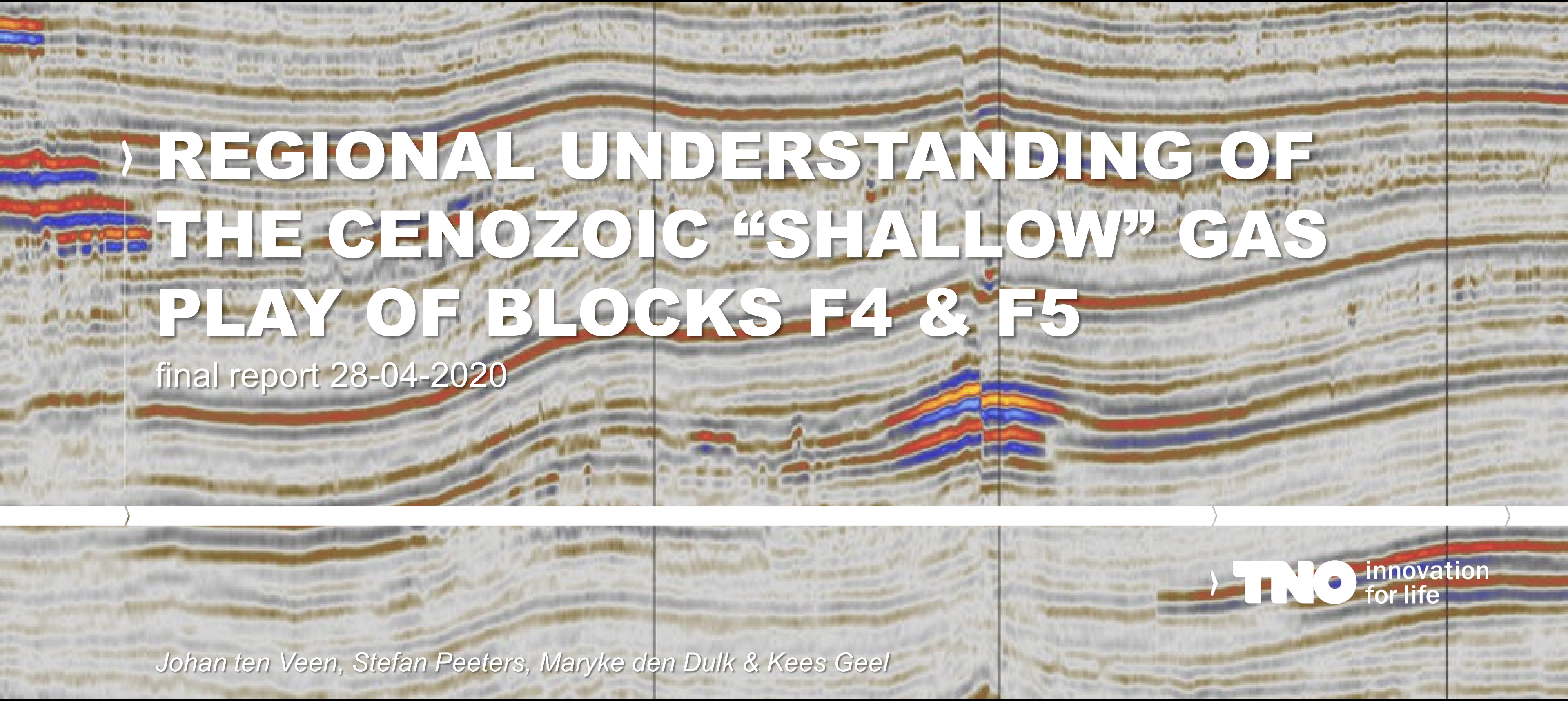


REGIONAL UNDERSTANDING OF THE CENOZOIC “SHALLOW” GAS PLAY OF BLOCKS F4 & F5

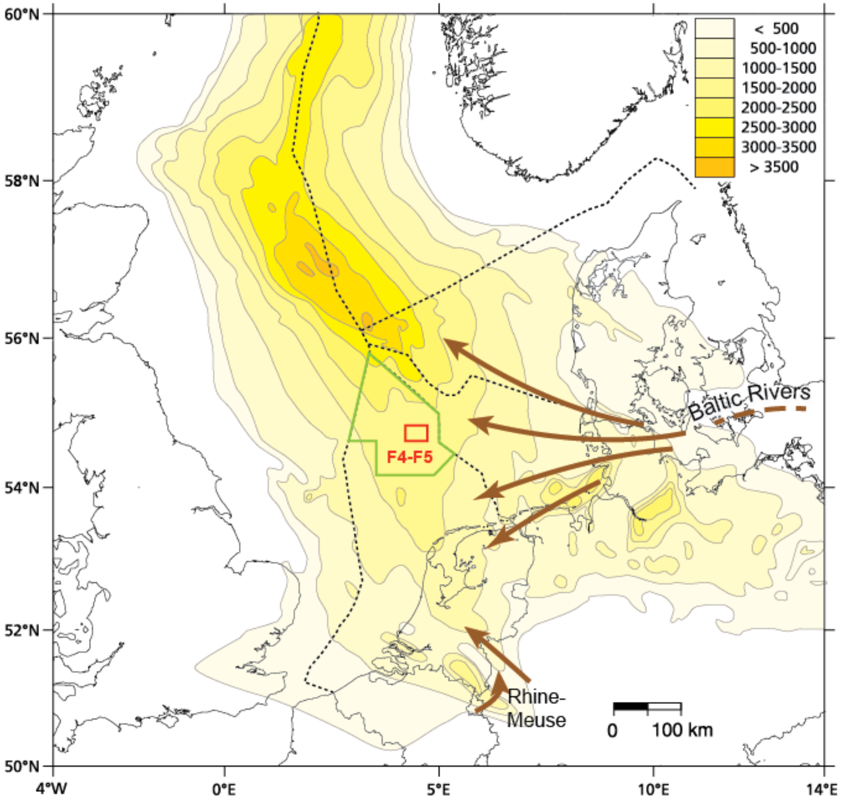
final report 28-04-2020

TNO innovation for life

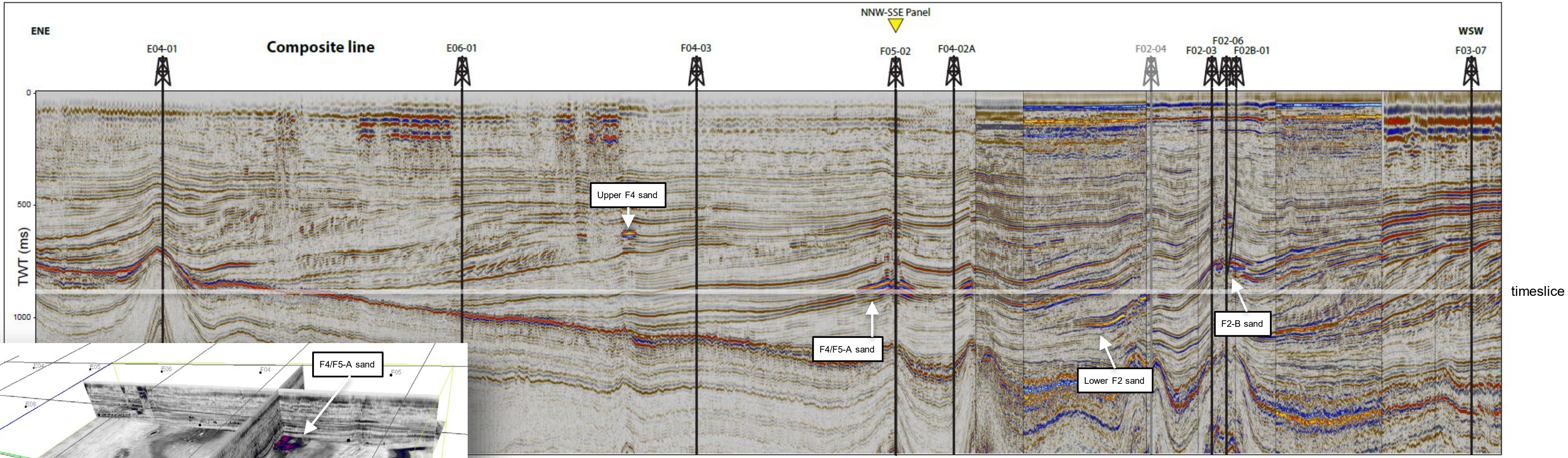
Johan ten Veen, Stefan Peeters, Maryke den Dulk & Kees Geel

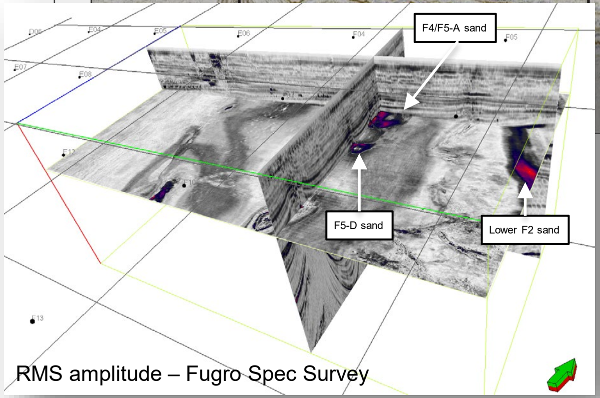
SCOPE OF THE PROJECT

- Area of interest (AOI): The Cenozoic of the blocks F4 and F5 s.l. (AOI)
- Distribution in time and space of DHI's
- Their link to depositional facies
- The properties of the sediments they occur in



TARGETED BRIGHT SPOTS





RMS amplitude – Fugro Spec Survey

This seismic section through the F4-F5 AOI shows the main bright spots*, the regional setting and geological understanding which is the subject of this study

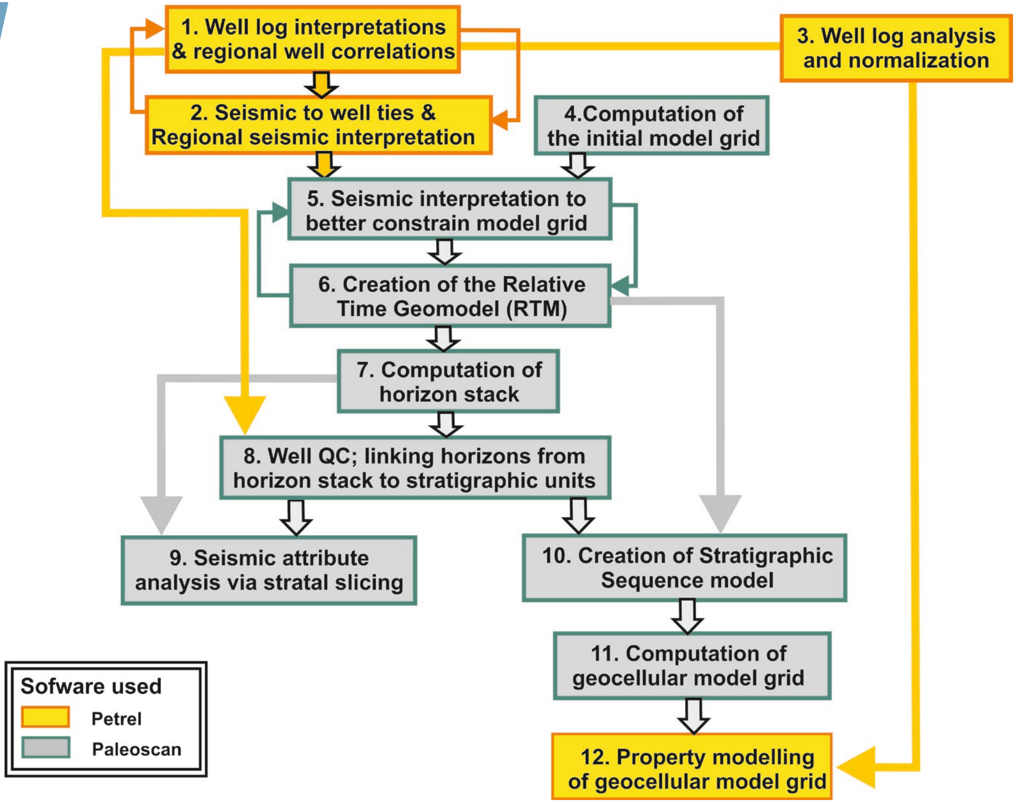
* *Where applicable the nomenclature of Neptune was used*

WORKPACKAGES

Workplan Cenozoic/Shallow Gas Play F4/5 blocks		
Workpackage	Activity	Description
WP1 - Depositional framework	a	Compilation of a depositional framework based on the existing and released regional model (TNO Eridanos Study)
WP 2 - Seismic interpretation	a	Integration and embedding of the multiproxy framework with AOI (F4/F5 blocks)
	b	Seismic to well tie study of the available wells
	c	High-resolution, multi-horizon seismic interpretation (using Palaeoscan)
	d	Detailed (amplitude) mapping, classification and database of individual bright spots
WP3 - Property Modelling	a	Construction of 3D geomodel, based on Paleoscan results
	b	Incorporate well data (Enhancement, correction and petrophysical well log evaluation (GR, Vsh) will be input by Neptune)
	c	Construction of pseudo porosity model (property modeling). 3D seismic amplitude signal to be used as secundary input parameter in a co-krieged model
	d	Qualitative assignment of sediment properties (porosity) to brightspots
WP 4 - Dissemination and Reporting	a	Generating compilation maps (Arc GIS), seismic panels and well correlation panels
	b	Reporting through Powerpoint presentations

Use the workpackage and activity hyperlinks to jump to the appropriate sections in this presentation and ⮌ to return here

WORKFLOW

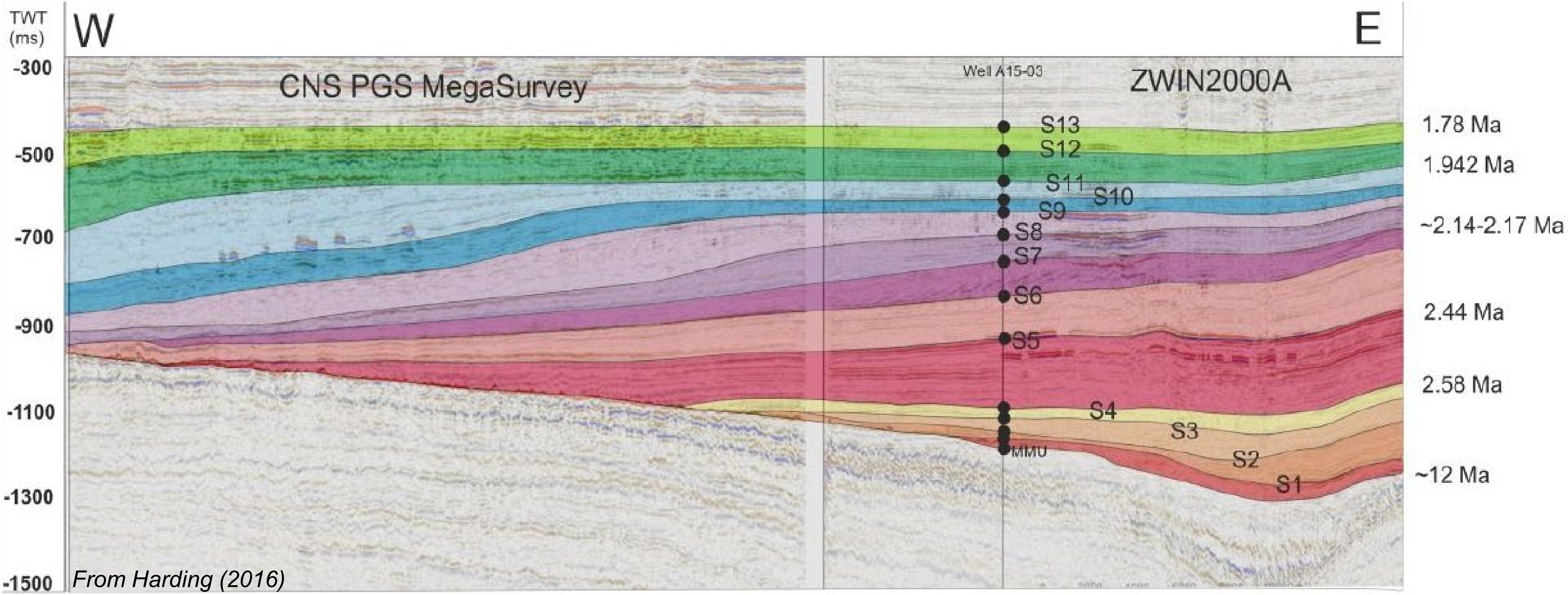


1. Well log interpretations & regional well correlations
2. Seismic to well ties & Regional seismic interpretation
3. Well log analysis and normalization
4.Computation of the initial model grid
5. Seismic interpretation to better constrain model grid
6. Creation of the Relative Time Geomodel (RTM)
7. Computation of horizon stack
8. Well QC; linking horizons from horizon stack to stratigraphic units
9. Seismic attribute analysis via stratal slicing
10. Creation of Stratigraphic Sequence model
11. Computation of geocellular model grid
12. Property modelling of geocellular model grid
Sofware used
Petrel
Paleoscan

WP1 – DEPOSITIONAL FRAMEWORK

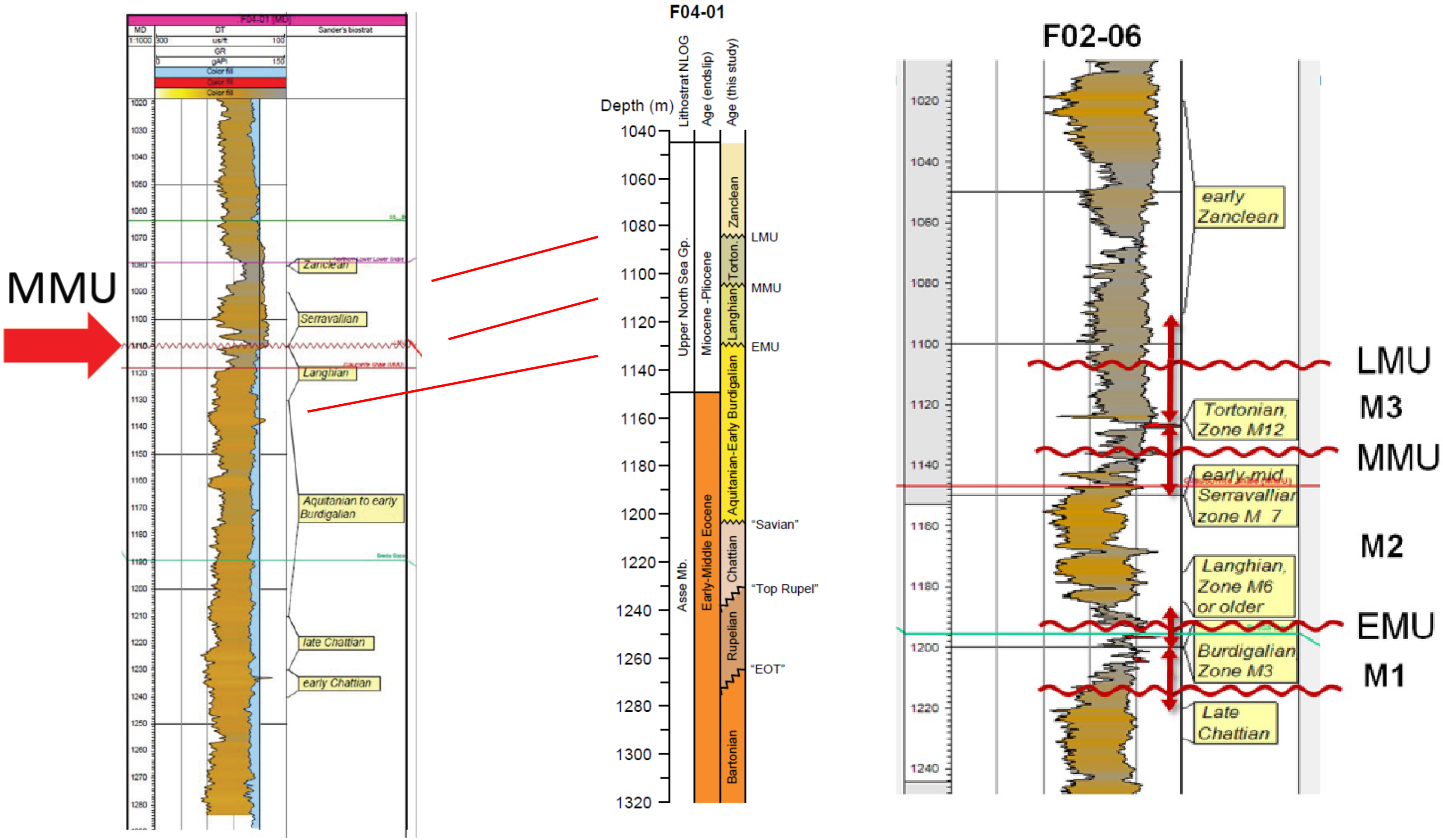
- Inventory and compilation and of current knowledge through
  - study of publicly available (TNO) reports
  - scientific studies
  - grey literature
  - mapping products
- Update of TNO’s multiproxy chronostratigraphic, seismo-stratigraphic and depositional model
- Study/inventory of- and comparison with Neptune data to be used in the project

SNS (SHELF EDGE) DELTA: E-W PROGRADATION
(LATE MIOCENE – EARLY PLEISTOCENE)

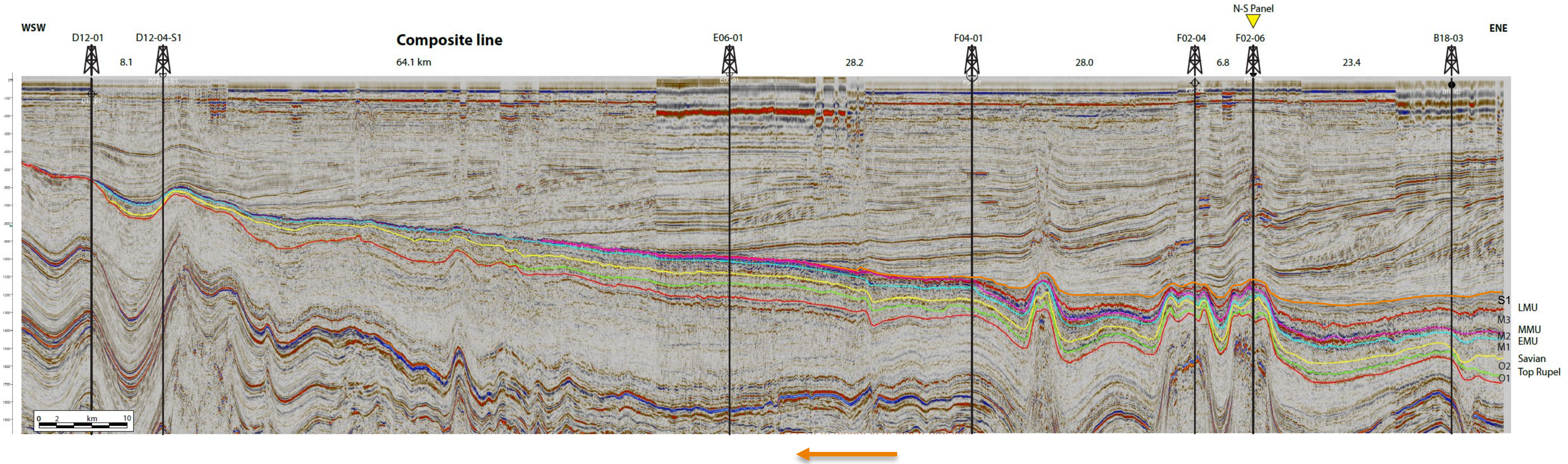


This colour coding is used throughout this presentation and in all dissiminated products

CURRENT KNOWLEDGE: MMU PROJECT



F02 PANEL (MMU PROJECT)



LMU/MMU merge

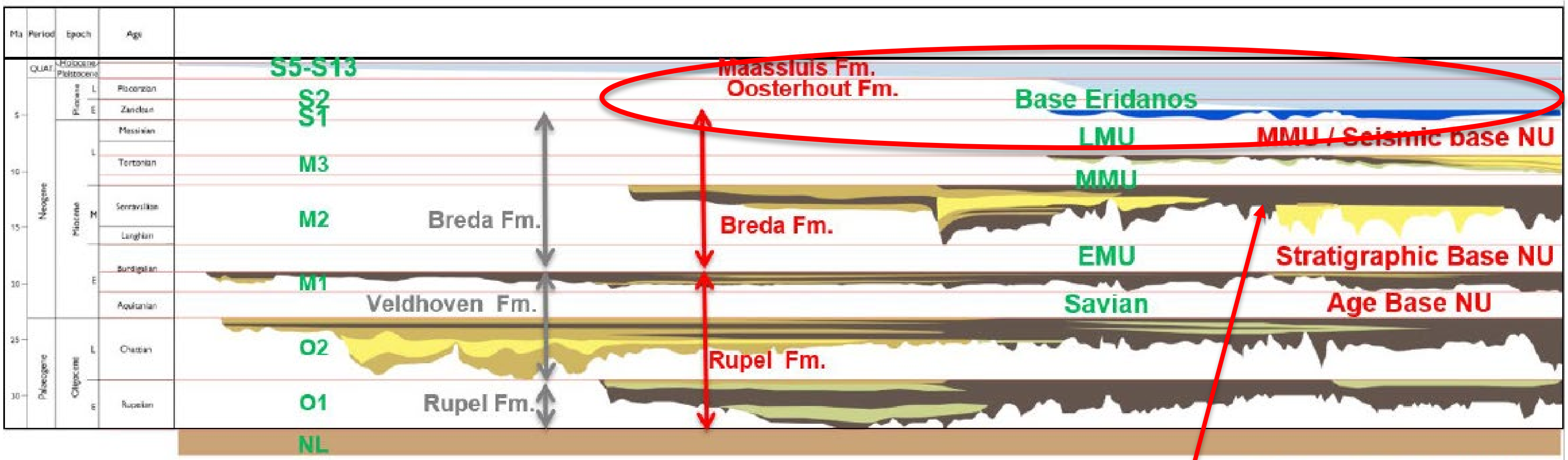
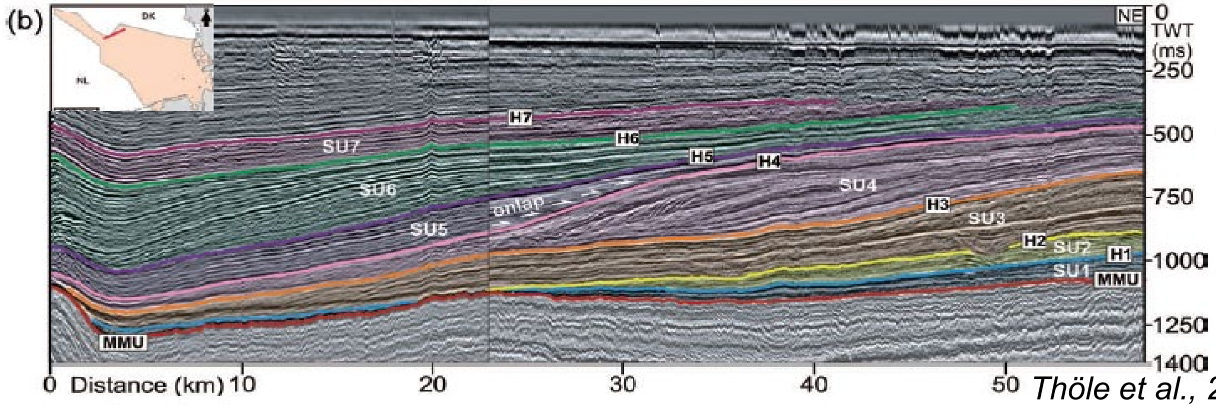


Figure 8.2: Chronostratigraphic diagram of the F02 panel depicting the old terminologies and the new subdivision.



Thöle et al., 2014

Eridanos delta in the Netherlands is placed above the LMU

NEW VS OLD STRATIGRAPHIC POSITION OF THE 3 MIOCENE UNCONFORMITIES

SEISMOSTRATIGRAPHY (COMPARISON)

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Adopted in TNO shallow gas study 2013 (→ Kuhlmann et al.)

Age (Ma)	Stages		Magneto-stratigraphy	Seismic Units Harding (2016)	Newton et al. (Chapter 6)	Sorensen et al. (1997)	Kuhlmann et al. (2004, 2006ab, 2008)	Rasmussen et al. (2005)	Thöle et al. (2014)	Key Surfaces Harding (2016)
		Calabrian								
1.78 Ma	Pleistocene	Gelasian (Expanded Section)	Olduvai	1.78 Ma Pleisto 5	SU5	Composite Sequence IX	SU12-13	J	—	Top Pleisto 5
				1.94 Ma Pleisto 4	SU4	IX	SU9-11	J	—	Top Pleisto 4
			Reunion?	2.15 Ma Pleisto 3	SU3	VIII	SU7-8	J	—	Top Pleisto 3
			Matuyama	2.35 Ma Pleisto 2	SU2	VIII	SU6	J	—	Top Pleisto 2
			X Event	2.43 Ma Pleisto 1	SU1	VI-VII	SU5	I	—	Top Pleisto 1
2.58 Ma	Pliocene	Piacenzian	Gauss	2.58 Ma Plio 1	—	IV-V	SU3-4	G-I	SU7	Top Plio 1
3.6 Ma		Zanclean		4.2 Ma						Top Mio 3
5.33 Ma	Miocene	Messinian		Mio 3	—	Within IV	Upper SU2	Lower G	SU5-6	
7.2 Ma		Tortonian		Mio 2	—	Early IV	Lower SU2	Upper F	SU3-4	Top Mio 2
11.6 Ma 13 Ma		Serravalian		Mio 1	—	I-III	SU1	E-F	SU1-3	Top Mio 1

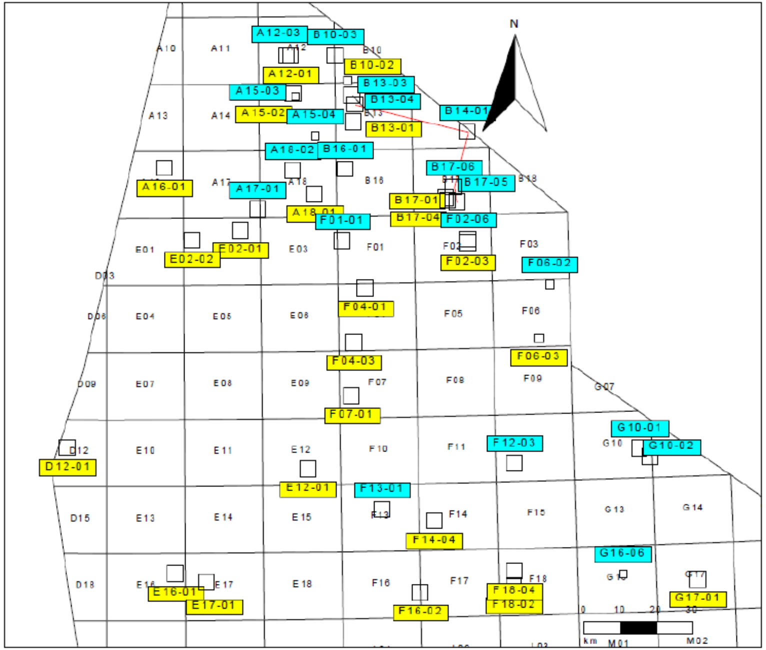
More differentiation in TNO (2013)

More differentiation in Harding (2016)

This study: combination

Comparison from Harding (2016); SU – Seismostratigraphic unit

	well	logzones	biozones	AP/NAP	SD	SSTdino	Sample type	pollen interval	pollen res	dinocyst interval	dinocyst resolution	forams interval	foram res	other	Remark
							SW= side wall								
→	A12-3	x	x	x	x	part	core	467-921	high	488.5-915.35	low				TNO data
→	A15-3	x	x	x	x	x	core, SW, cut	400-1280	high	400-1280	high	400-1280	high	magneto	TNO data
→	A15-4	x	x	x	x	x	core	918-1089	high	918-1089	high				TNO data
	A17-1	x	x		x	x	cuttings	no		440-1140	high				TNO data
	A18-2	x	x	x	x	part	core, SWS	350-1143	high	350-1143	low				TNO data
	B10-3	x	x	x	x	part	core, SWS	374-1230	high	374-1230	low	250-1350	high		TNO data
→	B13-3	x	x	x	x	part	core, SWS	325-1143	high	325-1143	low	300-1350	high		TNO data
	B13-4	x	x			x	SWS	no		406-923	med				TNO data
	B14-1	x	x			x	cuttings	no		500-1400	low			nannos	TNO data
→	B16-1	x	x	x	x	x	SWS	282-1093	med	282-1093	med			magneto	TNO data
	B17-5	x	x	x	x		core, SWS	386-1079	high	no		320-1100	high		TNO data
	B17-6	x	x			x	Cuttings, core	no		240-850	high				TNO data
→	F06-02	x	x	x	x	x	Cuttings	300-1130	med	300-1130	med				TNO data
	F12-03	x	x	x	x	x	Cuttings	620-1130	med	620-1130	med				TNO data
	~~F01-01~~	~~x~~	~~x~~	~~x~~	~~x~~	~~x~~	~~Cuttings~~	~~600-1140~~	~~med~~	~~600-1140~~	~~med~~			~~bad quality~~	~~TNO data~~
→	F2-06	x	x				Cuttings	450-1150	med	450-1150	med				TNO data
	G10-01	x	x		x	x	Cuttings			480-1000	med				TNO data, slump study
	G10-02	x	x		x	x	Cuttings			480-920	low				TNO data, slump study
	G16-06		x				Cuttings			600-1010	med				TNO data
	A12-01		x				Cuttings			232-1340	med	232-1340	med		literature, reinterpreted
	A15-02		x				Cuttings			400-1320	med	400-1320	med		literature, reinterpreted
→	A18-01		x				Cuttings			360-1300	med	360-1300	med		literature, reinterpreted
	B10-02		x				Cuttings					150-1270	med		literature, reinterpreted
	B13-01		x				Cuttings			378-1260	med	378-1260	med		literature, reinterpreted
	B17-01		x				Cuttings					285-1080	low		literature, reinterpreted
	B17-04		x				Cuttings					137-1061	med		literature, reinterpreted
	D12-01		x				Cuttings					300-560	low		literature, reinterpreted
	E02-01		x				Cuttings					70-990	med		literature, reinterpreted
	E02-02		x				Cuttings					470-1070	med		literature, reinterpreted
	E12-01		x				Cuttings					520-948	med		literature, reinterpreted
	E16-01		x				Cuttings					229-625	low		literature, reinterpreted
	E17-01		x				Cuttings					70-650	med		literature, reinterpreted
→	F02-03		x				cuttings & core			1203-1205	low	550-1203	med		literature, reinterpreted
→	F04-01		x				Cuttings					76-1060	med		literature, reinterpreted
→	F04-03		x				Cuttings					475-1131	med		literature, reinterpreted
→	F06-03		x				Cuttings					510-1135	med		literature, reinterpreted
	F07-01		x				Cuttings					89-989	low		literature, reinterpreted
	F13-01		x				Cuttings					150-1000	med		literature, reinterpreted
	F14-04		x				Cuttings					360-1120	med		literature, reinterpreted
	F16-02		x				Cuttings					140-1010	med		literature, reinterpreted
	F18-02		x				Cuttings					88-1034	med		literature, reinterpreted
	F18-04		x				Cuttings					110-1050	med		literature, reinterpreted
	G17-01		x				Cuttings					98-646	med		literature, reinterpreted



TNO 2013 biostrat (palynology)

Reinterpreted literature biostrat (palynology)

→ used as “TNO well tops” in this project

BIO / LITHOSTRAT CORRELATION A15-03

Current work: lithostratigraphic subdivision at individual sand/clay levels (~marine isotope stages)

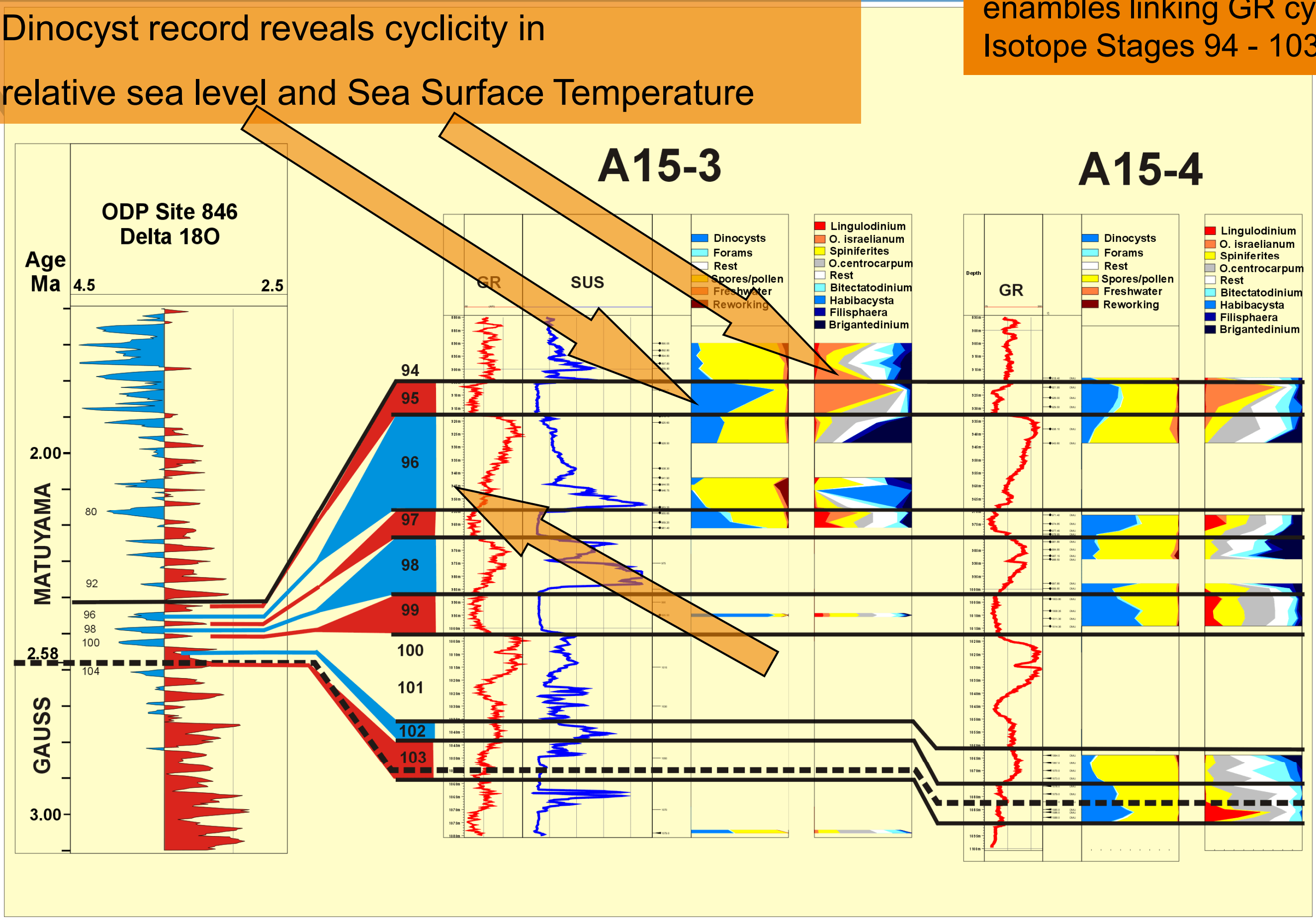
well	MD top	MD base	Kuhlmann 2006 Log Unit	Kuhlmann & Wong, 2008 Seismic Unit	Ma top	Ma base	Age	NL Chronostrat Sea	NL Chronostrat Land
A15-03	431	482	18	S13	1.8			Markham hole Fm	Peize Fm
A15-03	482	539	17	S12		1.9		Winterton shole Fm	Peize/Maassluis
A15-03	539	597	16	S11				Ijmuiden Ground Fm	
A15-03	597	643	15	S10					
A15-03	643	660	14	S9				Westkappele	Maassluis
A15-03	660	712	13	S8				Ground Fm	Fm
A15-03	712	769	12	S7			Gelasian		
A15-03	769	802	11	S6		2.16		Brielle Ground Fm	Oosterhout
A15-03	802	918	10		2.16	2.44		Ground Fm	Fm
A15-03	918	967	9		2.44				
A15-03	967	1003	8	S5					Kiezeloolite
A15-03	1003	1028	7						Fm
A15-03	1028	1070	6			2.58			
A15-03	1070	1100	5	S4	2.58				
A15-03	1100	1142	4				Piacenzian		
A15-03	1142	1182	3	S3		3.6			
A15-03	1182	1205	2	S2			Zanclean		
A15-03	1205	1243	1	S1		5.2			
A15-03	1280					12.5	Serravalian		
A15-03	1340					19	Burdigalian		
A15-03	1400					26.5	Chattian		

