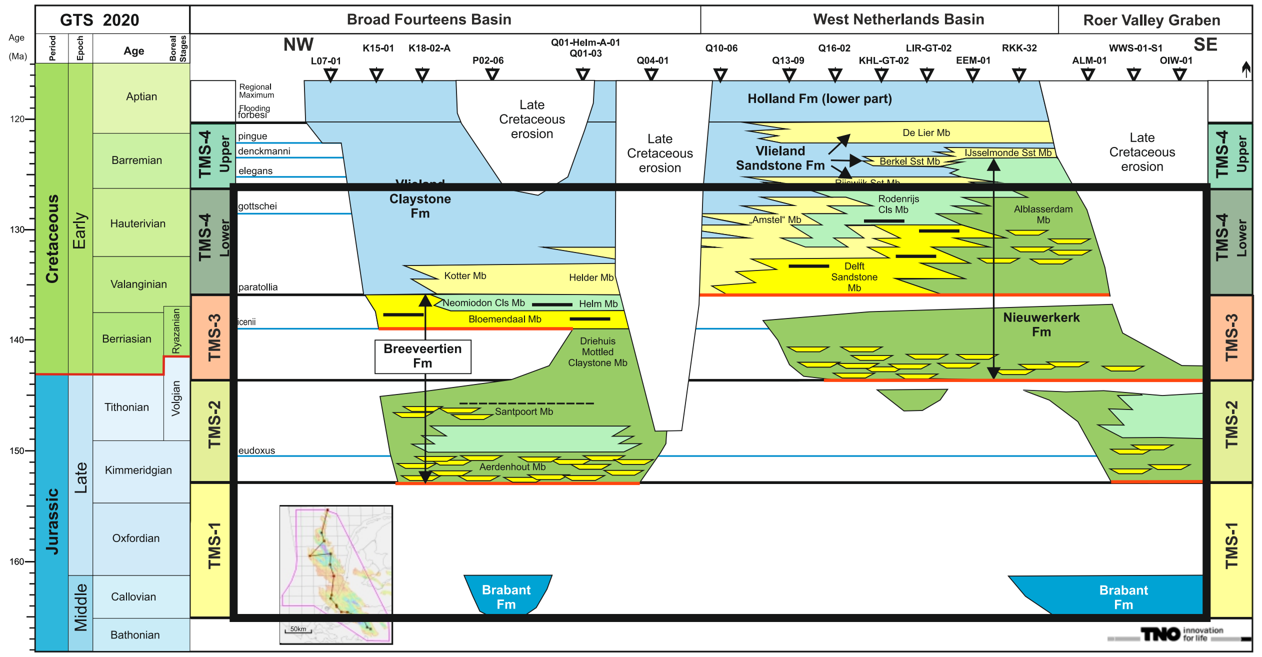
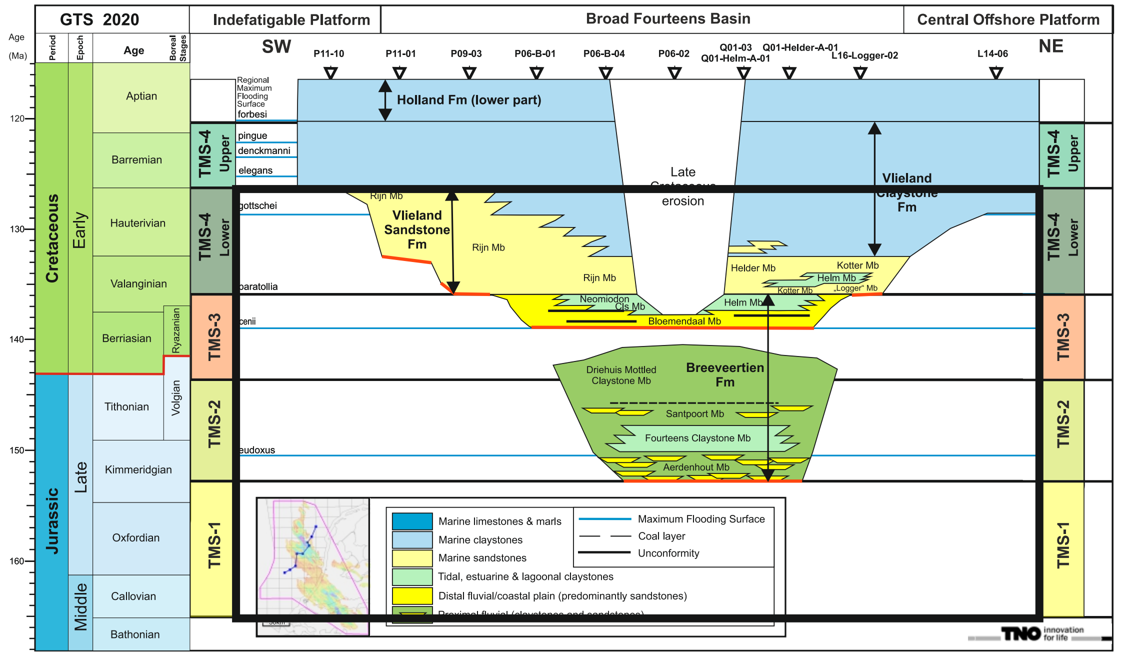
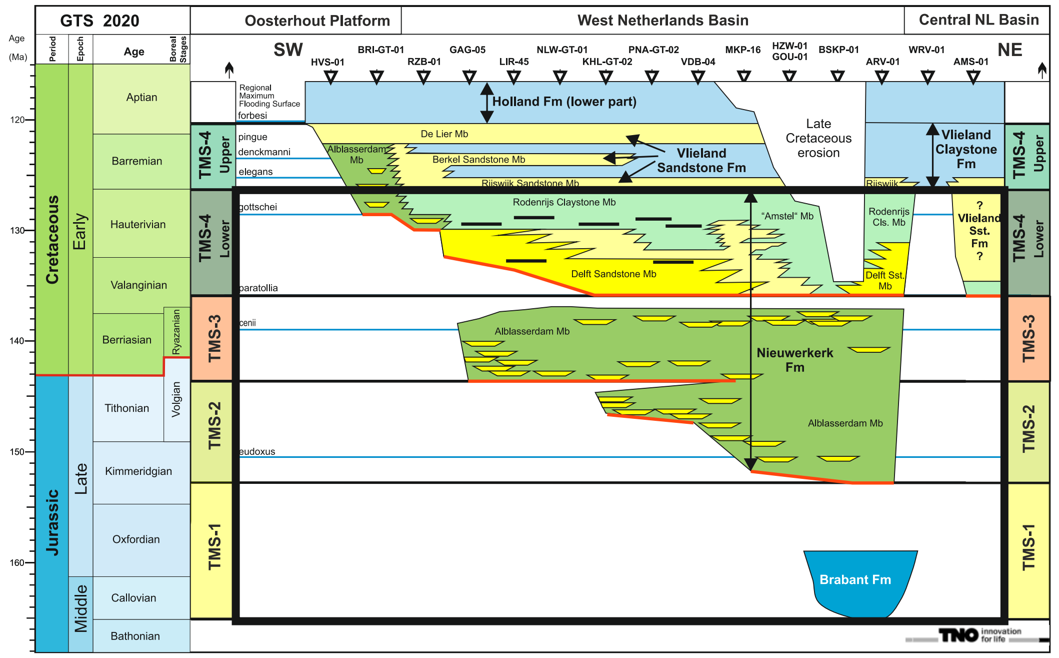
TMS-1, TMS-2, TMS-3 and TMS-4 Lower combined (Callovian-Hauterivian)









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