LMU
MMU

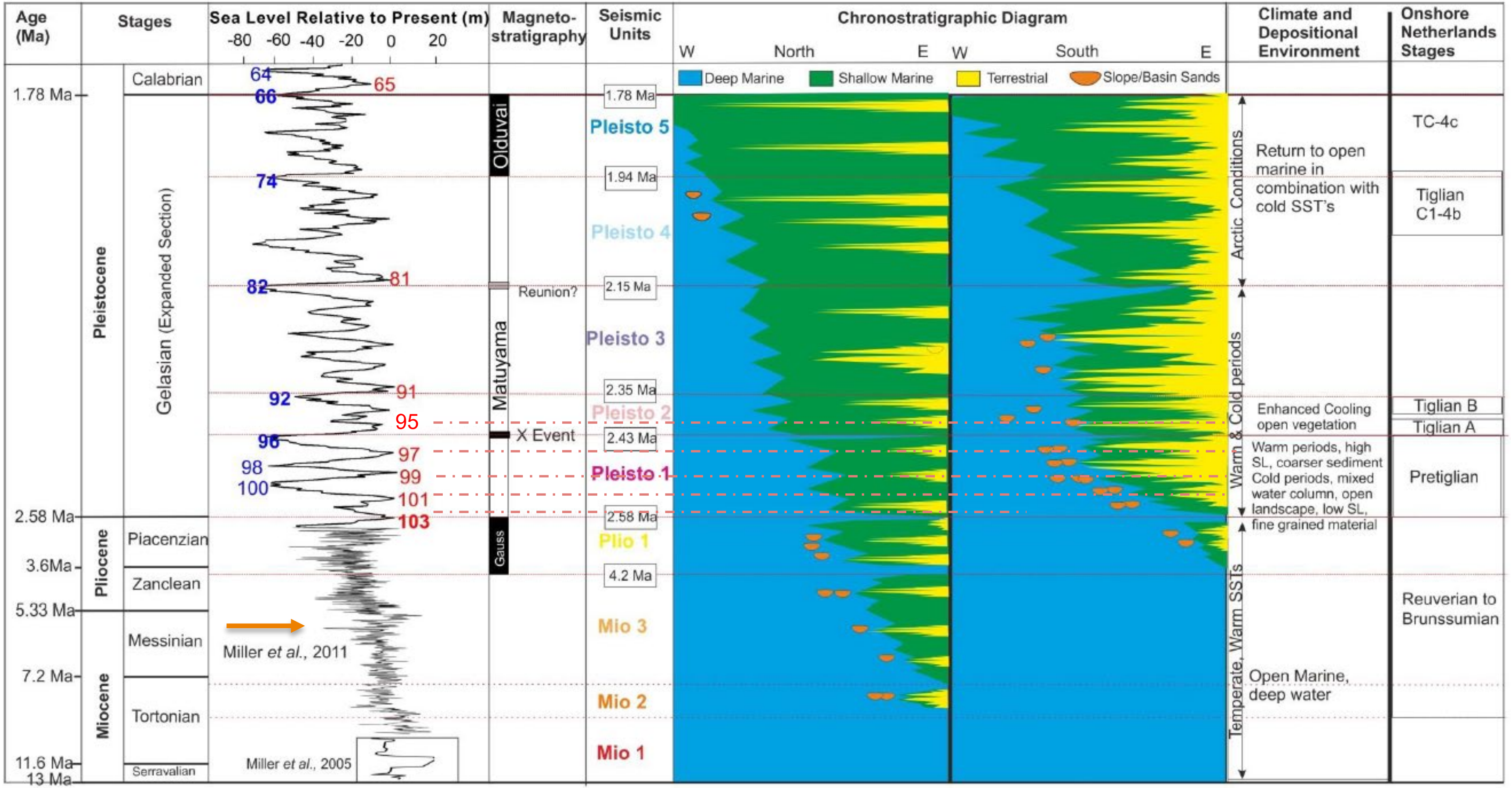
Accurate chronostratigraphic calibration enambles linking GR cycles to Marine Isotope Stages 94 - 103

PALY

Dinocyst record reveals cyclicity in relative sea level and Sea Surface Temperature



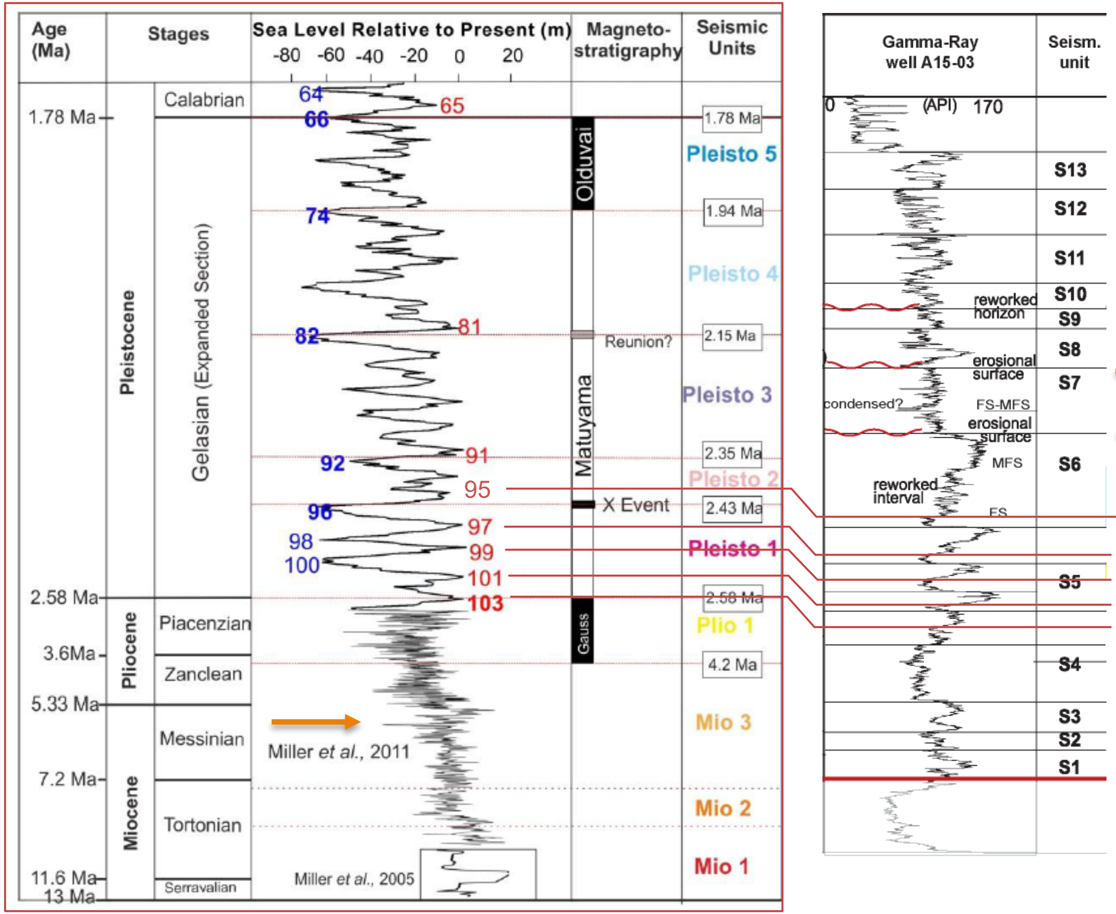
Marine Isotopic Stages (MIS)



Comparison form PhD. thesis Rachel Harding, 2016

LABELLING OF RESERVOIR SANDS

TNO innovation for life



Comparison from PhD. thesis Rachel Harding, 2016

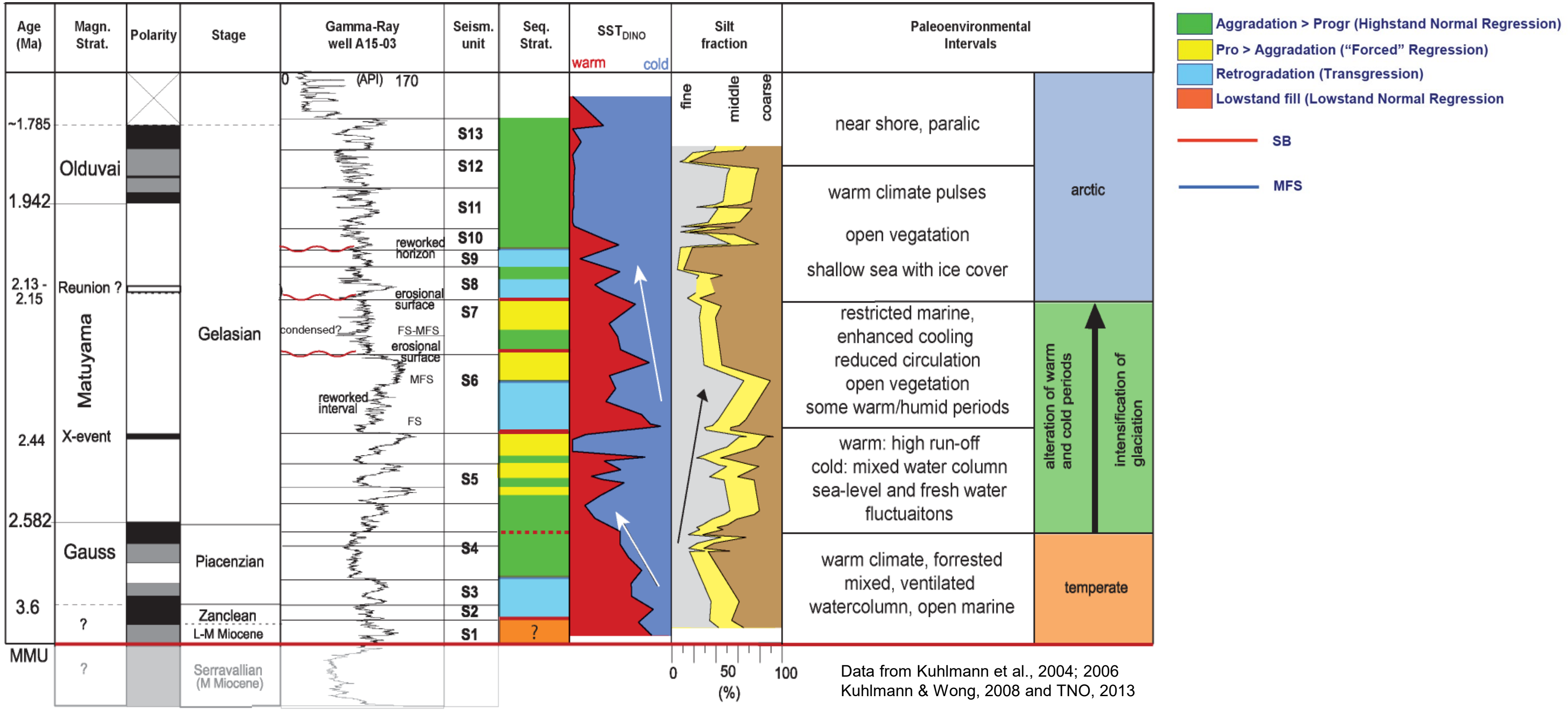
This study	Neptune	Wintershall
Base S12	horiz 0	
Top S8	horiz 1	
Topset truncation		
Tiglian Unconformity		
2 prograding clinoforms topped by MFS and onlapping unit		
Top 95	horiz 2	D10
Top 97 =		D20
Top 99 =	horiz 3	D30
Top 101		
Top 103		
Top S5 lst*	horiz 2	D40
Near Base 5	horiz 5	D10

Top S8, Topset truncation, Tiglian Unconformity: One shelf-edge unit

*lowstand wedge in base S5 (not present in A15-03)

A15-03 SEQ. STRAT– MULTIPROXY FRAMEWORK

innovation for life



Data from Kuhlmann et al., 2004; 2006
Kuhlmann & Wong, 2008 and TNO, 2013

WP2 – SEIMIC INTERPRETATION

- Seismic-to-well tie study of the available wells and interpretation approach
  - Seismic character (mainly studied within AOI to avoid different vintages)
  - Picking well tops in TWT (generating a TD relationship for TVD → TWT)

- Integration and embedding of the multiproxy framework with the AOI
  - Regional seismic panels (in TWT)
  - Well correlation panels based on well top interpretation (in TVD)

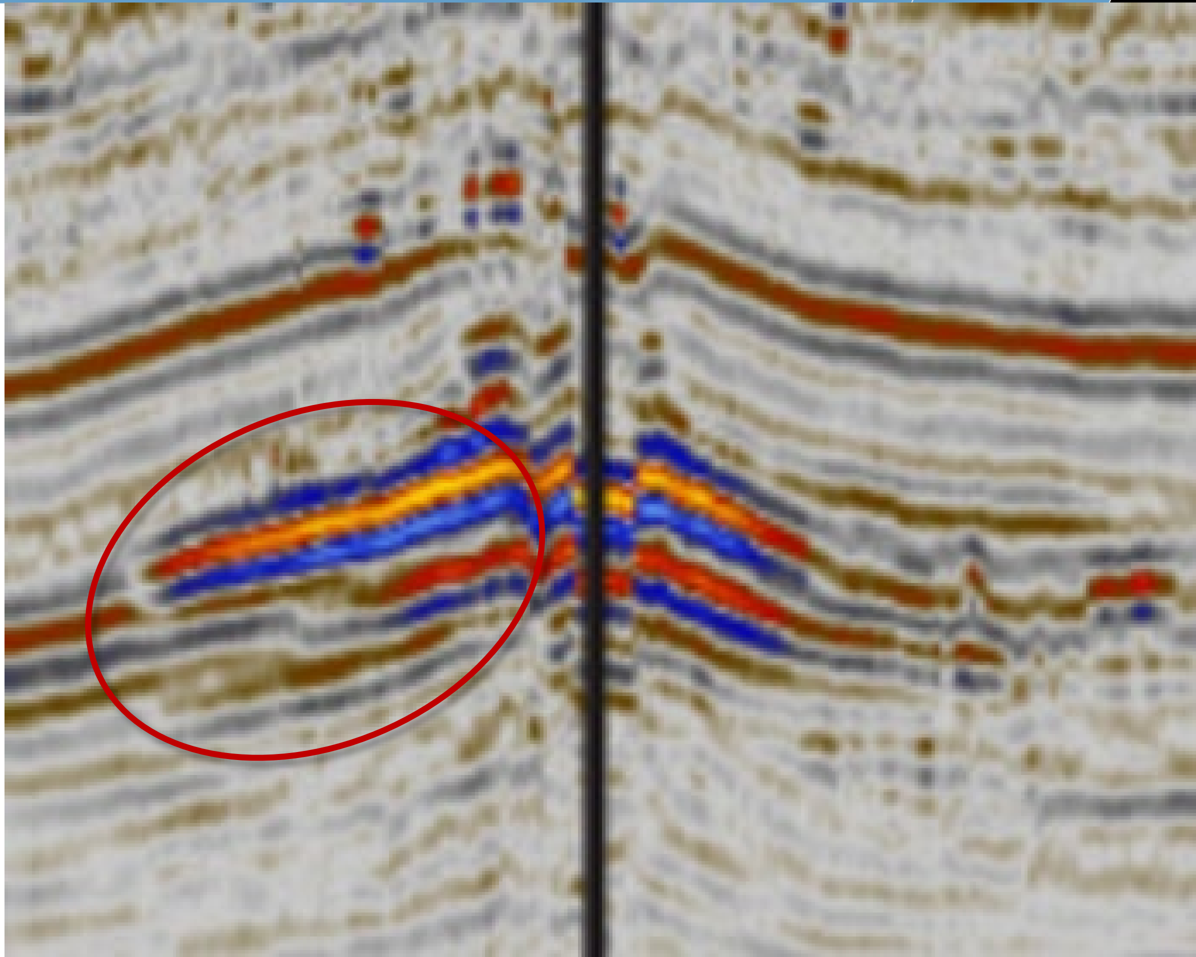
- High-resolution, multi-horizon seismic interpretation (using Paleoscan)

- Mapping of depositional facies (Paleoscan) and classification individual bright

WHAT'S GOING ON?

F05-02

- The F05-02 bright spot show thickening and increase of bright reflectors
- Possibel explanations are:
  - Wedging?
  - Thinning?
  - Fault-related issues?
  - Phase change and /or
  - Gas-fill related velocity / acoustic impedance issues?

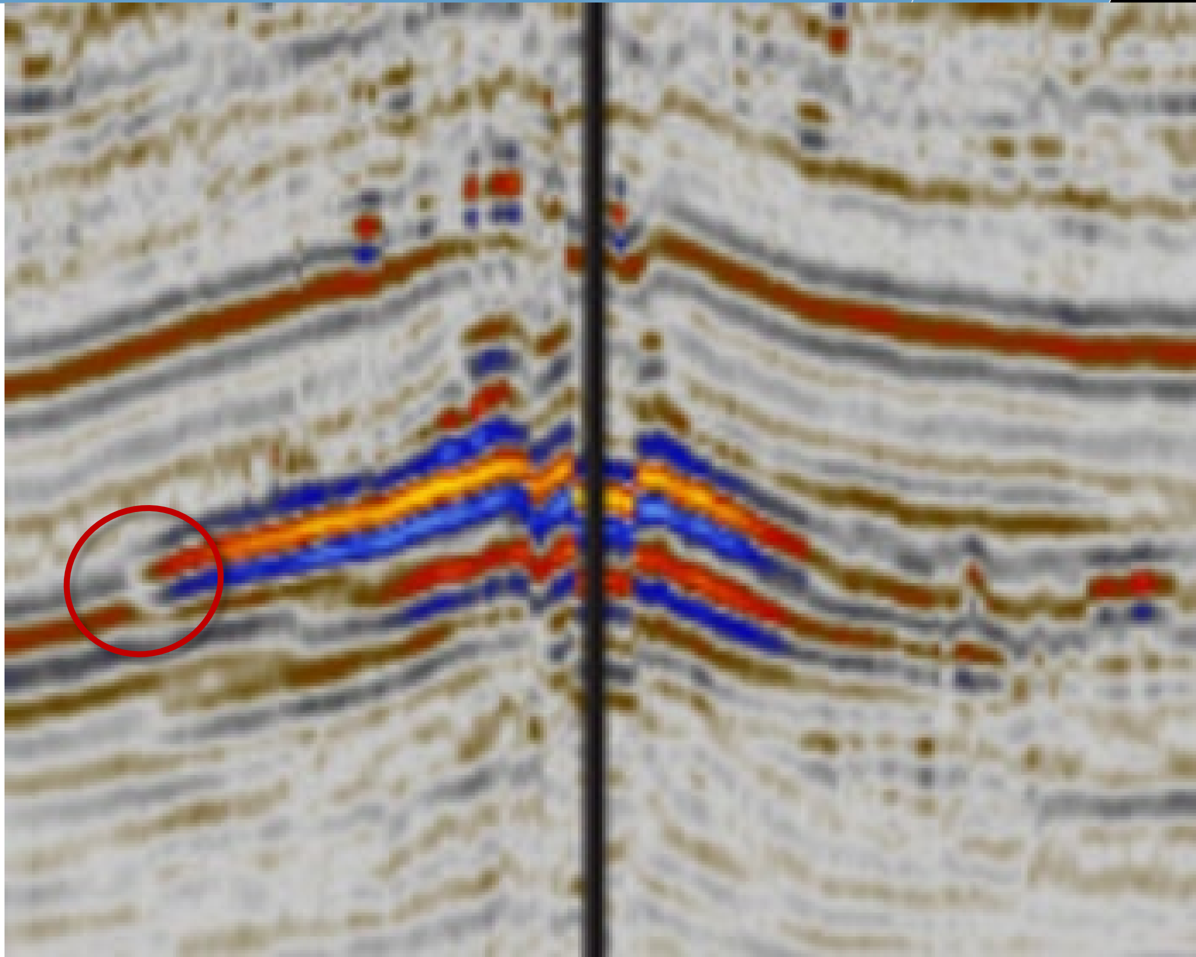


WHAT'S GOING ON? #1

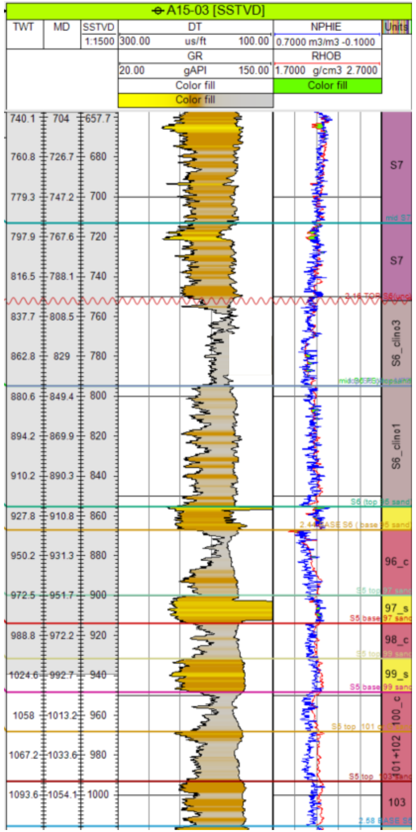
F05-02

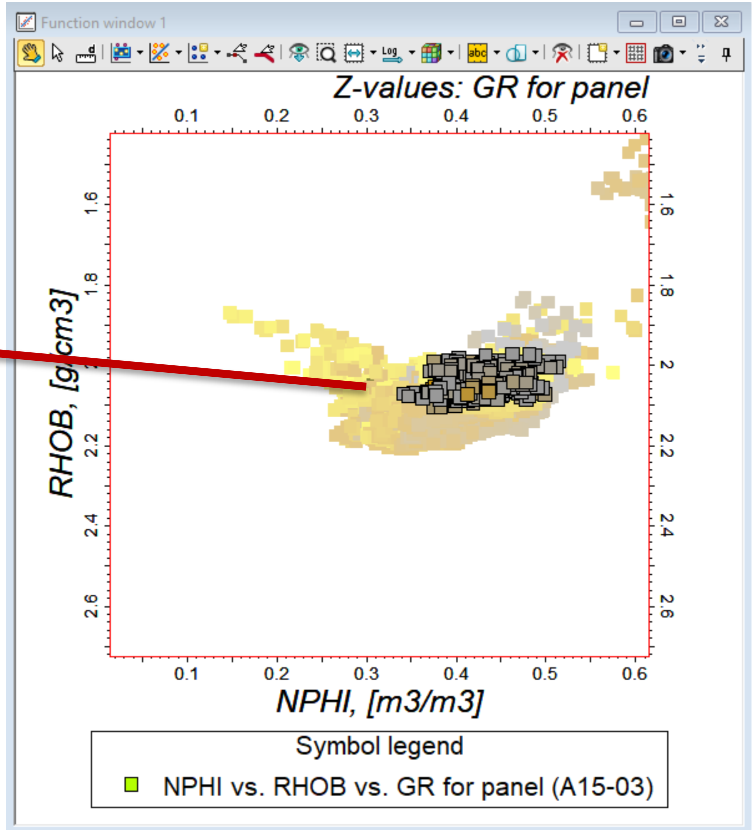
TNO innovation for life

- Looks like a classical phase reversal in gas bearing sands.
- Thi means that the AI jump in water bearing sands must be negative.
  - i.e. density of shale is smaller than the density of sand…
  - Let's have a look at a well with decent logs: A15-03.



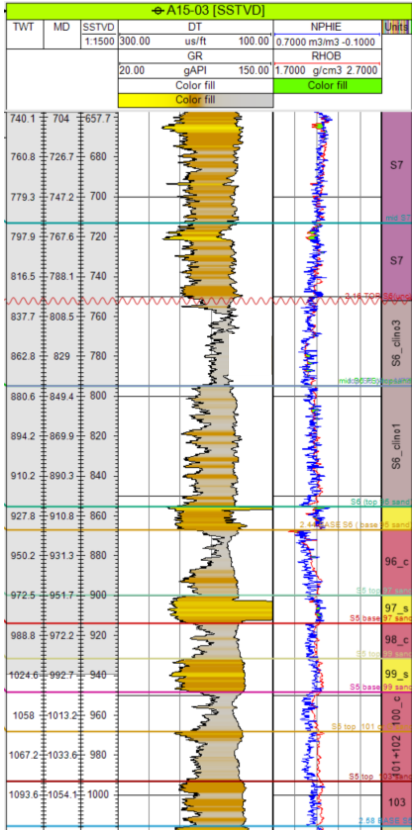
A15-03 - TOP S6 ONLAPPING SHALES

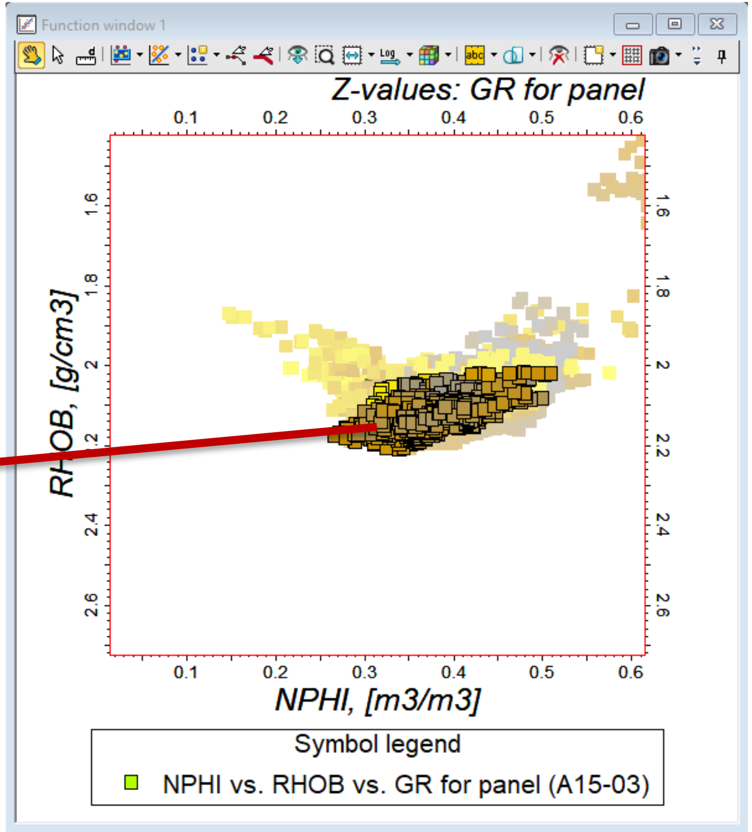




Sands are tighter & denser than shale

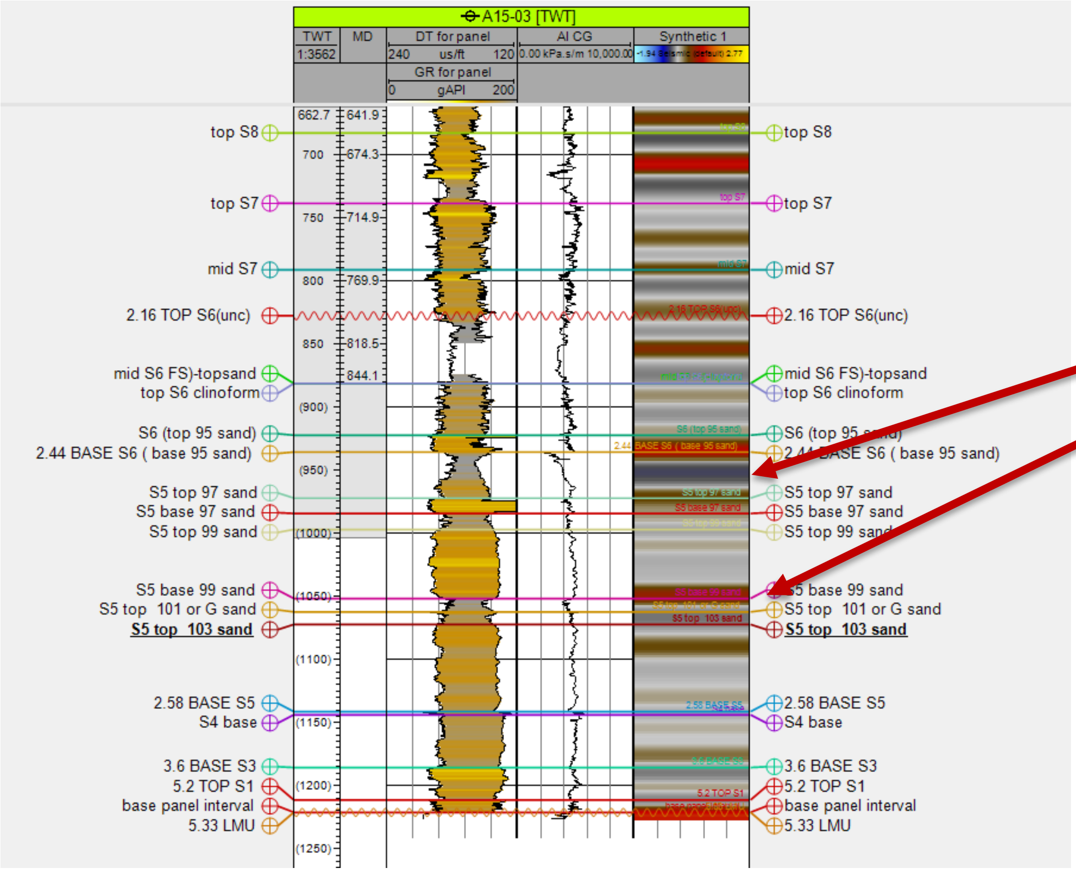
A15-03 S6 CLINOFORM SAND





Sands are tighter & denser than shale

SYNTHETIC SEISMOGRAM A15-03

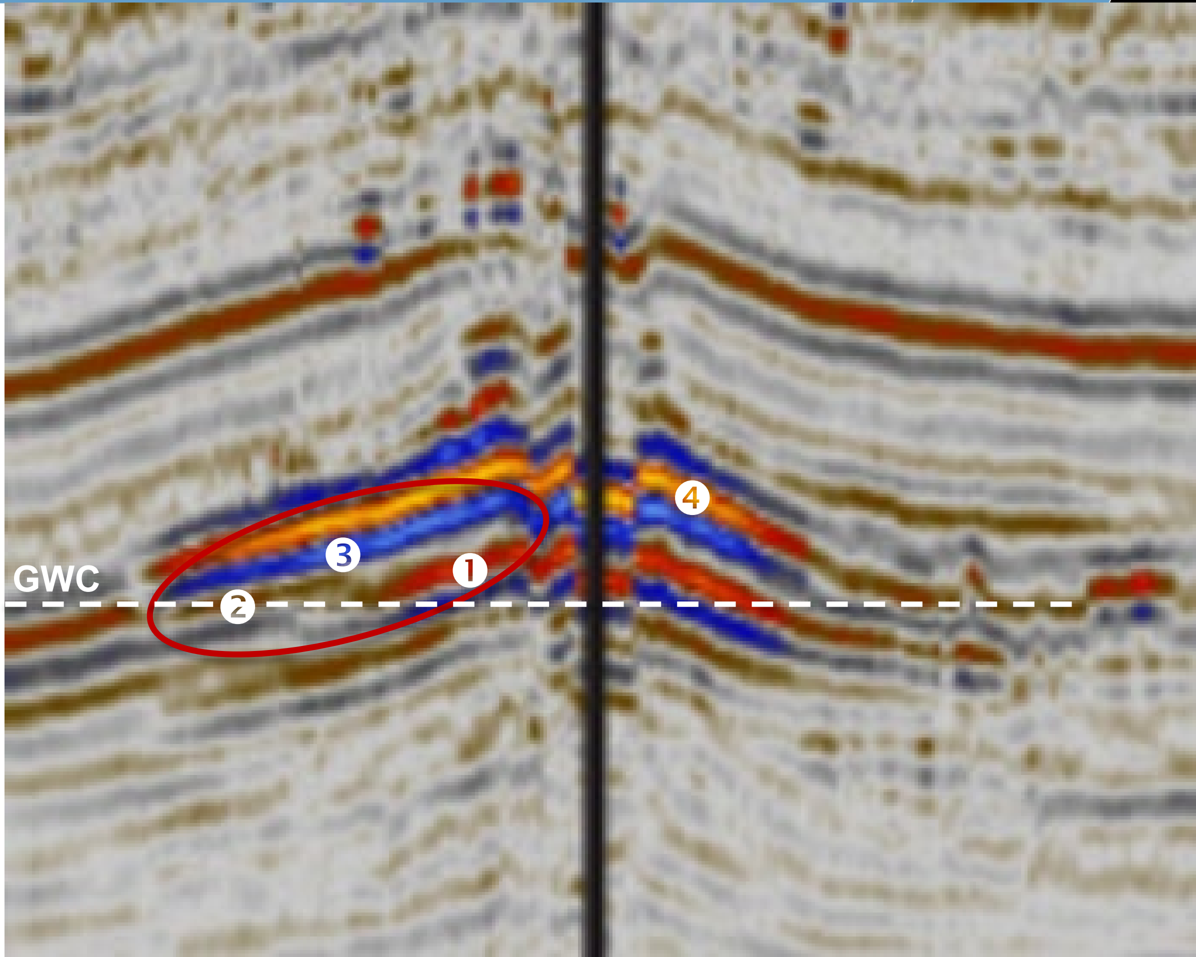


- Synthetic seismic with 30 Hz Ricker Wavelet, European polarity. Yes I know the A15 cube is American polarity, but the idea is to prove that sands are hard kicks for the rest of the F blocks which have European polarity.
- In general: Top sand is hard kick (blue), top shale is soft kick (red).
- So, if this relation holds for the rest of the sands and shales in the F blocks, gas-bearing sands with gas densities of ~40 kg / m3 wil have a very soft kick, and thus a phase reversal!

WHAT'S GOING ON? #2

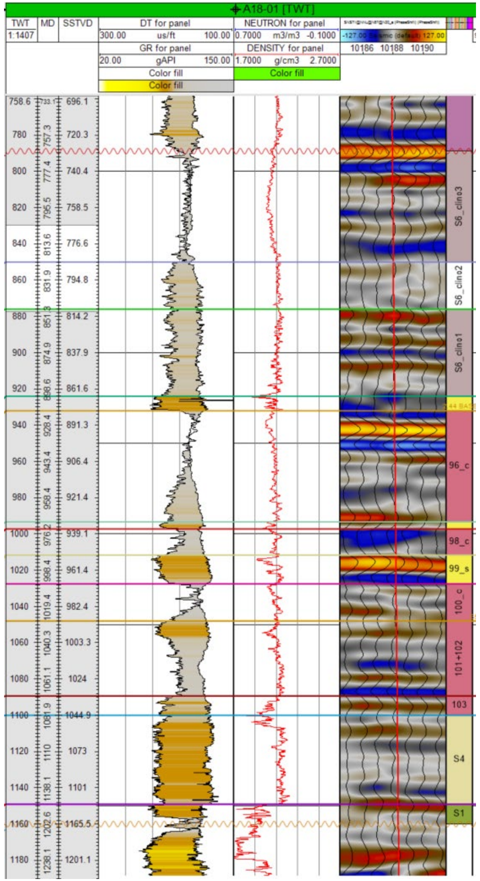
F05-02

- Top water-bearing sand is a hard kick (blue in European polarity & standard Petrel colours)
- Top gas-bearing sand is a soft kick (red in European polarity & standard Petrel colours)
- Why the jumps and disappearing red reflector?
- Interpretation: a GWC, causing a soft kick on gas bearing sand (1), and a red side lobe (2) at the base of the overlying gas-bearing sand (3).
- Side lobes are more pronounced when the central reflector amplitude is large. See e.g. (4).

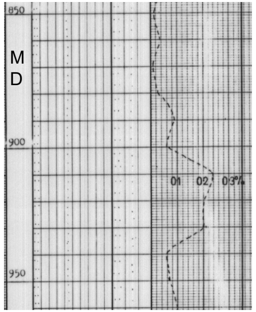


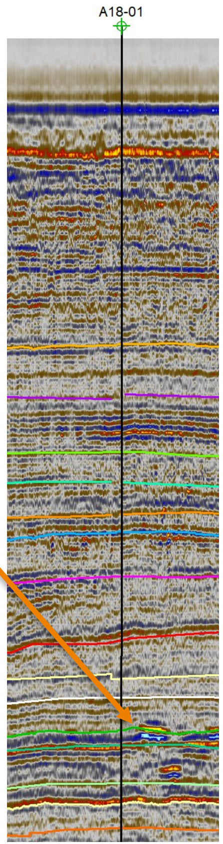
DOES THIS REASONING HOLD FOR THE F4/F5 AREA ?
(WHERE NO RHOB/NPHI LOGS ARE AVAILABLE)

S5 SANDS IN A18-01



Which sands will show polority reversal when gas filled?
Used gas log for gas check = only positive for S6-95 sand,
Nearby bright spot without/unclear phase reversal

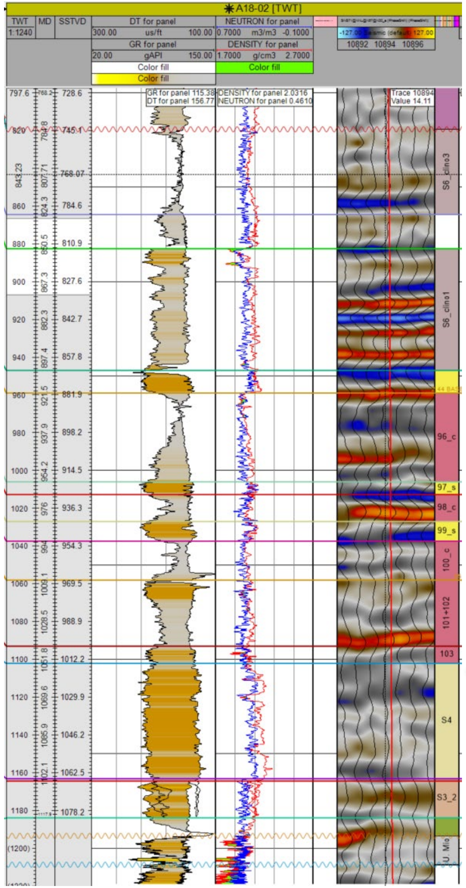




Acoustic impedance at top:

- S6-95 sand = same average density but lower in top (gas?) = trough (close to well increase in Amp, with reversal ?)
- S5-97 sand = lower density, no gas
- The top of S5-99 sands have higher (more variable) density than overlying shale, no gas, trough
- The S5-101 sand have lower density than the shales, no gas, peak
- The S4 sands clearly have higher densities, no gas, trough

S5 SANDS IN A18-02



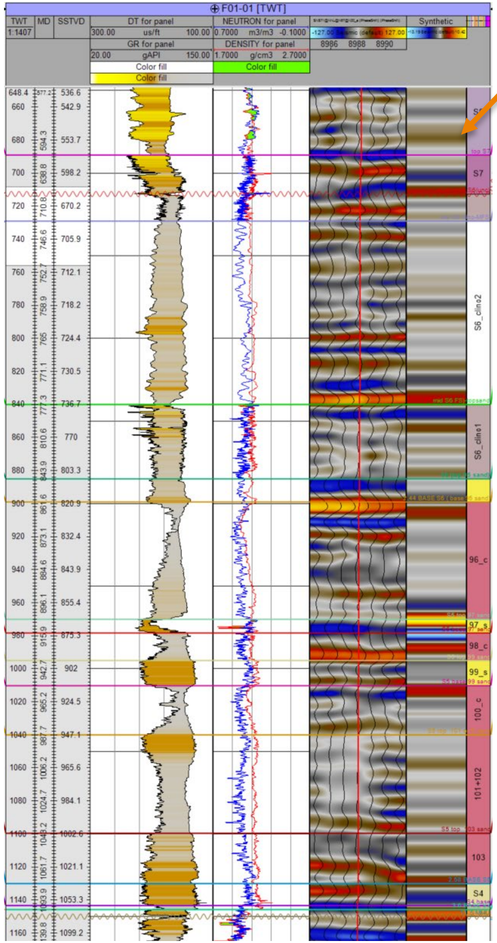
Which sands will show polority reversal when gas filled?
Use RHOB/NPIE cross-over for gas indication

Note A18-02 is in pull down and 2 km off the seismic line

Acoustic impedance at top:

- S6-95 sand = same average density(low in top, high in base) this might be related to gas (see DT (HARD TO SEE IN SEISMIC DUE TO PULL DOWN?), trough
- S5-97 sand = higher density, no gas, trough
- The top of S5-99 sands have a higher (more variable) density than overlying shale, no gas, through
- The S5-101 sand hear has lower density than the shales, gas?, peak
- The S4 sands clearly have higher densities, no gas, trough

S5 SANDS IN F01-01



Synthetic with Ricker 50 Hz wavelet (~extracted)

Which sands will show polarity reversal when gas filled?
Use NPHI/RHOB cross over for gas check,
→ no gas in S5 sands in F01-01, gas in top S7 is biogenic (ARCO report), gas <2,5% in part above

Note F01-01 is 2 km off the seismic line

Acoustic impedance at top:

- S6-95 sand = higher average density (esp base) trough
- S5-97 sand = lower density, peak (also velocity effect may hint at gas???). Peak not seen in seismic, but well is projected
- The S5-99 sands have a higher (more variable) density than overlying shale, trough
- The S5-101 sand have higher density (but higher velocity) than the shales (probably faint trough)
- The S4 sands clearly have slightly higher density, trough

DIRECTIONS FOR SEISMIC INTERPRETATION

- The S5 water-saturated “sheet” sand generally show higher densities than surrounding shales
- The top of the sand would produce a hard kick (trough with European polarity & standard Petrel colours)
- If the sands become gas filled, the density decreased, such that a acoustic polarity reversal occurs (peak with European polarity & standard Petrel colours
- The reversal may coincide with a GWC, although we cannot exclude that multiple GWC’s exist. Density and sonic logs sometimes show the presence of a gas “cap” which would imply the existence of a GW interface within the sand layer (probably too thin to be detectable in seismic). Structure-related GWC’s may have differente heights at either side of a fault. This required further investigation.
- Alternatively (or in addition), the gas-filled sand can be limited by erosional features (and their infill) as can be deduced from sudden lateral amplitude dimming (as confirmed with RMS maps)

SEISMOSTRATIGRAPHY APPLIED

- Detailed seismic interpretation is only performed in the AIO, other seismic interpretation supports the generation of regional seismic panel that are constructed in parallel with the interpretation of key wells
- We use the Seismic Units (SU) of Kuhlmann (2004) and their correlation with log units as much as possible.
- For units S5 and S6 we adopt the concept that the sands (and/or coarser grained silts) are deposited during highstand shedding (e.g. ten Veen et al., 2013; Harding, 2016) and the clays (and/or finer-grained sitls) represent the glacial minima during which sediment influx is low.
- Thus the fines demarcate the low-stand period and the major down drops (sequence boundaries) and associated features are to be found at the transition from sand to clay, i.e.,at an in the top of the sands
- Consequently the flooding surfaces (FS) occur below the sand.
- As the log units of Kuhlmann are rather arbitrarily chosen ("*Unit boundaries were placed at both trend reversals and distinct gamma-ray log breaks*"), we choose to adjust them (slightly) to the top sands as these levels correspond to the reservoir/seal transitions and are therefore more usable for demarcating the top of gas sands (i.e., bright spots). As such, there is also better correlation with marine isotopic stages (MIS).
- The gas sands of unit S5 and S6 are labelled according the MIS

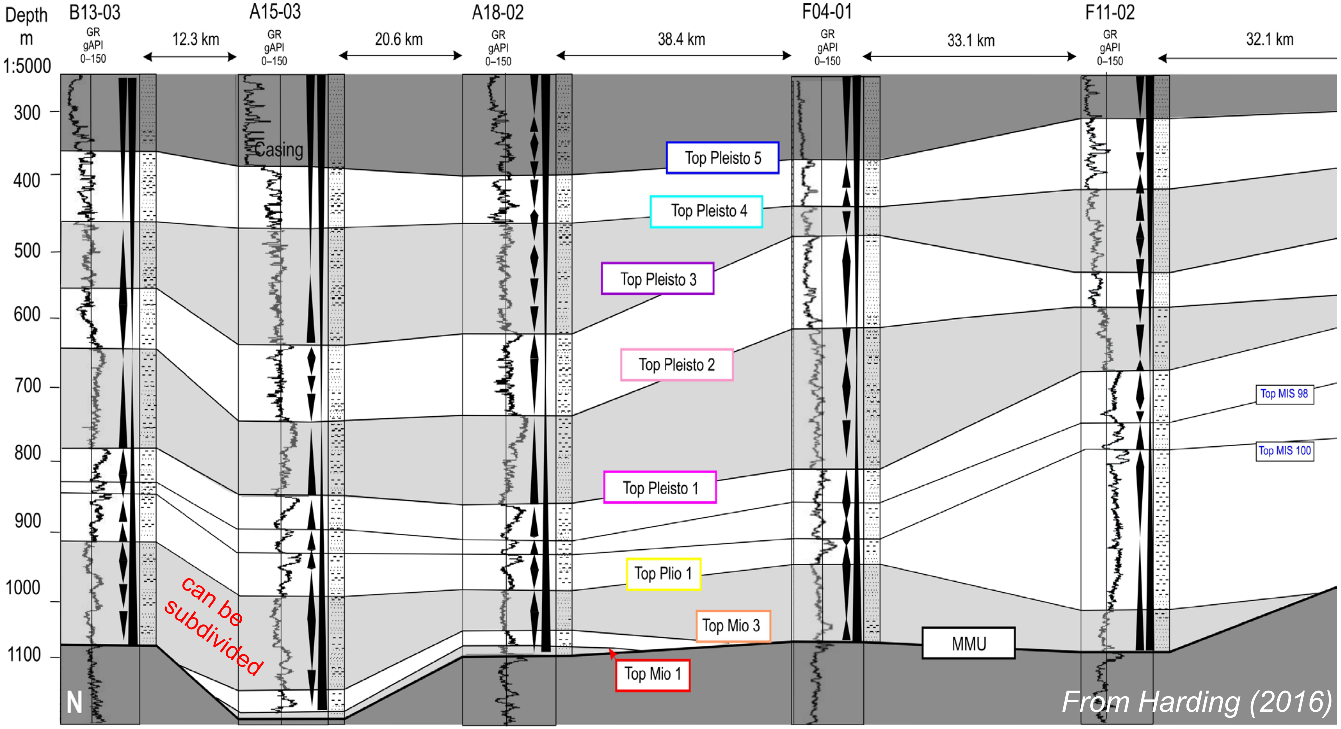
WP2 – SEIMIC INTERPRETATION

- Seismic-to-well tie study of the available wells and interpretation approach
  - Seismic character (mainly studied within AOI to avoid different vintages)
  - Picking well tops in TWT (generating a TD relationship for TVD → TWT)

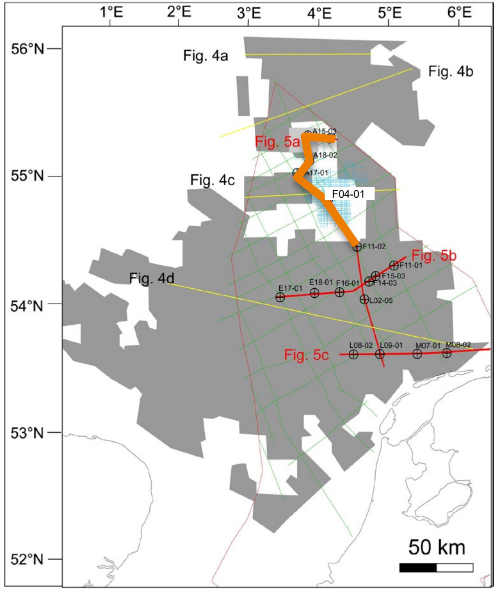
- Integration and embedding of the multiproxy framework with the AOI
  - Regional seismic panels (in TWT)
  - Well correlation panels based on well top interpretation (in TVD)

- High-resolution, multi-horizon seismic interpretation (using Paleoscan)

- Mapping of depositional facies (Paleoscan) and classification individual bright spots

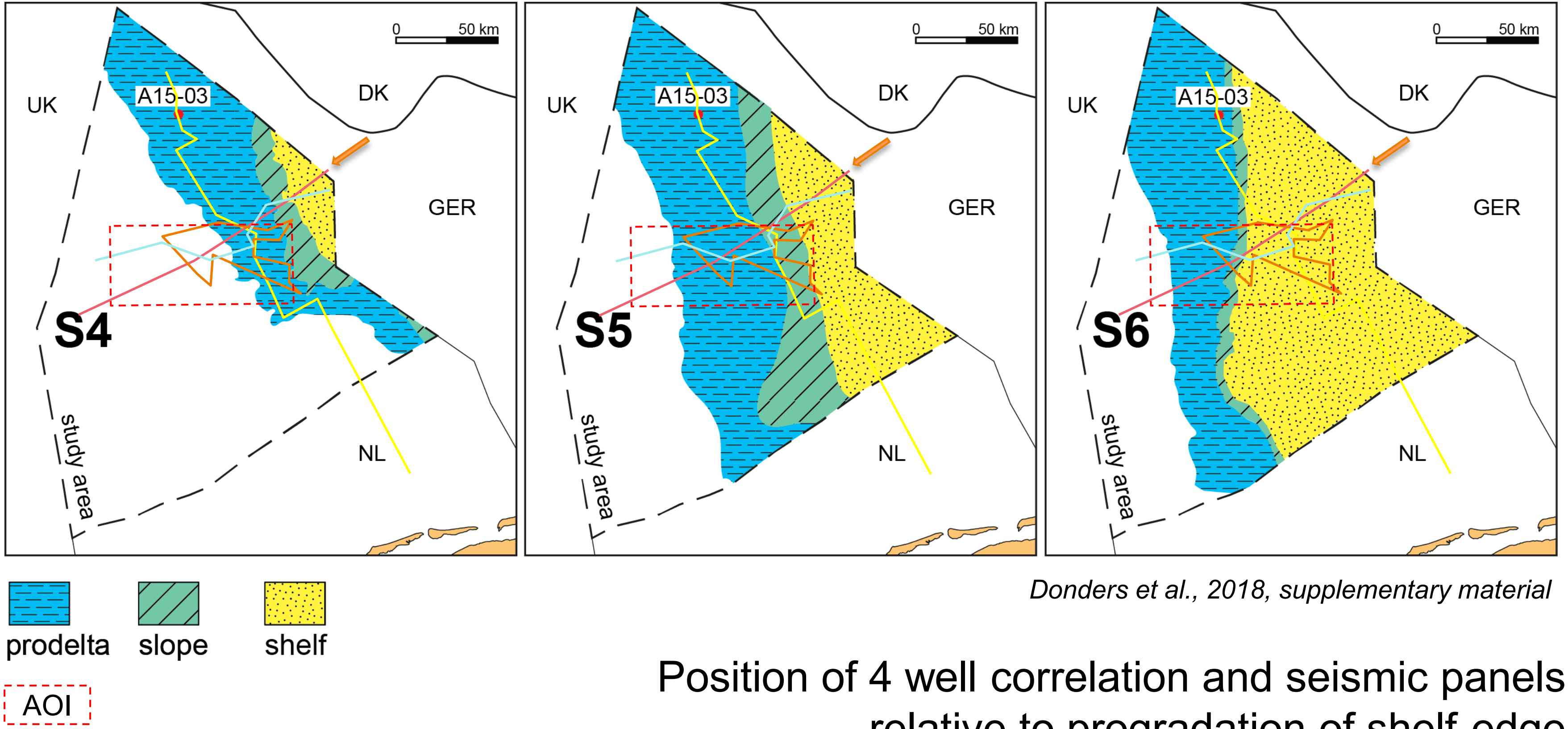


S5



Well correlation is an extension/adaption of the work presented in Kuhlmann (2008) and Harding (2016) and focusses on tracing the "sands"

OVERALL PROGRADATION S4 - S6



Donders et al., 2018, supplementary material

Position of 4 well correlation and seismic panels relative to progradation of shelf-edge

WELL PANELS

Well section A12-03- to F12-03		normalized by Neptune	well tops in TWT	TD using TWT pick
A12-03		batch 3.1	x	x
B13-03		2nd batch	no SI	no
A15-03		batch 3.1	x	x
A15-04		batch 3.1	x	x
B16-01		batch 3.1	x	x
A18-02		batch 3.1	x	x
A18-01		batch 3.1	x	x
F01-01		batch 3.1	x	x
F4-2A	model DEF survey	batch 3.1	x	x
F04-01	model DEF survey	batch 3.1	x	x
F05-02	model DEF survey	batch 3.1	x	x
F5-5	model DEF survey	batch 3.1	x	x
F11-01		batch 3.1	needs work	
F12-03		batch 3.1	needs work	

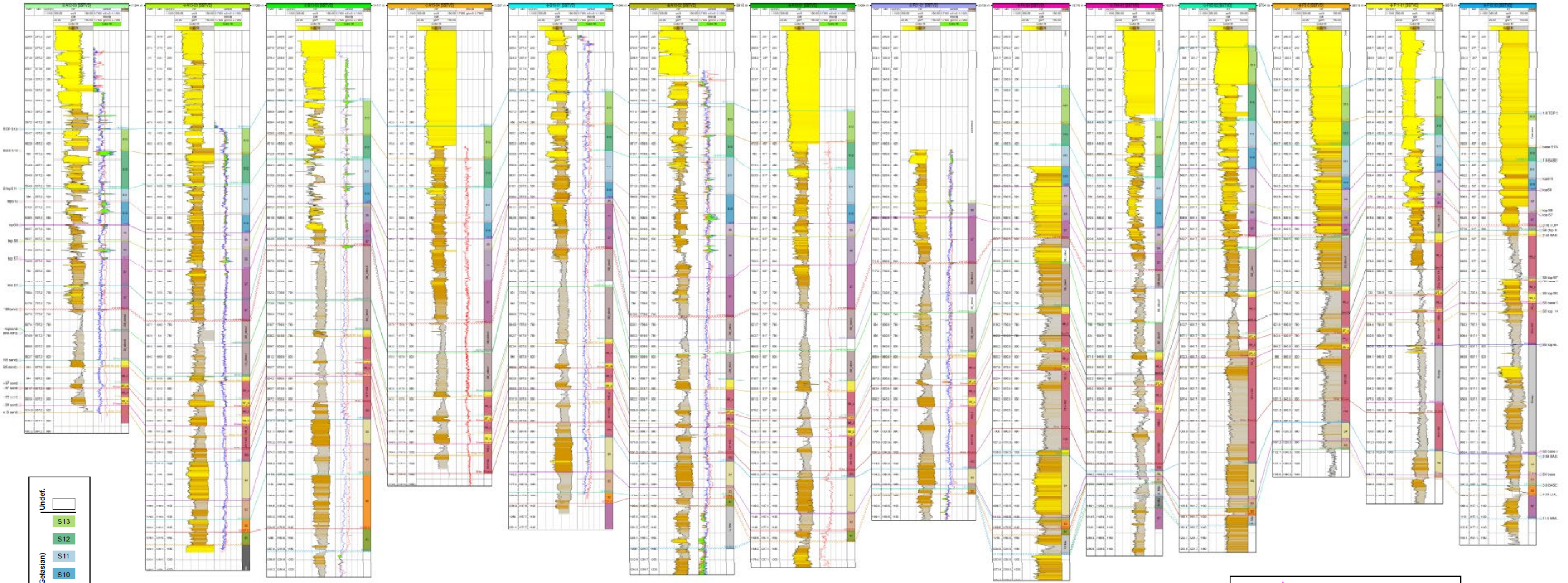
Well section F03-07 - E04-01		normalized by Neptune	well tops in TWT	TD using TWT pick
E04-01	model DEF survey	batch 3.2	x	x
E06-01	model DEF survey	batch 3.1	x	x
F04-03	model DEF survey	batch 3.1	x	x
F04-01	model DEF survey	batch 3.1	x	x
F4-2A	model DEF survey	batch 3.1	x	x
F05-02	model DEF survey	batch 3.1	x	x
F5-1	model DEF survey	batch 3.1	x	x
F5-3	model DEF survey	batch 3.1	x	x
F2-1			x	x
F6-1	model DEF survey	batch 3.1	x	x
F03-03		batch 3.1	x	x
F03-06		batch 3.1	x	x
F03-05-S1		batch 3.1	x	x
F03-02		batch 3.1	x	x
F03-07		batch 3.1	x	x

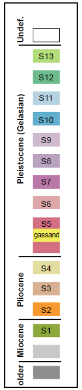
Well section DEF area		normalized by Neptune	well tops in TWT	TD using TWT pick
E06-01	model DEF survey	batch 3.1	x	x
E09-01	model DEF survey	batch 3.1	x	x
F07-01	model DEF survey	batch 3.2	x	x
F04-03	model DEF survey	batch 3.1	x	x
F09-02	model DEF survey	batch 3.1	x	x
F8-2	model DEF survey	batch 3.1	x	x
F08-01	model DEF survey	not possible	x	x
F5-5	model DEF survey	batch 3.1	x	x
F05-02	model DEF survey	batch 3.1	x	x
F05-04	model DEF survey	batch 3.1	x	x
F5-3	model DEF survey	batch 3.1	x	x
F6-1	model DEF survey	batch 3.1	x	x
F5-1	model DEF survey	batch 3.1	x	x
F4-2A	model DEF survey	batch 3.1	x	x
F04-01	model DEF survey	batch 3.1	x	x

Well sectionalternative F03-07 - E04-01 (via F2B)		normalized by Neptune	well tops in TWT	TD using TWT pick
E04-01	model DEF survey	batch 3.1	x	x
E06-01	model DEF survey	batch 3.1	x	x
F04-03	model DEF survey	batch 3.1	x	x
F05-02	model DEF survey	batch 3.1	x	x
F4-2A	model DEF survey	batch 3.1	x	x
F2-4		batch 3.1	x	x
F2-3		batch 3.1	x	x
F2-6		batch 3.1	x	x
F02B-01		batch 3.1	x	x
F03-07		batch 3.1	x	x

Overview of selected well for the well correlations panels

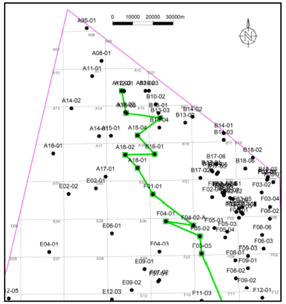
NNW - SSE well panel from A12-03 to F12-03



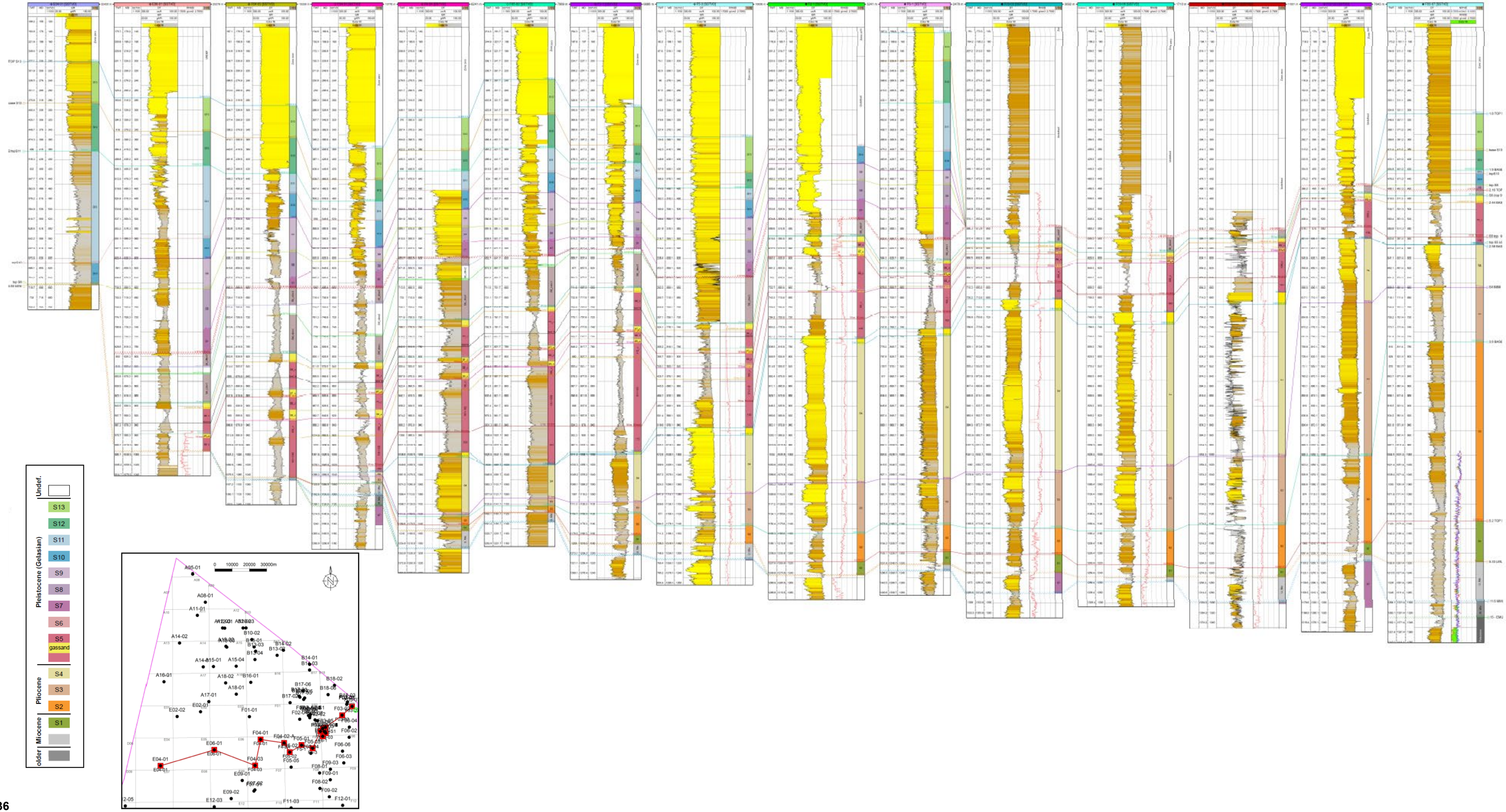


Remarks:

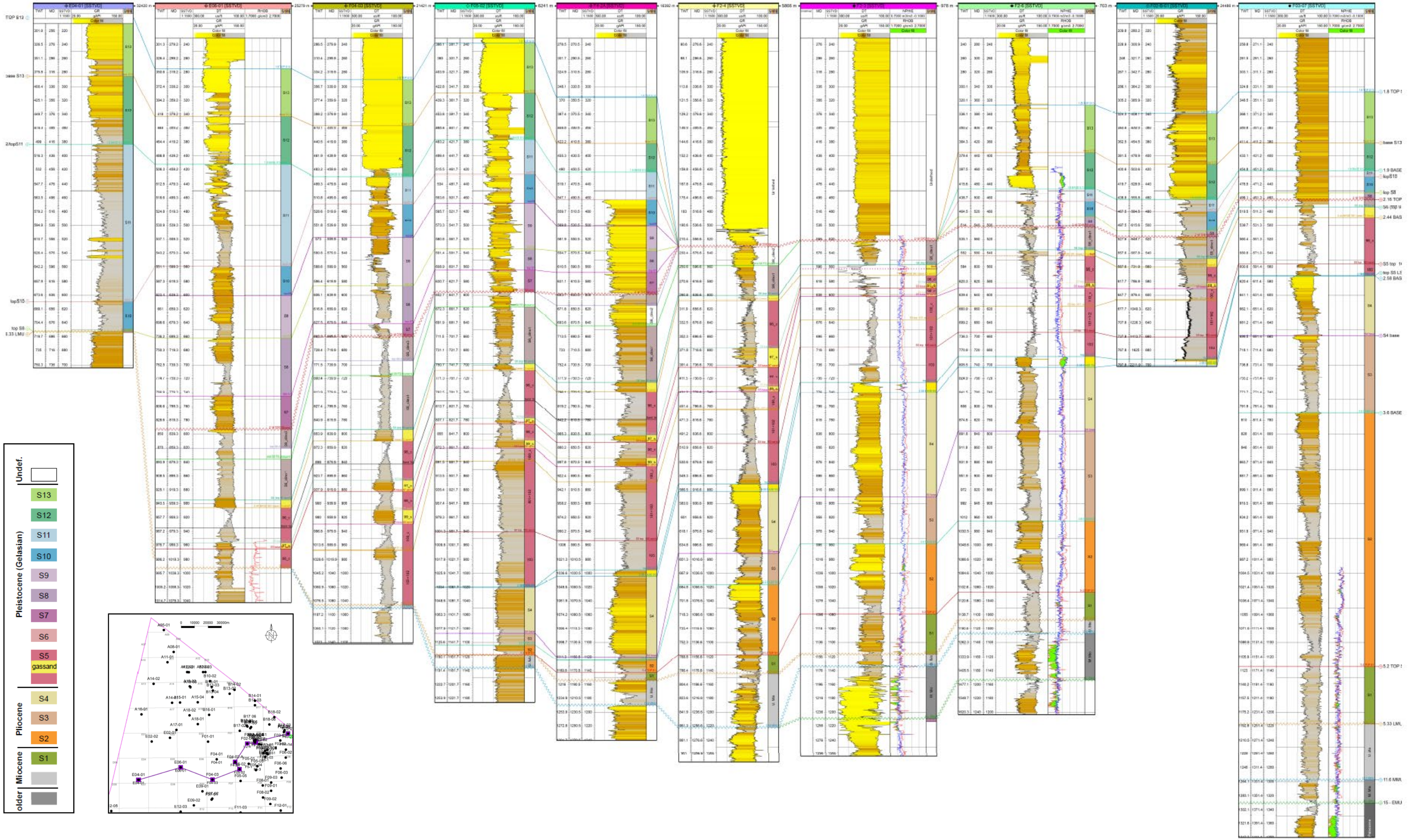
- All used GR logs are normalized
- For distinct sand layers within S5 tops and bases are interpreted
- For gradual (coarsening upward) sequences only the tops are interpreted
- Log patterns below the LMU are highly variable and interpretation is less confident
- NPHI/RHOB cross-over is used to trace gas sands; in their absence, sonic (DT) can used as indicator
- In general, well log interpretation above S8 is less confident due to casing issues
- Well tops indentified in the wells (in MD) are tied to seismic horizons (in TWT), providing a TD relationship that is more precise than by using sonic or check shots



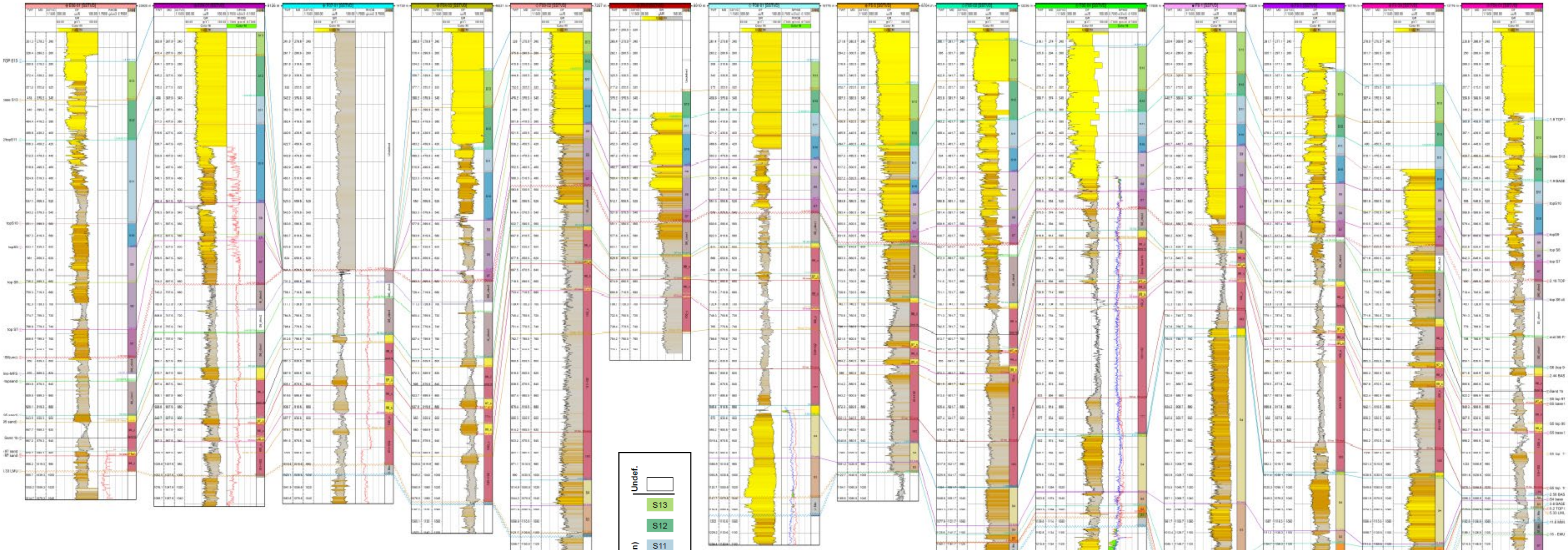
ENE-WSW well panel from F03-01 through F03 to E04-01

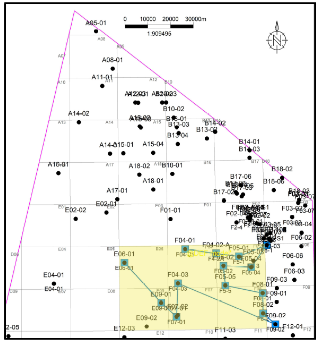


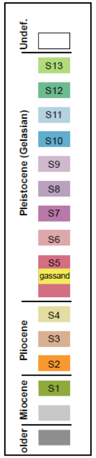
ENE-WSW well panel from F03-01 through F02B to E04-01



Well panel through F4,5,7,8-E7,9 model area

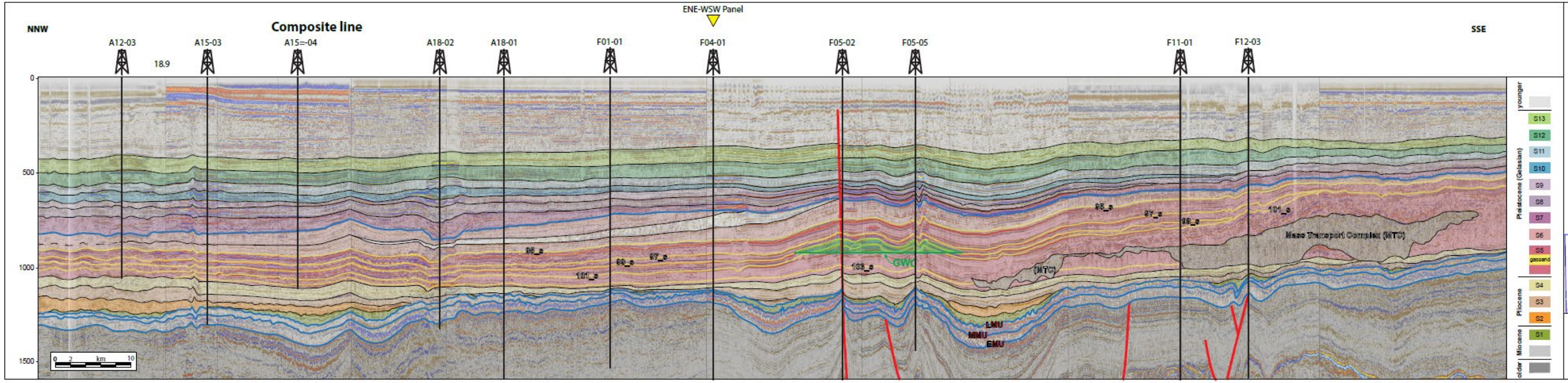


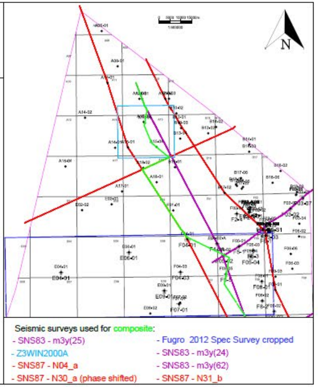


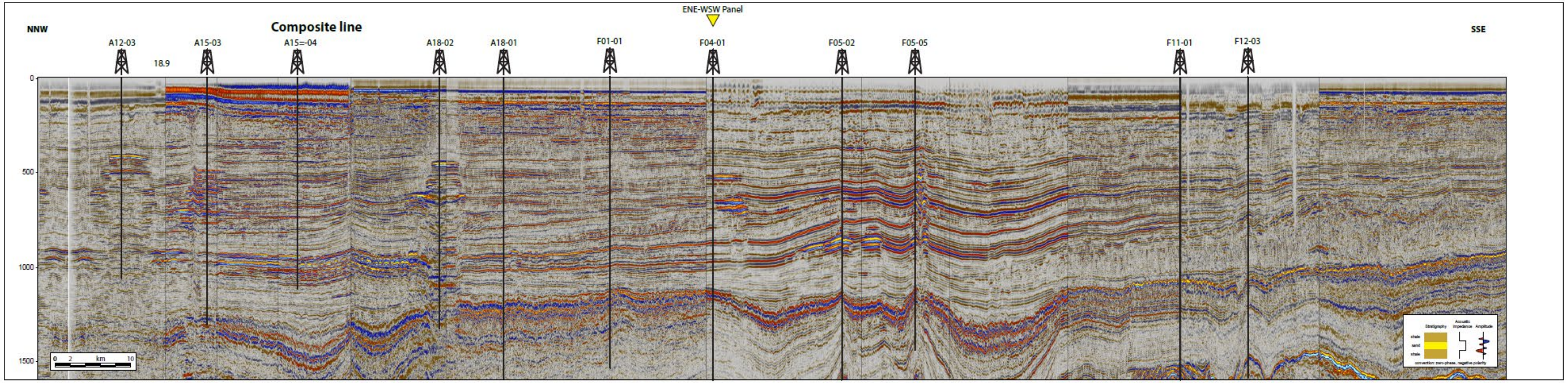


SEISMIC PANELS

NNW-SSE seismic composite panel from A12-03 through F12-03



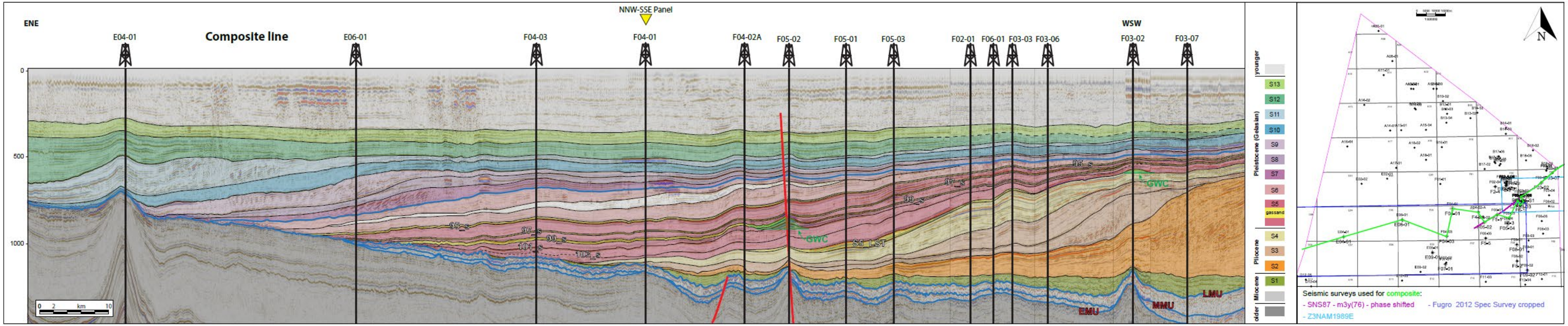


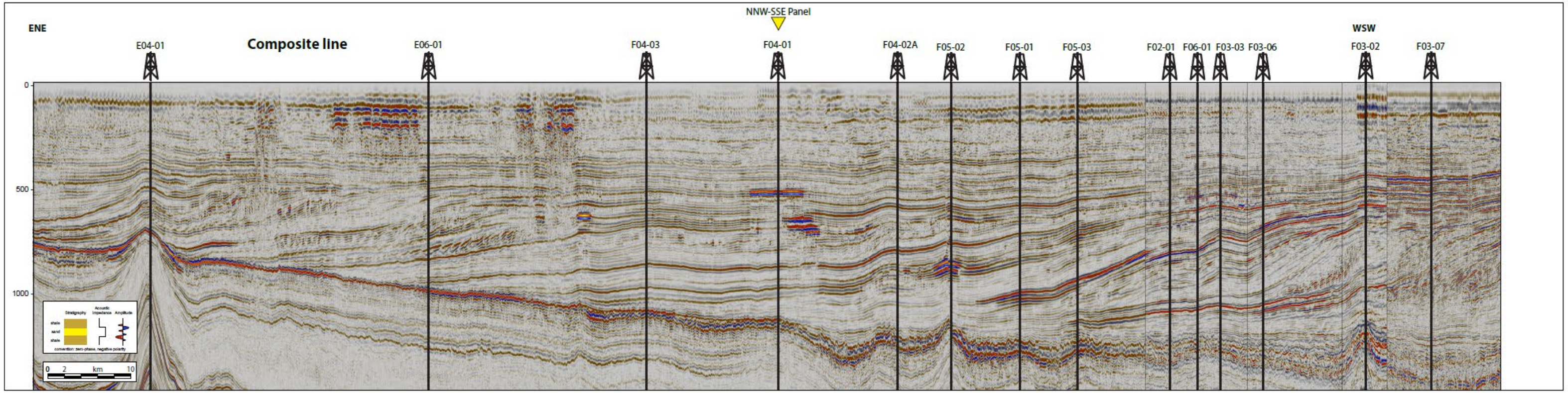


Main features observed:

- Good continuation of the S5 sands, where top of these sands are discontiuous (erosive) the occurrence of bright spots (BS) is high (e.g. A15-03/4 and F05-02)
- This section runs somewhat oblique to the paleo shelf trend and higher up the slope (right) individual S5 sand amalgamate or are truncated
- The presence of MTC's suggest major slope failure during early S5 time
- Stacked (X-mas tree) occur in the >S6 units in the north but are relatively absent in the F4/5 area with the exception of the near F04-01 BS's that reside in S7,S8 and S11, i.e., above the top S6 unconformity

ENE-WSW seismic composite panel from F03-01 through F03 to E04-01

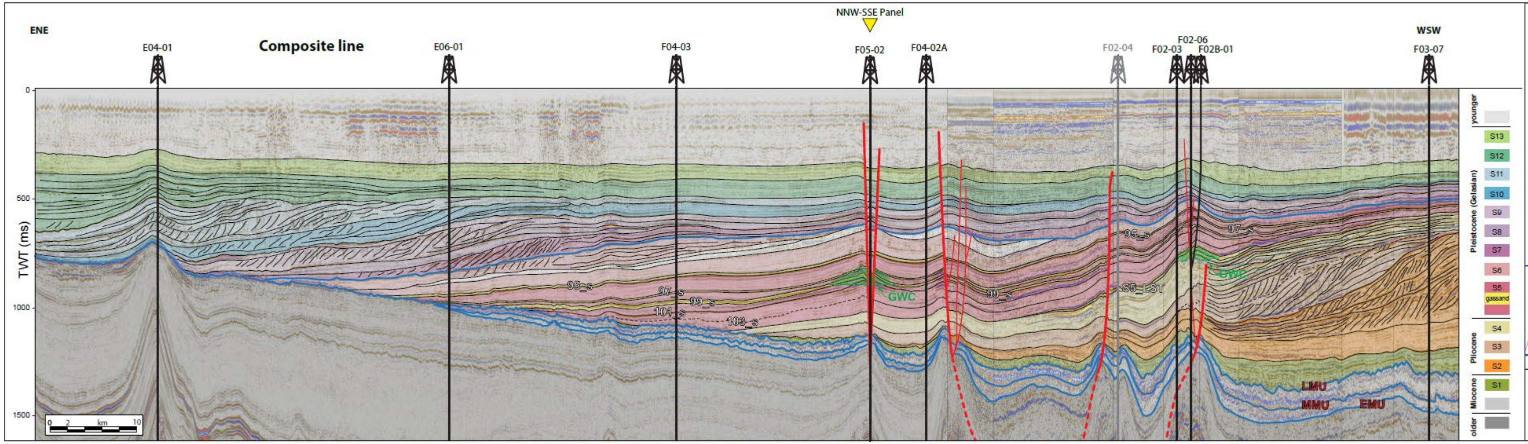


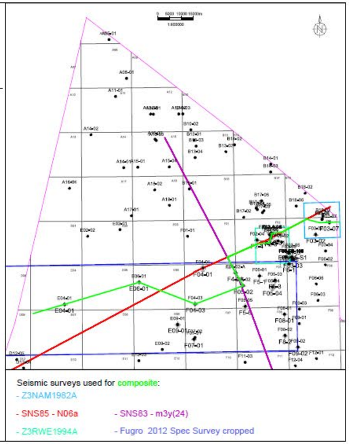


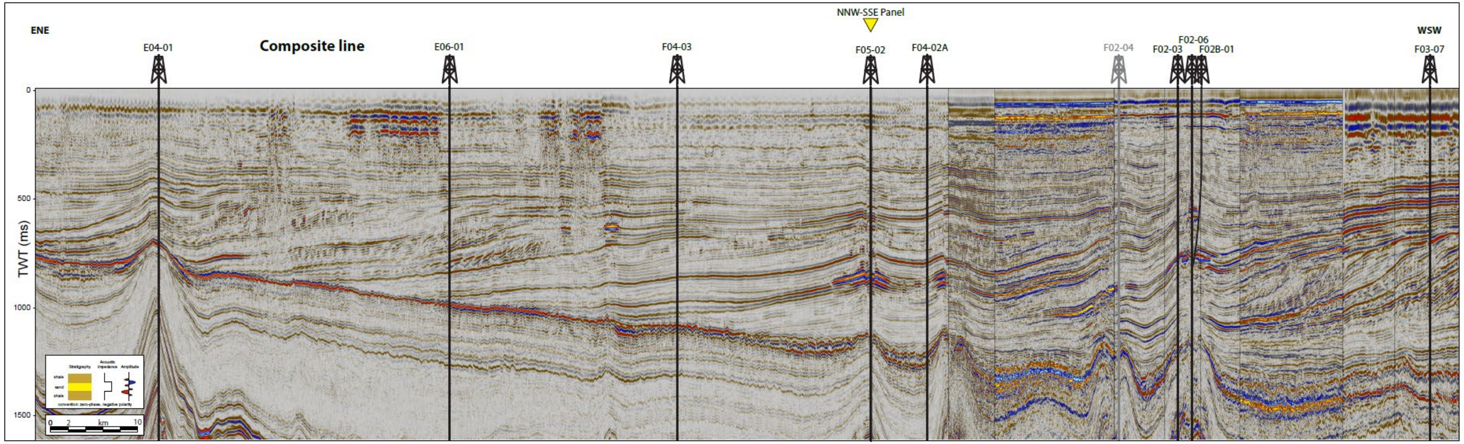
Main features observed:

- Good continuation of the S5 sands; higher up the slope (right) individual S5 sand amalgamate or are truncated
- A large BS occurs at the transition of S4-S5 in a “dish-like” package interpreted as low-stand wedge (S5-LST). This may represent a stratigraphic trap bounded by both down- and onlap.
- The F03-02 gas accumulation in top S4 seems to be sealed by slightly younger onlapping shales in the base of S5 base (the MIS-103 highstand)

Alternative ENE-WSW seismic composite panel from F03-01 through F02B platform to E04-01







Main features observed:

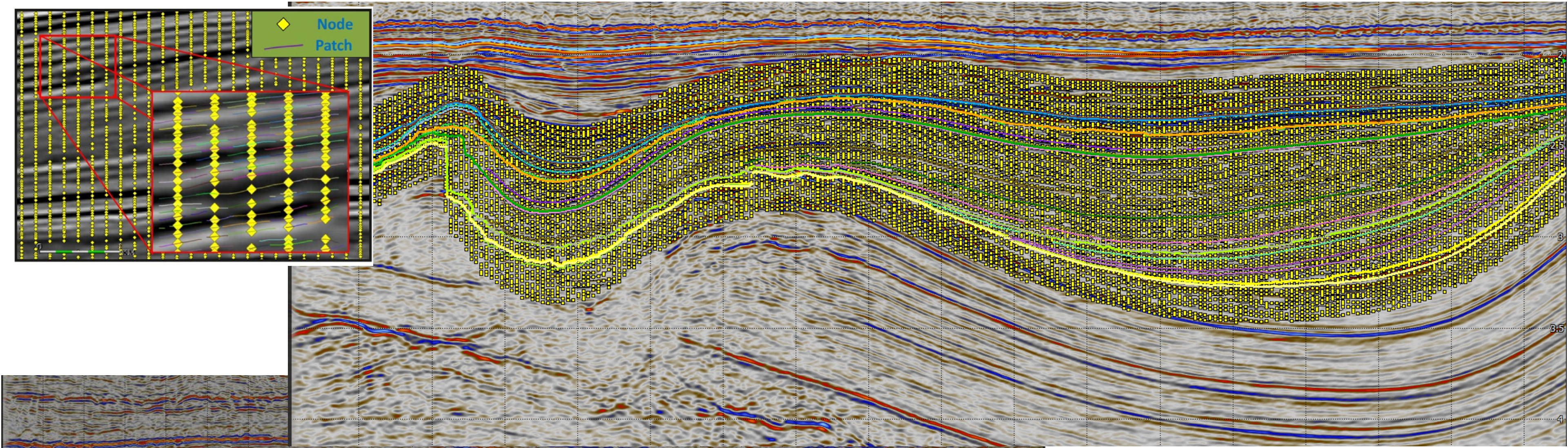
- Most observations concur with the previous ENE-WSE sections; higher up the slope (right) individual S5 sand amalgamate or are truncated
- The F02B gas accumulation in top S4 is stratigraphically similar to F03-02 (i.e, sealed by slightly younger onlapping shales in the base of S5 base). Here, the (salt dome related) structure is more prominent and faulted.