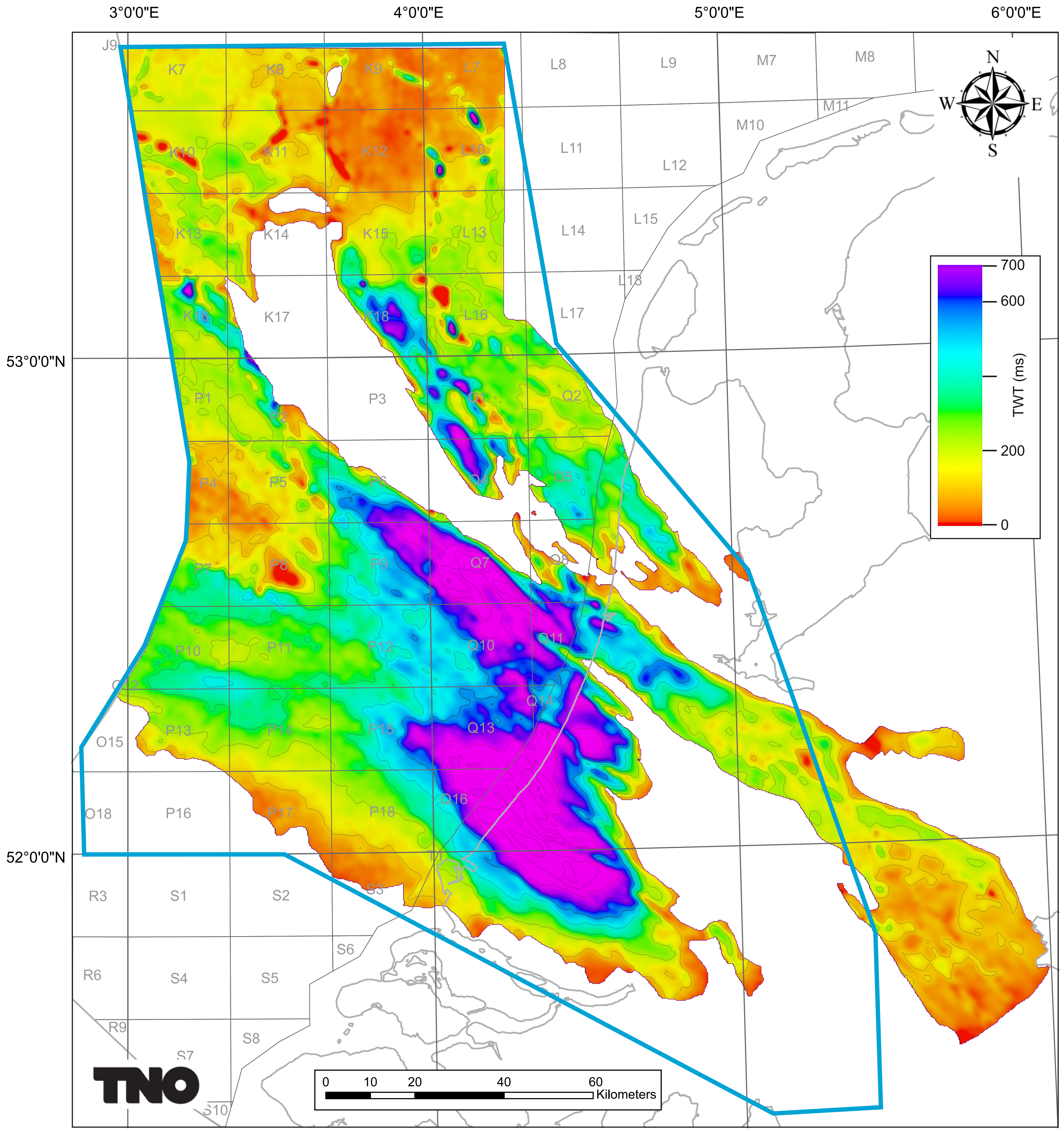
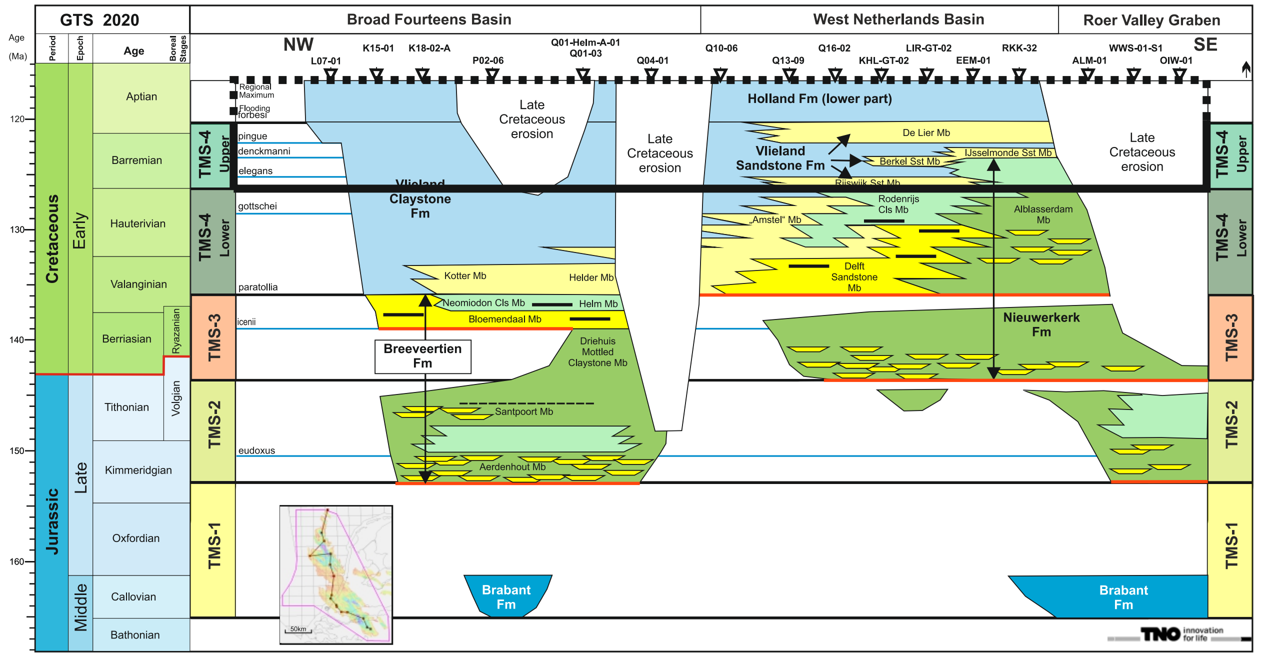
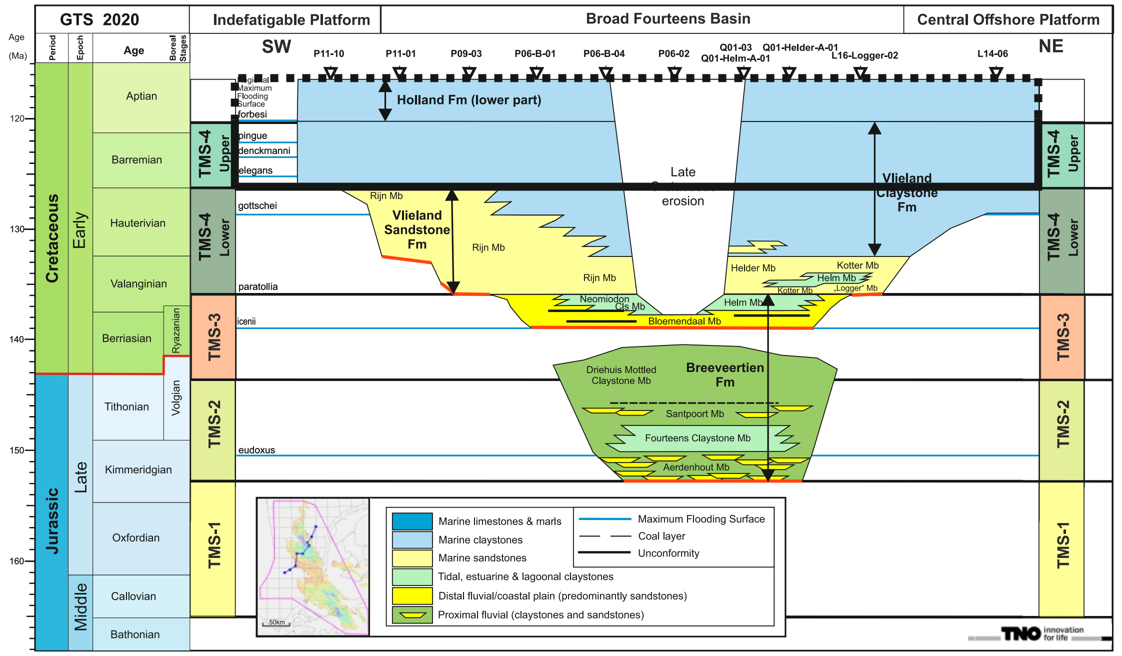
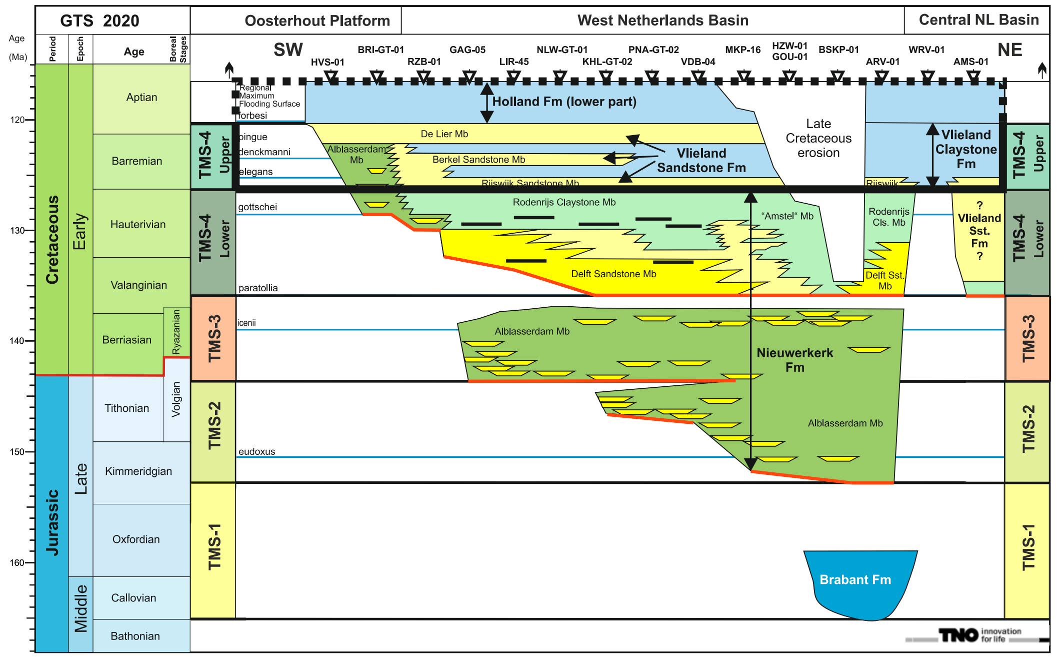
TMS-4 Upper and TMS-5 combined (Barremian - Albian)