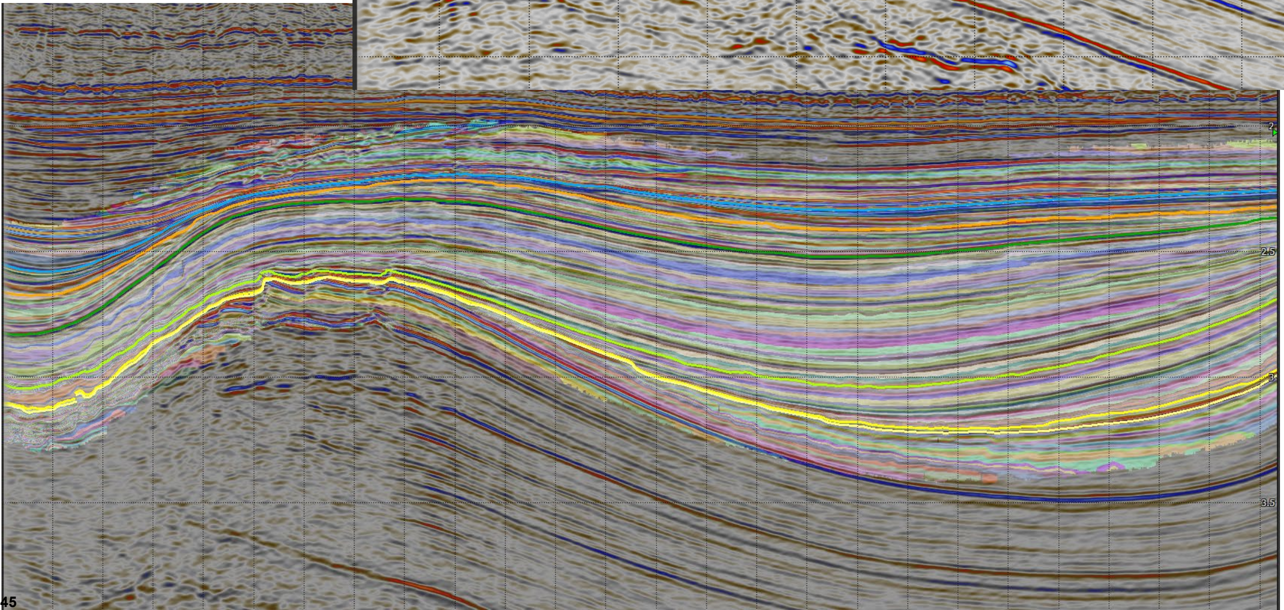
CONCLUSIONS - REGIONAL INTEGRATION

- Within the AOI mainly units S4-S13 are present
- Throughout the northern offshore, the correlatability of individual (reservoir) sands within units S5- S8 appears high, both in wells and in seismics
- Compared to untis below and above, S5 comprises very low angle clinoforms. No steep, coastal clinoforms are present.
- In the eastern part of the AOI (landward of the offshore) sands are truncated by younger units and individual sands amalgamate. This especially holds for the S5 sands.
- The base S6 forms a major unconformity. Steep, coastal clinoforms in unit S6 occur at least 70 km west compared to unit S5

WP2 – SEIMIC INTERPRETATION

- Seismic-to-well tie study of the available wells and interpretation approach
  - Seismic character (mainly studied within AOI to avoid different vintages)
  - Picking well tops in TWT (generating a TD relationship for TVD → TWT)
- Integration and embedding of the multiproxy framework with the AOI
  - Regional seismic panels (in TWT)
  - Well correlation panels based on well top interpretation (in TVD)
- High-resolution, multi-horizon seismic interpretation (Relative Time model of Paleoscan)
- Mapping of depositional facies (Paleoscan) and classification individual bright spots

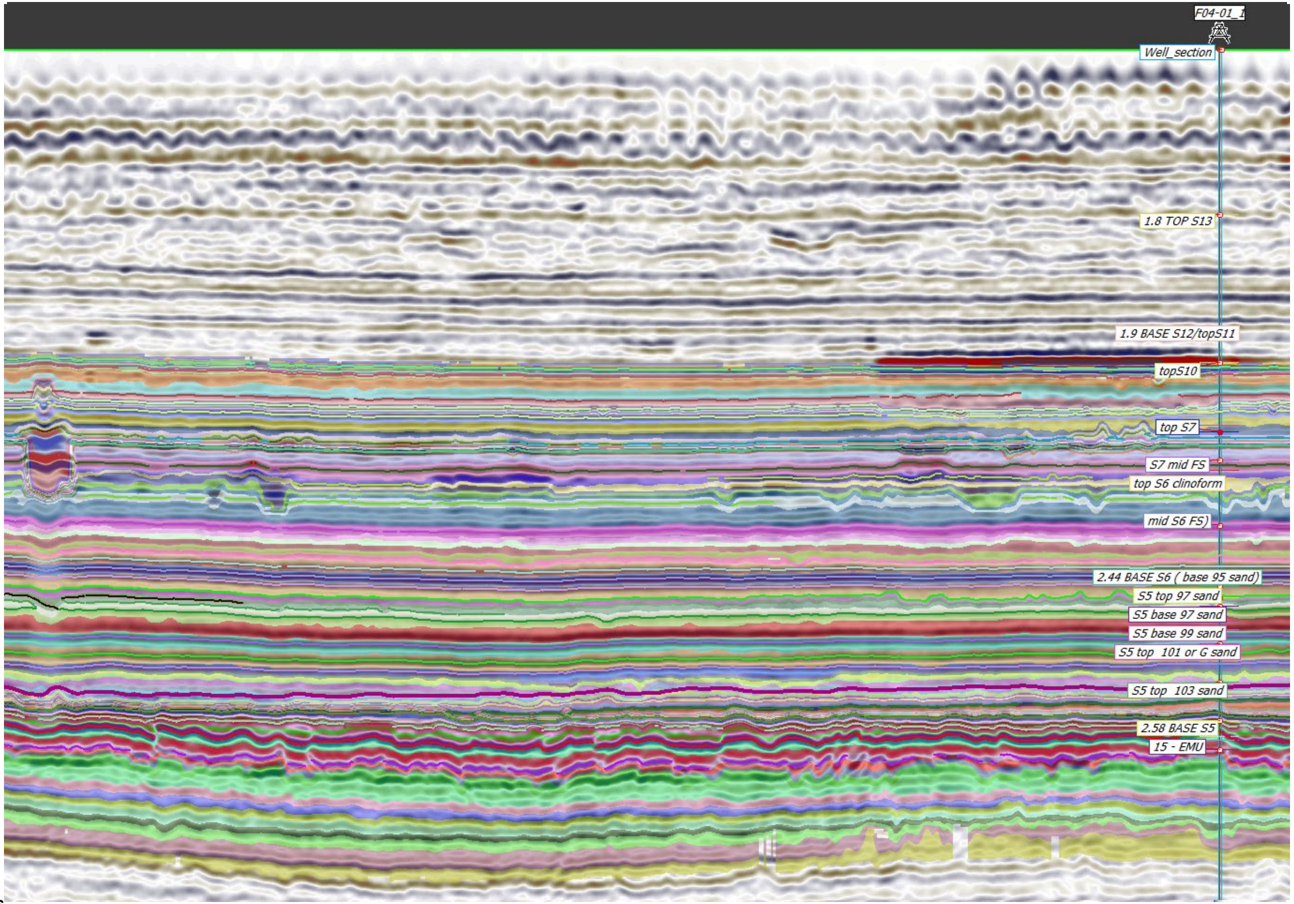




PALEOSCAN RELATIVE TIME GEOMODEL (RTM)

- Construction of an isochronous geomodel that allows stratal slicing and attribute mapping. The geomodel also forms the base for the sequence and geocellular model used for property modelling.

METHODS: CONSTRUCTION OF RELATIVE TIME GEOMODEL (RTM)



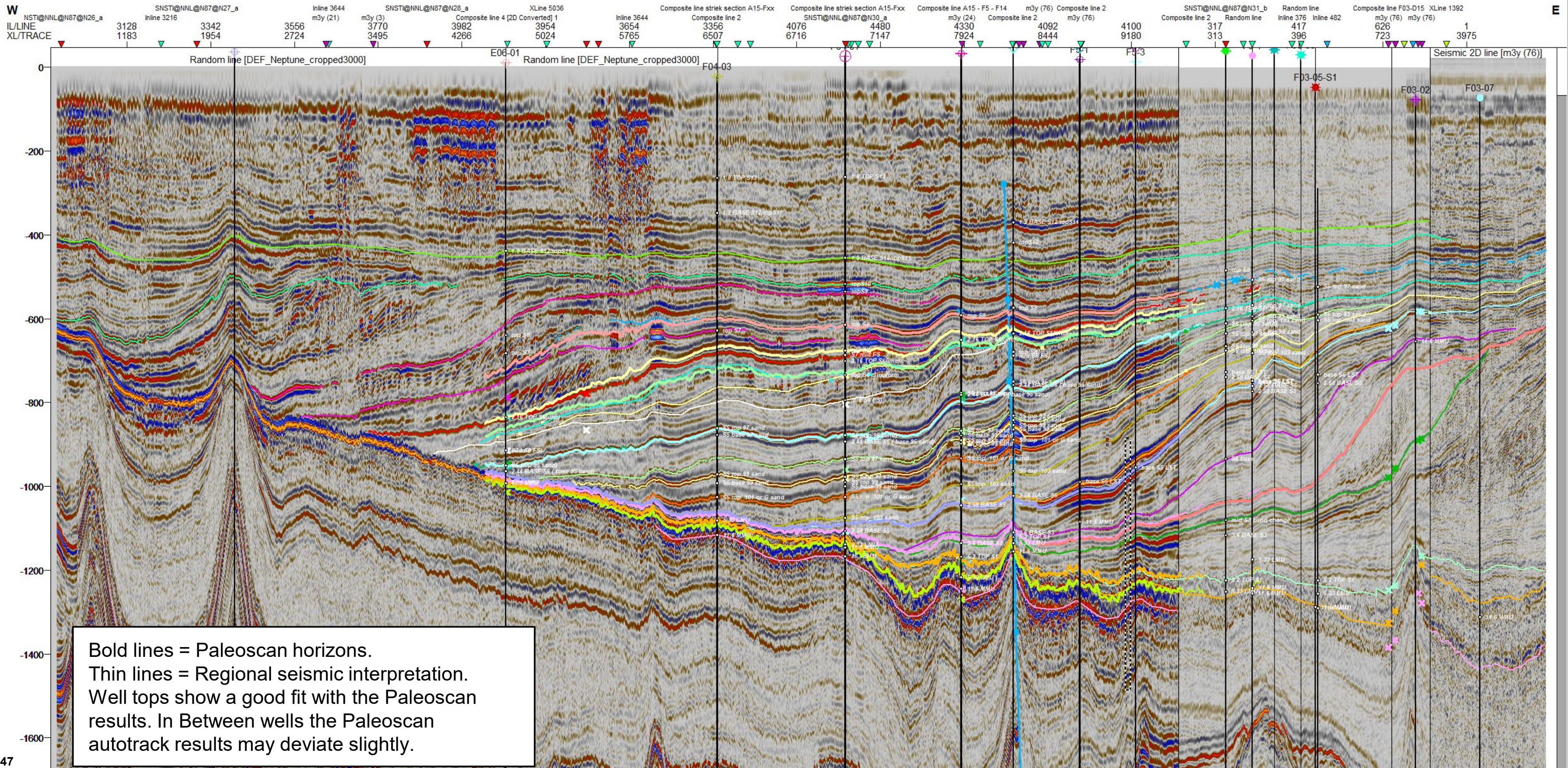
1. Base for the seismic interpretation is the initial model grid.

2. Seismic interpretation of horizons to constrain the model. Based on (regional) well correlation and seismic to well tie performed in Petrel.

3. Creation of the geomodel.

4. Computation of the horizon stack; final model contains 999 horizons. These horizons from the outline of the geomodel.

PALEOSCAN RESULTS VS. REGIONAL SEISMIC INT.



Bold lines = Paleoscan horizons.
Thin lines = Regional seismic interpretation.
Well tops show a good fit with the Paleoscan results. In Between wells the Paleoscan autotrack results may deviate slightly.

METHODS; LINKING PALEOSCAN HORIZONS TO SEISMIC UNITS

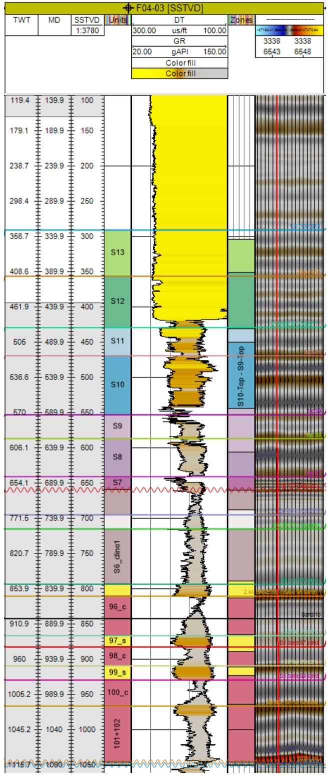
- To match the Paleoscan horizons from the horizon stack with the corresponding well markers, a well quality control was performed in Paleoscan.
- The table below shows the unit markers (2nd column) and the Paleoscan horizons of the horizon stack (1st column) that make the best fit with respect to all the wells. The columns 3-16 show the time deviation per well in milliseconds of the Paleoscan horizon with respect to the (overall best) corresponding unit marker.

Paleoscan Horizon	Unit Markers	F04-03	E09-01	F07-01	F05-04	F5-1	F4-2A	E06-01	F09-02	F05-02	F6-1	F04-01	F8-2	F08-01	F5-5
835	Top S13 (1.8Ma)	-4,57413	-1,5054	12,2502	4,17844	-11,8846	3,20099	-15,1003		7,98892	-4,43463	4,01434	-14,2876	-15,5238	-4,32681
781	Base S13	-0,01074	-2,06454	2,73889	1,70285	-3,13901	0,24823	-0,64072		5,97723	-11,6986	0,44574	-0,29981	4,22714	6,52106
715	1.9 BASE S12/topS11 (1.9Ma)	-1,30957	-8,19653	0,488007	-1,71954	-6,7486	-3,12964	-1,9267		-13,3703	0,147949	-1,17603	-3,11905	-5,60516	-9,00461
699	Top S10	10,9497	10,91	21,9186	19,7232	29,3387	35,6675	-0,19476		7,724	29,2732	30,783	13,4336	7,759	7,67285
650	Top S9	4,35077	-3,46472	15,5193	13,2917	4,75018	9,19464	-7,18018		4,59222		7,74438	0,216888	-0,20828	8,94574
610	Top S8	-12,4076	-1,65778	-3,71436	-6,82288	-10,6328	-8,64191	4,66571		-8,84796	-6,38333	-1,91302		-7,4447	-7,60901
592	Top S7	-1,19916	-14,785	2,56067	5,4292	5,04272	2,7262	4,41418		5,5459	10,4633	-1,17316		1,75183	-2,45172
560	Top S6(unc) (2.16Ma)	-1,92993	-1,71533	-0,41803	19,5433	23,2986	17,7533	-0,35144		23,832	17,5391	-3,88116	16,4764	13,3642	26,9605
525	top S6 clinoform	15,5938	9,32294	19,1279		2,01794	2,2674	-0,69562				-10,3686			-1,39415
503	mid S6 FS-topsand	1,25836	4,11346	0,435242		-4,83786	4,31915	-2,83063				-8,77289			-20,518
461	S6-top 95 sand	3,42395	2,59784	-1,09644	-8,11102	5,89026	-0,12958	-3,58881		-2,56069	14,9635	2,34064		12,3729	-11,315
450	Base S6-base 95 sand (2.44Ma)	-2,0274	-2,15045	-1,79559	-6,34247	3,58921	-0,98169	5,20111		-6,92456	22,4774	-2,01953			-23,2881
396	S5 top 97 sand	2,03174	-6,39154	0,401672	1,79596	-4,98541	4,30829			-3,64954	5,98383	-3,52087	42,0903	-8,46228	-1,09174
386	S5 base 97 sand	-10,0588	-3,46936	0,183044	-11,3531	-12,5028	-0,16487			0,923584		-8,55695			-0,97308
374	S5 top 99 sand	-1,00055	-1,46423	-0,93683	-1,44287	-3,23444	-10,7465			-2,68188	23,0302	0,109436	-38,8398	0,700439	3,43384
369	S5 base 99 sand	8,33178	4,04529	5,89651	-3,62852	6,07172	-8,21418			-2,06891		0,317017			7,9416
353	S5 top 101 or G sand	2,34955	11,5423	15,9136	-4,70111	-3,51367	-5,4621			-24,8936		-5,65472	44,9738	6,71814	0,509766
324	S5 top 103 sand				-16,0305	-32,8436	-13,5092			-0,05597	16,2427	-0,05249	32,7002	15,7819	2,54871
280	Base S5 (2.58Ma)				-4,69971	-0,35382	-2,04431			-0,76221	-1,2757	-5,85437	5,63459	-2,64429	3,13086
250	Base S4				-4,50012	4,94641	-2,27808			-2,73413	0,779175	1,89136	-20,4846	-13,7883	6,02124
235	Base S3 (3.6Ma)				0,200928	-4,08984	2,04883			22,1974	-5,48438				22,4987
218	Top S1 (5.2Ma)					-14,516	-0,08167			23,6805	-2,54346				
197	LMU (5.33Ma)	-6,8562	16,564	13,1736	-7,09241	-5,72986	1,00769	-3,47791		4,54321	-1,93921	-7,40906	-10,5736	-14,9189	-0,84912
171	MMU (11.6Ma)	5,84558	-0,79041	-2,17236	3,14844	6,95581	-0,95081			7,94885	-4,87805	9,97205	-20,3629	-1,83228	
157	EMU (15Ma)											22,0145			
		*								*			*		

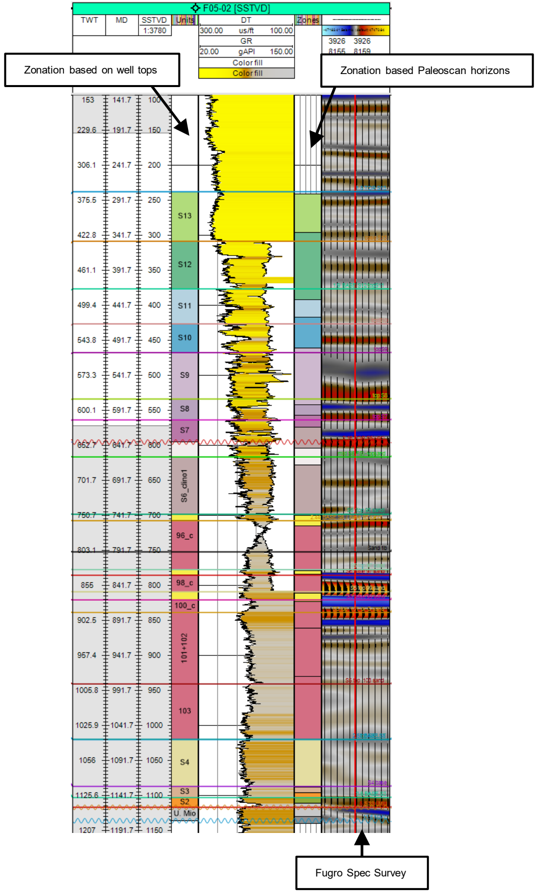
* Examples on next slide

EXAMPLES WELL TOPS VS. PALEOSCAN HORIZONS

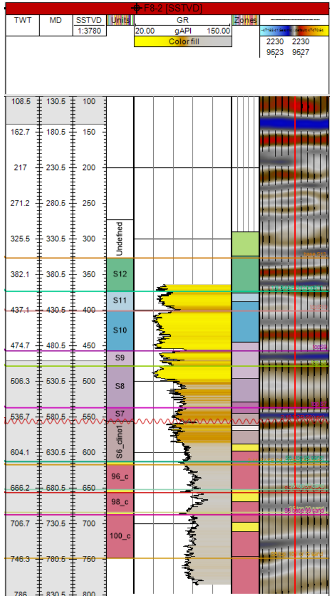
Overall good fit



Moderate fit



Poor fit



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WP2 – SEIMIC INTERPRETATION

- Seismic-to-well tie study of the available wells and interpretation approach
  - Seismic character (mainly studied within AOI to avoid different vintages)
  - Picking well tops in TWT (generating a TD relationship for TVD → TWT)

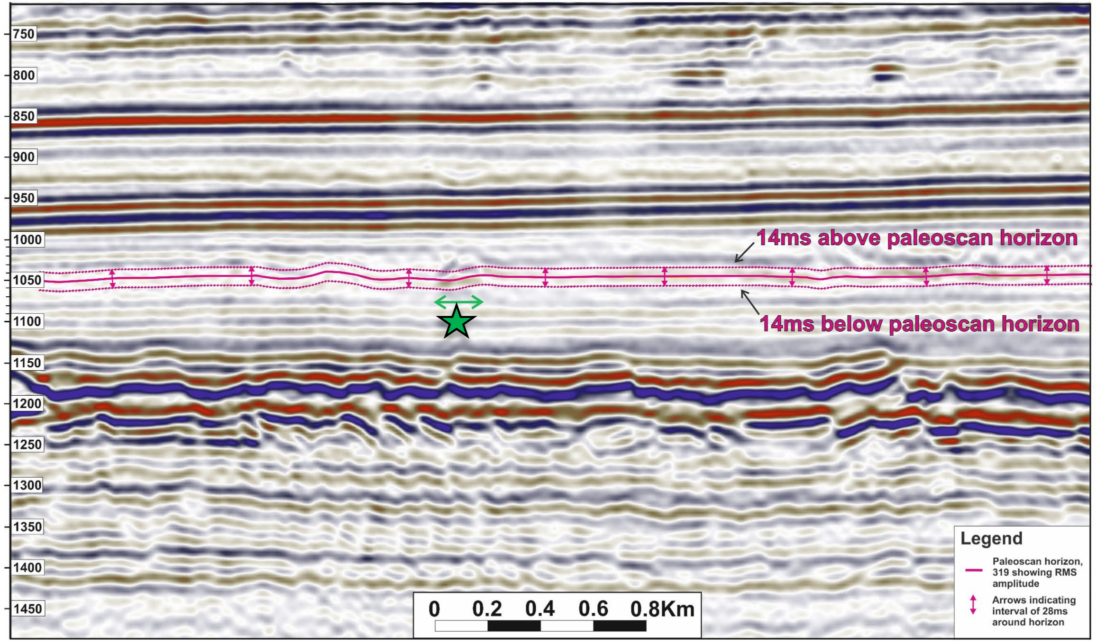
- Integration and embedding of the multiproxy framework with the AOI
  - Regional seismic panels (in TWT)
  - Well correlation panels based on well top interpretation (in TVD)

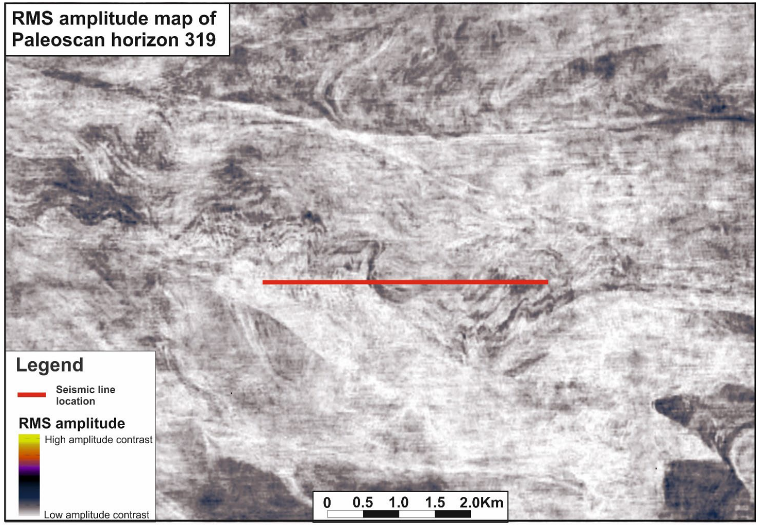
- High-resolution, multi-horizon seismic interpretation (Relative Time model of Paleoscan)

- Mapping of depositional facies (Paleoscan) and classification individual bright spots

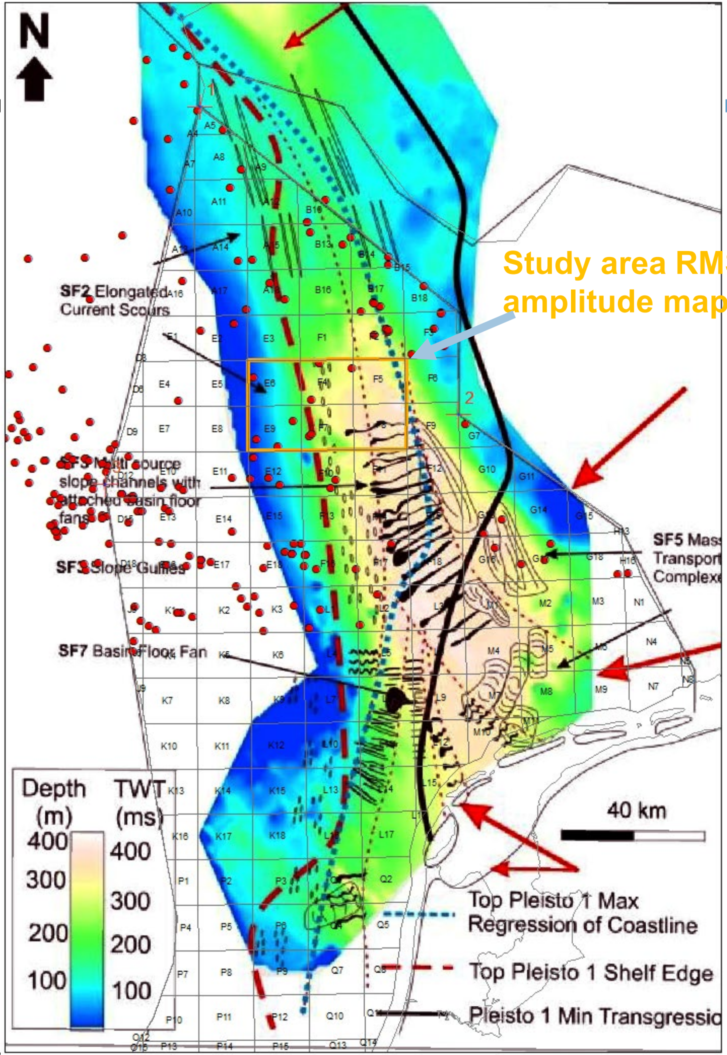
METHODS: RMS AMPLITUDE MAPPING

For the horizons of the horizon stack RMS (Root Mean Square) amplitude maps were calculated: RMS is a post-stack attribute that computes the square root of the sum of squared amplitudes divided by the number of samples within the specified window used.

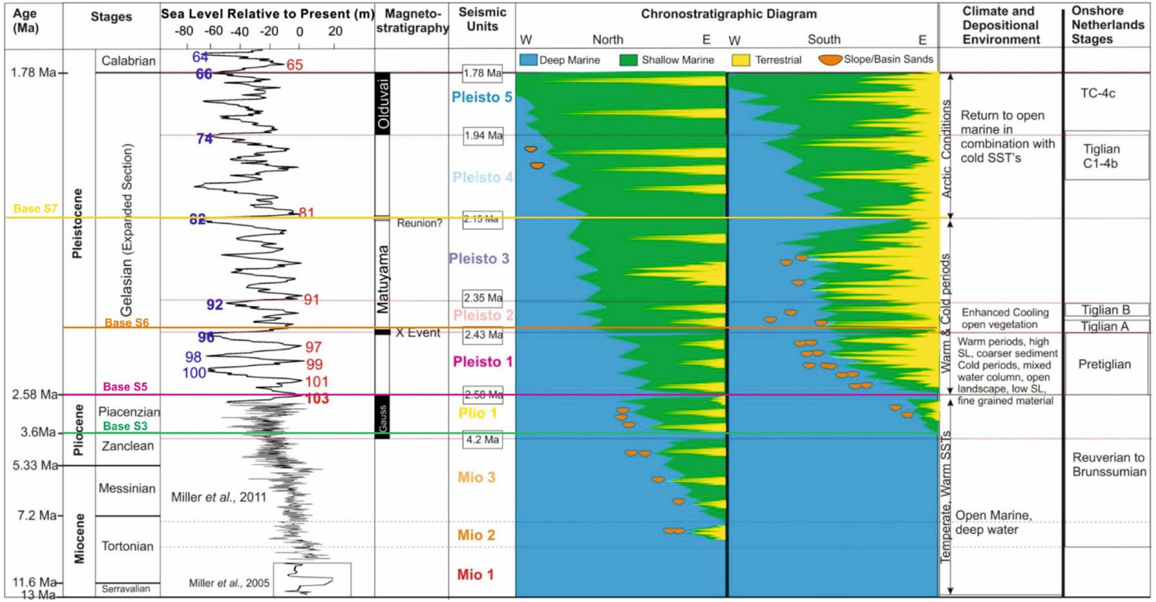




A sample window of 7 was chosen for the calculation of all the RMS amplitude maps, meaning: RMS of amplitude was calculated over a window of 28 ms around horizon of interest (i.e. 14ms above and 14ms below horizon of interest).

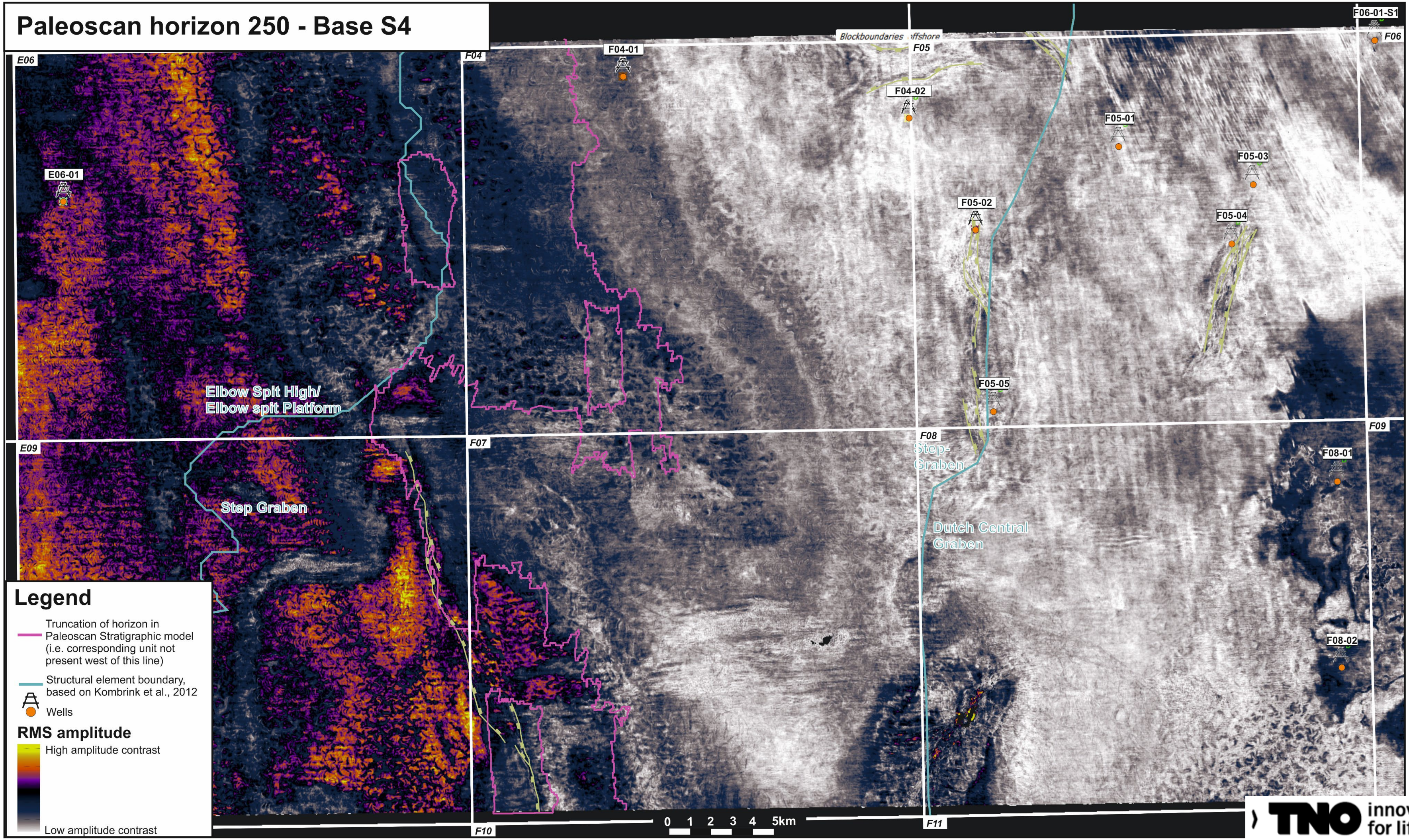


Thickness and TWT map of Pleisto 1 (Harding, 2015), corresponding to seismic unit S5

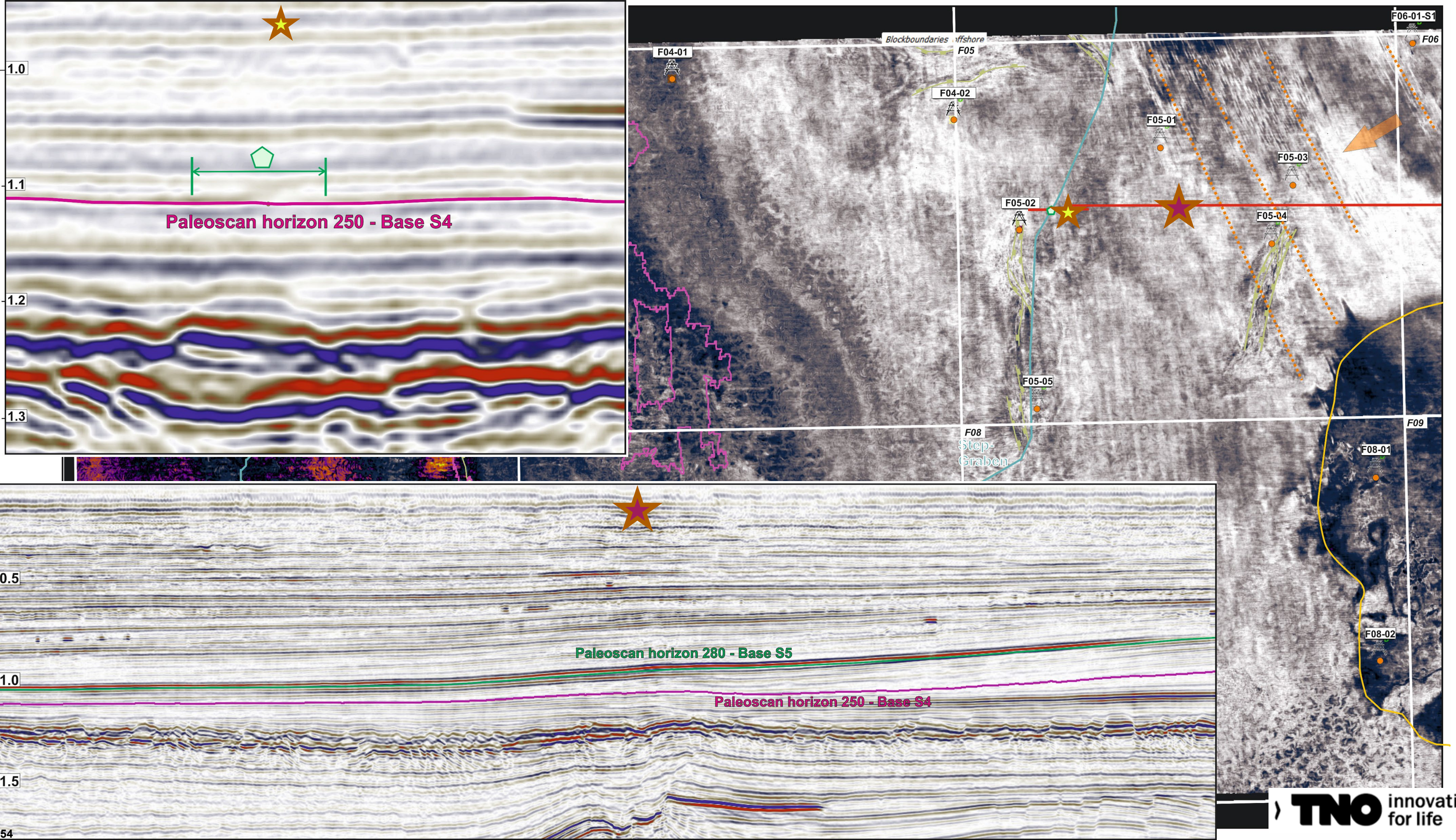


Both figures: modified from Harding, 2015

Paleoscan horizon 250 - Base S4



TNO innovation for life



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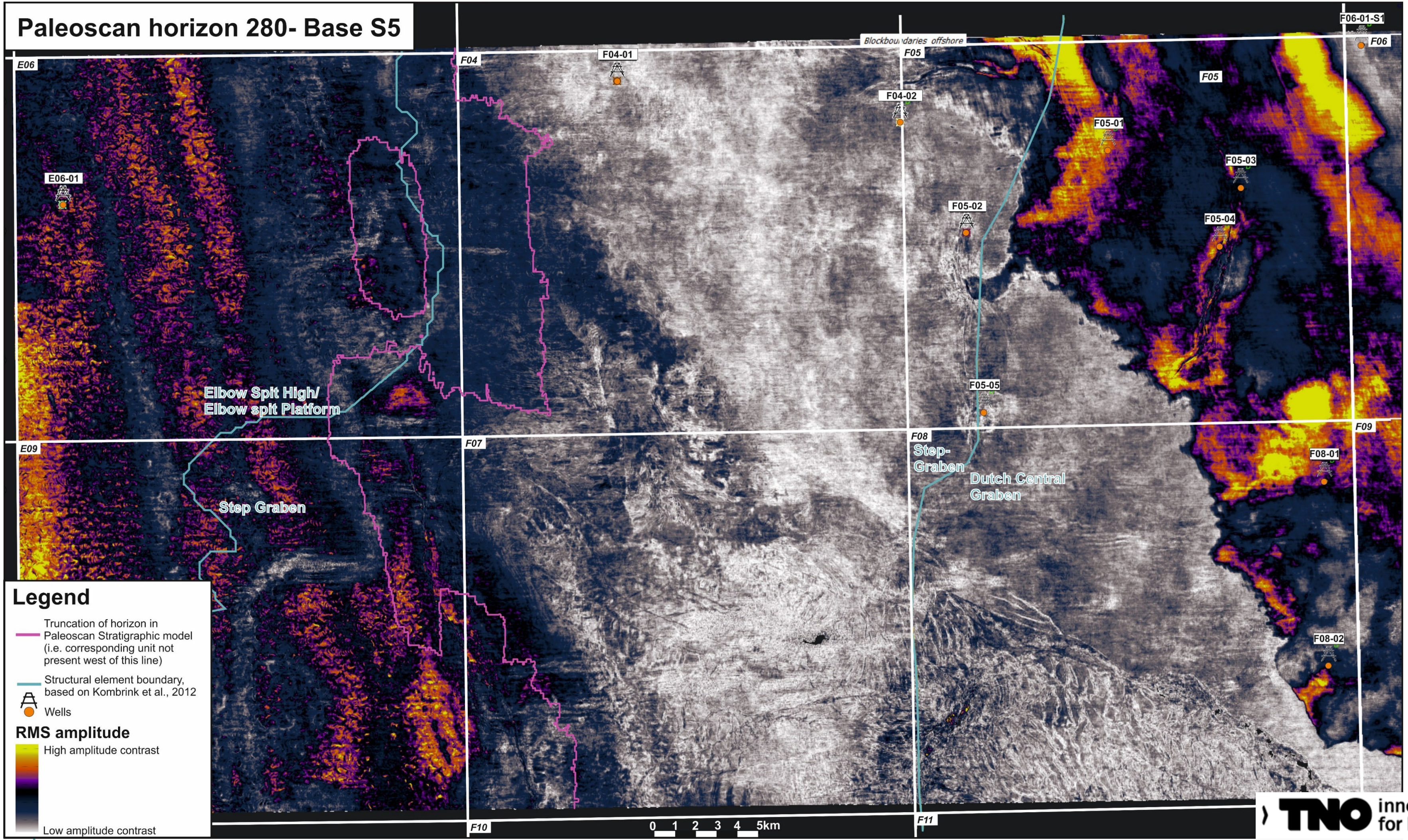
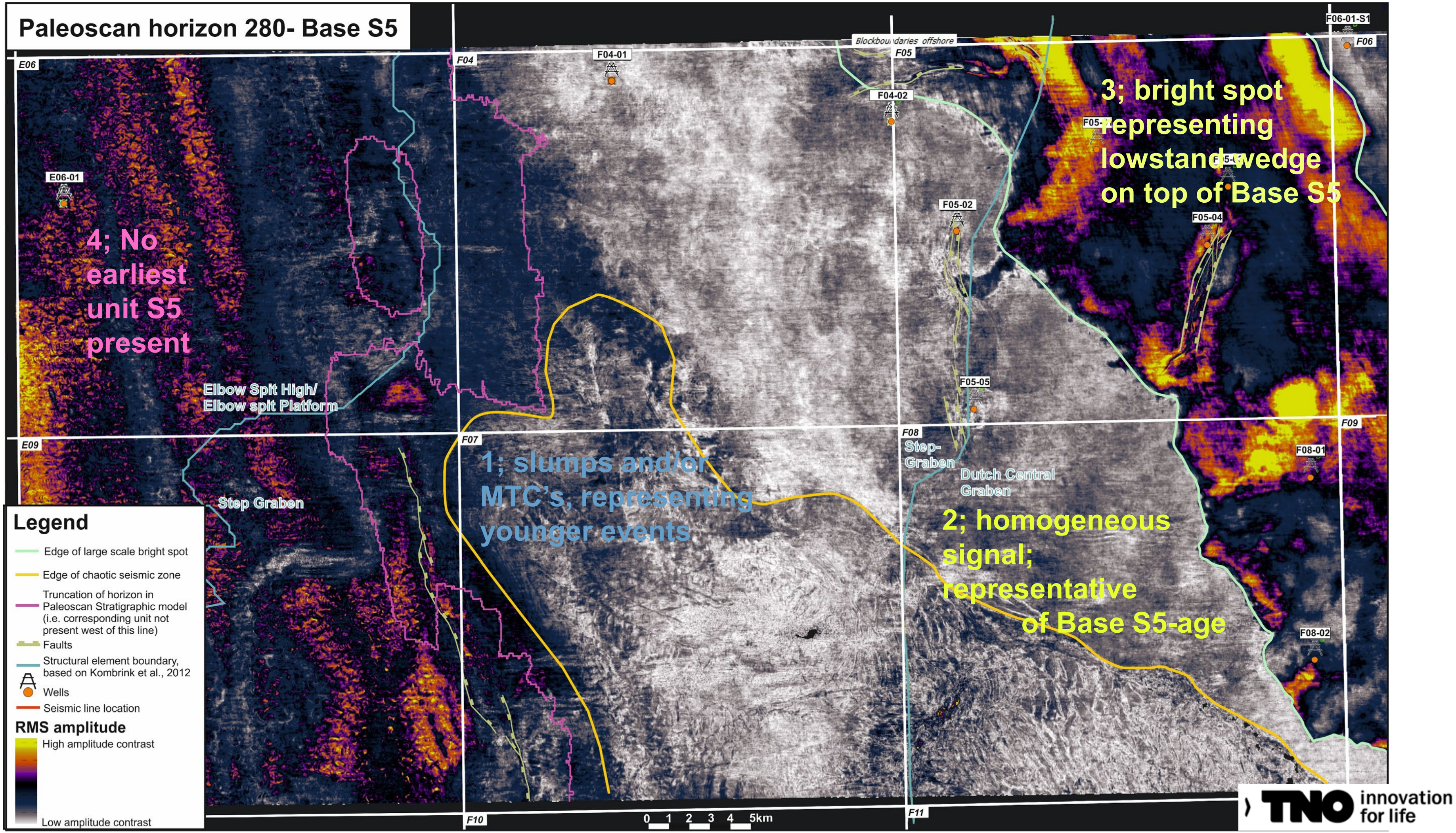
Paleoscan horizon 280- Base S5

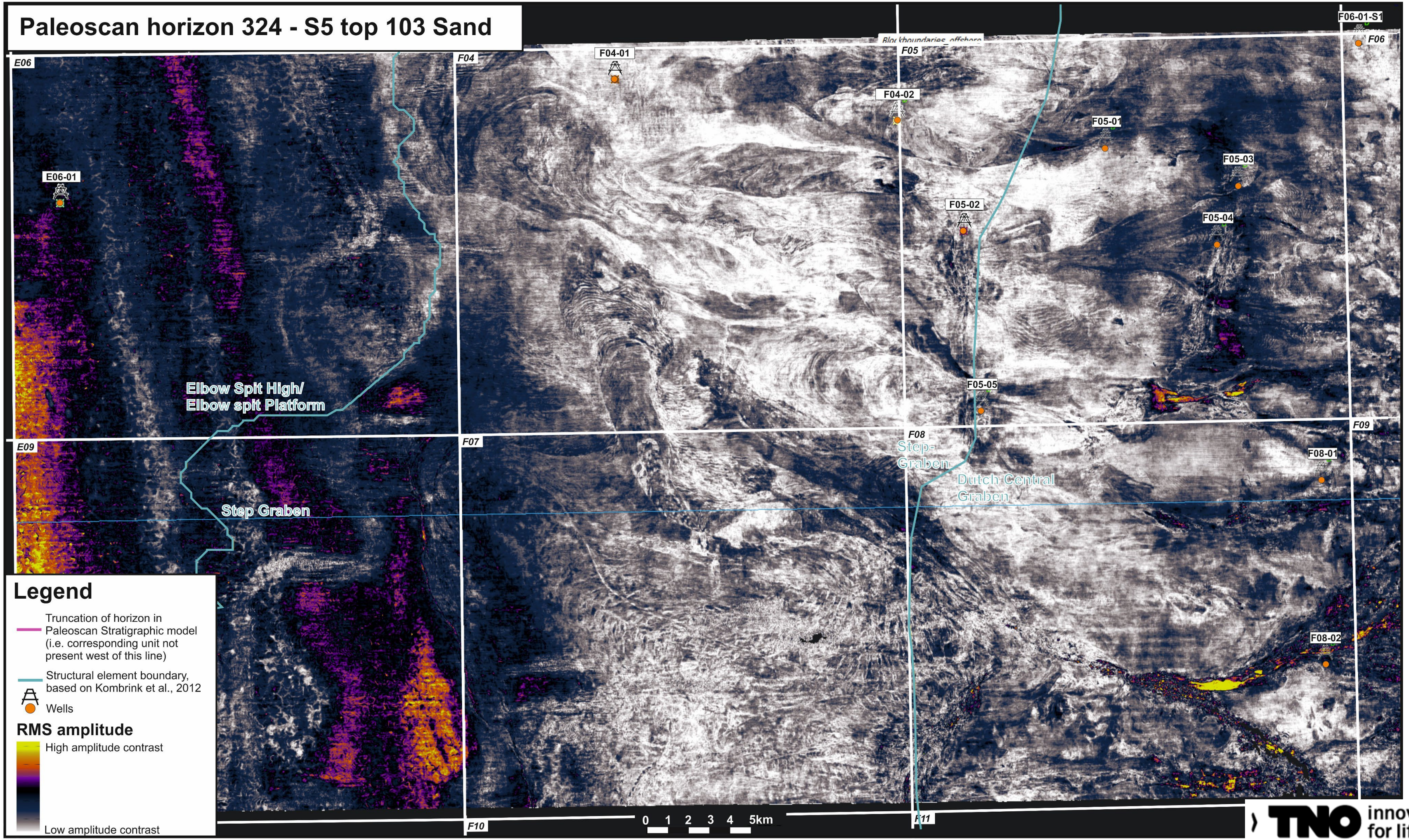


TNO innovation for life



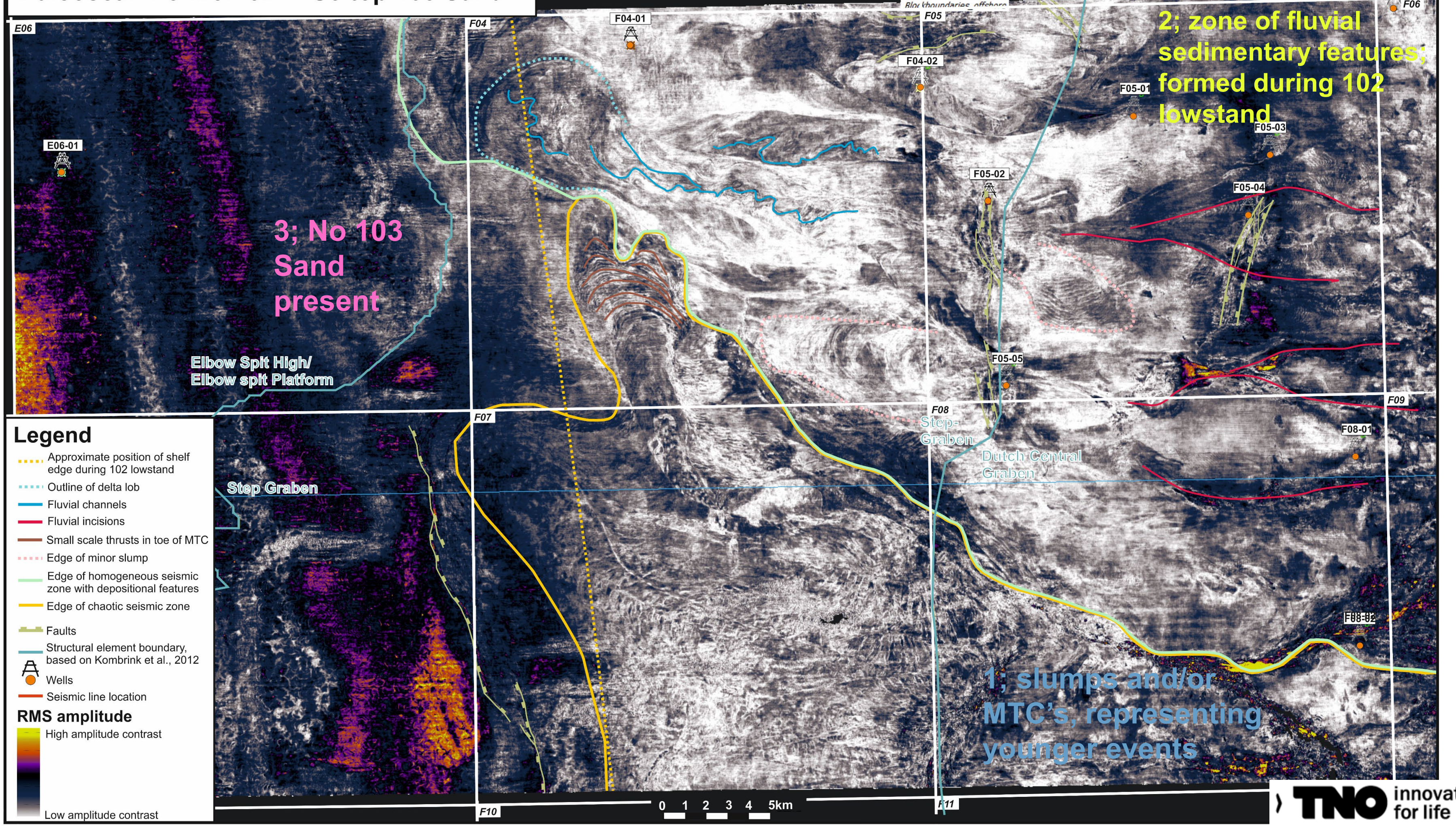
Paleoscan horizon 280- Base S5
E06
F04
F04-01
Blockboundaries offshore
F05
F06-01-S1
F06
F04-02
3; bright spot representing lowstand wedge on top of Base S5
E06-01
F05-02
F05-04
4; No earliest unit S5 present
F05-05
Elbow Spit High/ Elbow spit Platform
E09
F07
F08
F09
F08-01
1; slumps and/or MTC's, representing younger events
Step-Graben
Dutch Central Graben
Step Graben
2; homogeneous signal; representative of Base S5-age
F08-02
Legend
Edge of large scale bright spot
Edge of chaotic seismic zone
Truncation of horizon in Paleoscan Stratigraphic model (i.e. corresponding unit not present west of this line)
Faults
Structural element boundary, based on Kombrink et al., 2012
Wells
Seismic line location
RMS amplitude
High amplitude contrast
Low amplitude contrast
F10
0 1 2 3 4 5km
F11
TNO innovation for life

Paleoscan horizon 324 - S5 top 103 Sand

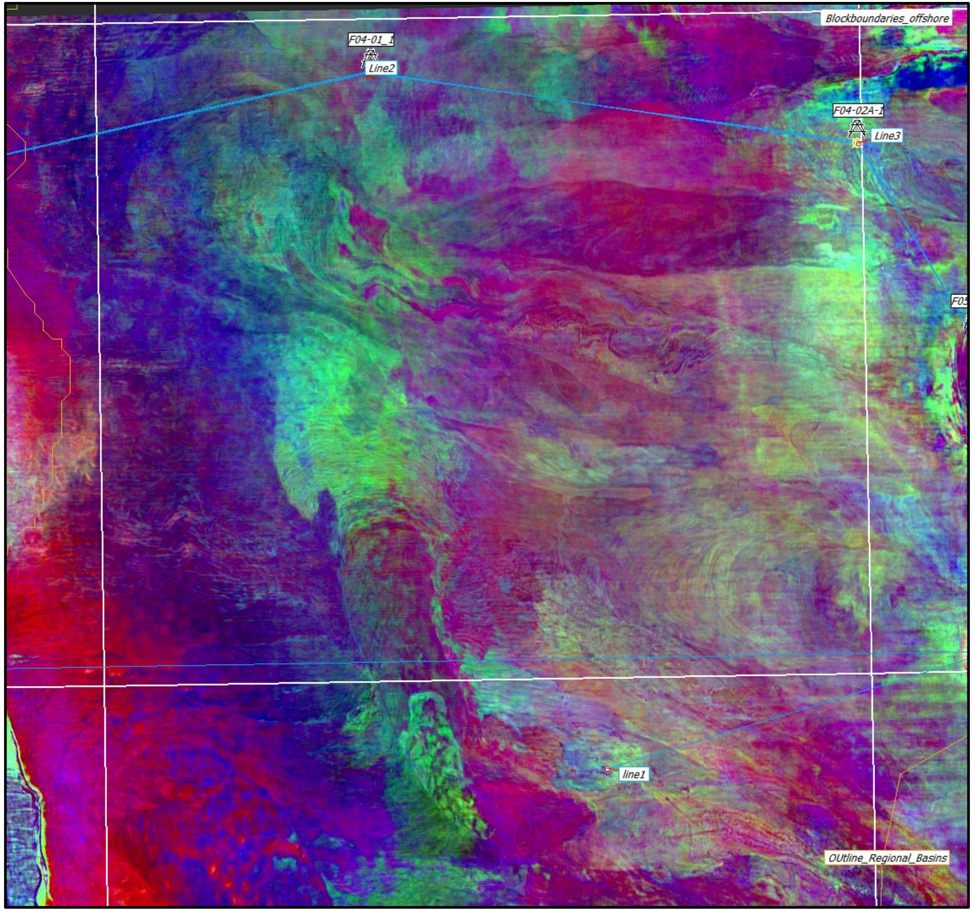


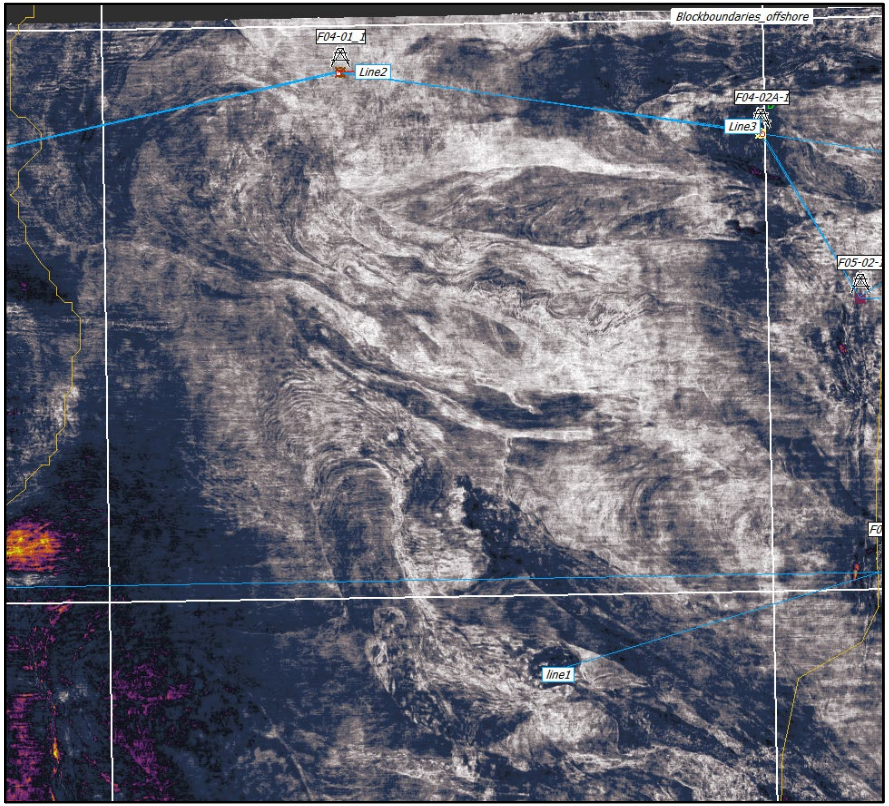
TNO innovation for life

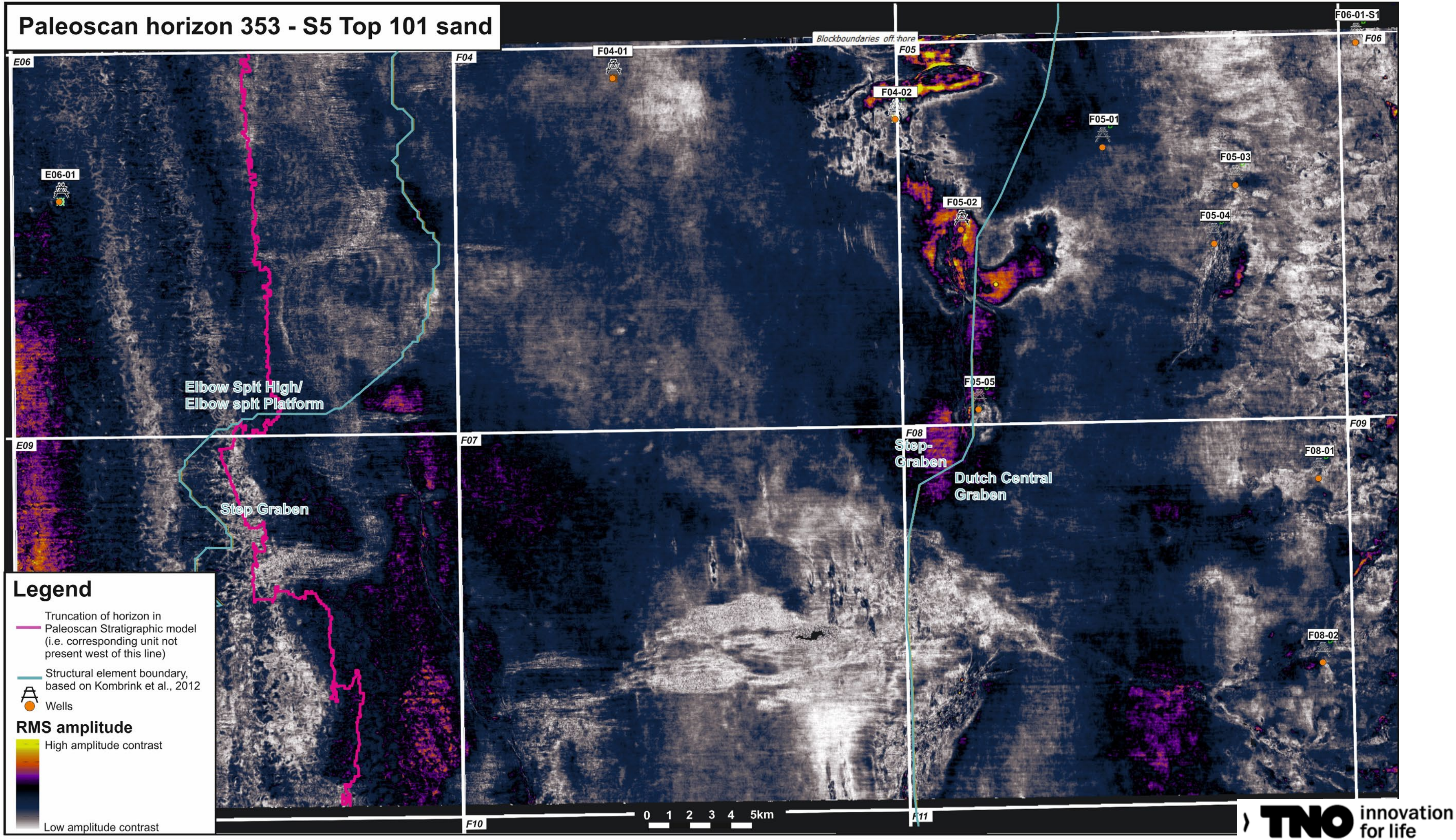
Paleoscan horizon 324 - S5 top 103 Sand



SPECTRAL DECOMPOSITION IMAGE OF PALEOSCAN HORIZON 324, REPRESENTING THE TOP OF THE 103 SAND






Paleoscan horizon 353 - S5 Top 101 sand
E06
F04
F04-01
F05
Blockboundaries offshore
F06-01-S1
F06
F04-02
F05-01
E06-01
F05-03
F05-02
F05-04
F05-05
Elbow Spit High/
Elbow spit Platform
E09
F07
F08
F09
Step-
Graben
F08-01
Dutch Central
Graben
Step Graben
F08-02
Legend
Truncation of horizon in Paleoscan Stratigraphic model (i.e. corresponding unit not present west of this line)
Structural element boundary, based on Kombrink et al., 2012
Wells
RMS amplitude
High amplitude contrast
Low amplitude contrast
0 1 2 3 4 5km
F10
F11
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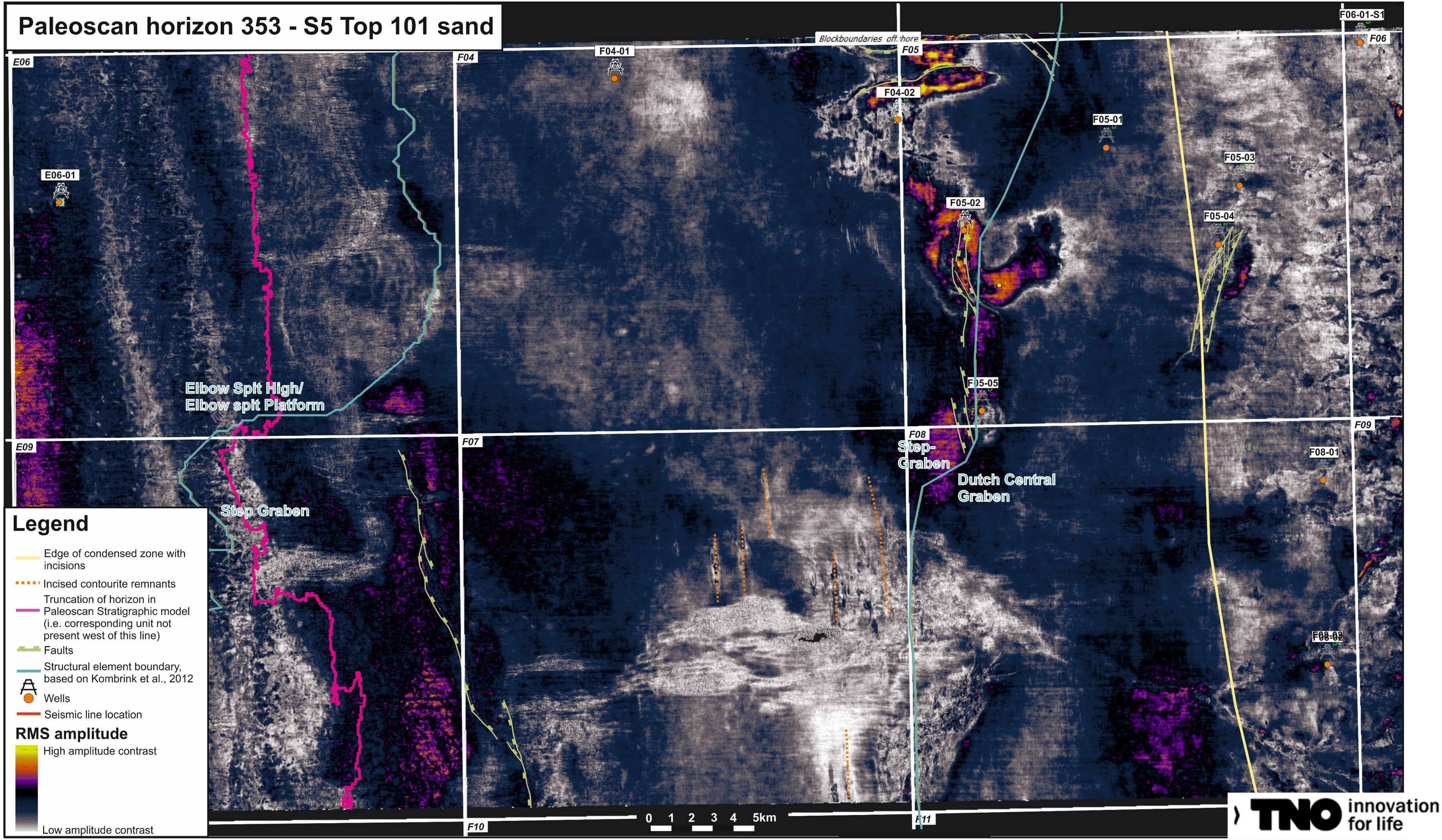
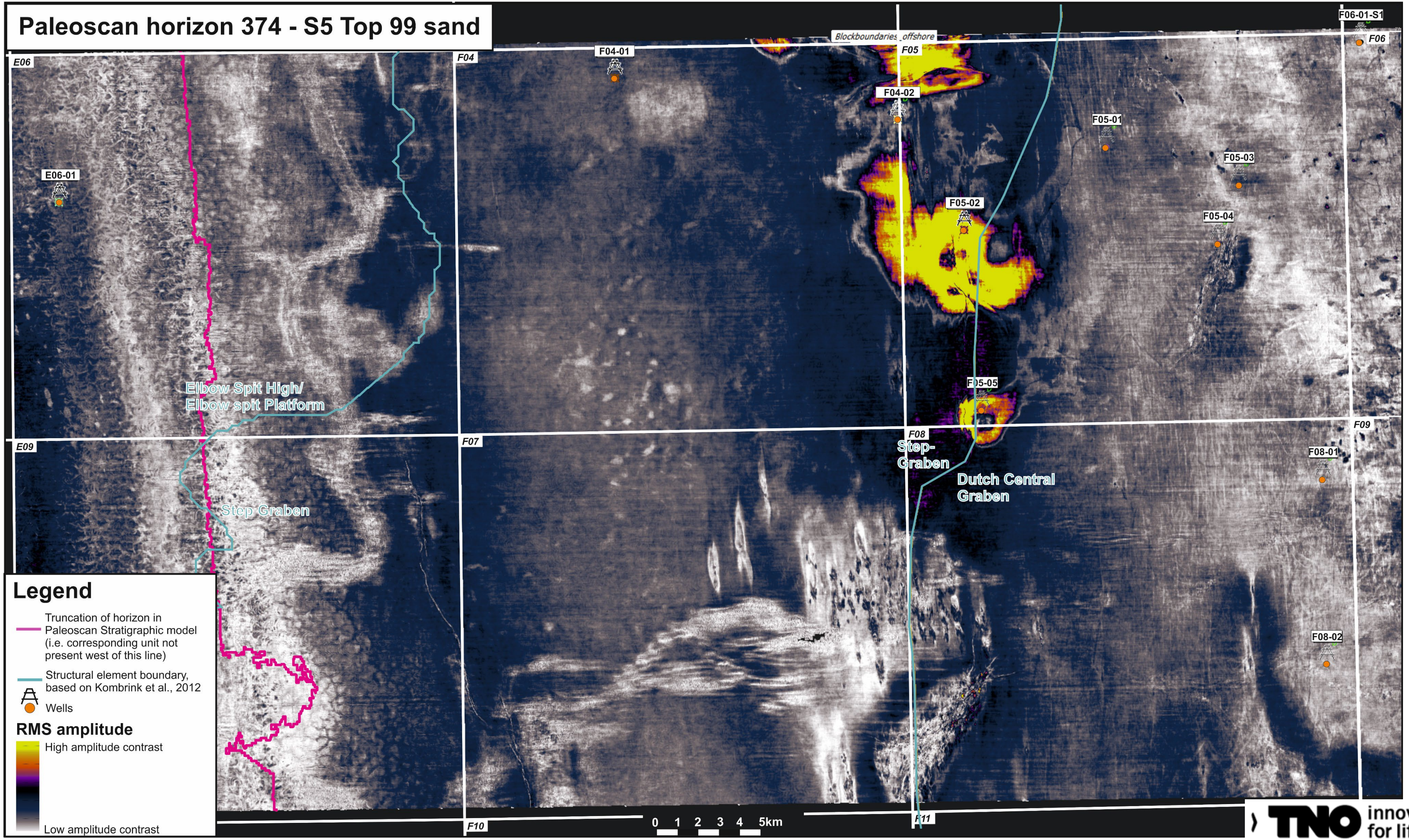
Paleoscan horizon 353 - S5 Top 101 sand




Paleoscan horizon 374 - S5 Top 99 sand
Blockboundaries_offshore
E06
F04
F05
F06
F06-01-S1
F04-01
F04-02
E06-01
F05-01
F05-03
F05-02
F05-04
F05-05
Elbow Spit High/
Elbow spit Platform
E09
F07
F08
F09
Step-
Graben
Dutch Central
Graben
F08-01
Step Graben
F08-02
F10
F11
0 1 2 3 4 5km
Legend
Truncation of horizon in Paleoscan Stratigraphic model (i.e. corresponding unit not present west of this line)
Structural element boundary, based on Kombrink et al., 2012
Wells
RMS amplitude
High amplitude contrast
Low amplitude contrast
innovation for life

Paleoscan horizon 374 - S5 Top 99 sand

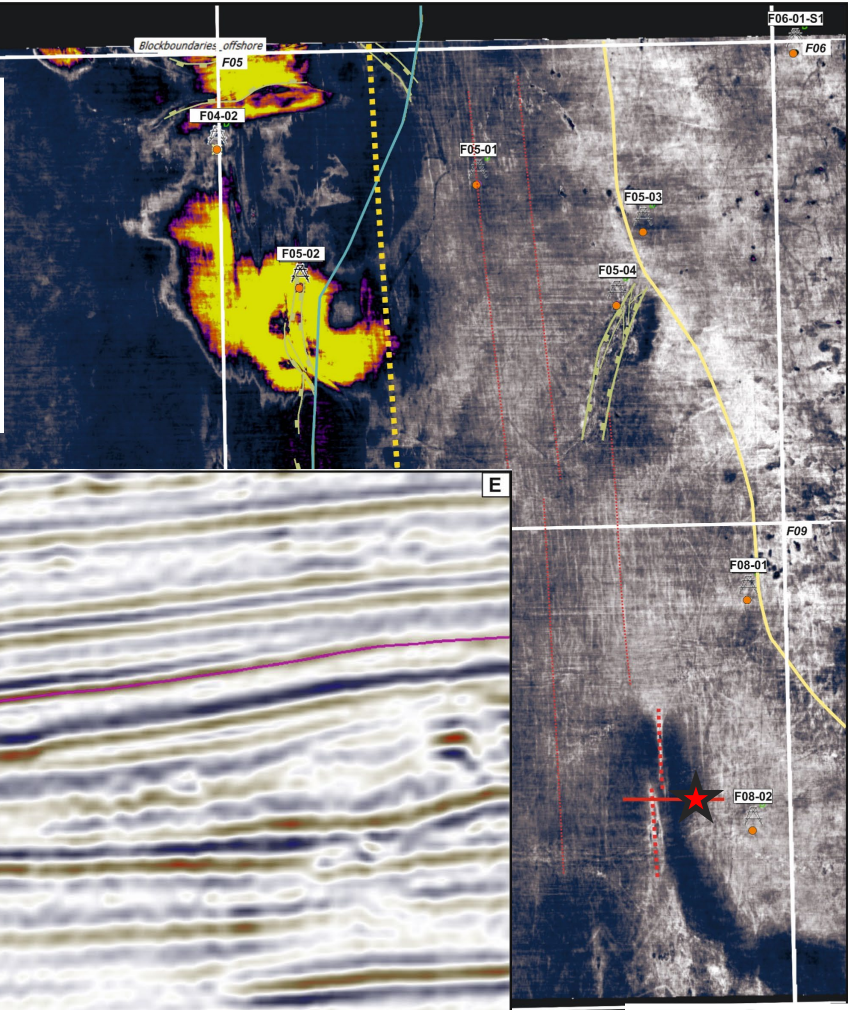
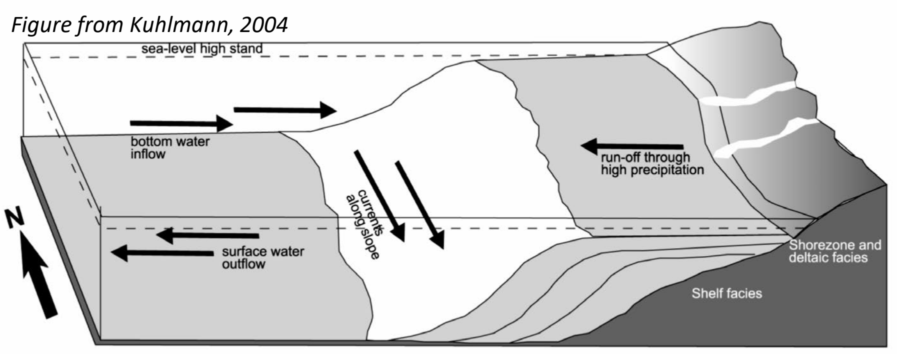
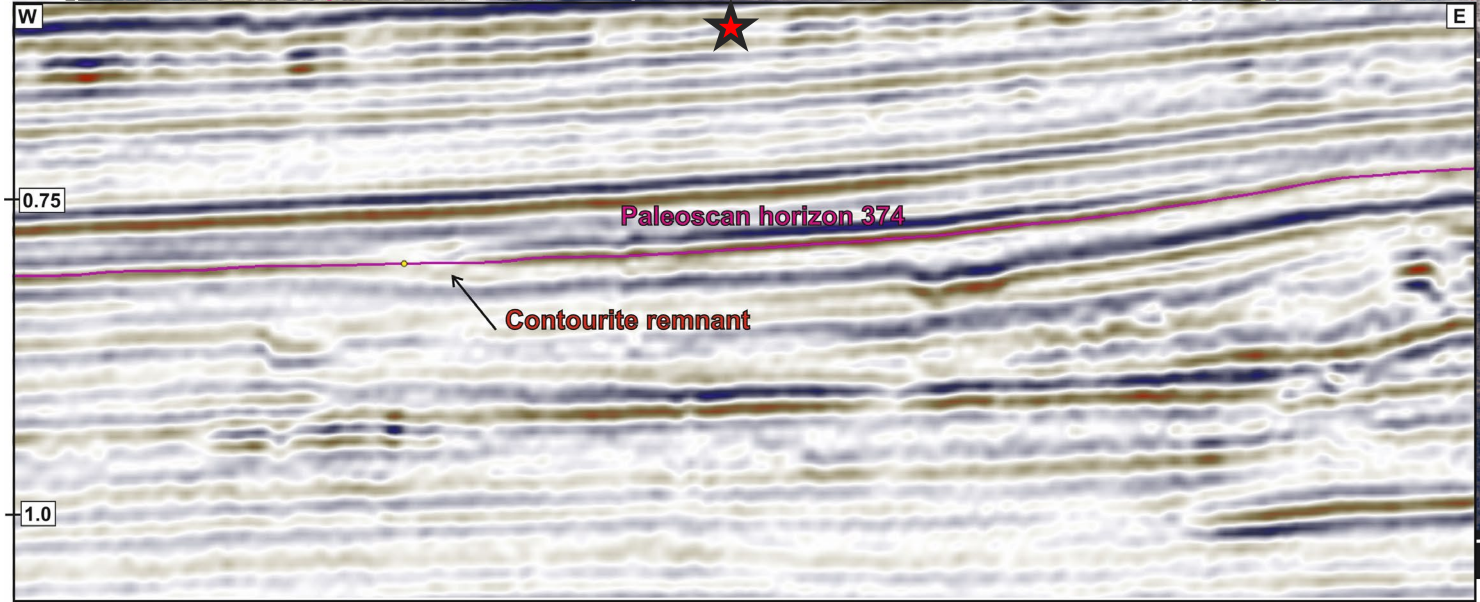


Figure from Kuhlmann, 2004





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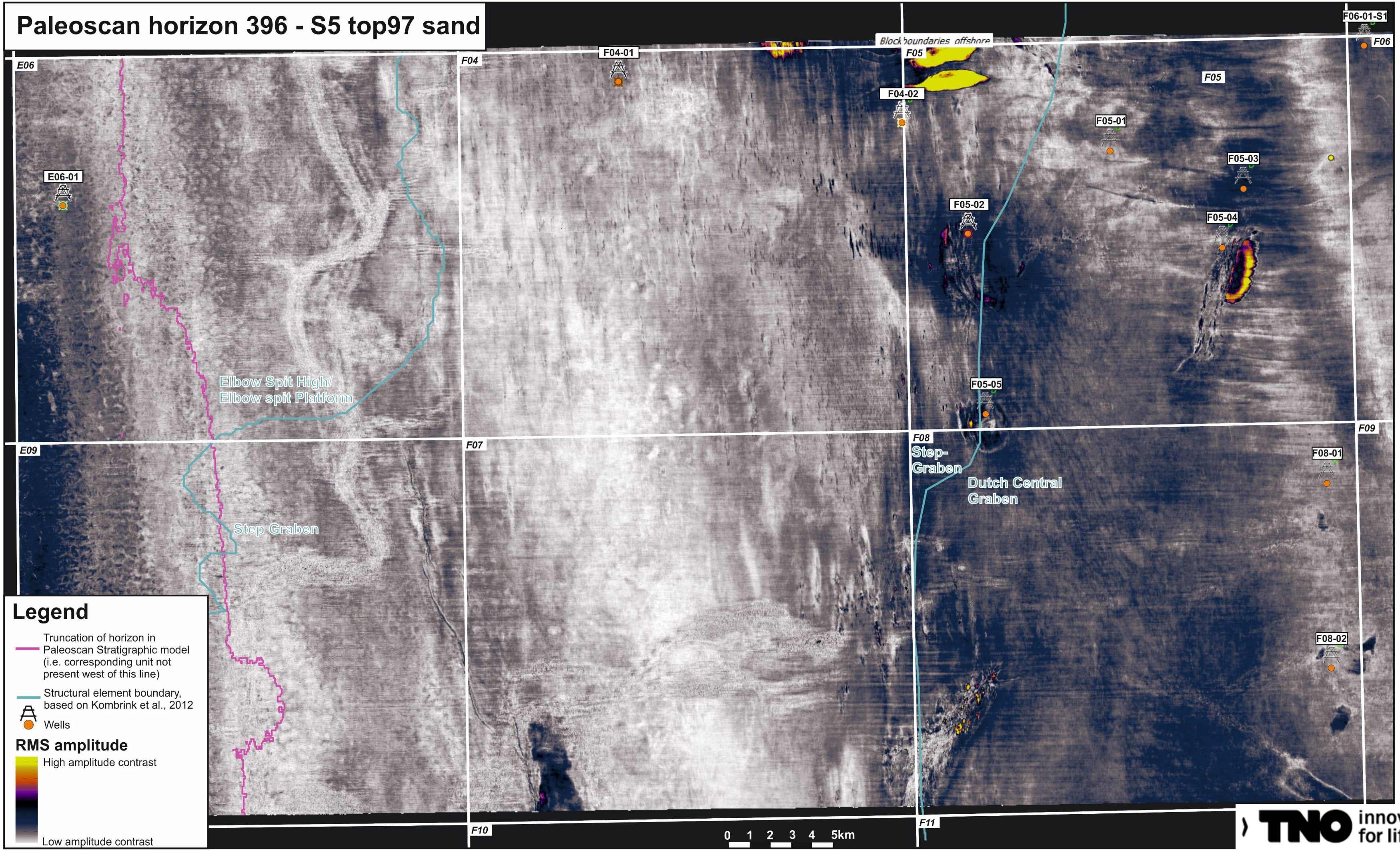
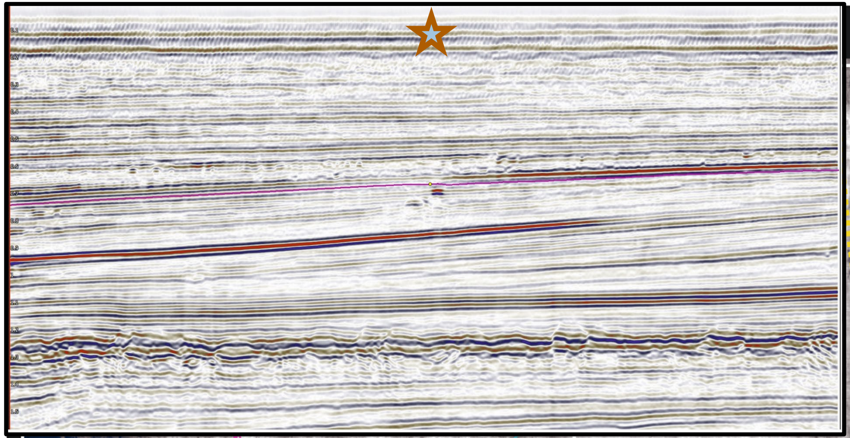
Paleoscan horizon 396 - S5 top97 sand





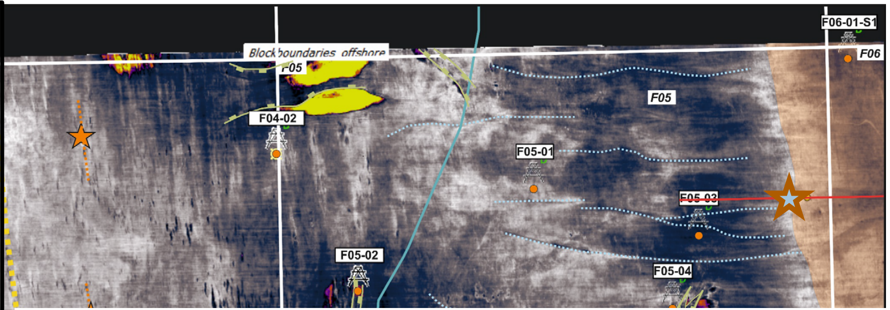
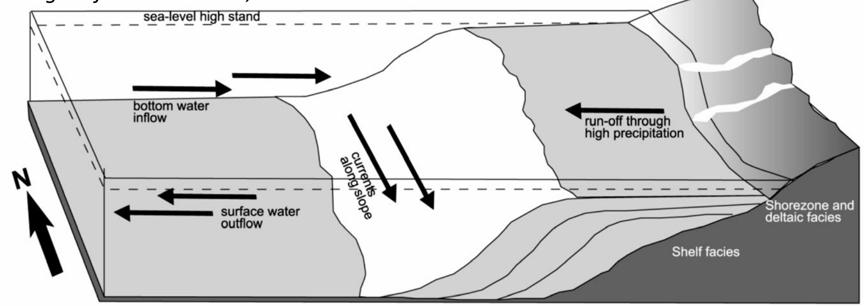
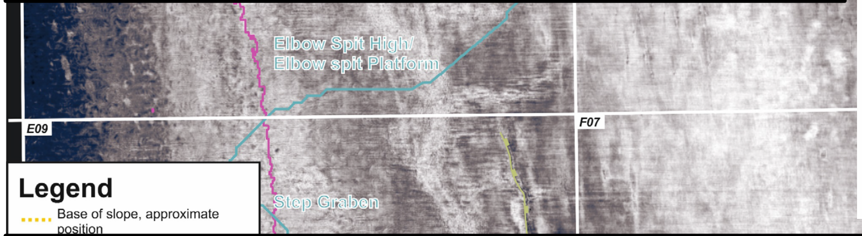