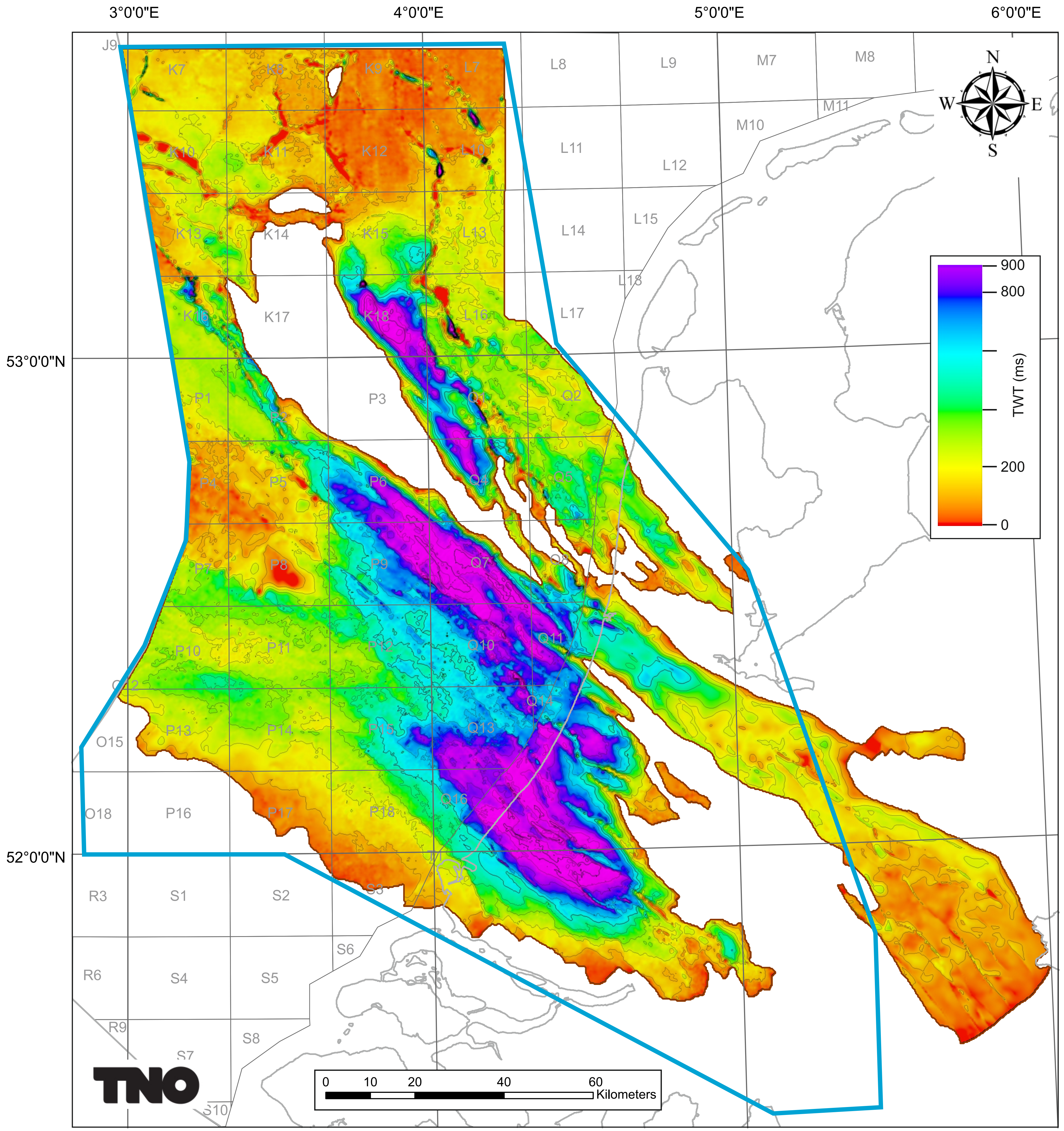


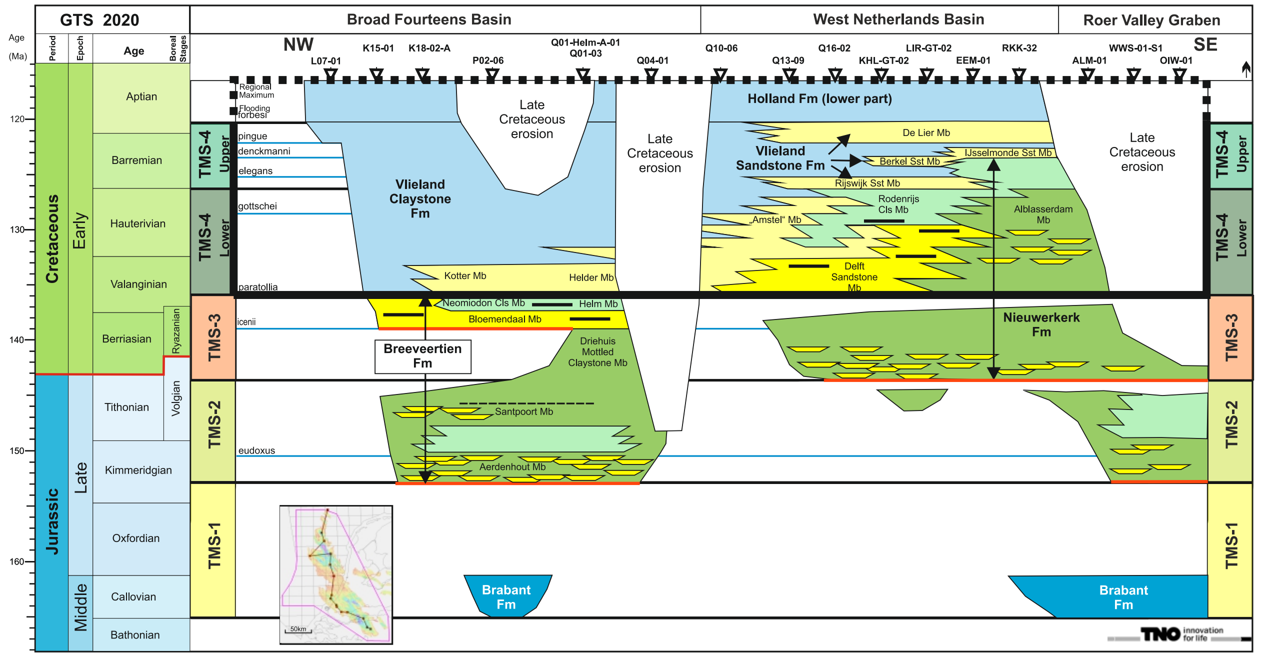


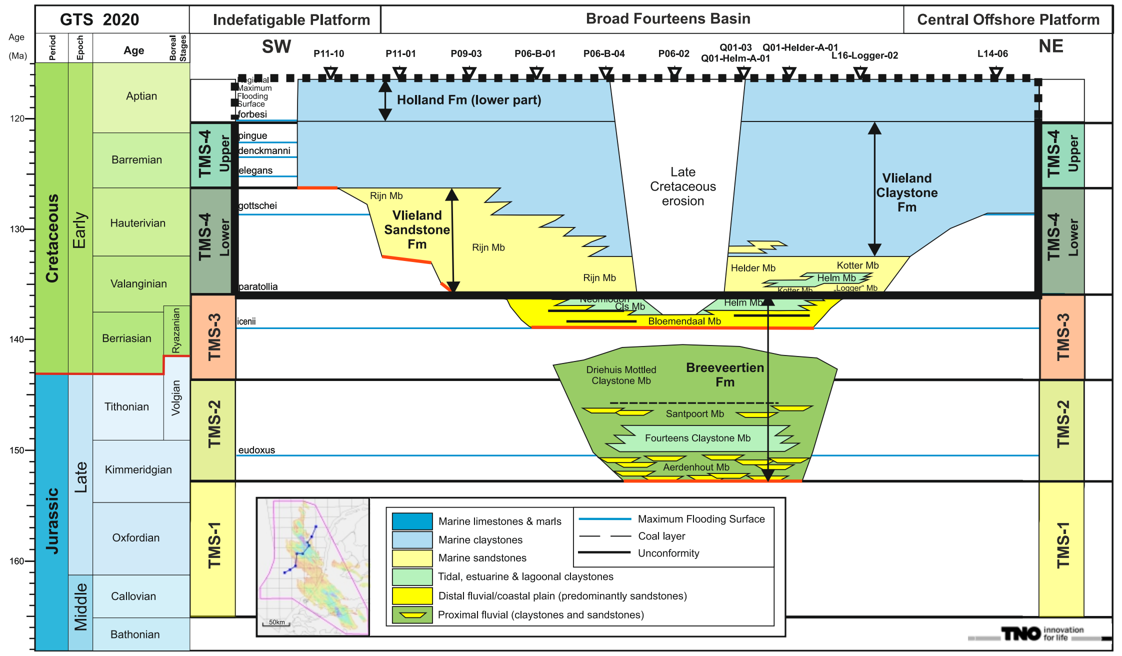


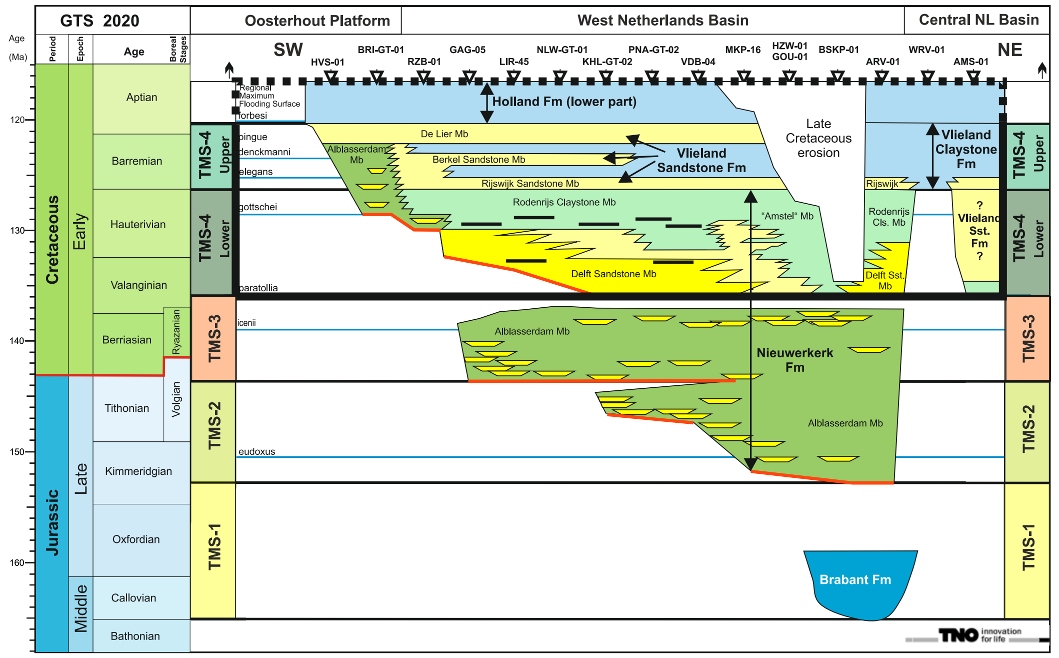
Thick black outlined rectangles correspond to the map to the left.

TMS-4 and TMS-5 combined (earliest Valanginian - Albian)





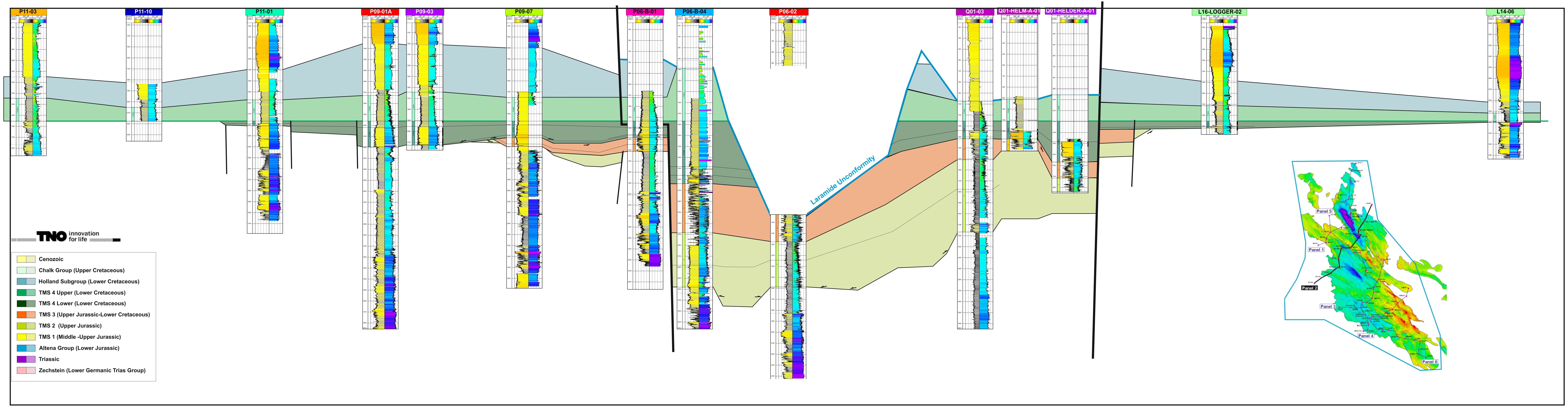




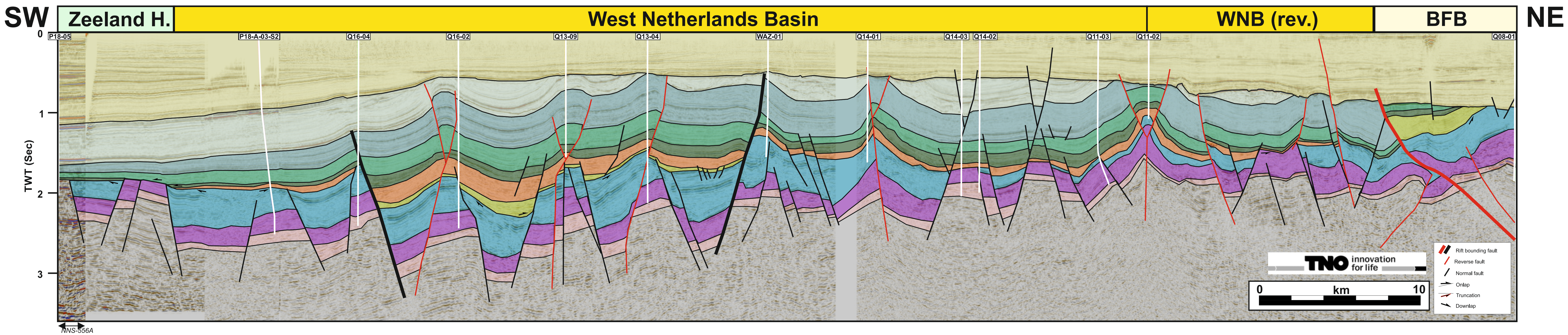
Thick black outlined rectangles correspond to the map to the left.