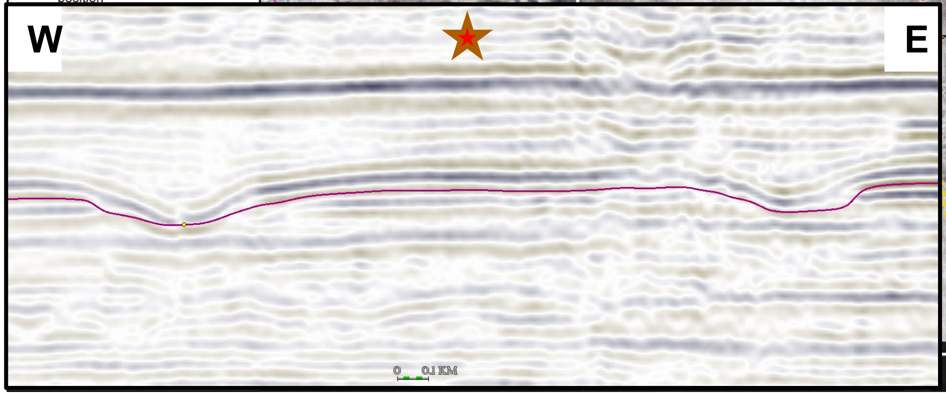
Figure from Kuhlmann, 2004

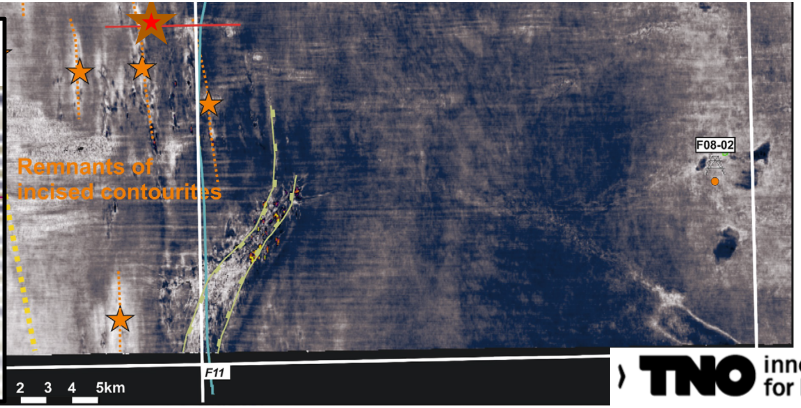




Legend

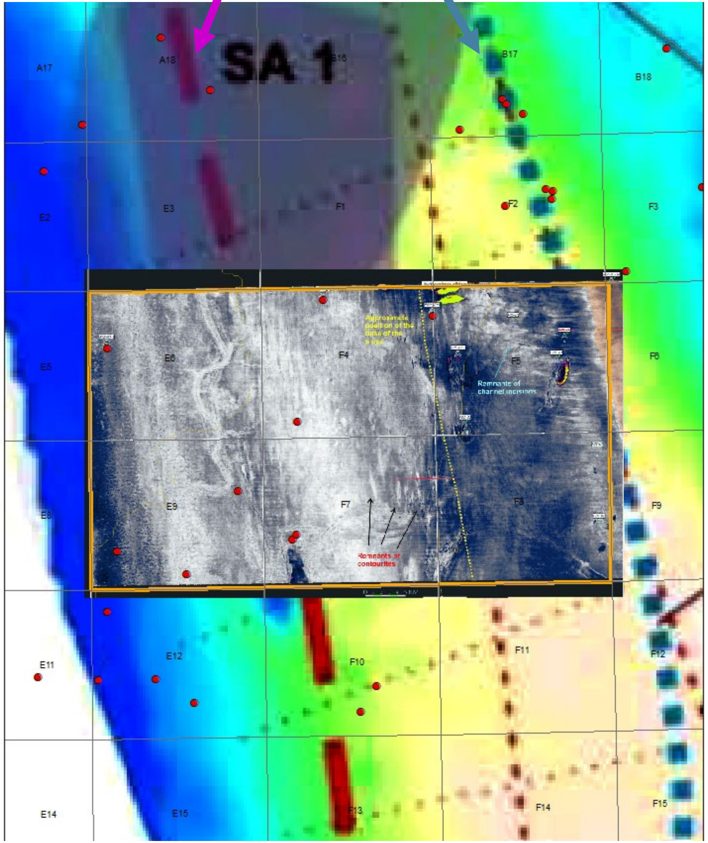
Base of slope, approximate position





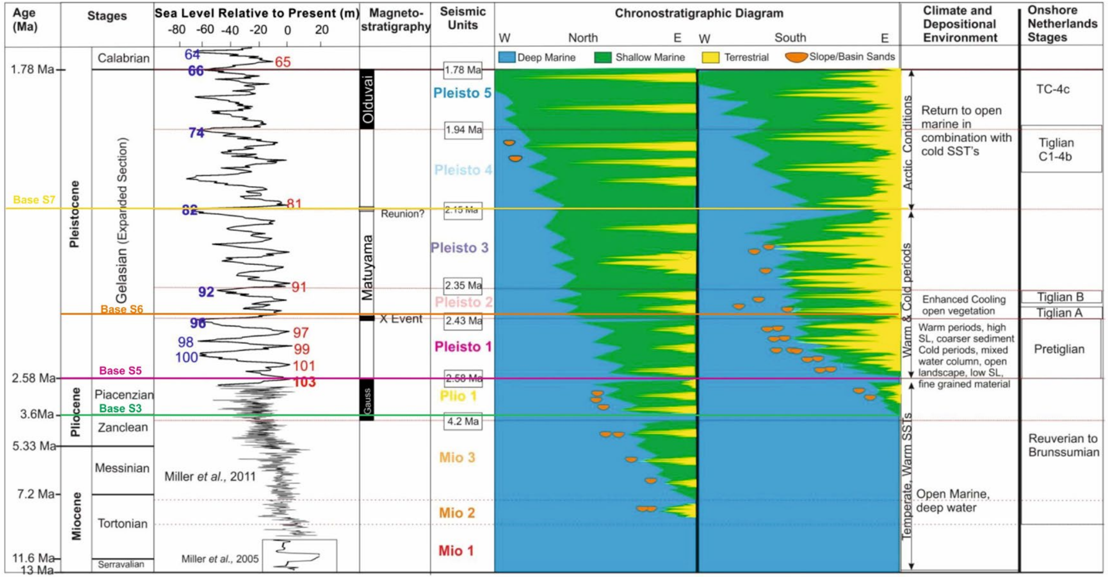
Max regression of coastline unit S5 (Harding, 2015); roughly corresponding to erosion of 97 (likely by 96 event)

Top Pleisto 1 shelf edge (Harding, 2015)



Main conclusions for regional context based on unit S5 RMS maps:

- Based on the occurence of depositional features (e.g. bottom currents, fluvial channel systems), it is often possible to gain understanding in the position of the paleo shelf edge and/or base of slope.
- The variety in interpreted sedimentary features (MTC's, fluvial systems, contourites, scour marks) within the unit S5 indicates that the relative sea level position strongly fluctuated between warmer and colder periods during unit S5 (see also figure below); Hence the position of the base of slope and shelf edge shifted several times within unit S5 by tens-, or possibly hundreds of kilometers.



Both figures: modified from Harding, 2015

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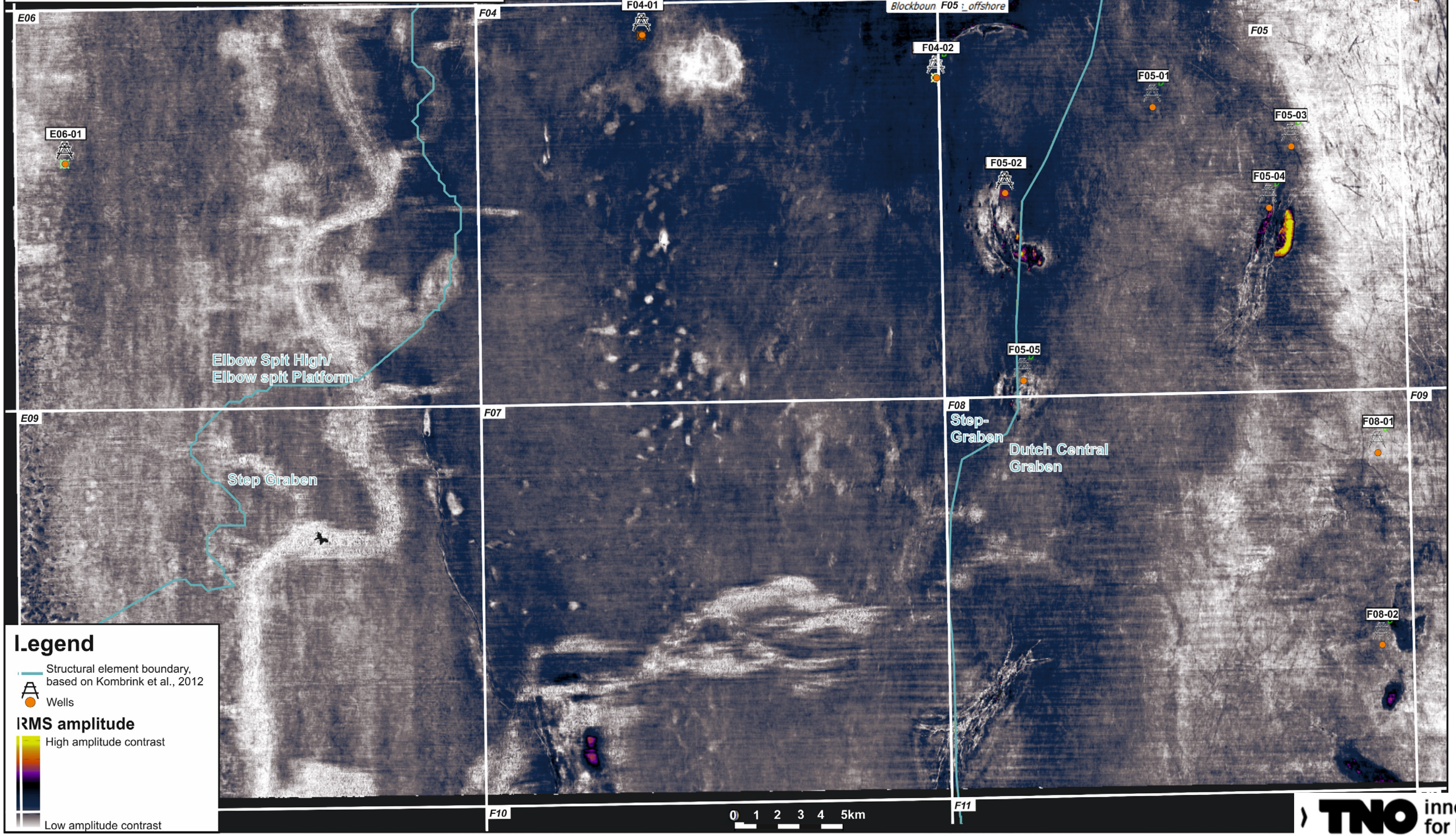
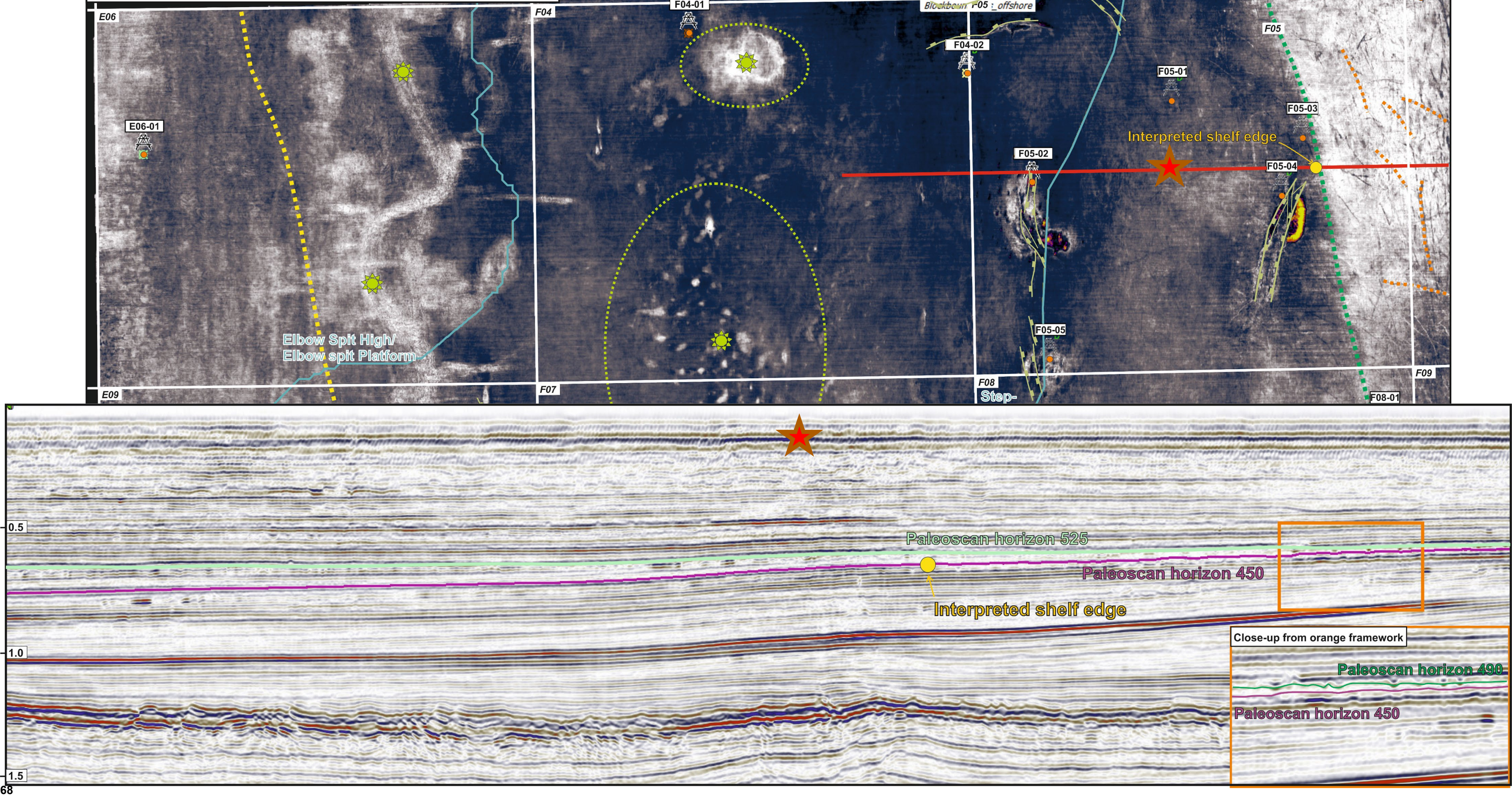
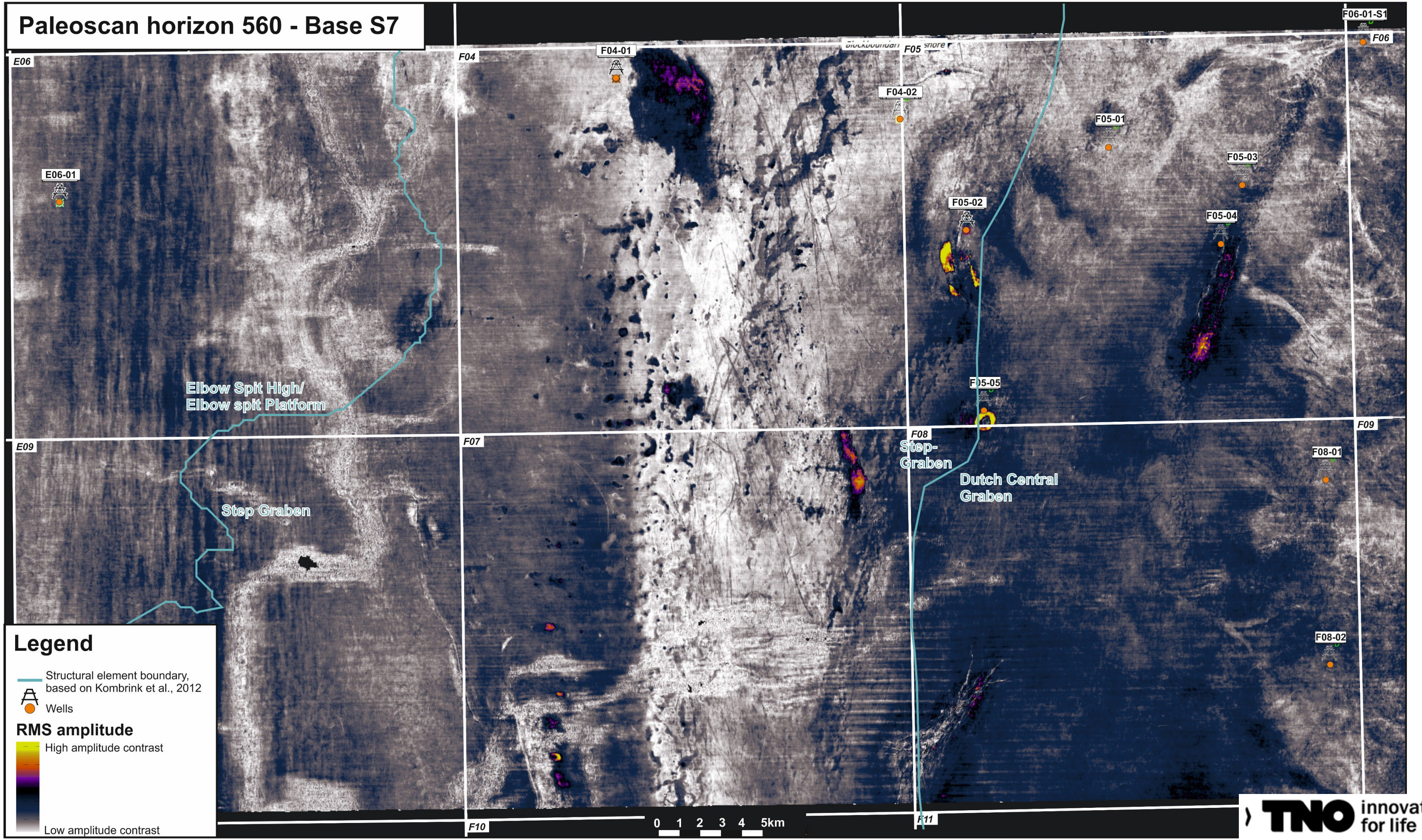
Paleoscan horizon 450- Base S6

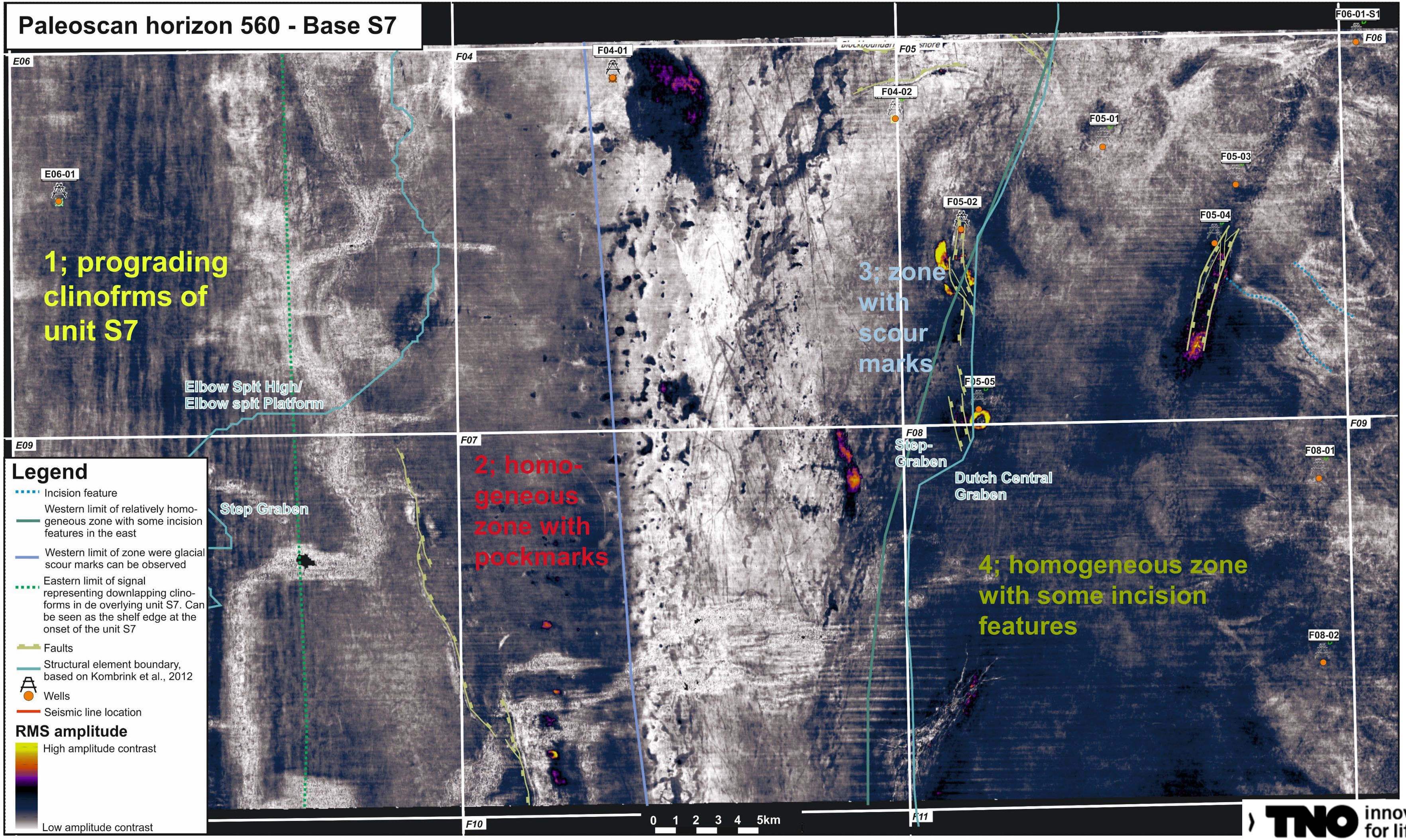


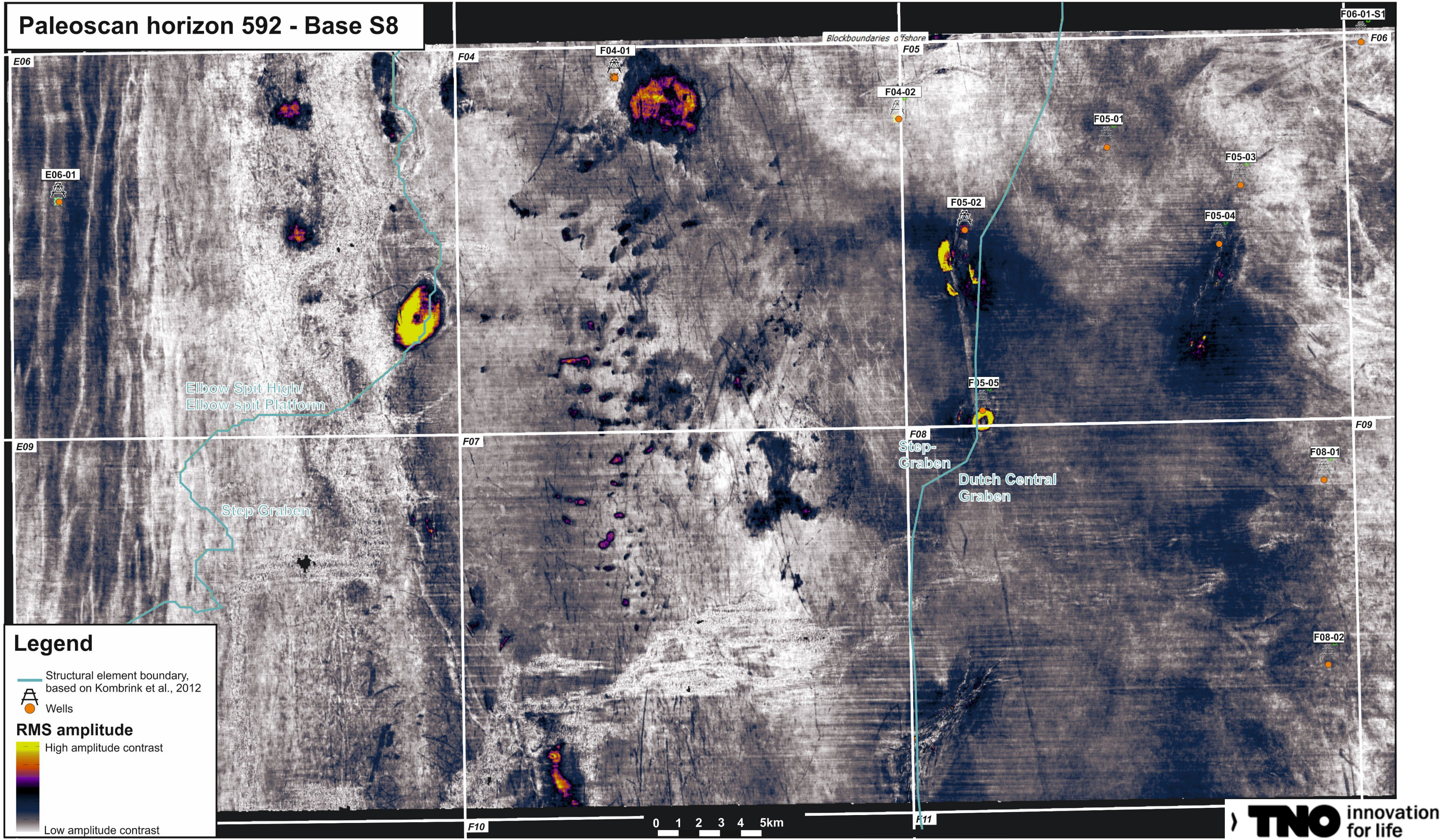
Paleoscan horizon 450- Base S6

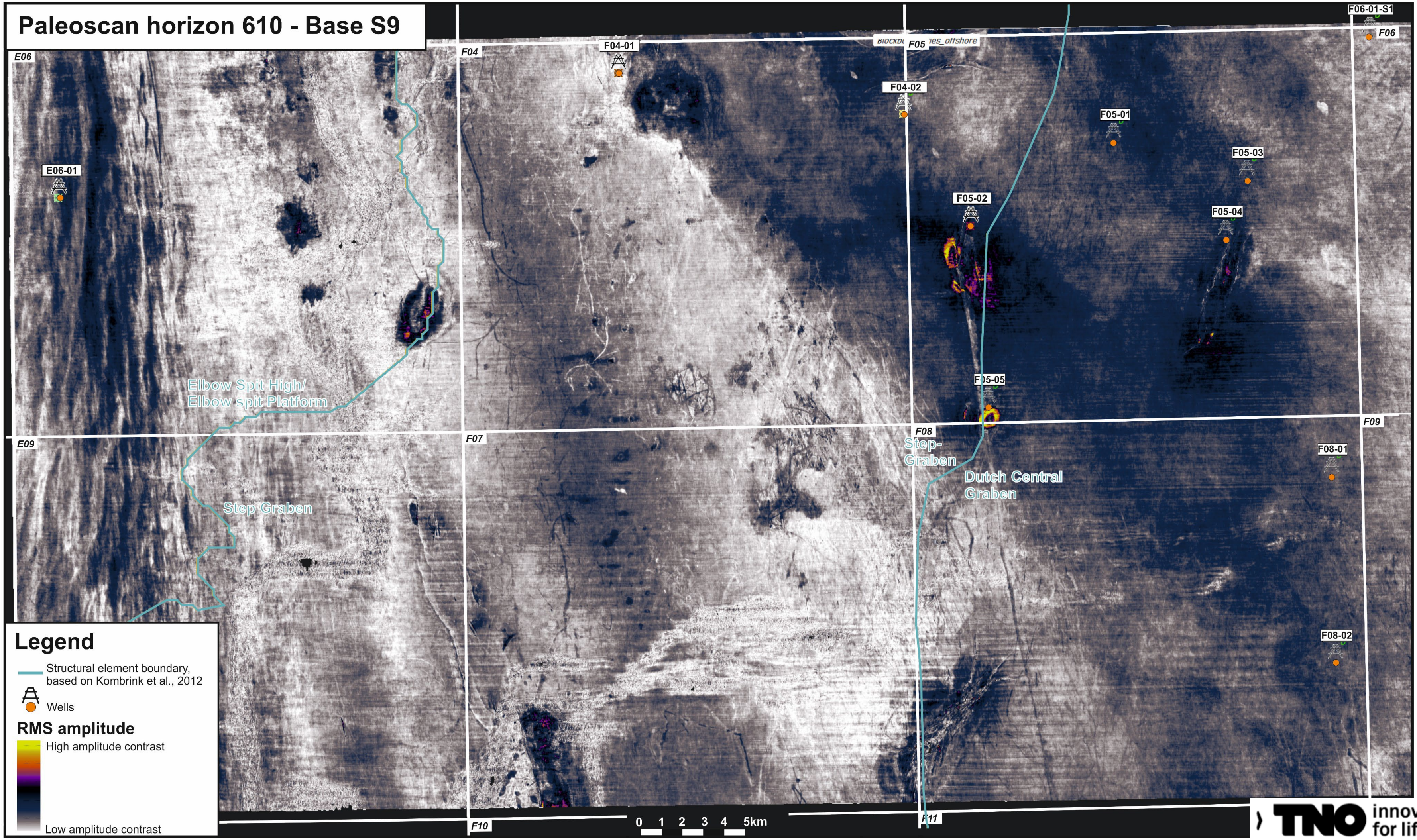




Paleoscan horizon 560 - Base S7
E06
F04
F05
F06
F06-01-S1
F04-01
F04-02
F05-01
F05-03
F05-02
F05-04
E06-01
F05-05
E09
F07
F08
F09
F08-01
F08-02
F10
F11
Elbow Spit High/
Elbow spit Platform
Step Graben
Step-
Graben
Dutch Central
Graben
Legend
Structural element boundary,
based on Kombrink et al., 2012
Wells
RMS amplitude
High amplitude contrast
Low amplitude contrast
0 1 2 3 4 5km


Paleoscan horizon 560 - Base S7
E06
F04
F04-01
F05
F04-02
F06-01-S1
F06
E06-01
F05-01
F05-03
F05-02
F05-04
1; prograding clinofrms of unit S7
3; zone with scour marks
Elbow Spit High/ Elbow spit Platform
F05-05
E09
F07
F08
F09
F08-01
Legend
Incision feature
Western limit of relatively homogeneous zone with some incision features in the east
Western limit of zone were glacial scour marks can be observed
Eastern limit of signal representing downlapping clinoforms in de overlying unit S7. Can be seen as the shelf edge at the onset of the unit S7
Faults
Structural element boundary, based on Kombrink et al., 2012
Wells
Seismic line location
RMS amplitude
High amplitude contrast
Low amplitude contrast
2; homogeneous zone with pockmarks
Step Graben
Step-Graben
Dutch Central Graben
4; homogeneous zone with some incision features
F08-02
F10
F11
0 1 2 3 4 5km


Paleoscan horizon 592 - Base S8
Blockboundaries offshore
E06
F04
F05
F06
E09
F07
F08
F09
F10
F11
E06-01
F04-01
F04-02
F05-01
F05-02
F05-03
F05-04
F05-05
F06-01-S1
F08-01
F08-02
Elbow Spit High/
Elbow spit Platform
Step Graben
Step-
Graben
Dutch Central
Graben
0 1 2 3 4 5km
Legend
Structural element boundary,
based on Kombrink et al., 2012
Wells
RMS amplitude
High amplitude contrast
Low amplitude contrast
TNO innovation for life


Paleoscan horizon 610 - Base S9
E06
F04
F04-01
F05
F06-01-S1
F06
F04-02
F05-01
F05-03
E06-01
F05-02
F05-04
Elbow Spit High/
Elbow spit Platform
F05-05
E09
F07
F08
F09
Step-
Graben
Dutch Central
Graben
F08-01
Step Graben
F08-02
Legend
Structural element boundary,
based on Kombrink et al., 2012
Wells
RMS amplitude
High amplitude contrast
Low amplitude contrast
F10
0 1 2 3 4 5km
F11
TNO innovation for life

WP3 – PROPERTY MODEL

- Construction of 3D model (Sequence- and Geocellular modelling in Paleoscan)

- Property/reservoir modelling
  - Enhancement, correction and petrophysical evaluation of available well logs
  - 3D interpolation techniques

- Evaluation of sediment properties of brightspots

SEQUENCE- AND GEOCELLULAR 3D MODEL IN PALEOSCAN

1. **Approach and rationale for the modelling work in Paleoscan**
2. Final results paleoScan modelling : X-sections, Sequence boundary maps, Isochore maps

STRATI-VIEWER –SEQUENCE MODEL AND GEOCELLULAR MODEL

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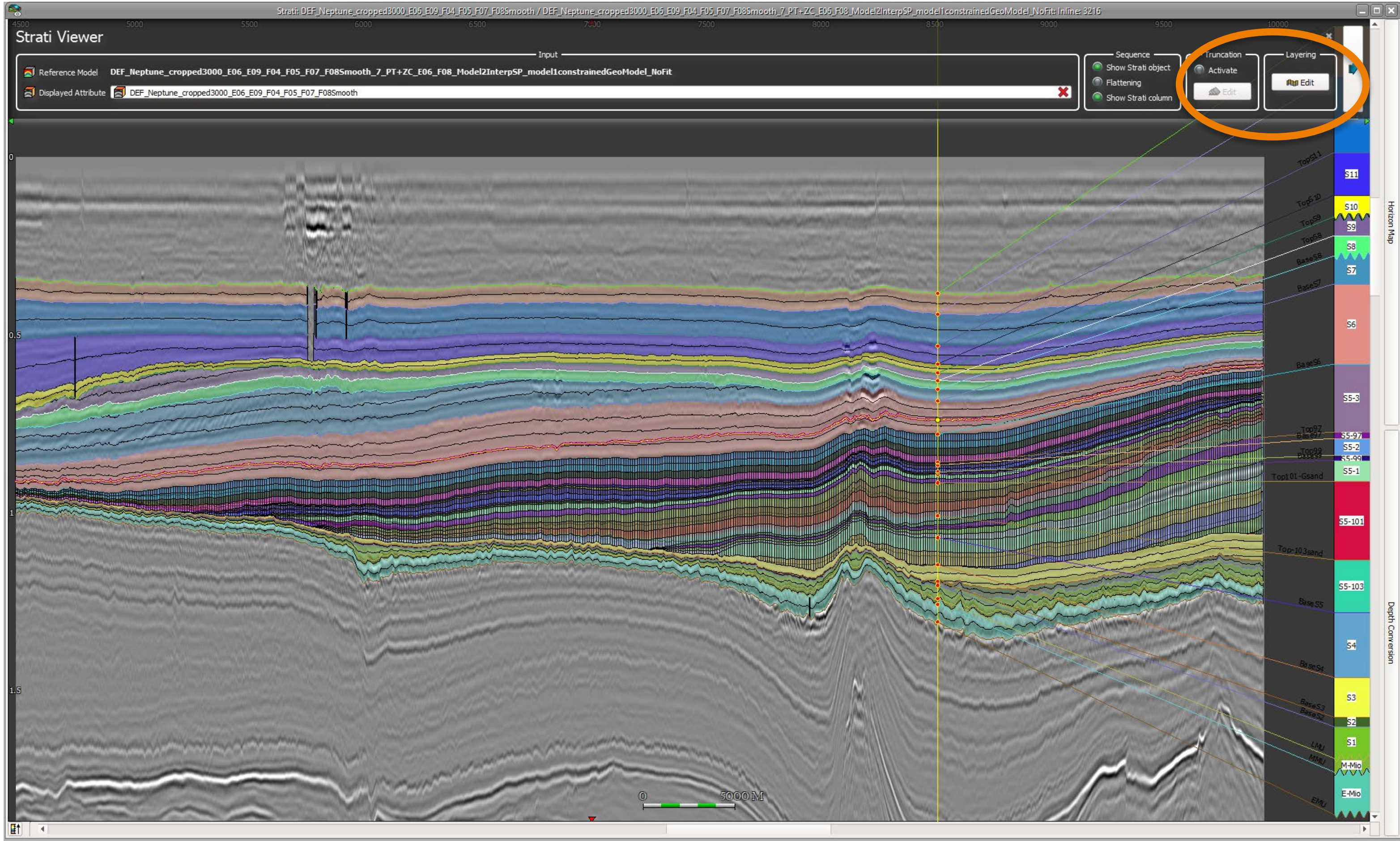
X-sextion shows the sequence model of EMU-TopS13 & the geo-cellular model of S5-sequence including S5 sands defined as sequence boundaries



STRATI-VIEWER –SEQUENCES, TRUNCATION, LAYERING

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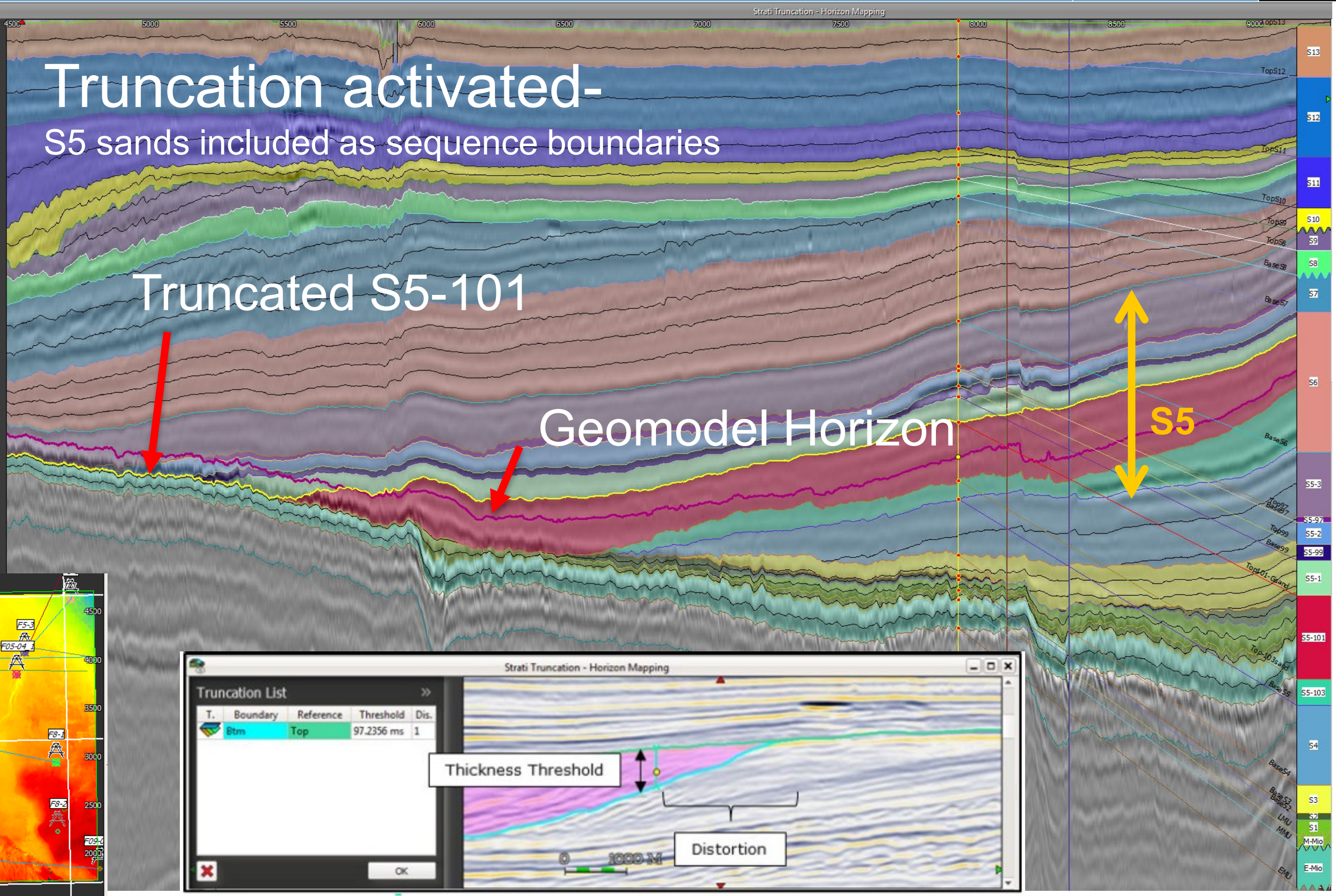
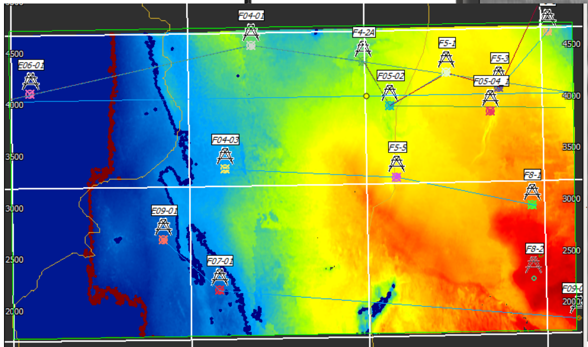
Truncation List

T.	Boundary	Reference	Threshold	Dis.
	BaseS4	BaseS3	0.025 s	0,1
	BaseS5	BaseS4	0.05 s	0,4
	BaseS2	LMU	0.04 s	0,1
	BaseS3	BaseS2	0.025 s	0,1
	Top-103sand	BaseS5	0.085 s	0,1
	Top101-Gs...	BaseS5	0.06 s	0,1
	Base99	BaseS5	0.06 s	0,1
	Top99	BaseS5	0.065 s	0,1
	Base97	BaseS5	0.071 s	0,1
	Top97	BaseS5	0.07 s	0,1