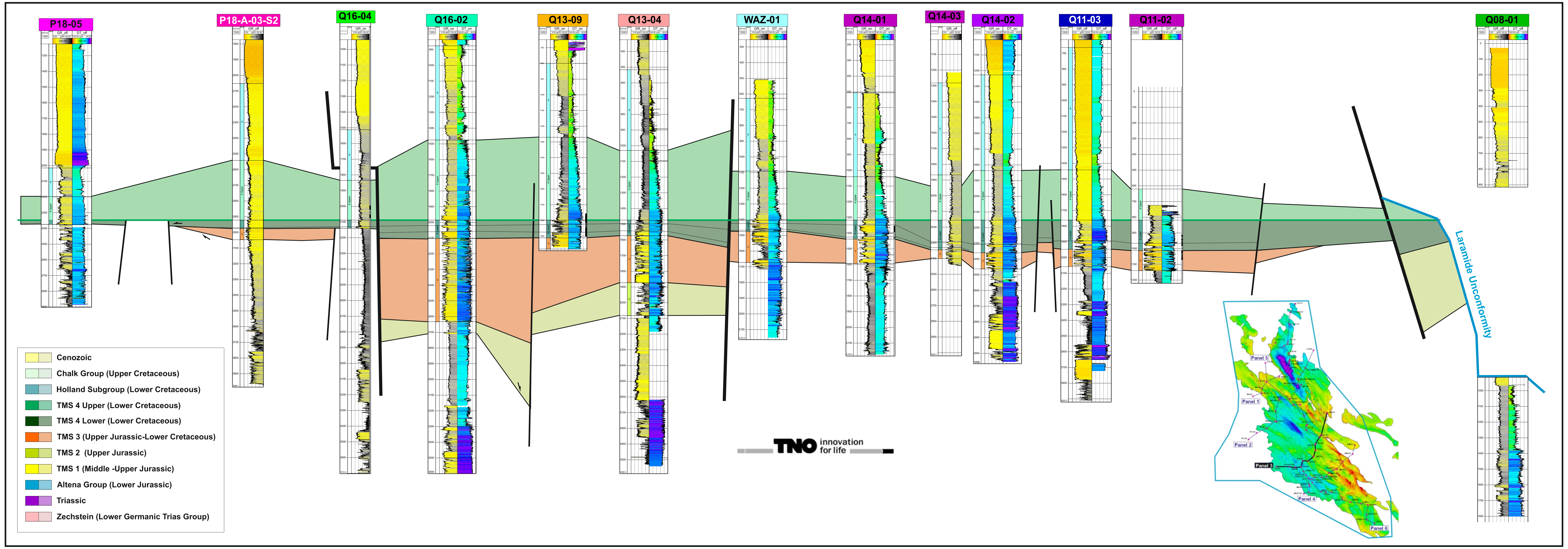
Devli Panel 1

Devli Panel 2

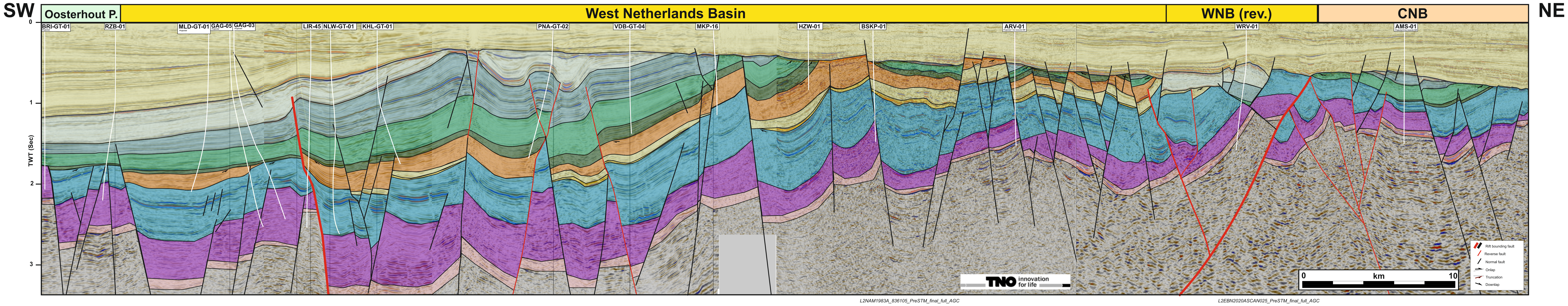


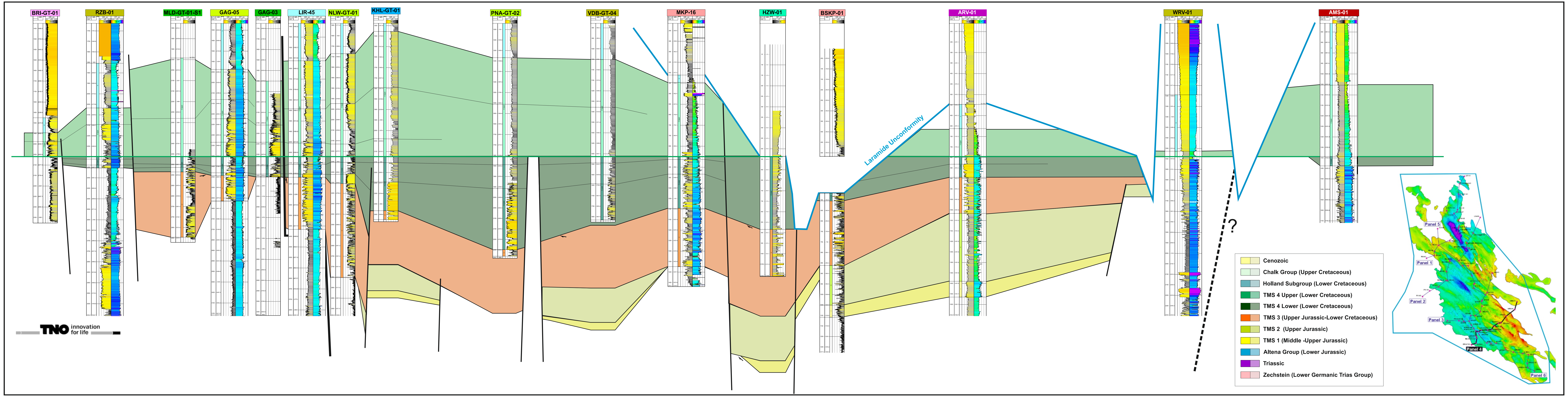
Devli Panel 3





Devli Panel 4





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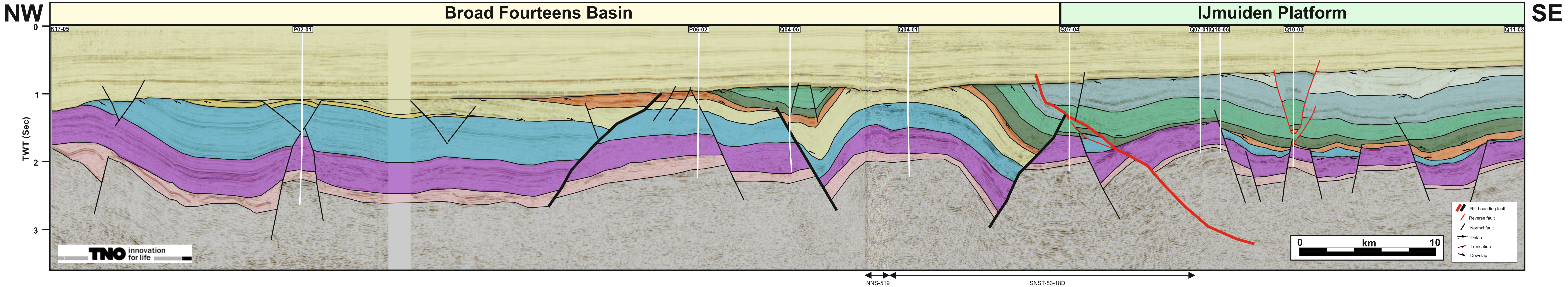
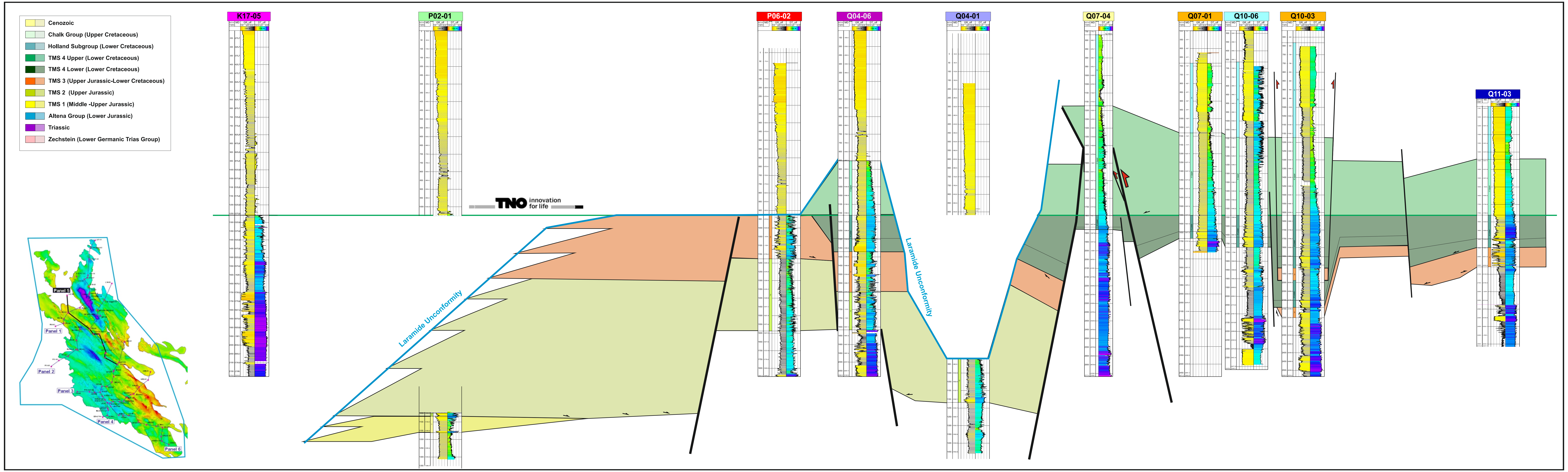
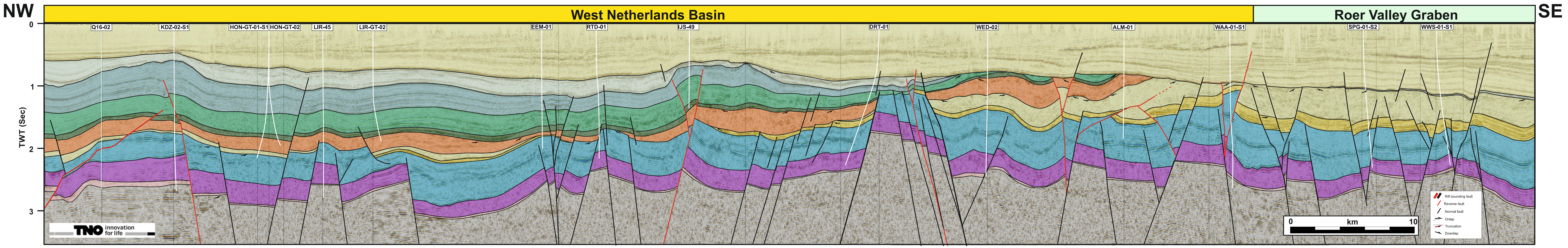
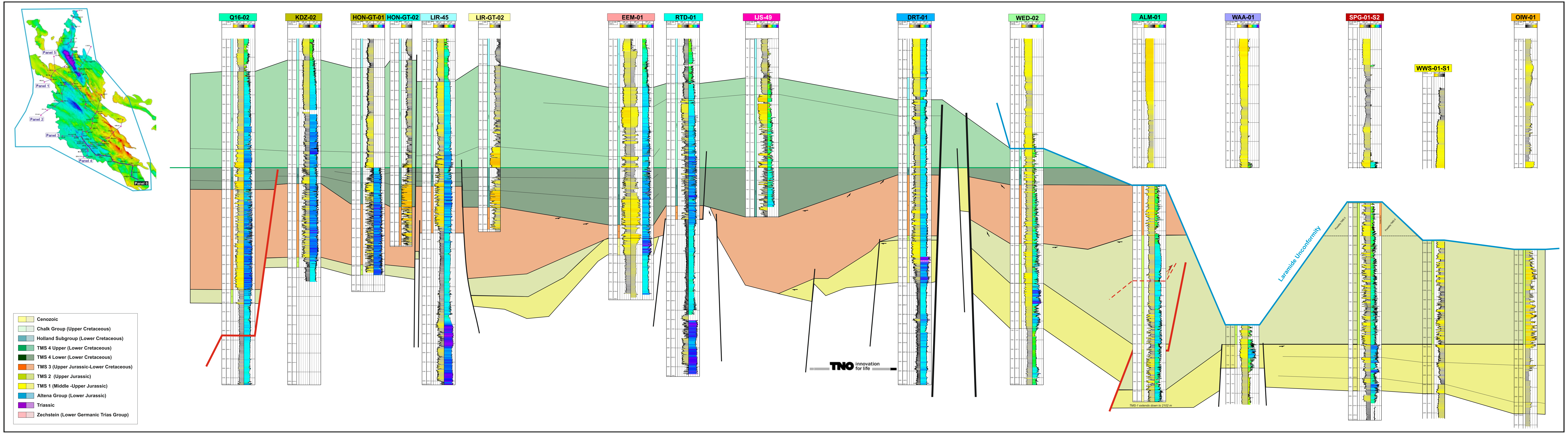




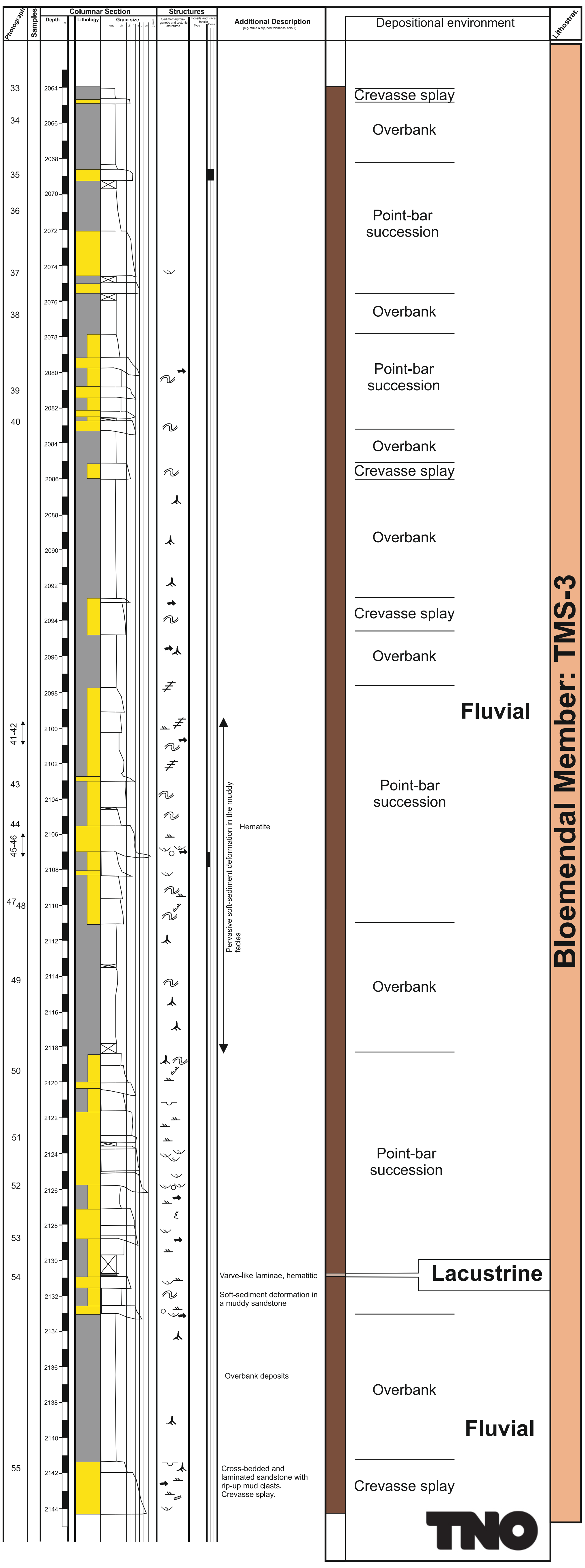
Devli Panel 6





K18-02-A core 1 (2064 to 2144 m)

Bloemendaal Member, Breeveertien Formation - TMS-3



SEDIMENTARY STRUCTURES

- Planar, parallel, horizontal lamination
- Planar, parallel, low angle lamination
- Planar, parallel, high angle lamination
- Concave, parallel lamination
- Wavy lamination
- Flaser bedding
- Starved bedding
- Bioturbation
- Heterolithic lenticular bedding
- Mud drapes
- Double mud drapes
- Hummocky cross-stratification
- Swalley cross-stratification
- Hummocky cross-bedding
- Herring bone cross-bedding
- Sigmoidal cross-bedding
- Lag
- Undifferentiated ripples
- Current ripples
- Wave ripples
- Climbing ripples
- Planar, tabular cross-bedding
- Trough cross-bedding
- CLASTS: Sideritic mud; Quartz

TRACE FOSSILS

- *Chondrites*
- *Diplocraterion*
- *Phycosiphon*
- *Ophiomorpha*
- *Planolites*
- *Paleophycus*
- *Skolithos*
- *Teichichnus*
- *Schaubcylindrichnus*
- *Thalassinoides*
- *Zoophycos*
- *Asterosoma*
- *Arenicolites*
- *Scolicia*
- *Monocraterion*
- *Rosselia*
- *Cylindrichnus*
- *Siphonichnus*
- *Bergaueria*
- *Glossyfungites*
- *Conichnus*
- *Rhizocorallium*

MISCELLANEOUS

- Siderite concretion
- Pyrite concretion
- Carbonate concretion
- Rip-up clast (shale)
- Coal particle
- Coal stringers
- Coal balls
- Ooid
- Wood fragments
- Dewatering
- Flame structure
- Bivalves
- Molluscs
- Shell bed
- Slumped strata
- Plant roots
- Homogenised
- Stylolites
- Fracture
- Normal or reverse fault
- Load structure
- Syneresis crack
- Desiccation crack
- Oversteepened strata
- Intraformation clasts, (rounded, angular)
- Sharp transition
- Gradual transition
- Erosional transition