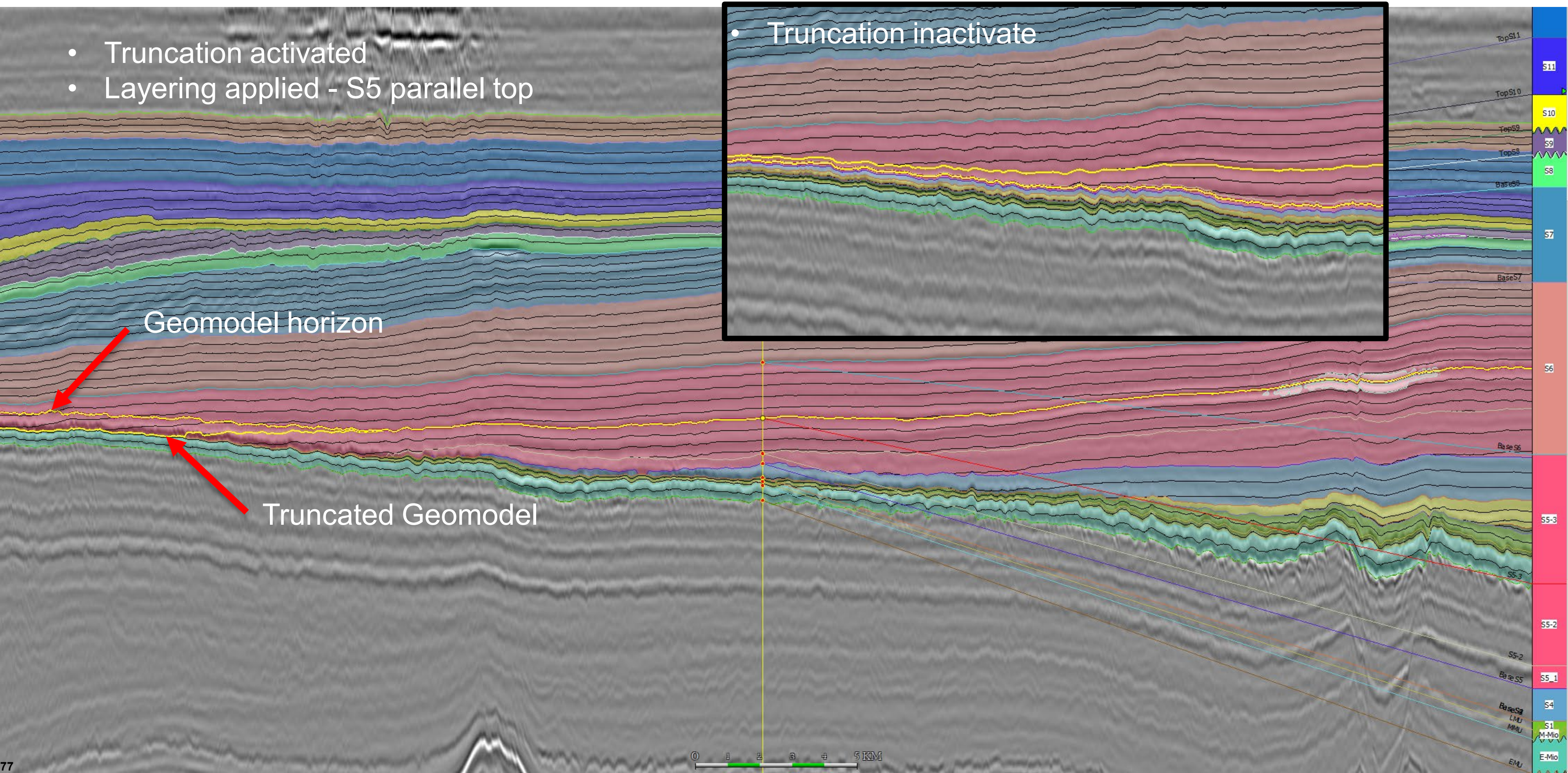


Map view truncated S5-101

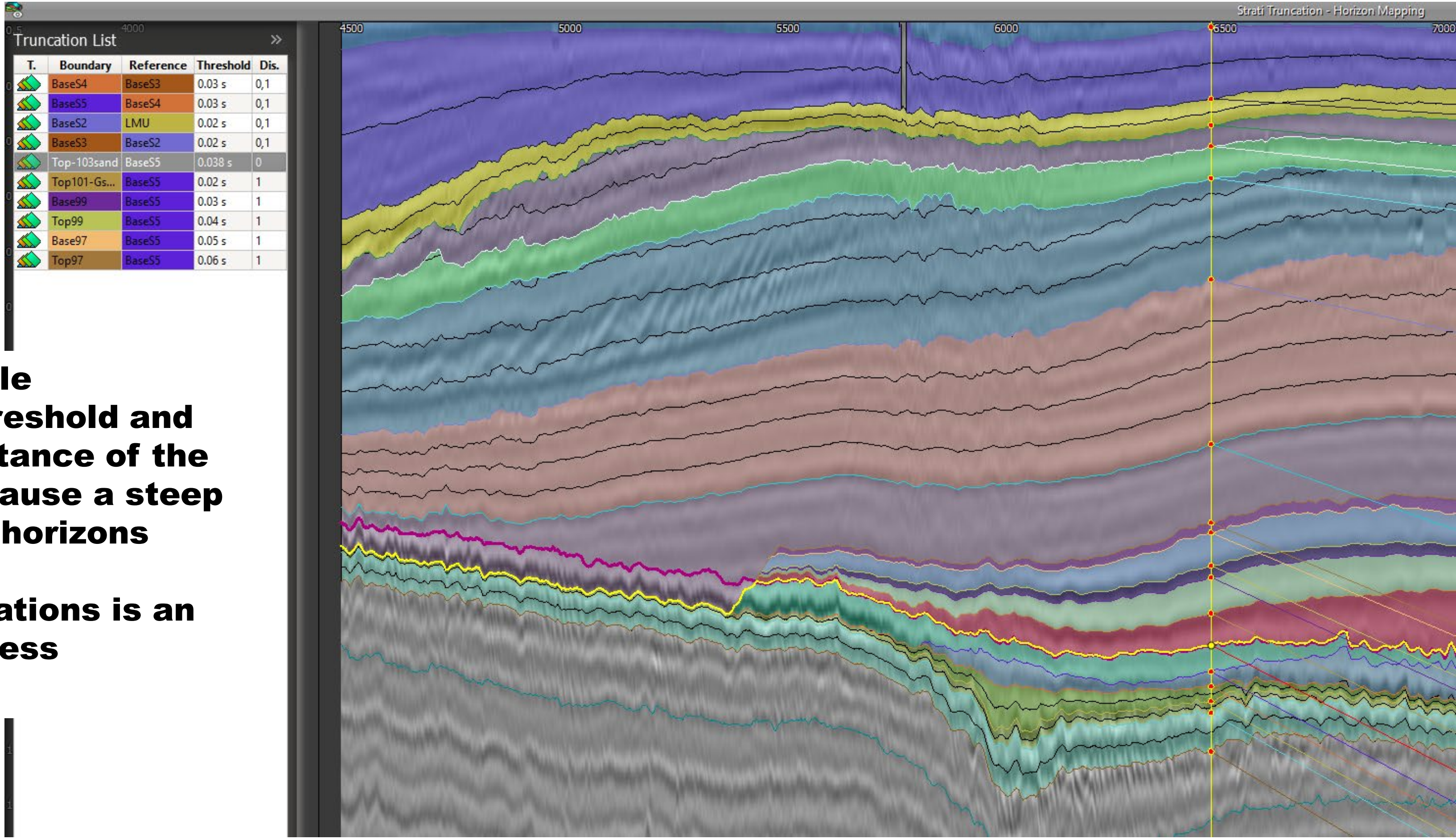


STRATI-VIEWER –SEQUENCES, TRUNCATION

TNO innovation for life



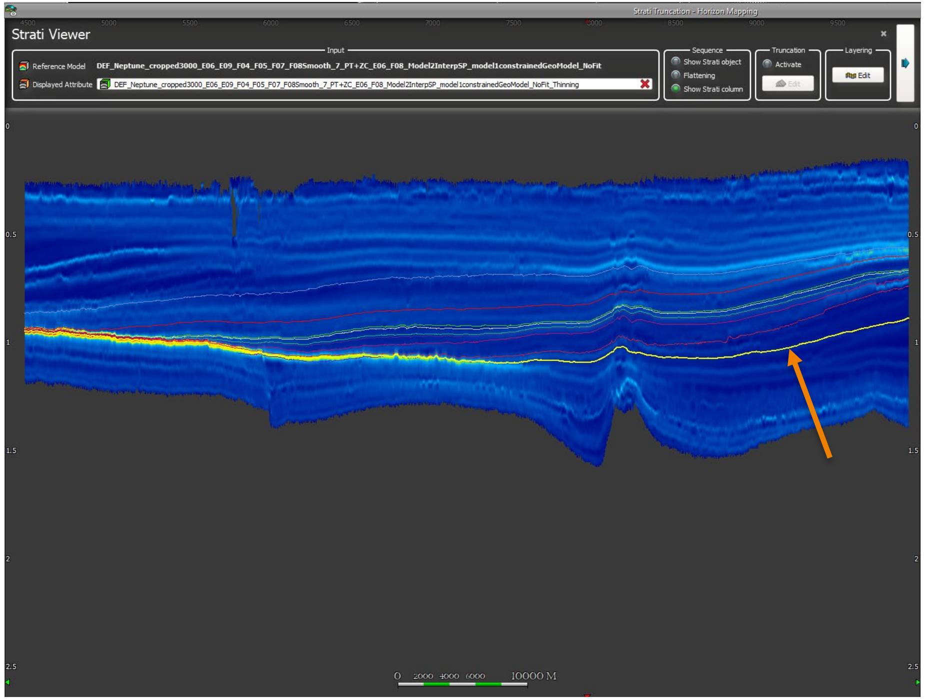
STRATI-VIEWER –SEQUENCES, TRUNCATION

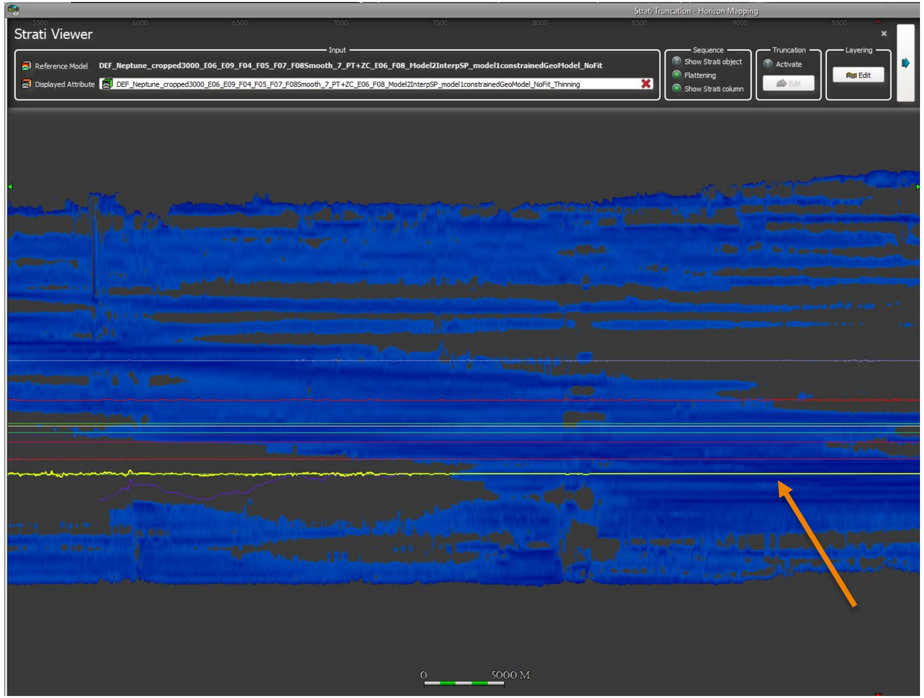


T.	Boundary	Reference	Threshold	Dis.
	BaseS4	BaseS3	0.03 s	0,1
	BaseS5	BaseS4	0.03 s	0,1
	BaseS2	LMU	0.02 s	0,1
	BaseS3	BaseS2	0.02 s	0,1
	Top-103sand	BaseS5	0.038 s	0
	Top101-Gs...	BaseS5	0.02 s	1
	Base99	BaseS5	0.03 s	1
	Top99	BaseS5	0.04 s	1
	Base97	BaseS5	0.05 s	1
	Top97	BaseS5	0.06 s	1

In this example Thickness threshold and distortion distance of the top 97 sand cause a steep truncation of horizons below.
Setting truncations is an iterative process

STRATI-VIEWER – THINNING ATTRIBUTE & FLATTENING

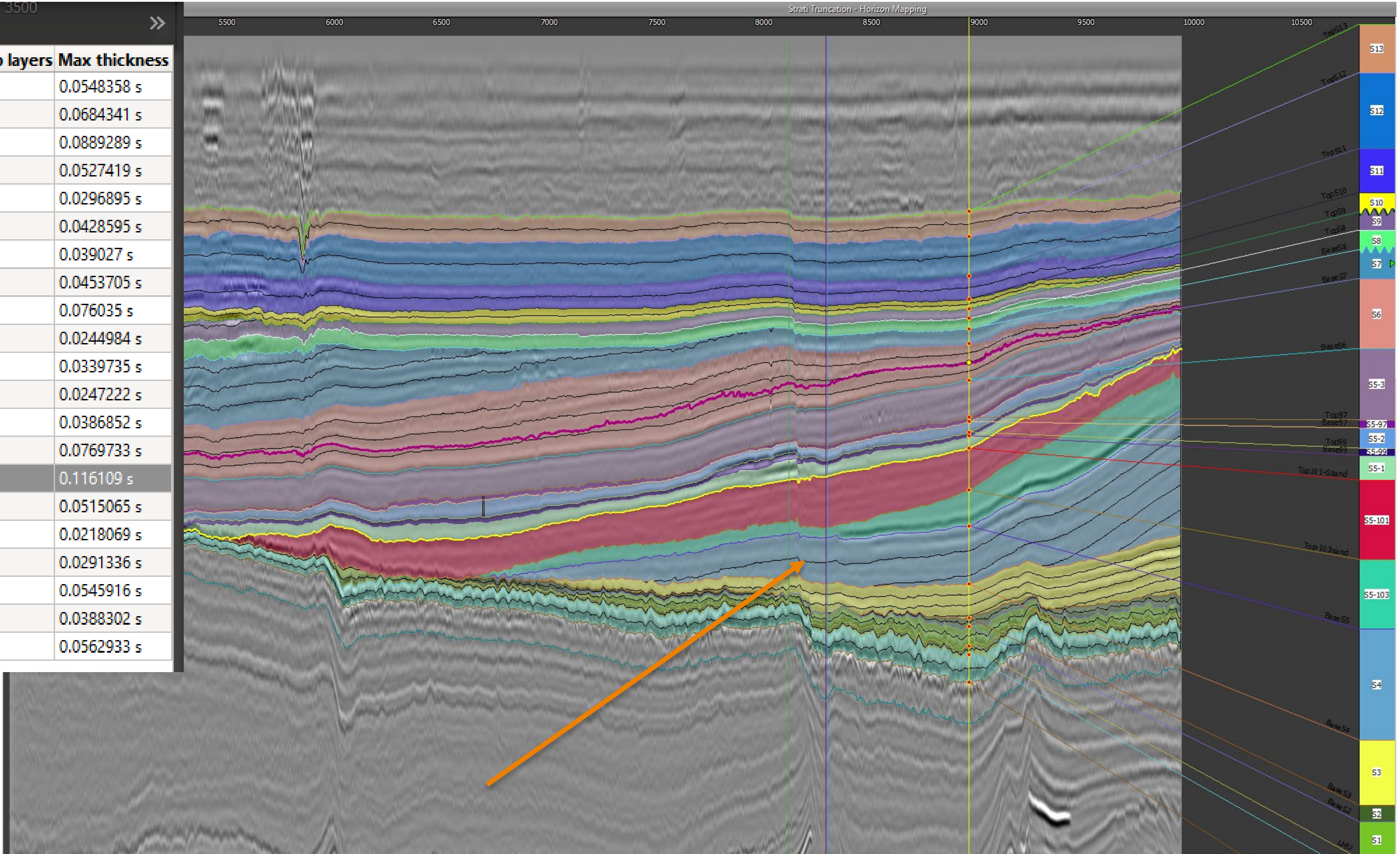




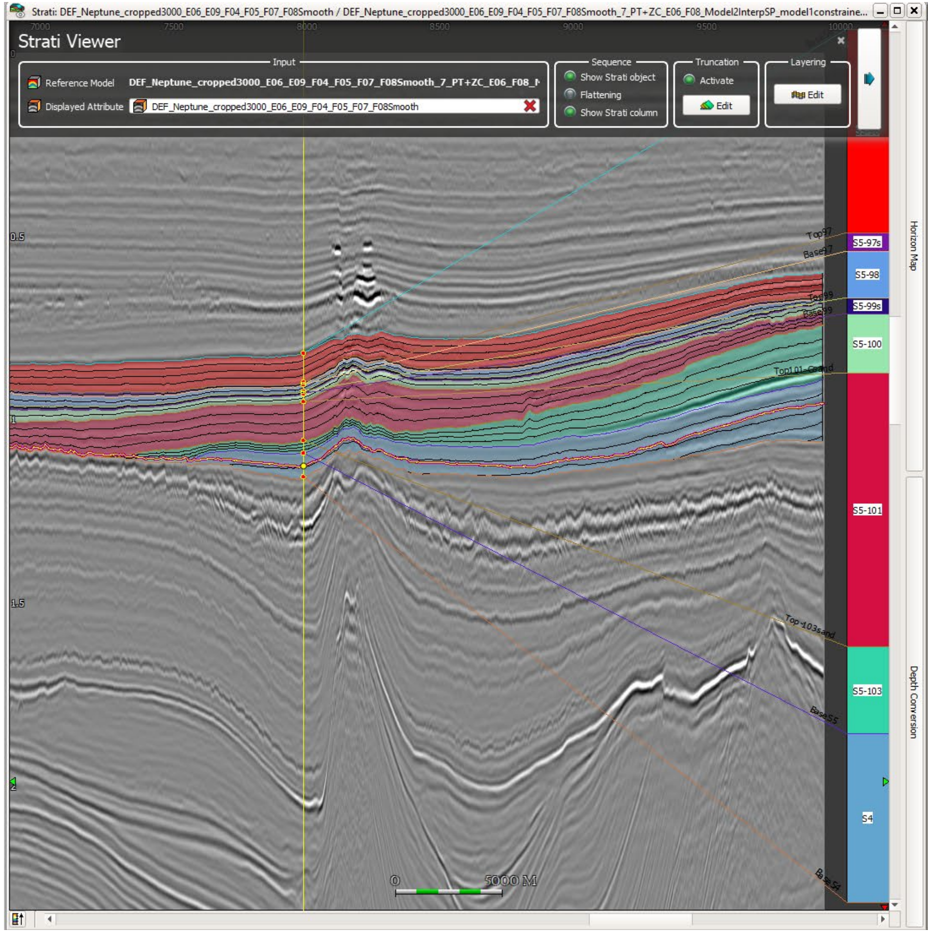
STRATI- VIEWER: INTERNAL LAYERING

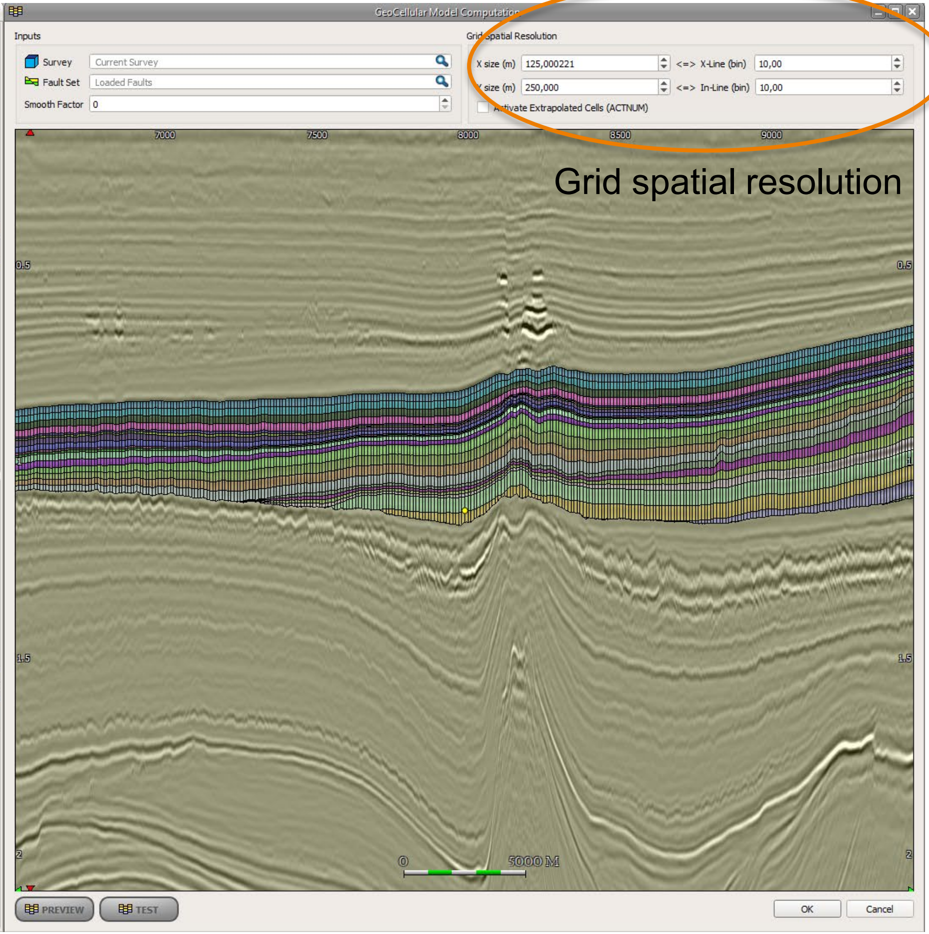
Sub-layering per unit

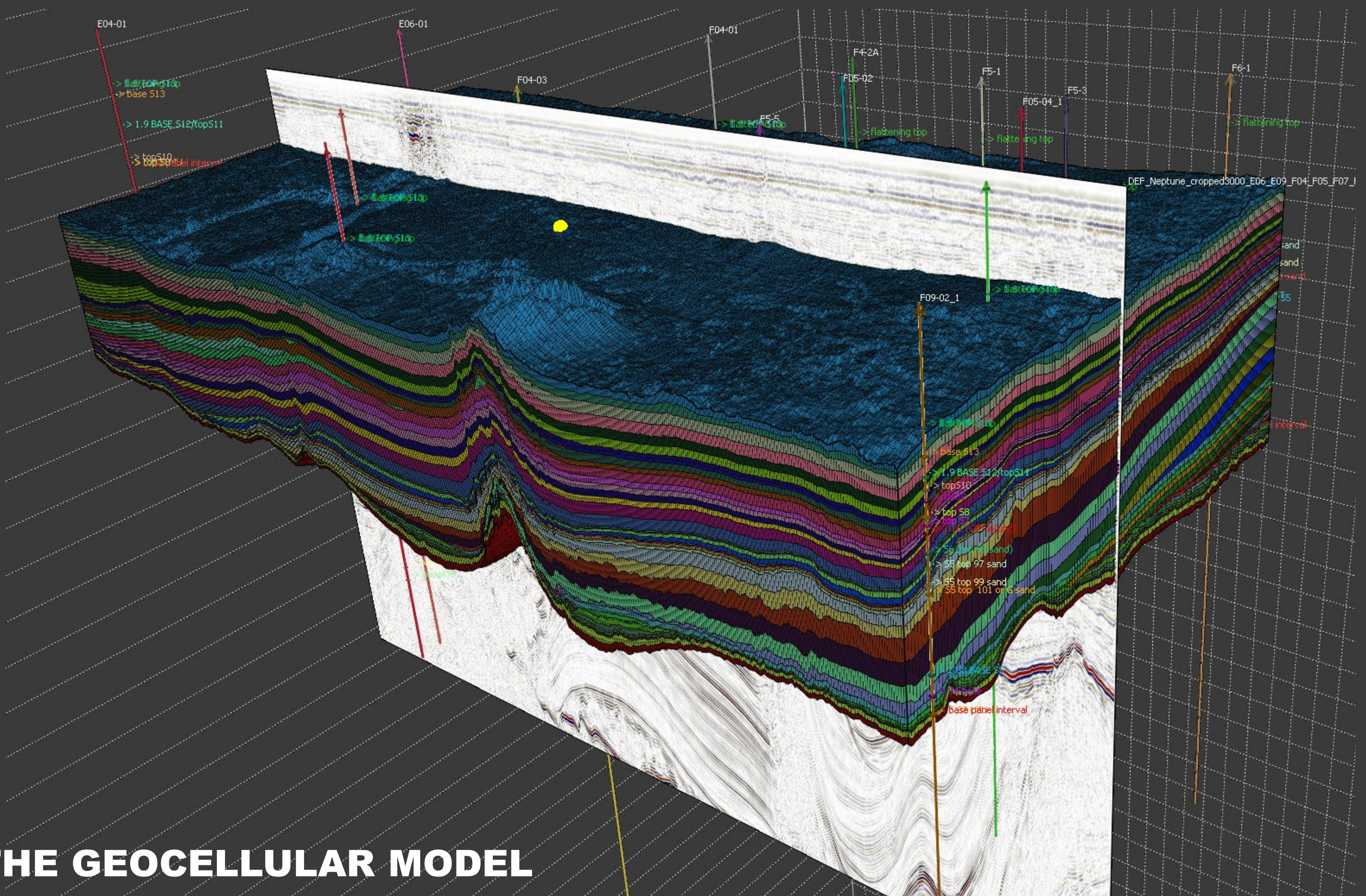
Name	Litho	Method	Nb layers	Max thickness
S13		Iso Proportional	2	0.0548358 s
S12		Iso Proportional	2	0.0684341 s
S11		Iso Proportional	2	0.0889289 s
S10		Iso Proportional	2	0.0527419 s
S9		Parallel Bottom	3	0.0296895 s
S8		Parallel Bottom	2	0.0428595 s
S7		Parallel Bottom	4	0.039027 s
S6		Iso Proportional	4	0.0453705 s
S5-3		Iso Proportional	2	0.076035 s
S5-97		Iso Proportional	2	0.0244984 s
S5-2		Iso Proportional	2	0.0339735 s
S5-99		Iso Proportional	2	0.0247222 s
S5-1		Iso Proportional	2	0.0386852 s
S5-...		Iso Proportional	2	0.0769733 s
S5-...		Iso Proportional	2	0.116109 s
S4		Parallel Top	6	0.0515065 s
S3		Parallel Top	8	0.0218069 s
S2		Iso Proportional	2	0.0291336 s
S1		Iso Proportional	2	0.0545916 s
M-...		Iso Proportional	2	0.0388302 s
E-...		Iso Proportional	2	0.0562933 s



TRUNCATED AND LAYERED SEQUENCE MODEL IS INPUT TO THE GEOCELLULAR MODEL

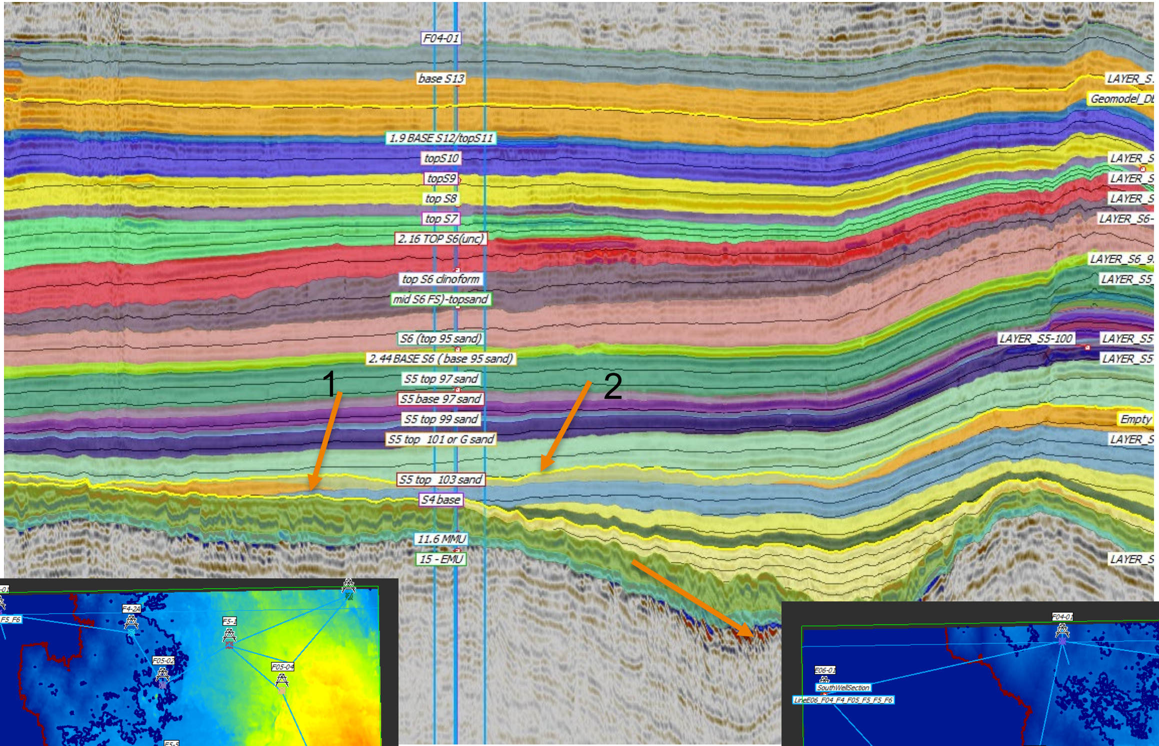


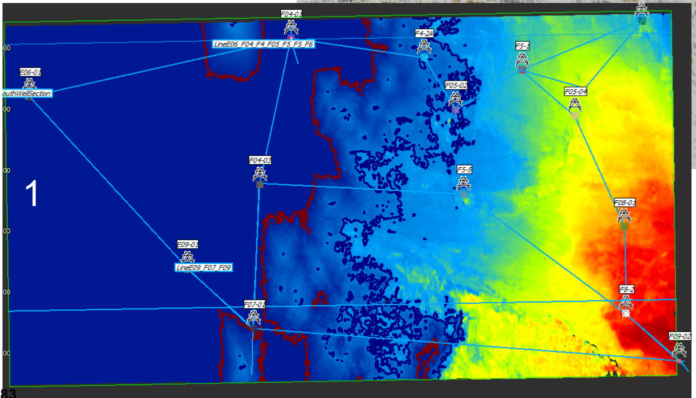


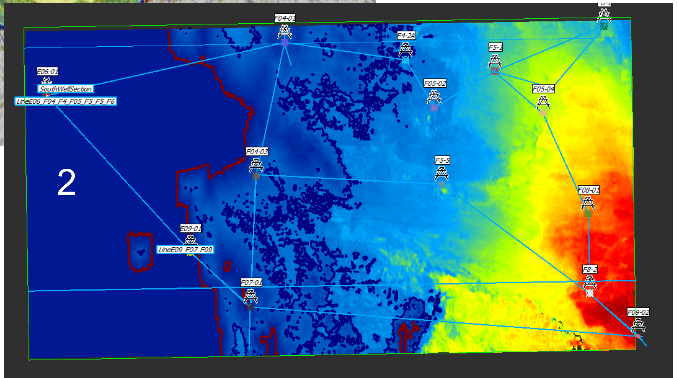


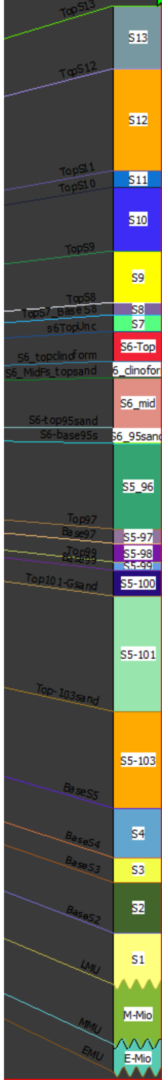
3D VIEW OF THE GEOCELLULAR MODEL

SEQ. MODEL X-SECTION WELL F04-01









PALEOSCAN MODELLING

1. Approach and rationale for the modelling work in Paleoscan

2. **Final results paleoScan modelling : X-sections, Sequence boundary maps, Isochore maps**

SETTINGS FOR FINAL SEQUENCE MODEL

TNO innovation for life

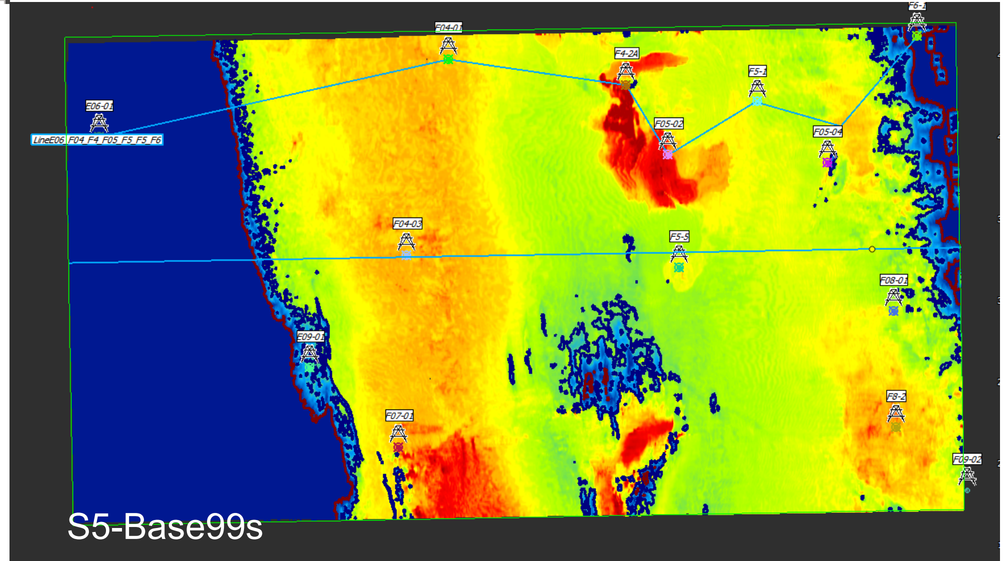
Sub-layering per unit

Name	Litho	Method	Nb layers	Max thickness
S13		Iso Proportional	2	0.0548358 s
S12		Iso Proportional	2	0.0684341 s
S11		Parallel Bottom	4	0.028007 s
S10		Iso Proportional	2	0.0650682 s
S9		Parallel Bottom	4	0.0308257 s
S8		Iso Proportional	3	0.0221985 s
S7		Parallel Bottom	3	0.0396142 s
S6-...		Iso Proportional	2	0.0598218 s
S6_...		Iso Proportional	2	0.0407115 s
S6-...		Iso Proportional	2	0.0586475 s
S6-...		Iso Proportional	1	0.0368696 s
S5-96		Parallel Top	6	0.025345 s
S5-...		Parallel Top	1	0.0664776 s
S5-98		Parallel Top	4	0.0150533 s
S5-...		Parallel Top	1	0.0494444 s
S5-...		Parallel Top	4	0.0193426 s
S5-...		Parallel Top	6	0.0191189 s
S5-...		Parallel Top	8	0.0301308 s
S4		Parallel Top	8	0.0231317 s
S3		Parallel Top	8	0.0257735 s
S2		Parallel Top	6	0.0217312 s
S1		Parallel Top	6	0.0175272 s
U-...		Iso Proportional	1	0.101608 s
M-...		Iso Proportional	1	0.0971855 s

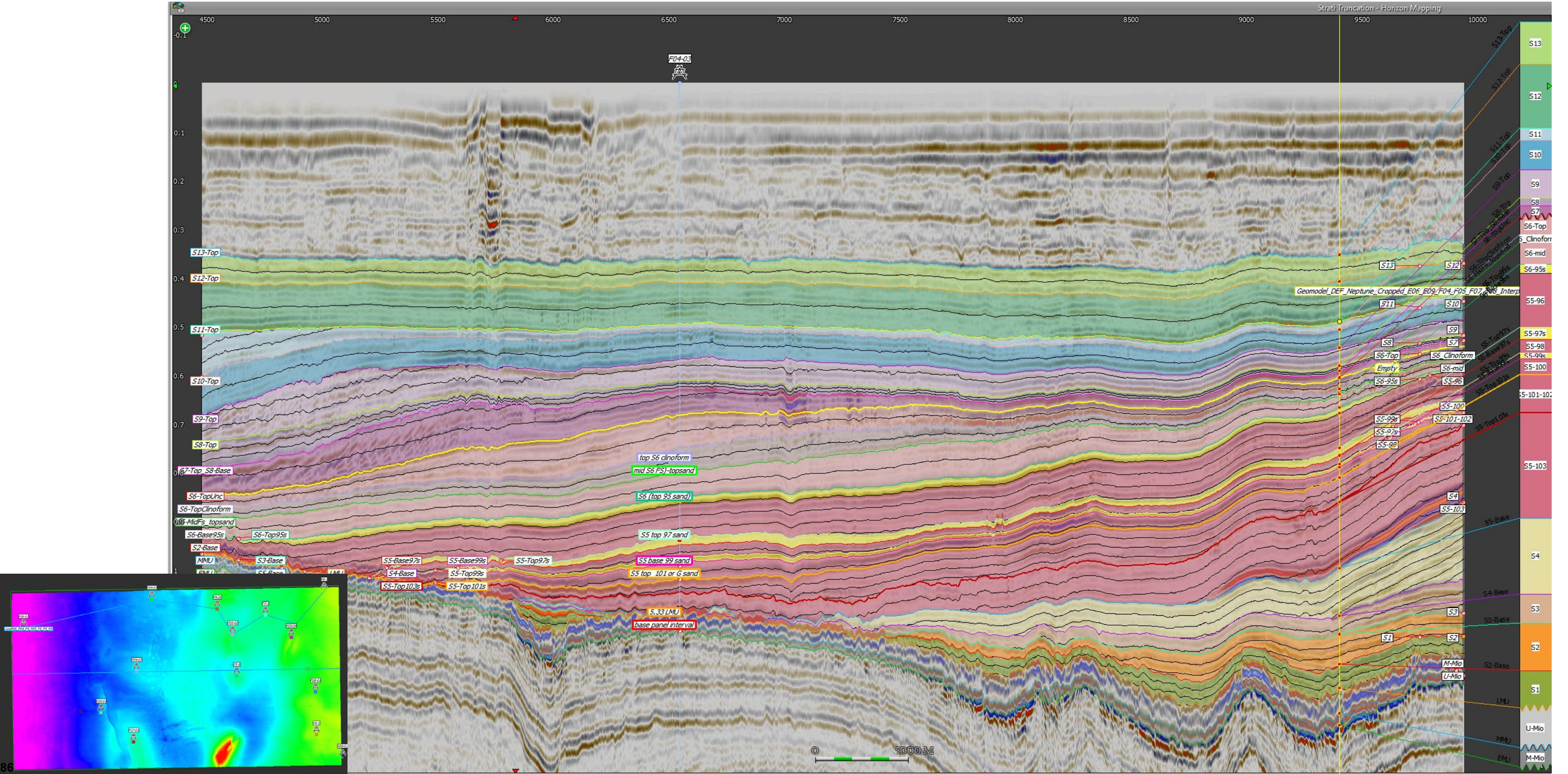
Truncation List

T.	Boundary	Reference	Threshold	Dis.
	S2-Base	LMU	0.02 s	0,4
	S3-Base	LMU	0.035 s	0,5
	S4-Base	LMU	0.036 s	0,5
	S5-Base	LMU	0.046 s	0,7
	S5-Top103s	LMU	0.047 s	0,1
	S5-Top101s	LMU	0.049 s	0,1
	S5-Top99s	LMU	0.051 s	0,2
	S5-Base97s	LMU	0.057 s	0,1
	S5-Top97s	LMU	0.058 s	0,2
	S5-Base99s	S5-Top99s	0.0055 s	1

- Left: Sub-layering and truncation settings set for the final sequence model in the strati-viewer.
- Below: Example of truncated horizon. Red line indicates the truncation line