LITHOLOGY

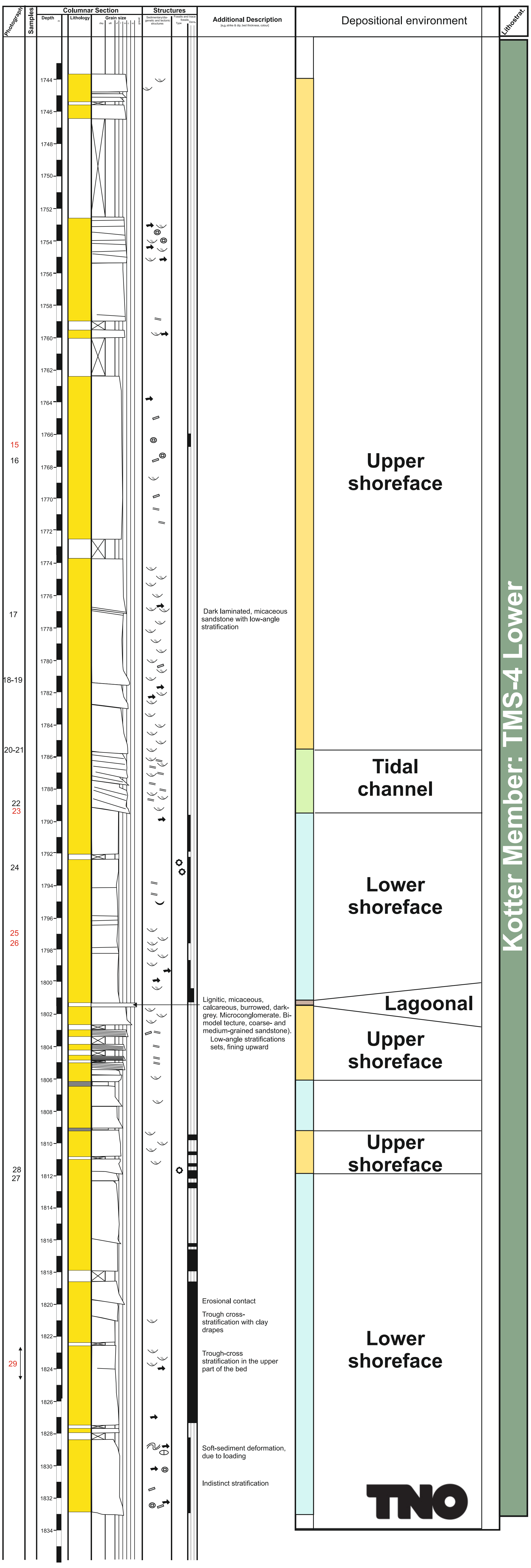
- Conglomerate
- Sandstone
- Siltstone
- Shale
- Limestone
- Coal

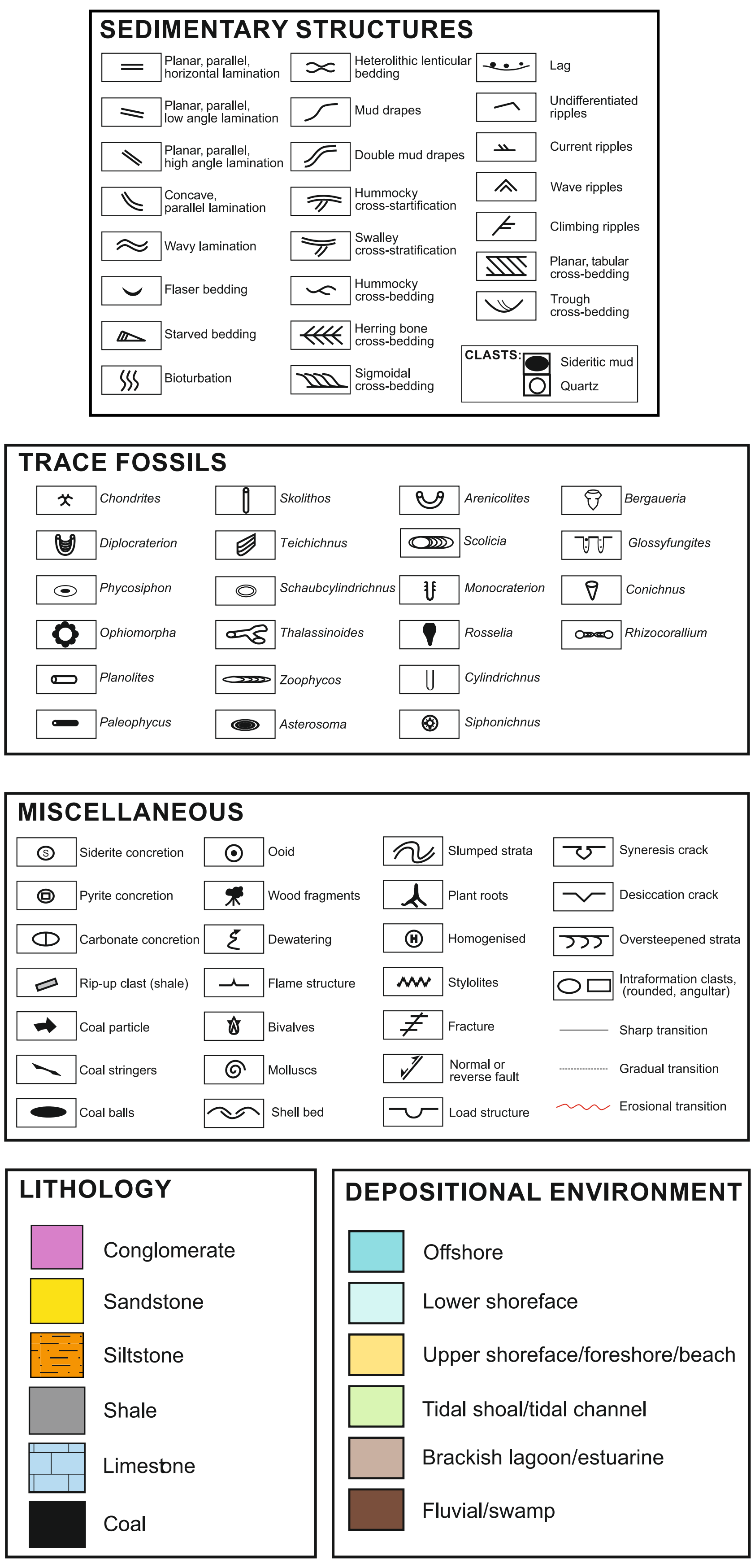
DEPOSITIONAL ENVIRONMENT

- Offshore
- Lower shoreface
- Upper shoreface/foreshore/beach
- Tidal shoal/tidal channel
- Brackish lagoon/estuarine
- Fluvial/swamp

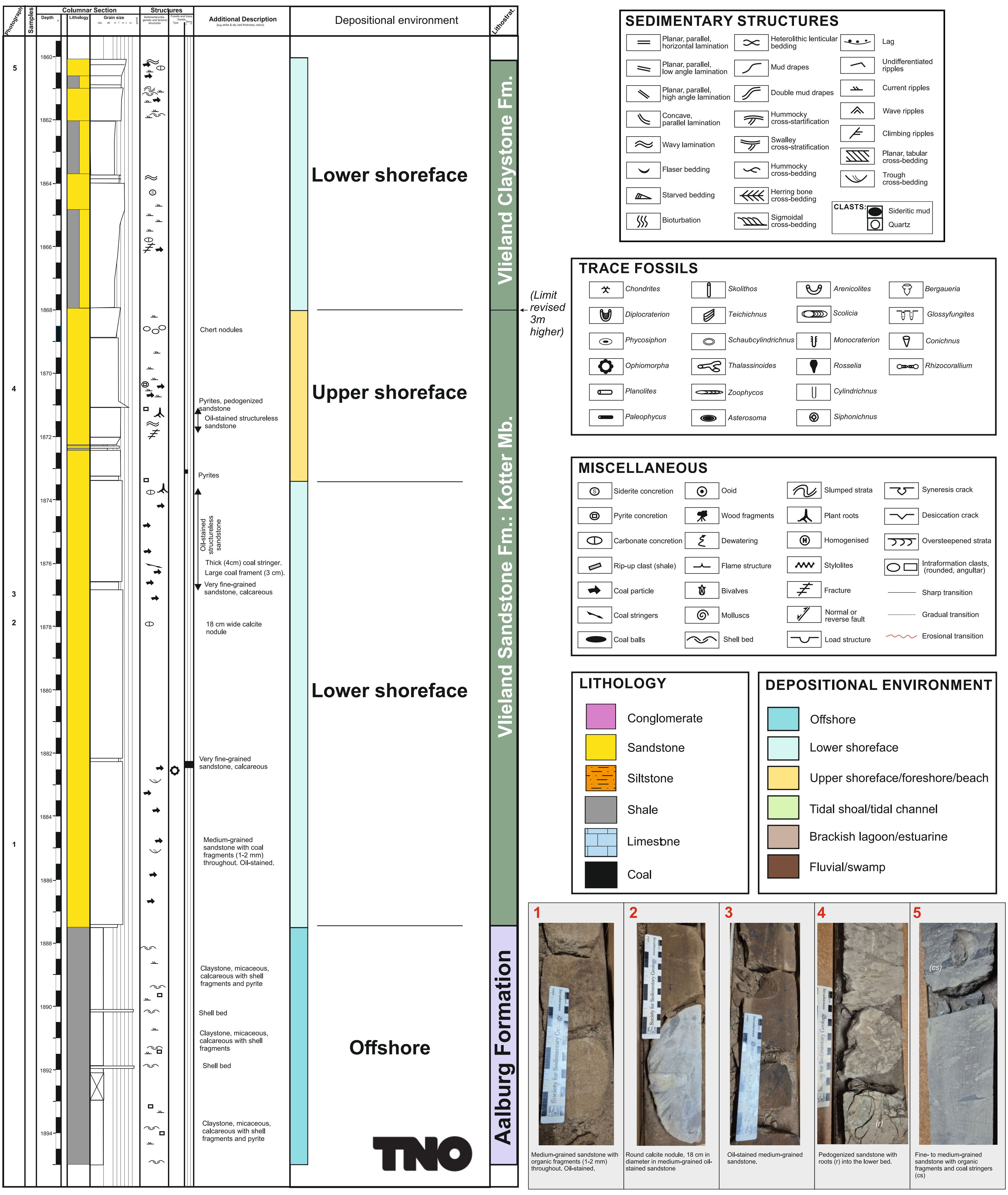
K18-02-A core 2 (1743,6 to 1833 m)

Kotter Member, Vlieland Sandstone Formation - TMS-4 Lower



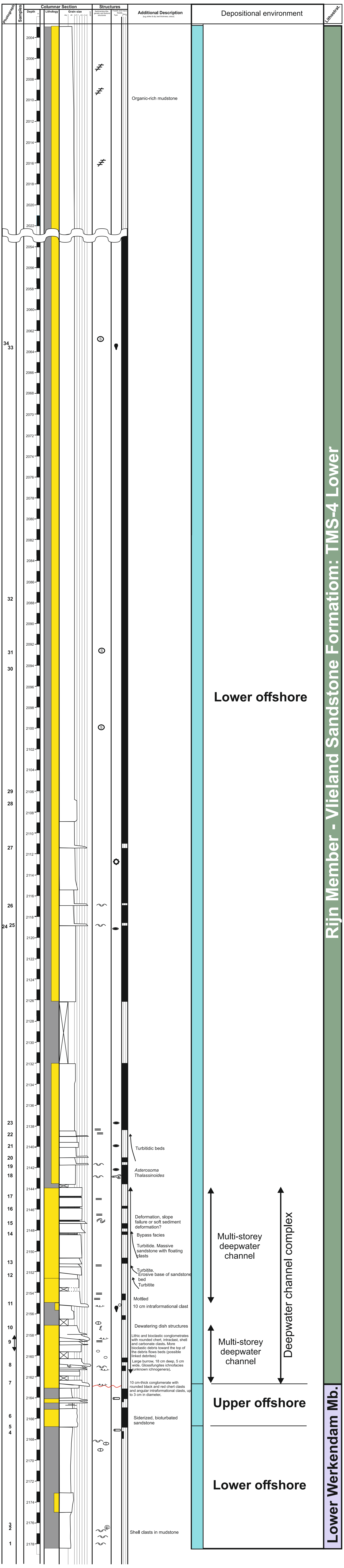


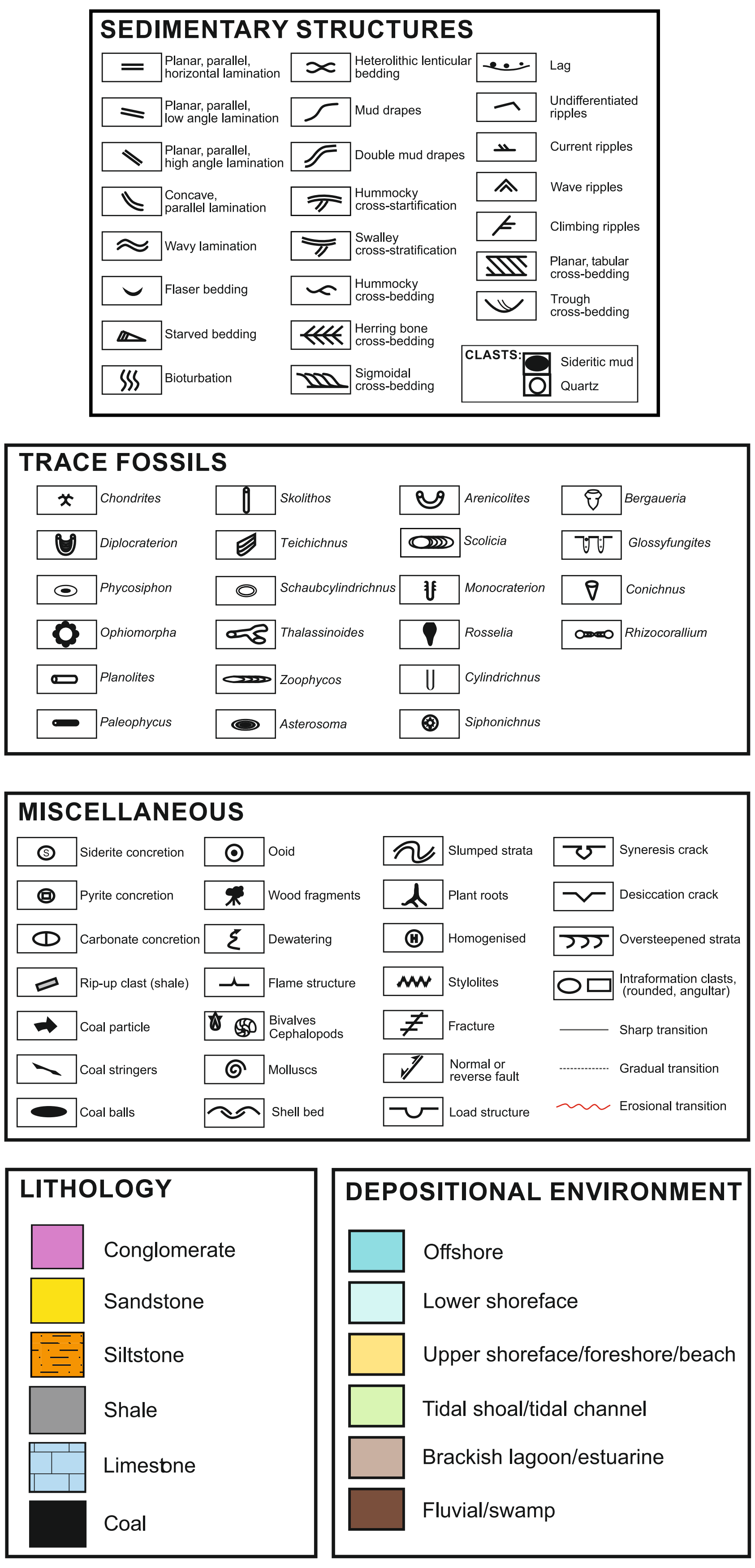
Kotter Mb. (Vlieland Sst. Fm.) and Vlieland Clst. Fm. - TMS-4 Lower

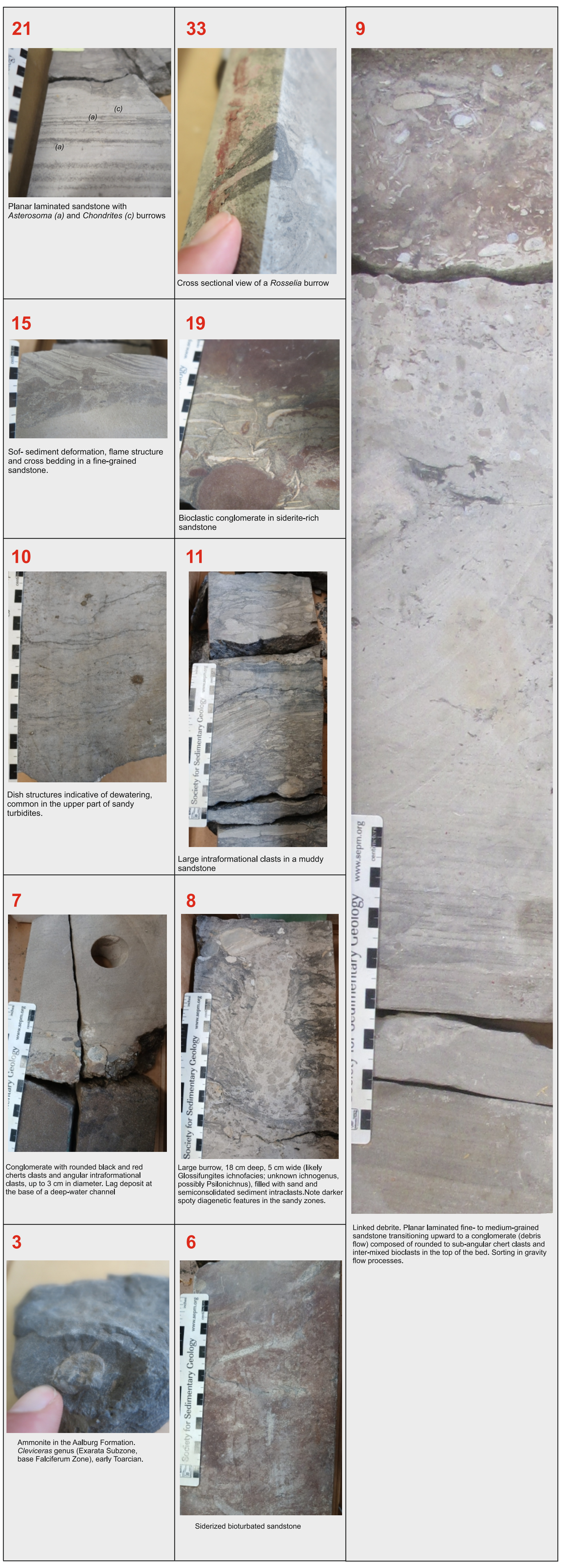


P09-03 core (2003 to 2179 m)

Rijn Member, Vlieland Sandstone Formation - TMS-4 Lower







21: Planar laminated sandstone with *Asterosoma (a)* and *Chondrites (c)* burrows

33: Cross sectional view of a *Rosselia* burrow

15: Sof- sediment deformation, flame structure and cross bedding in a fine-grained sandstone.

19: Bioclastic conglomerate in siderite-rich sandstone

10: Dish structures indicative of dewatering, common in the upper part of sandy turbidites.

11: Large intraformational clasts in a muddy sandstone

7: Conglomerate with rounded black and red cherts clasts and angular intraformational clasts, up to 3 cm in diameter. Lag deposit at the base of a deep-water channel

8: Large burrow, 18 cm deep, 5 cm wide (likely Glossifungites ichnofacies; unknown ichnogenus, possibly Psilonichnus), filled with sand and semiconsolidated sediment intraclasts.Note darker spoty diagenetic features in the sandy zones.

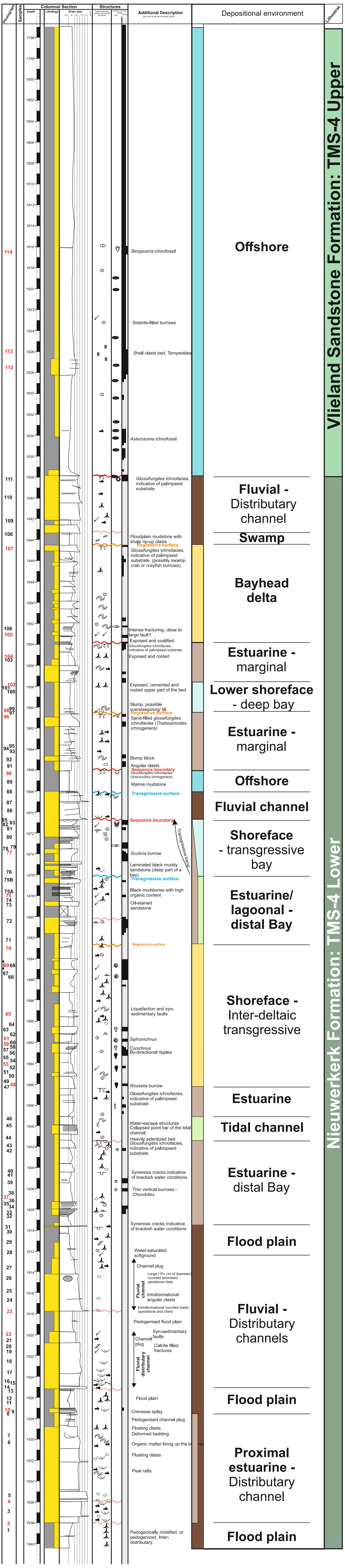
9: Linked debrite. Planar laminated fine- to medium-grained sandstone transitioning upward to a conglomerate (debris flow) composed of rounded to sub-angular chert clasts and inter-mixed bioclasts in the top of the bed. Sorting in gravity flow processes.

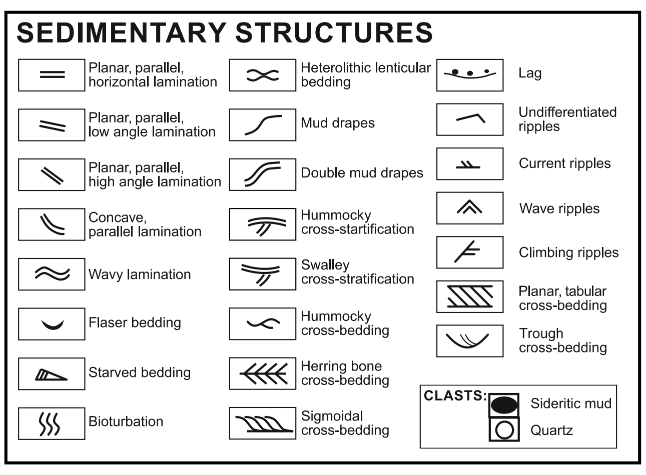
3: Ammonite in the Aalburg Formation. *Cleviceras* genus (Exarata Subzone, base Falciferum Zone), early Toarcian.

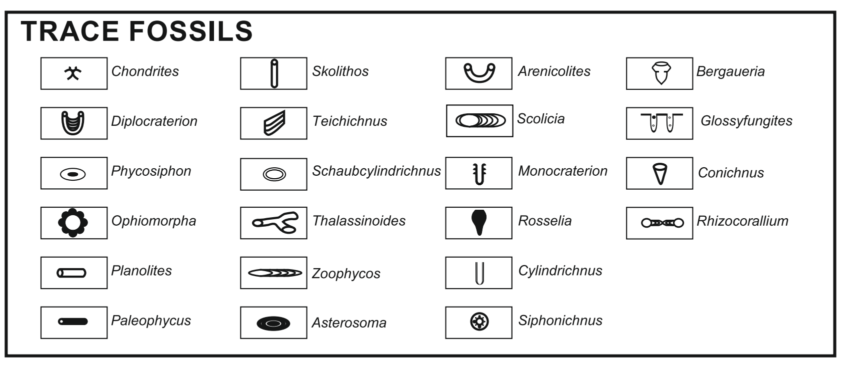
6: Siderized bioturbated sandstone

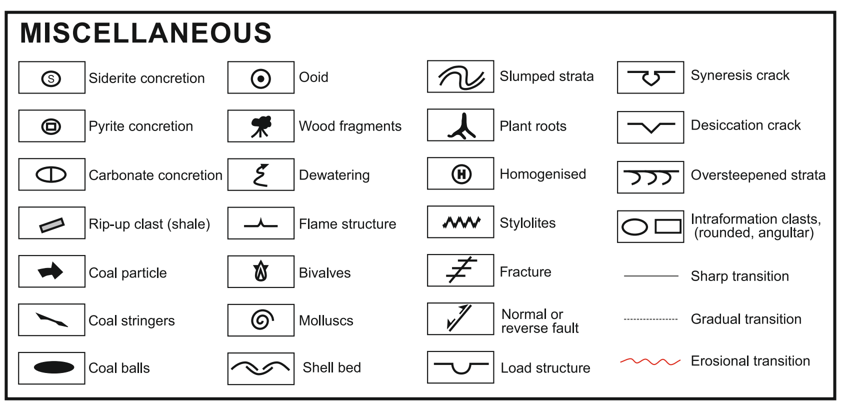
Q13-09 core (1795 to 1941 m)

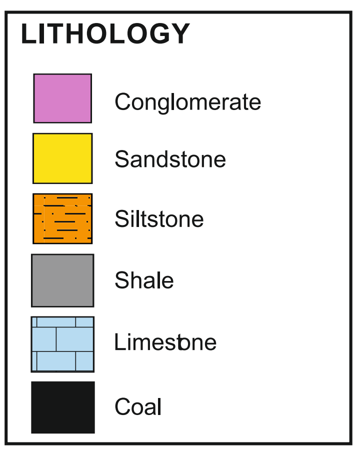
Nieuwerkerk Fm. (TMS-4 Lo.) and Vlieland Sst. Fm. (TMS-4 Up.)

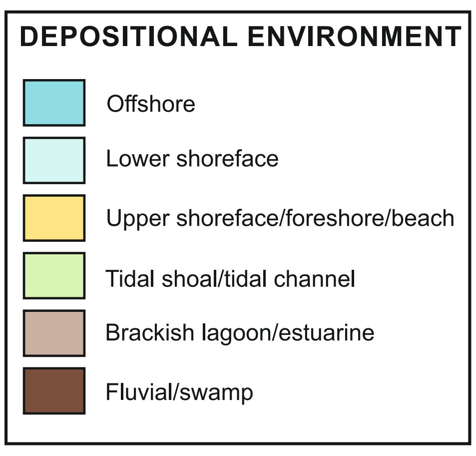




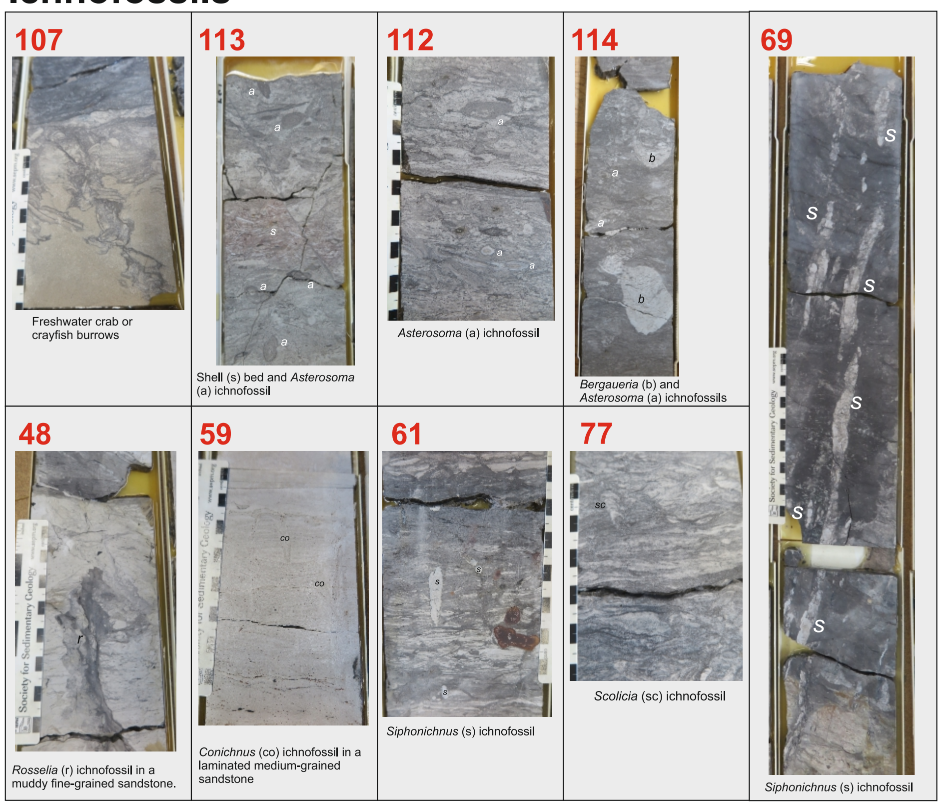




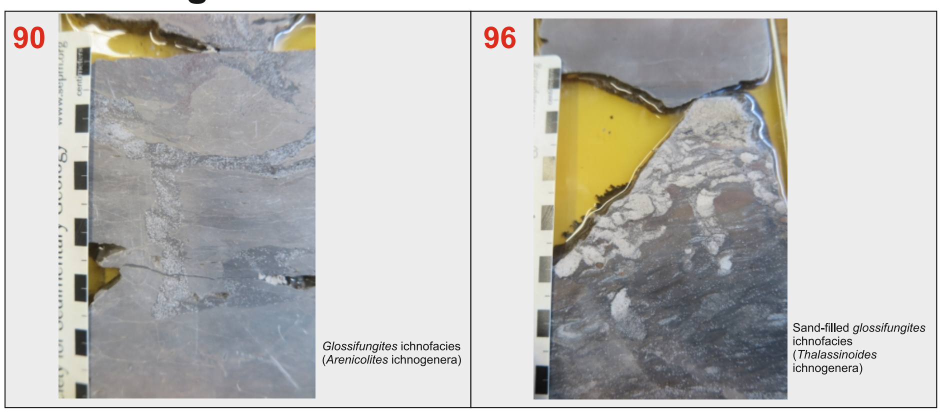




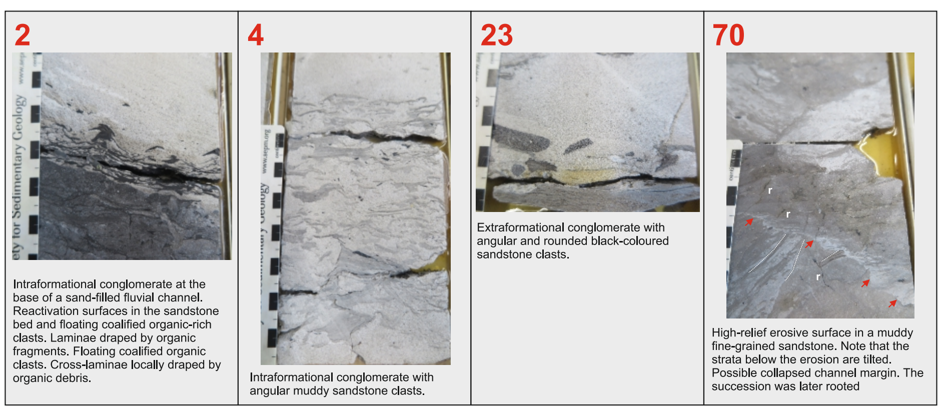
Ichnofossils



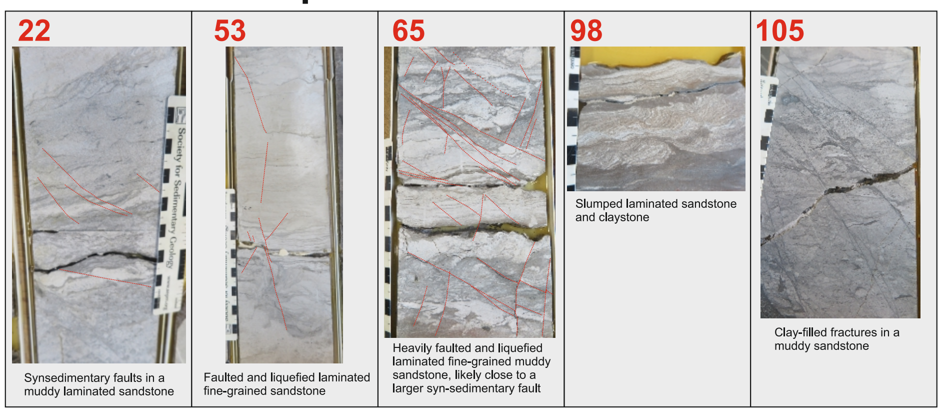
Glossifungites



Erosional surfaces and conglomerates

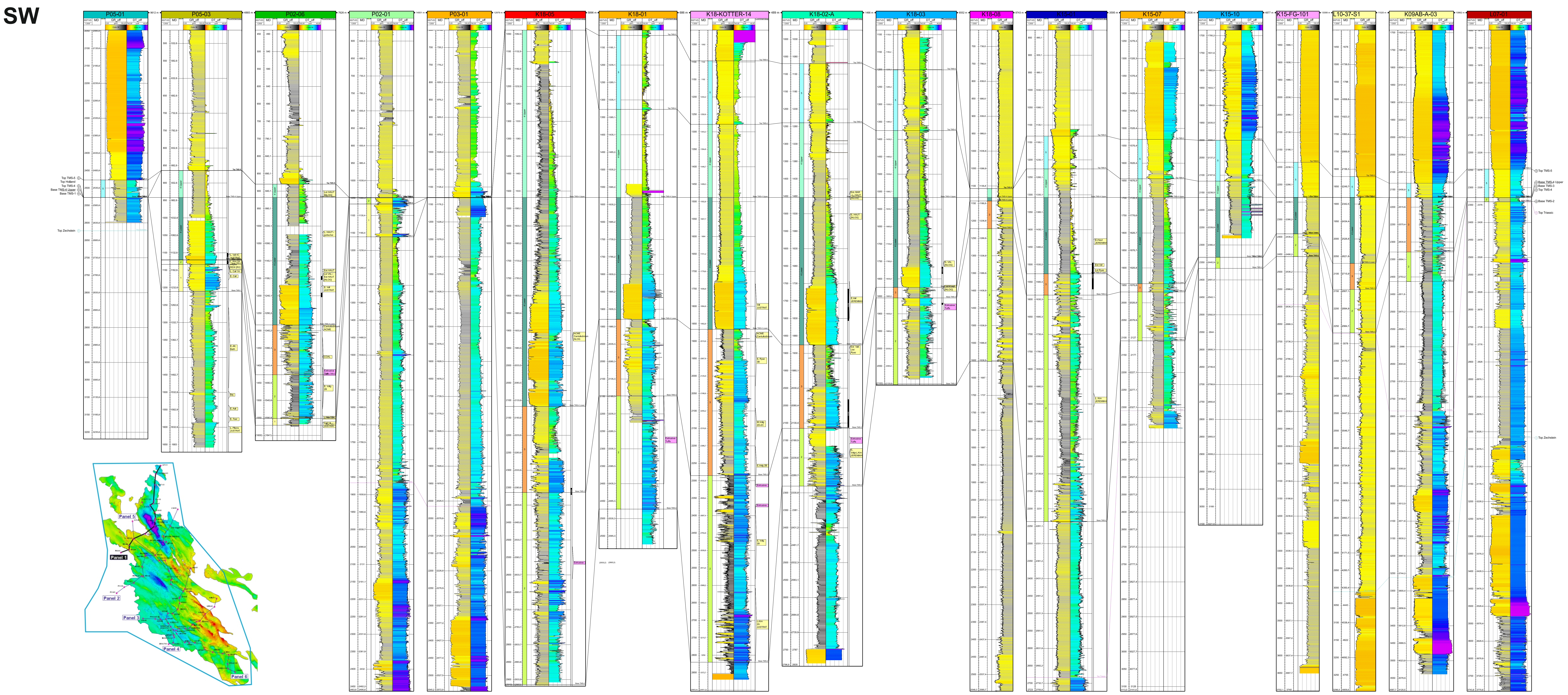


Faults and slumps



Miscellaneous

Devli Panel 1



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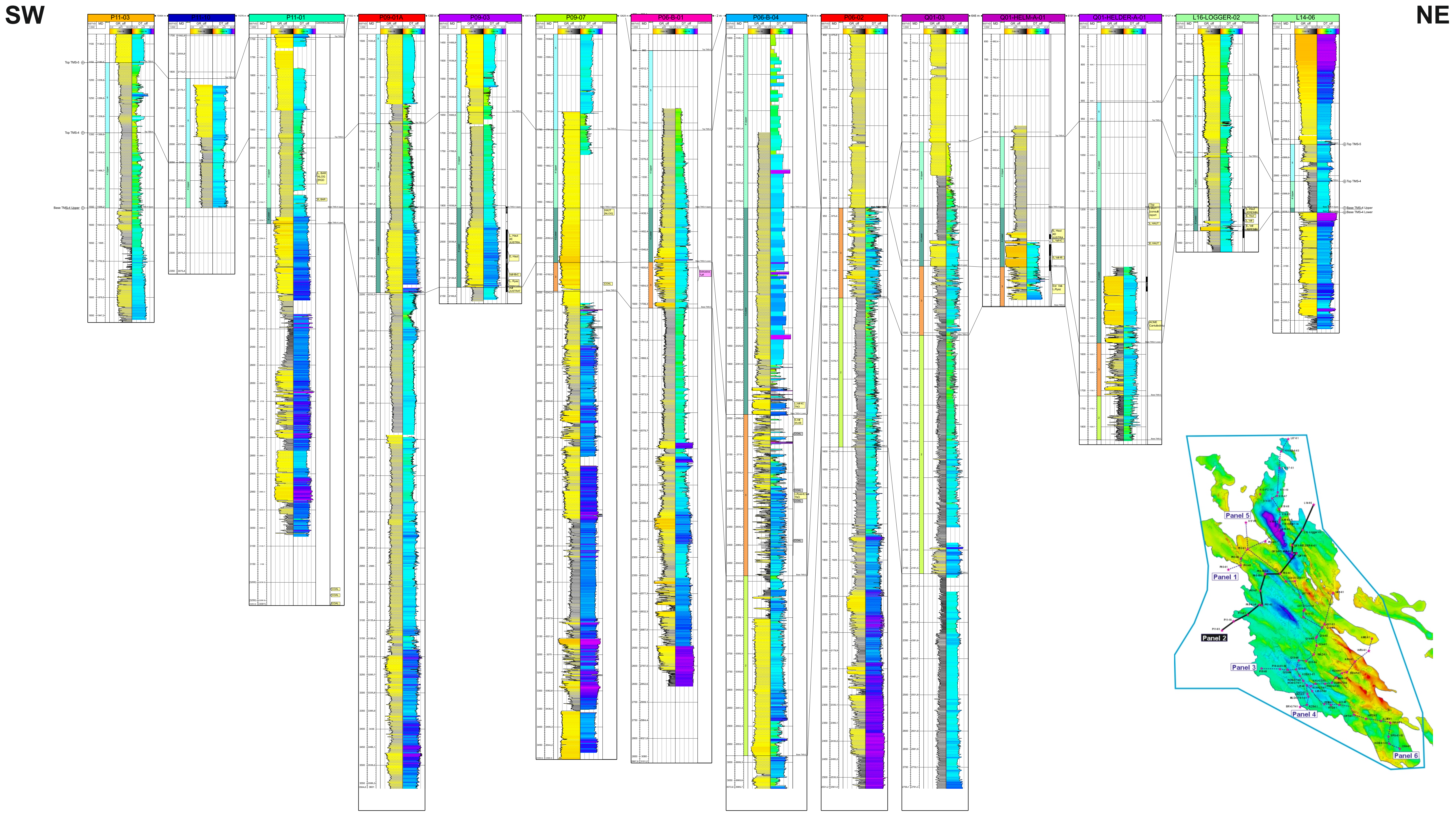
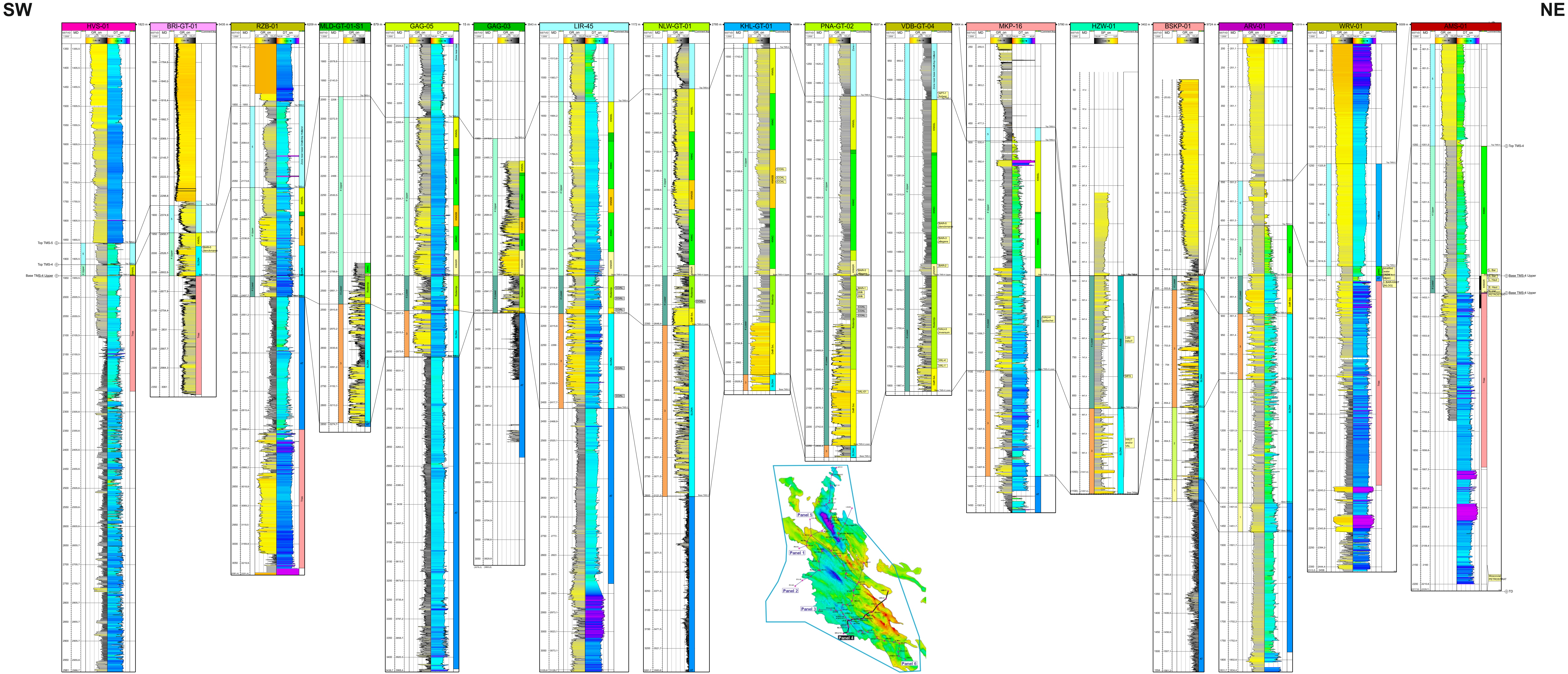


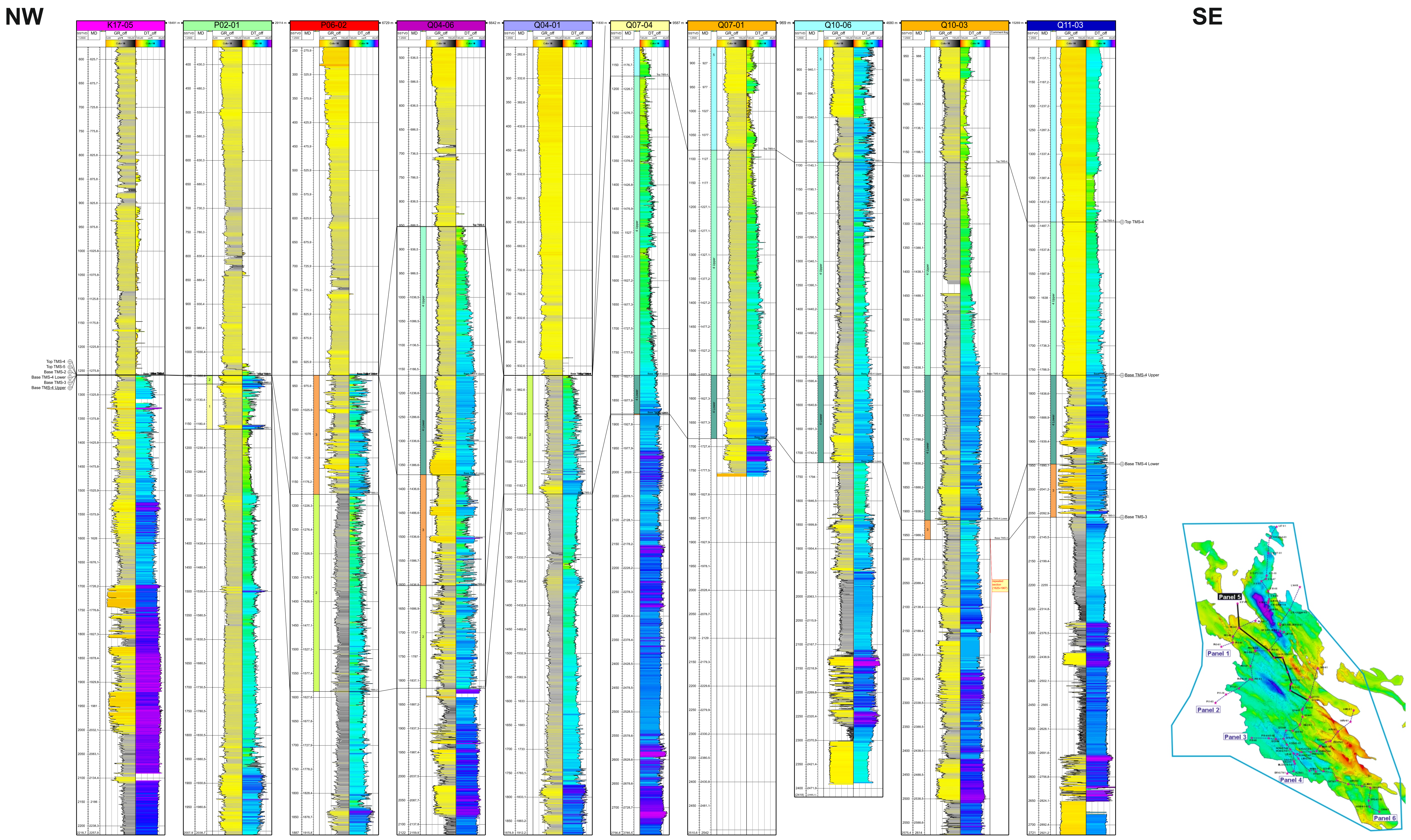
Appendix D: Well Correlation Panels

Devli Panel 3

Devli Panel 4

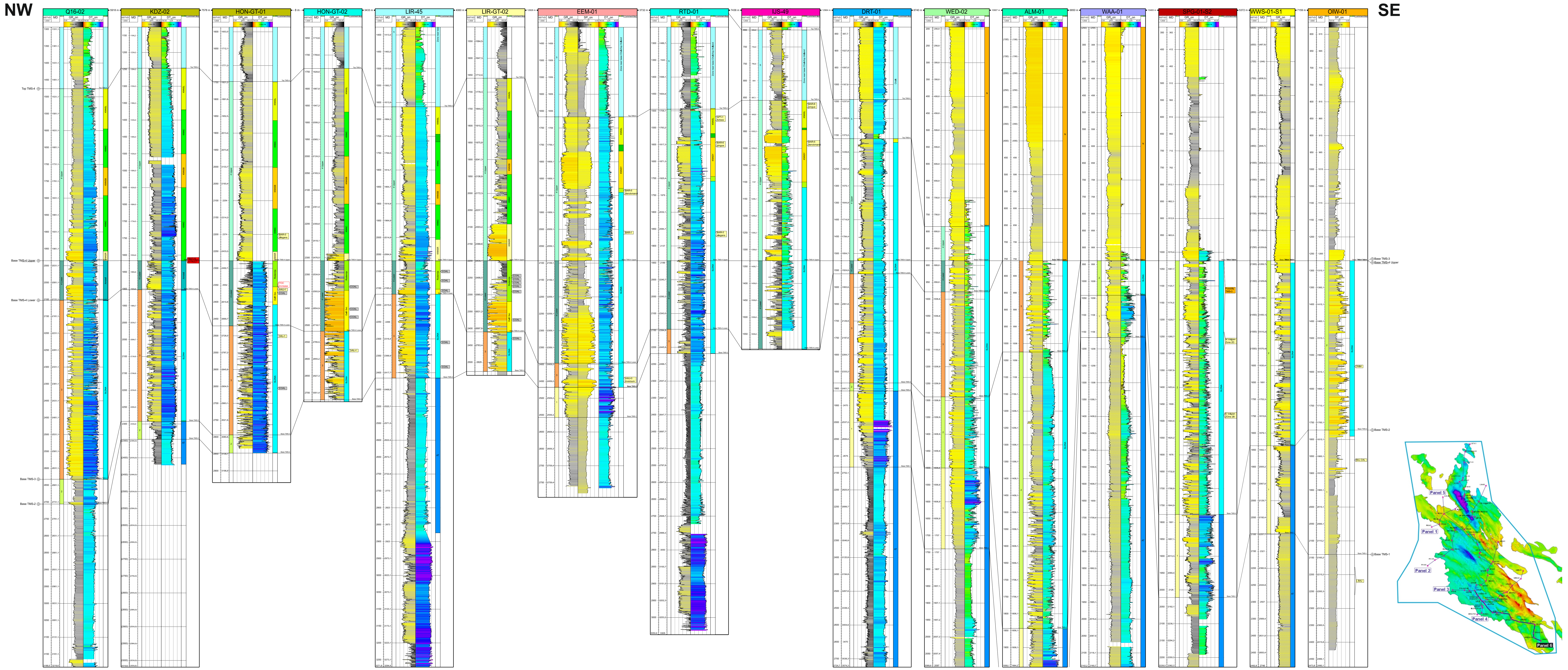


Devli Panel 5

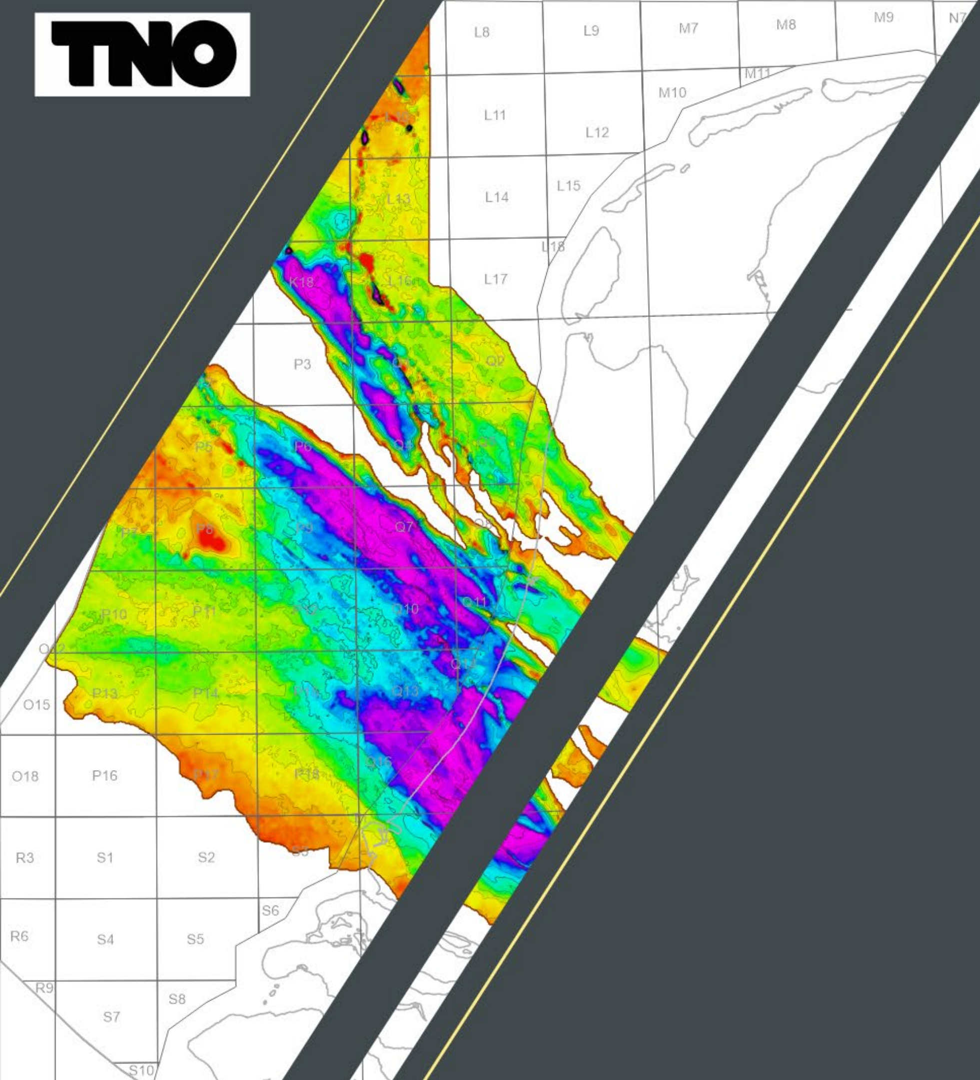


Appendix D: Well Correlation Panels

Devli Panel 6



TNO



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