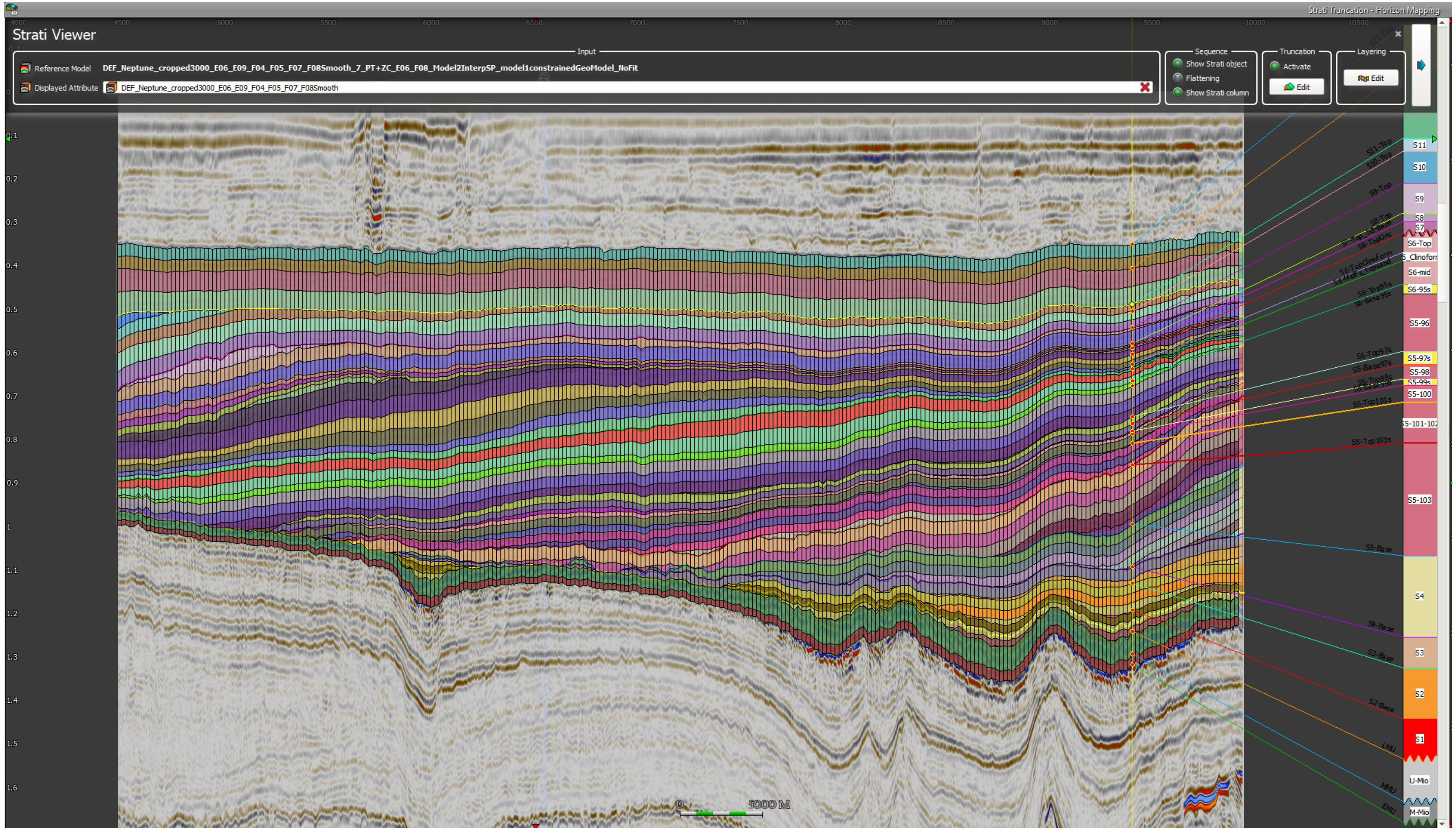


FINAL SEQUENCE MODEL

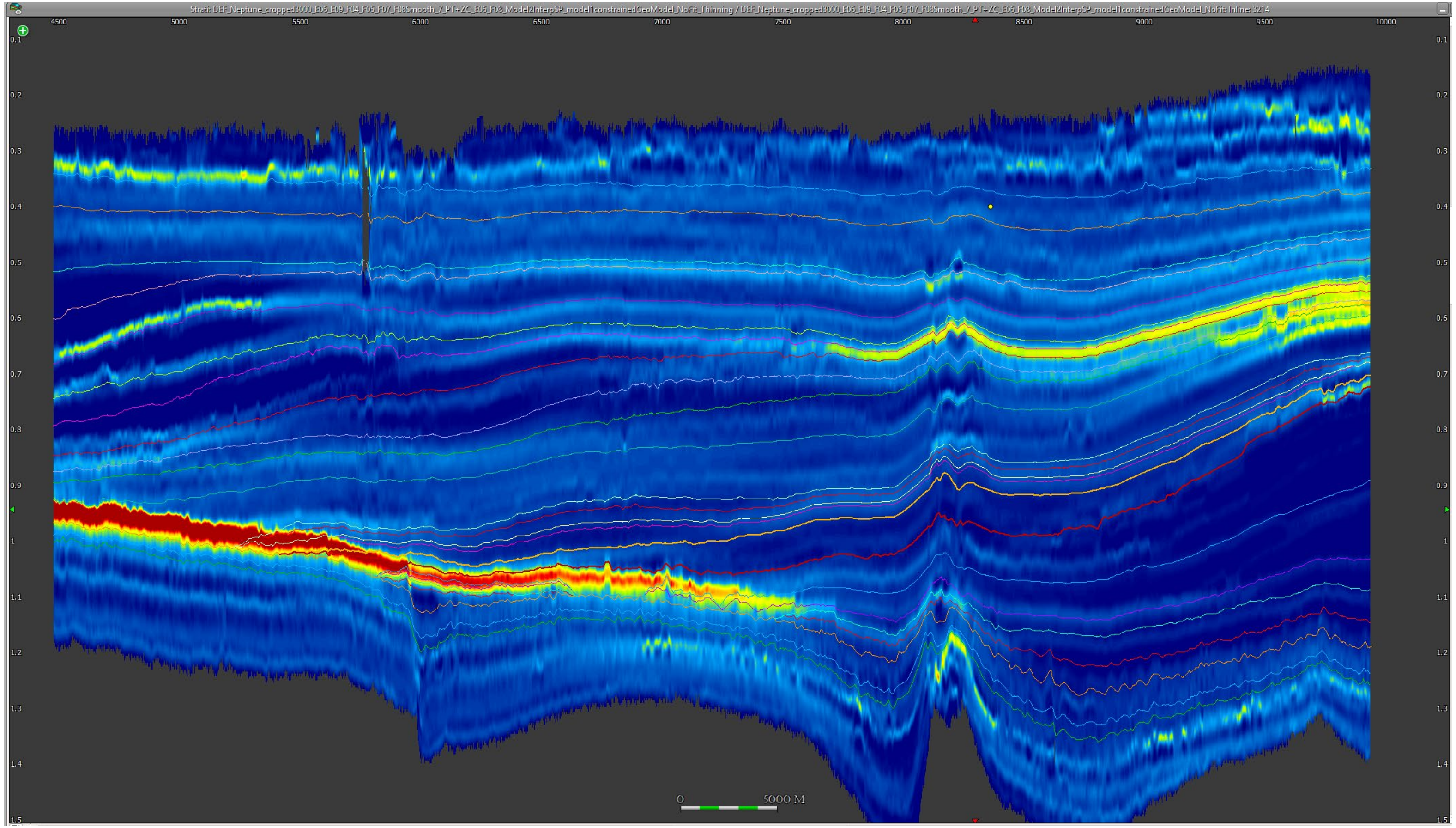


FINAL GEOCELLULAR MODEL

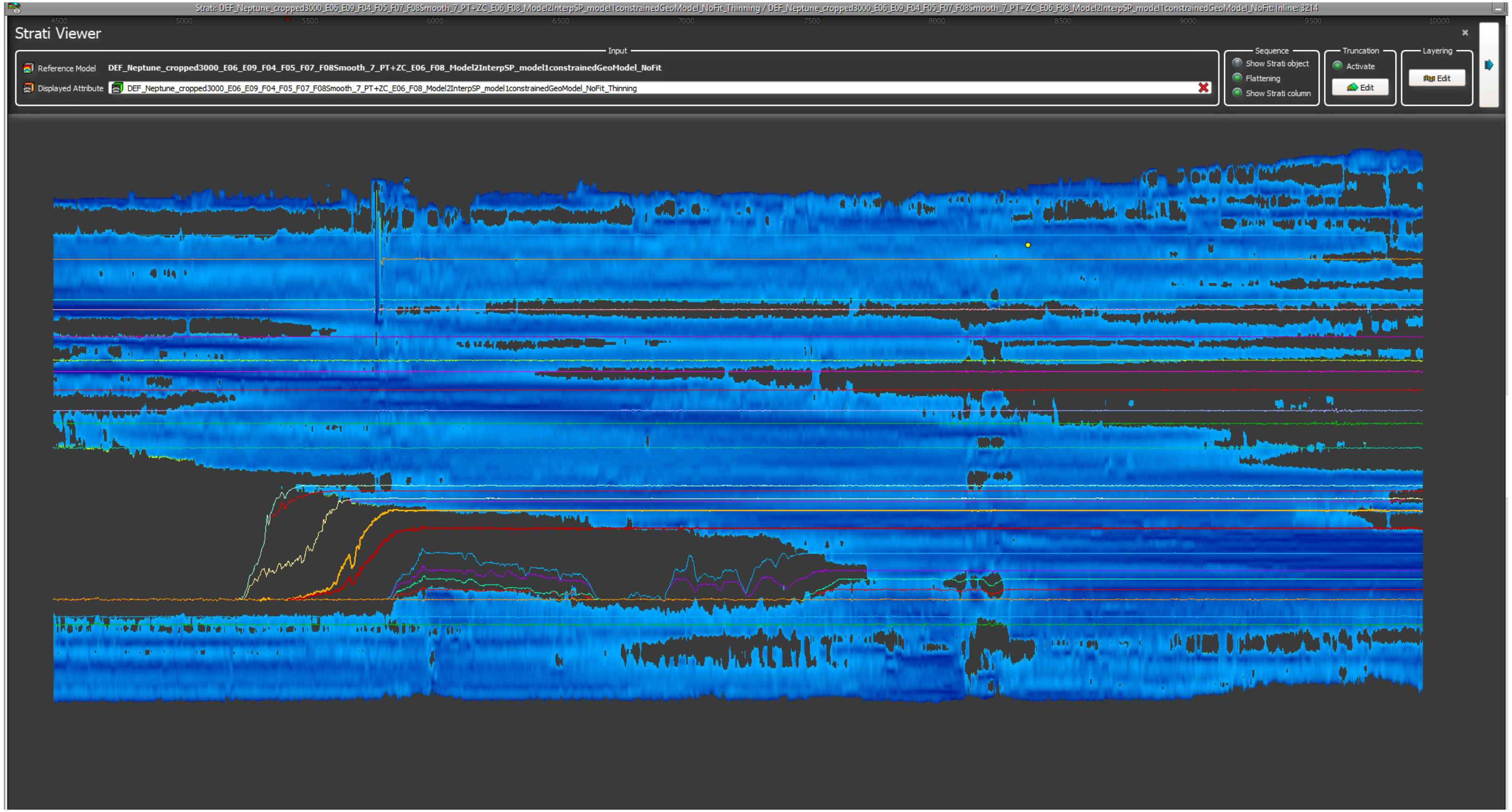
TNO innovation for life



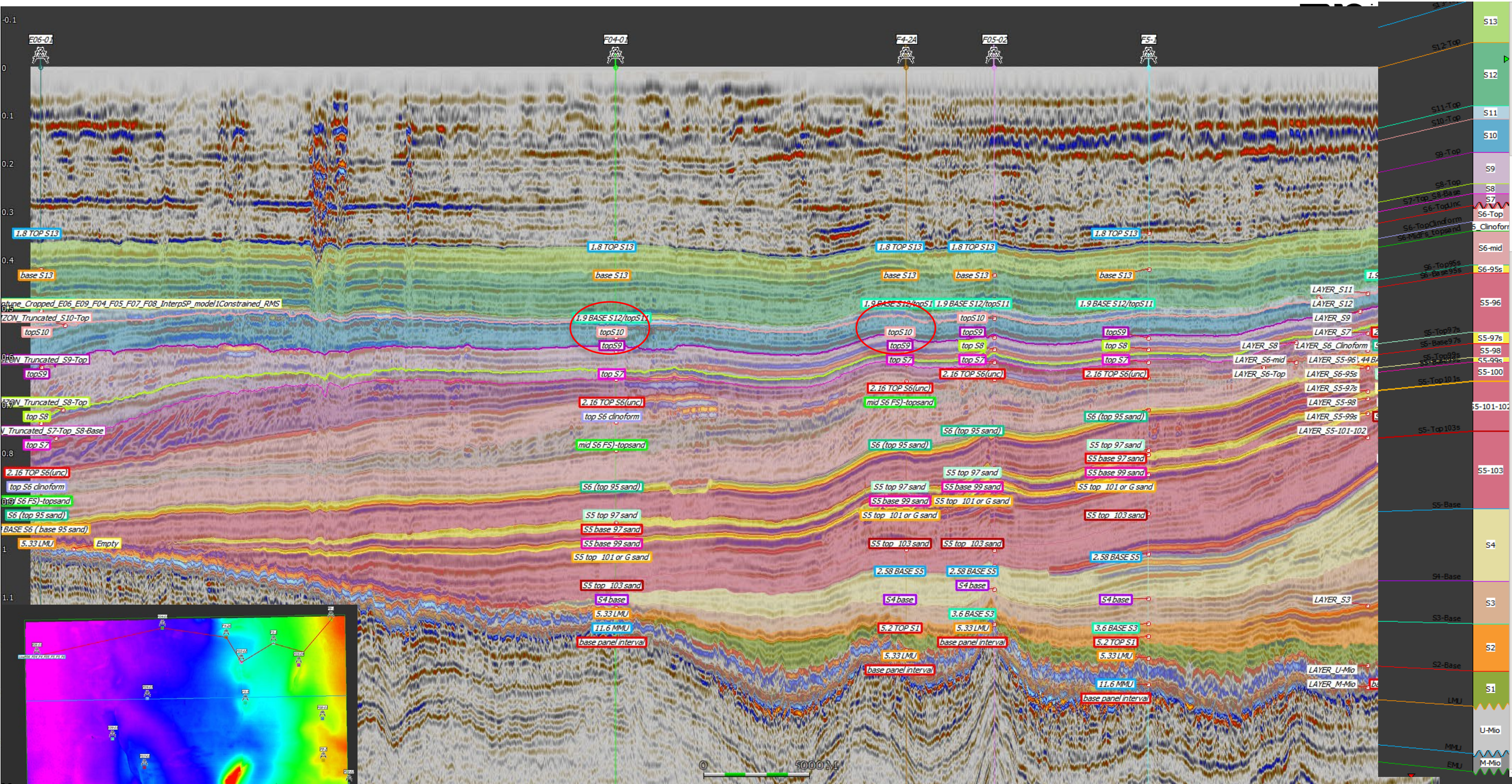
STRATI-VIEWER – THINNING ATTRIBUTE



STRATI-VIEWER – THINNING ATTRIBUTE & FLATTENING

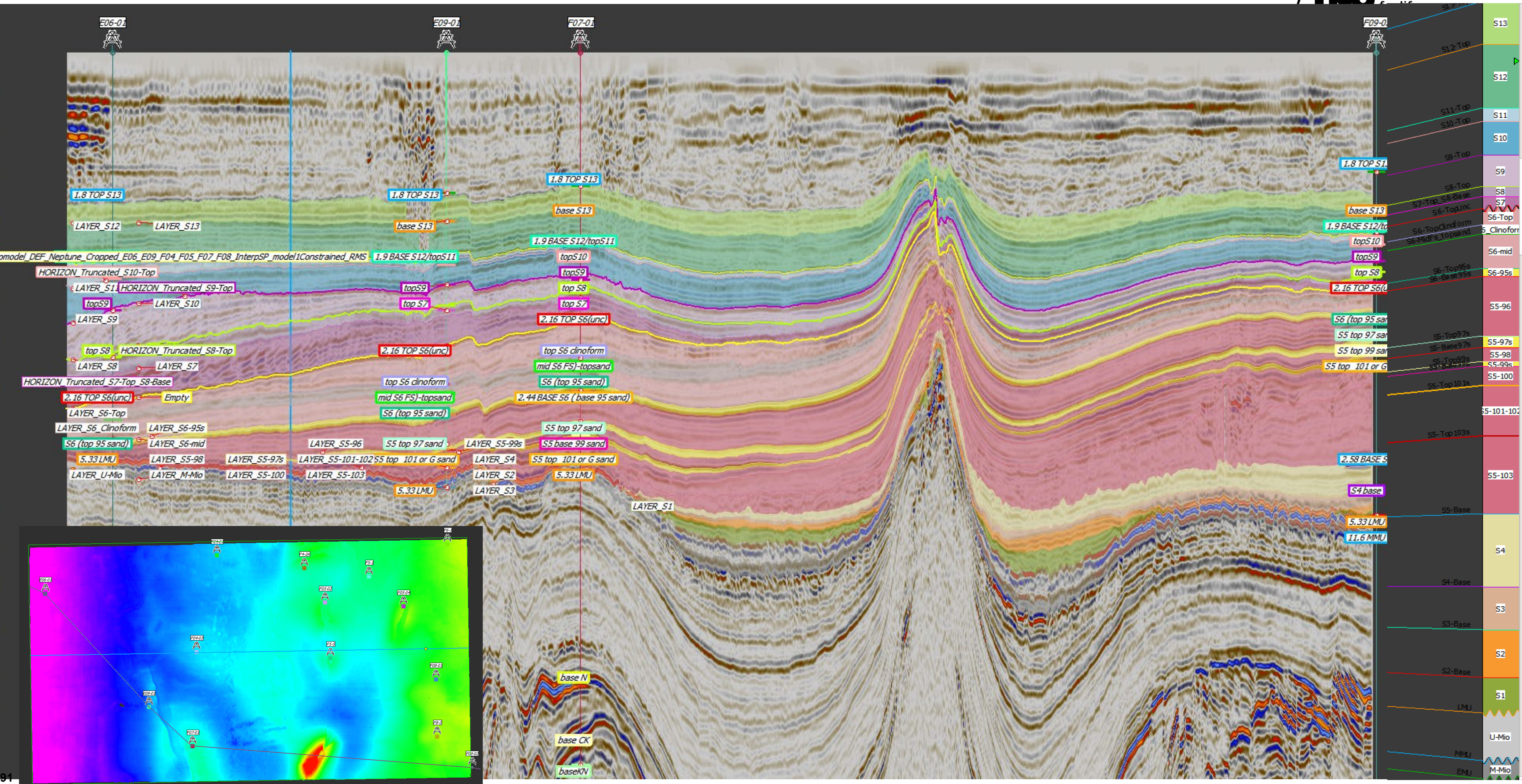


SEQ. MODEL X-SECTION WELLS E06-01, F04-01, F4-2A, F05-02, F5-1, F6-1

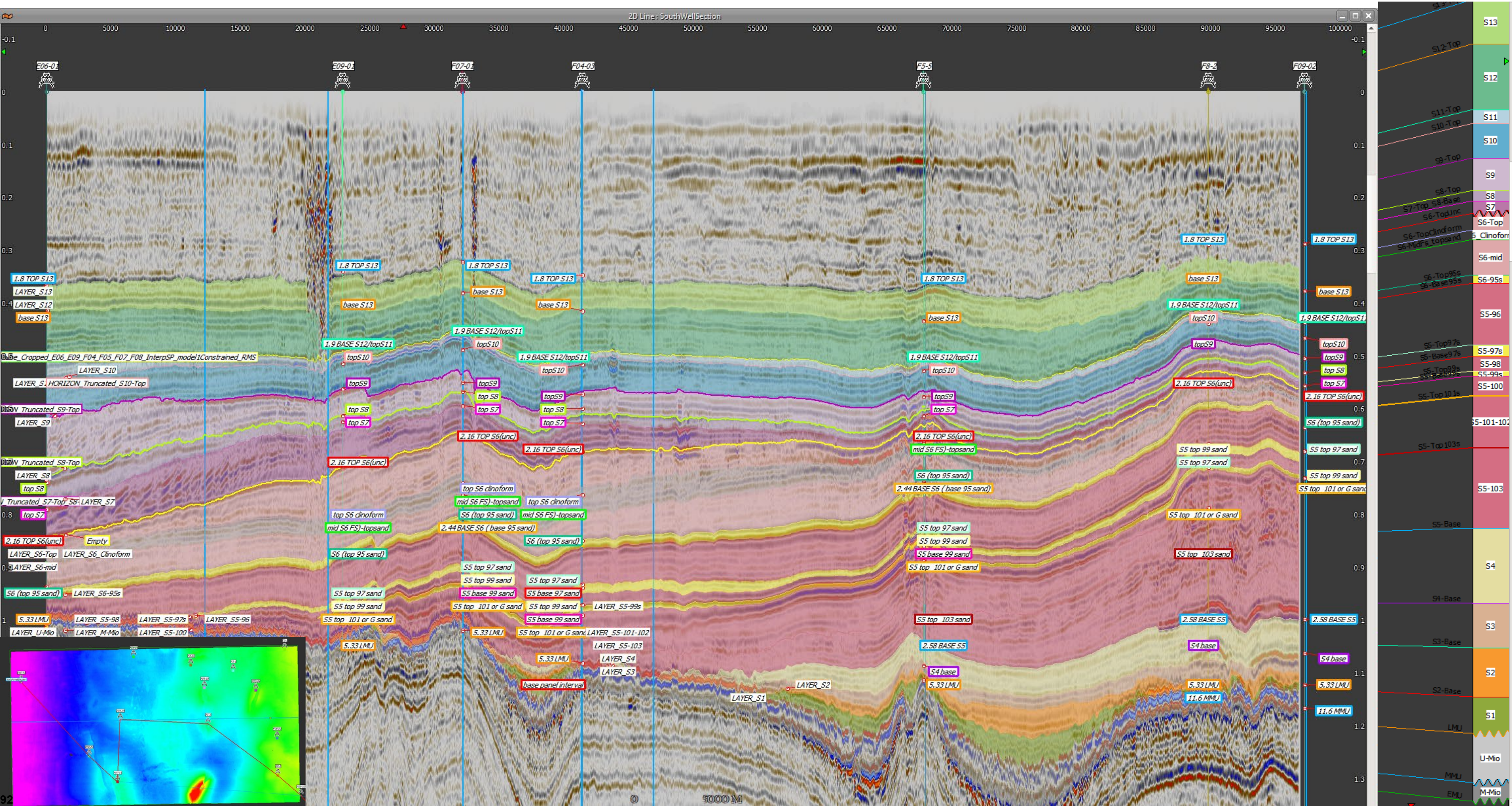


90

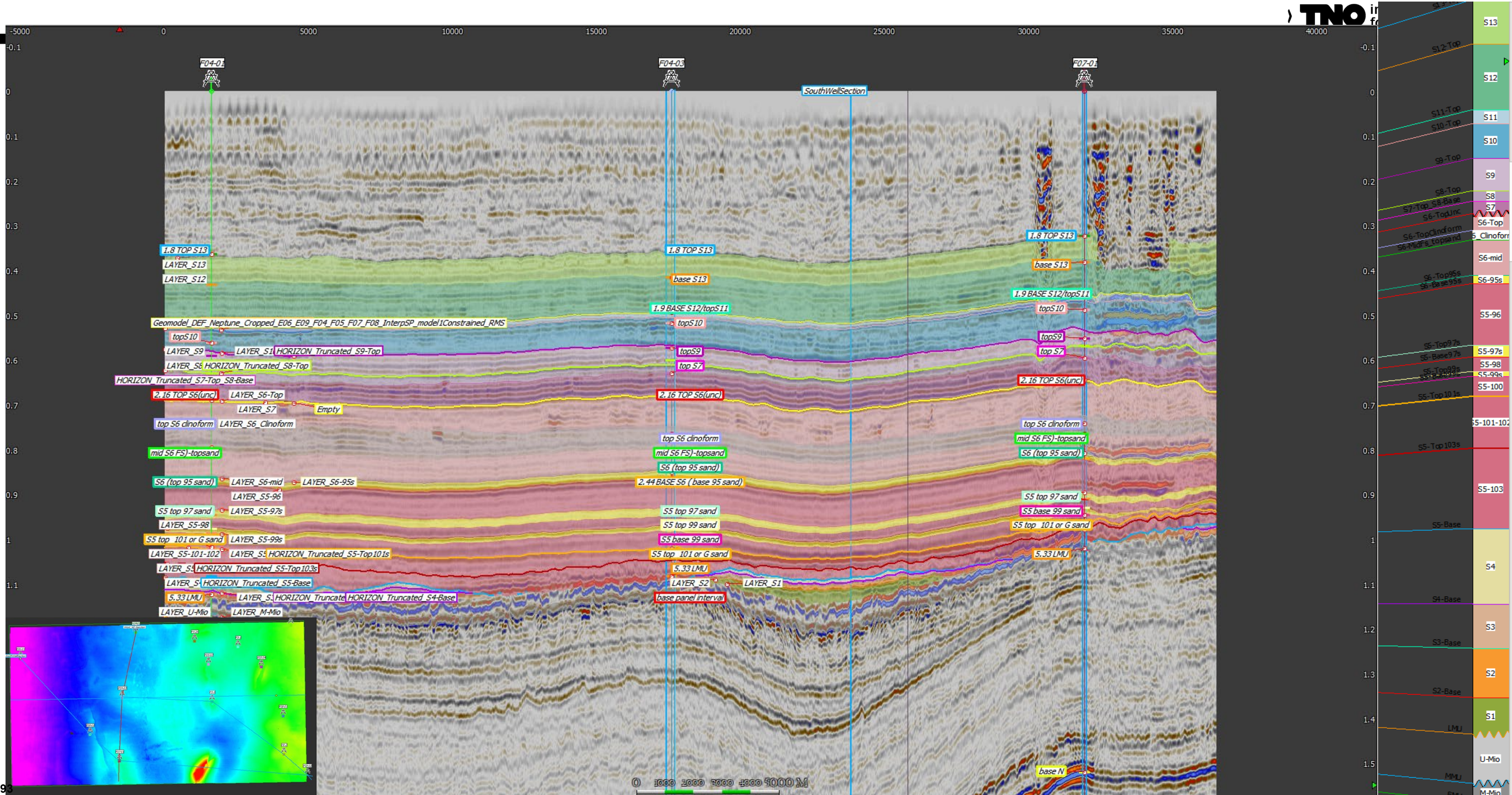
SEQ. MODEL X-SECTION WELLS E06-01, E09-01, F07-01, F09-02



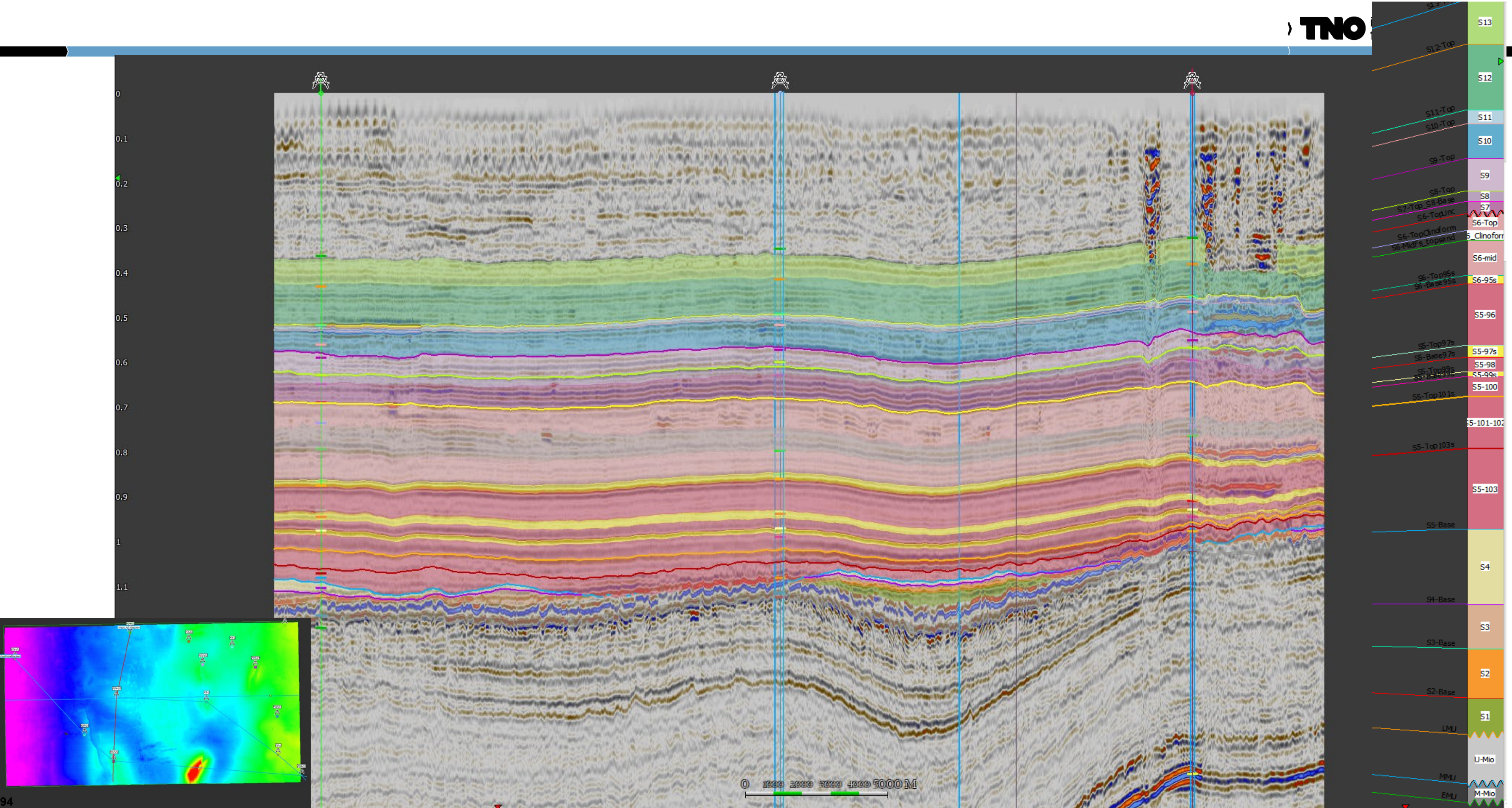
SEQ. MODEL X-SECTION WELLS E06-01, E09-01, F07-01, F04-03, F5-5, F8-2, F09-02



SEQ. MODEL NS-X-SECTION WELLS F04-01, F04-03, F07-01



SEQ. MODEL NS-X-SECTION WELLS F04-01, F04-03, F07-01



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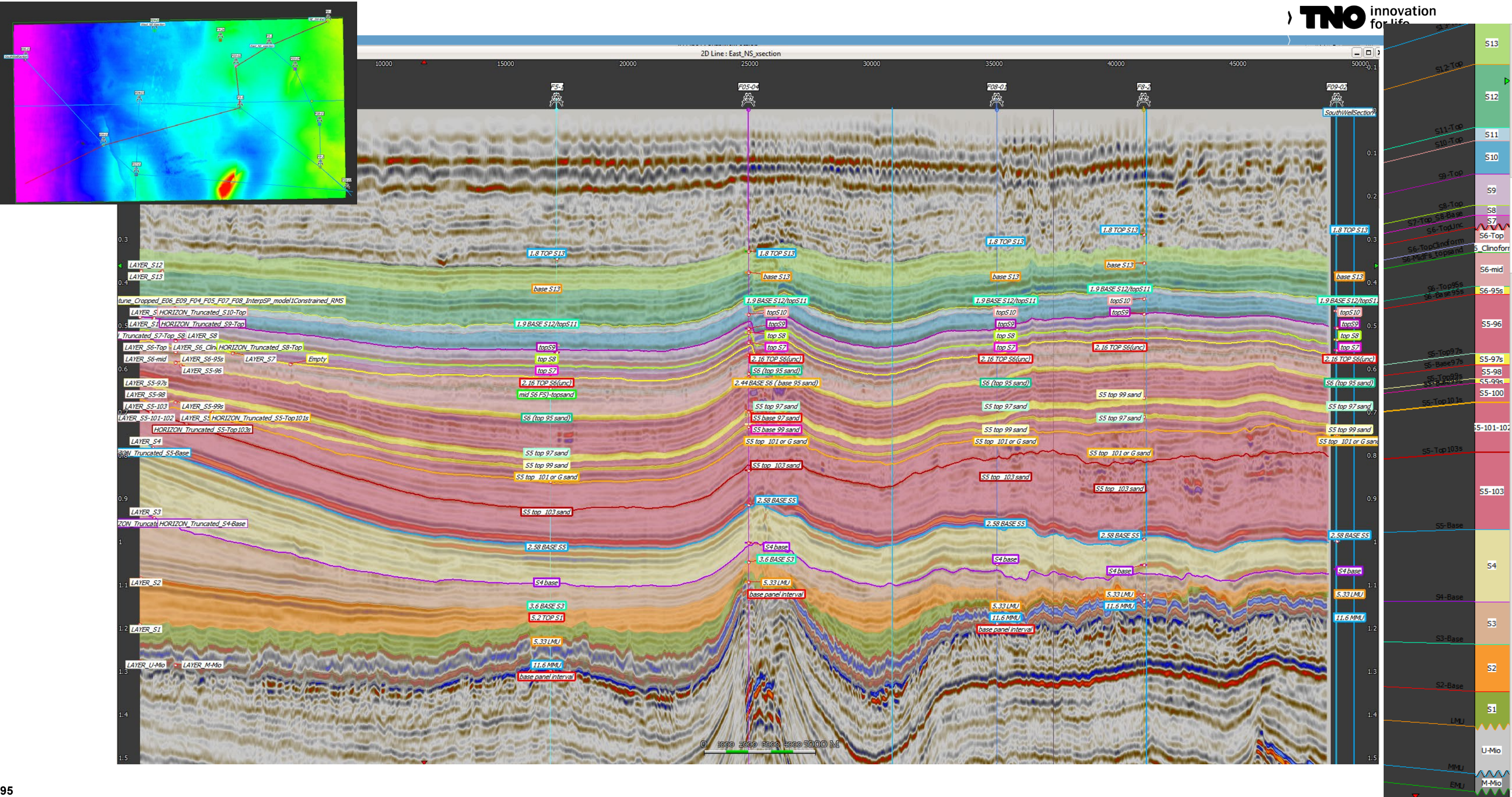
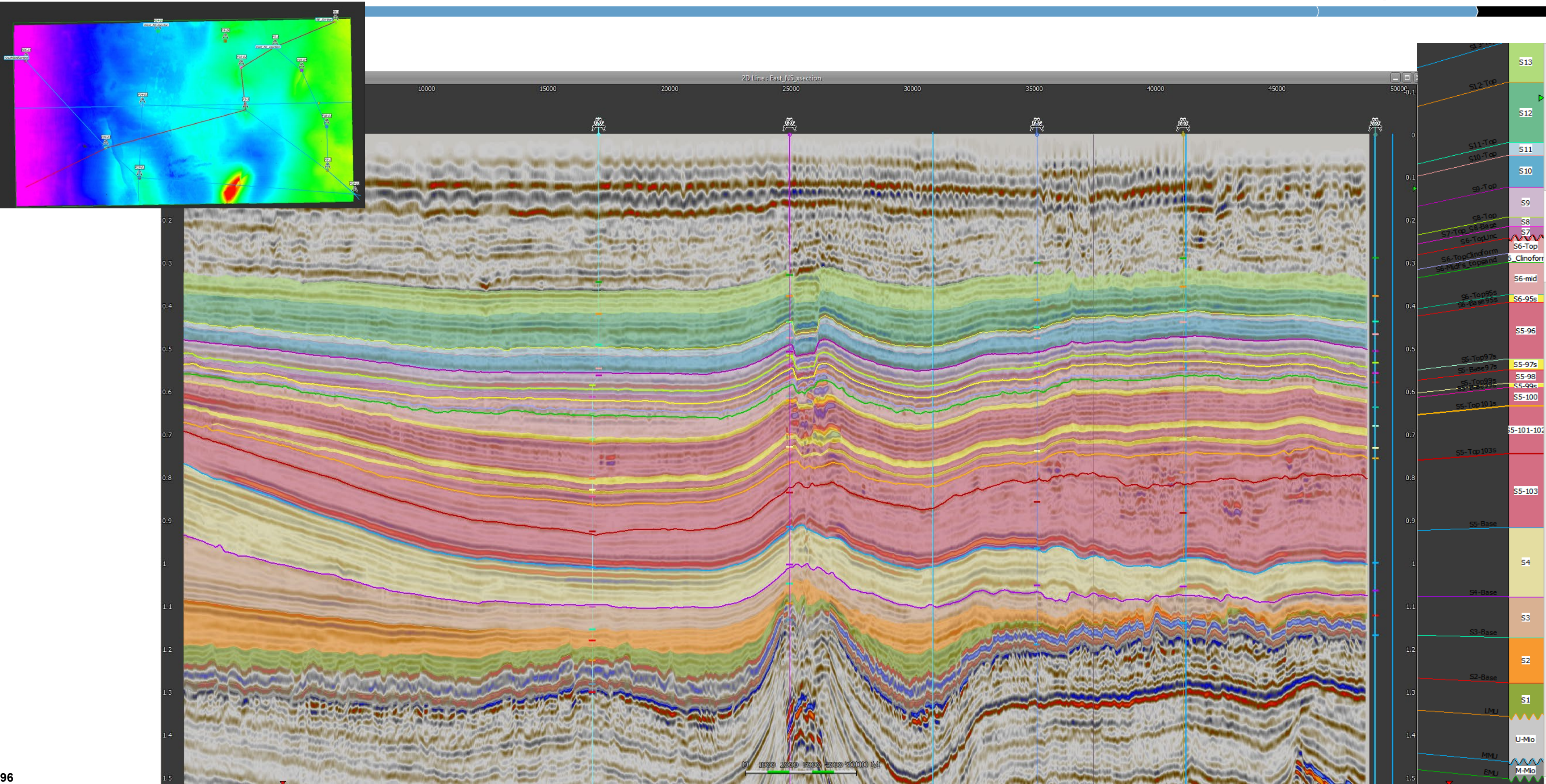
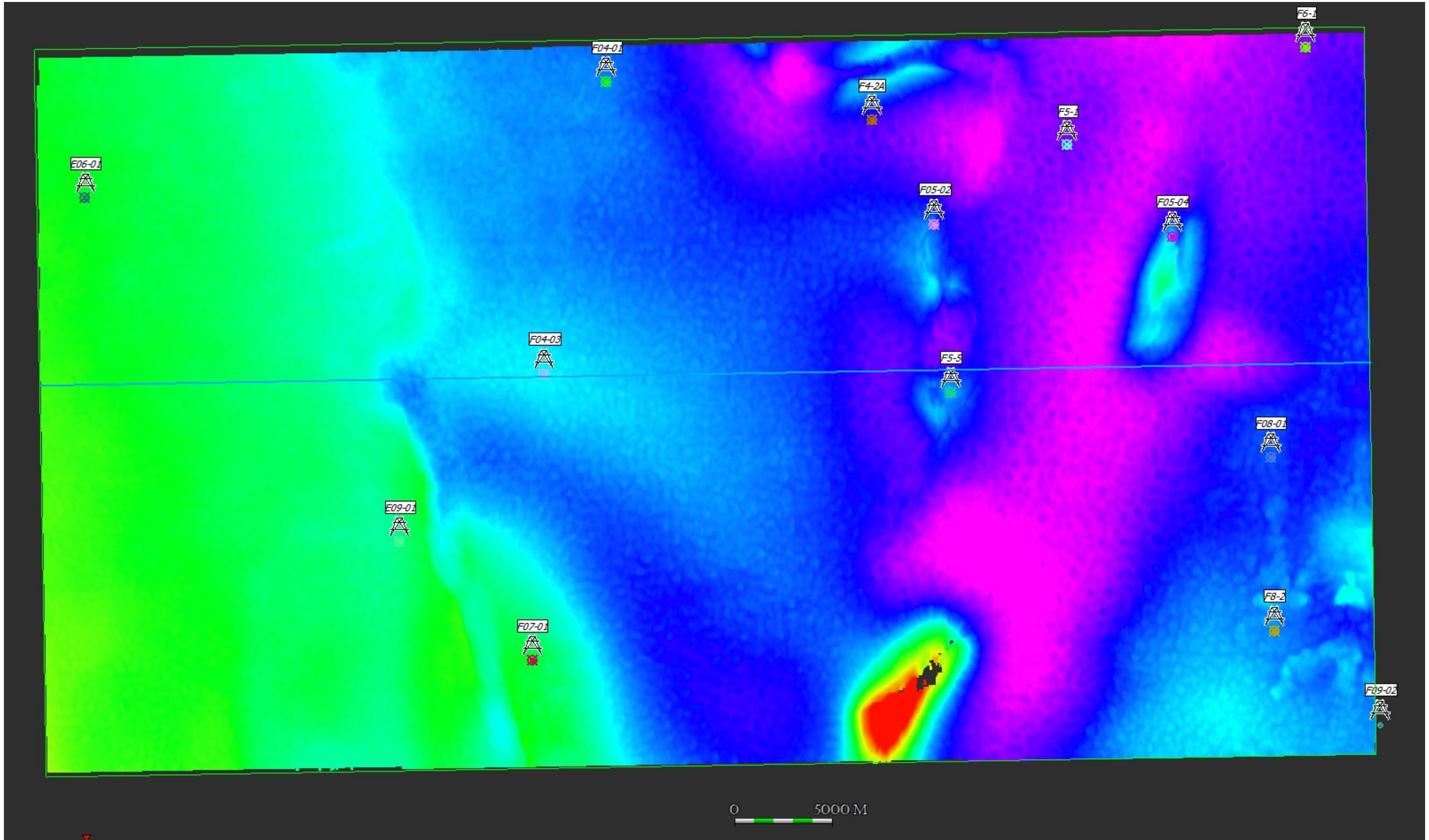


SEQ. MODEL NS-X-SECTION WELLS F5-1, F05-04, F08-01, F8-2, F09-02

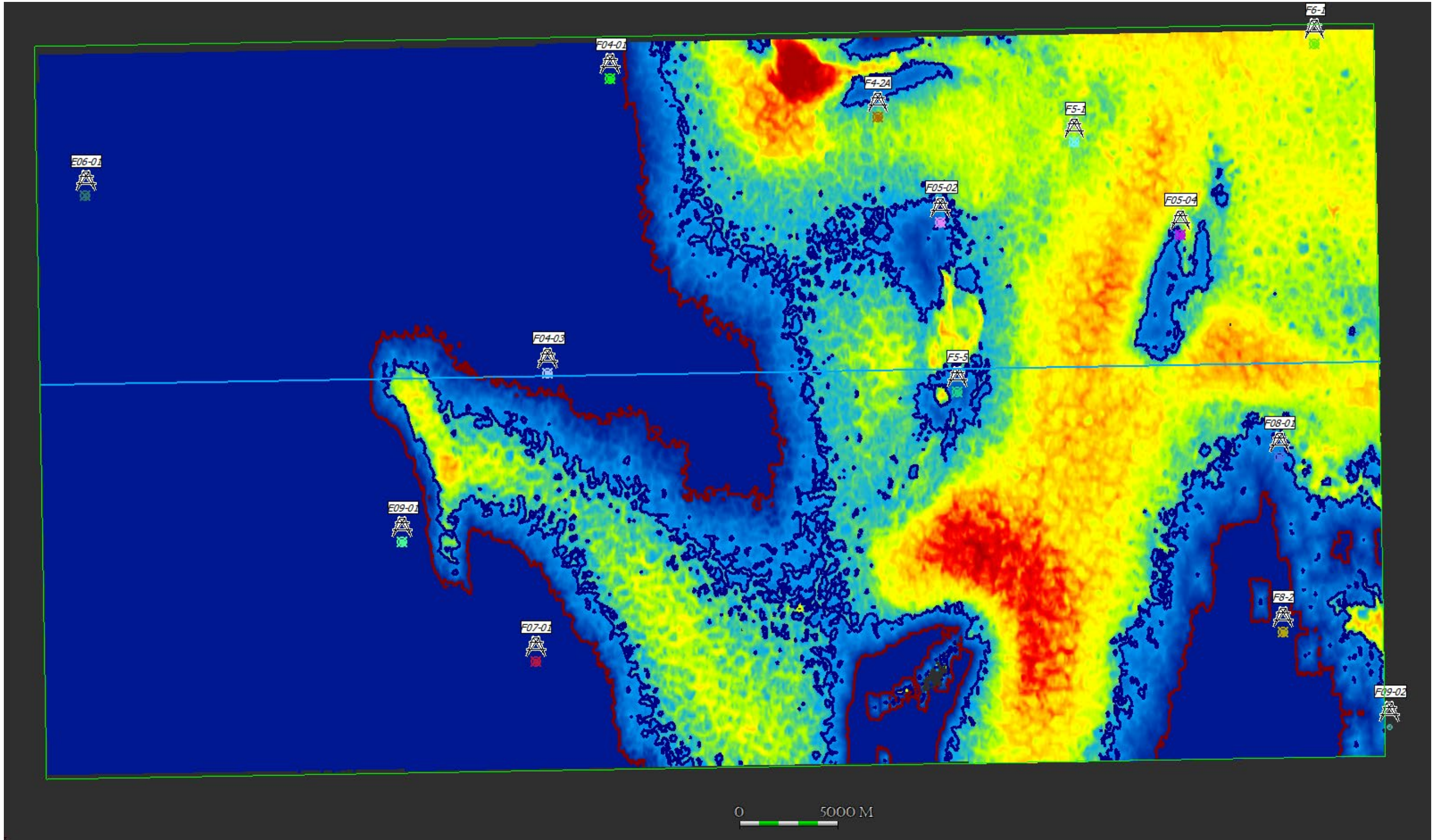


SEQ. MODEL TRUNCATED: HORIZON LMU_BASE-S1

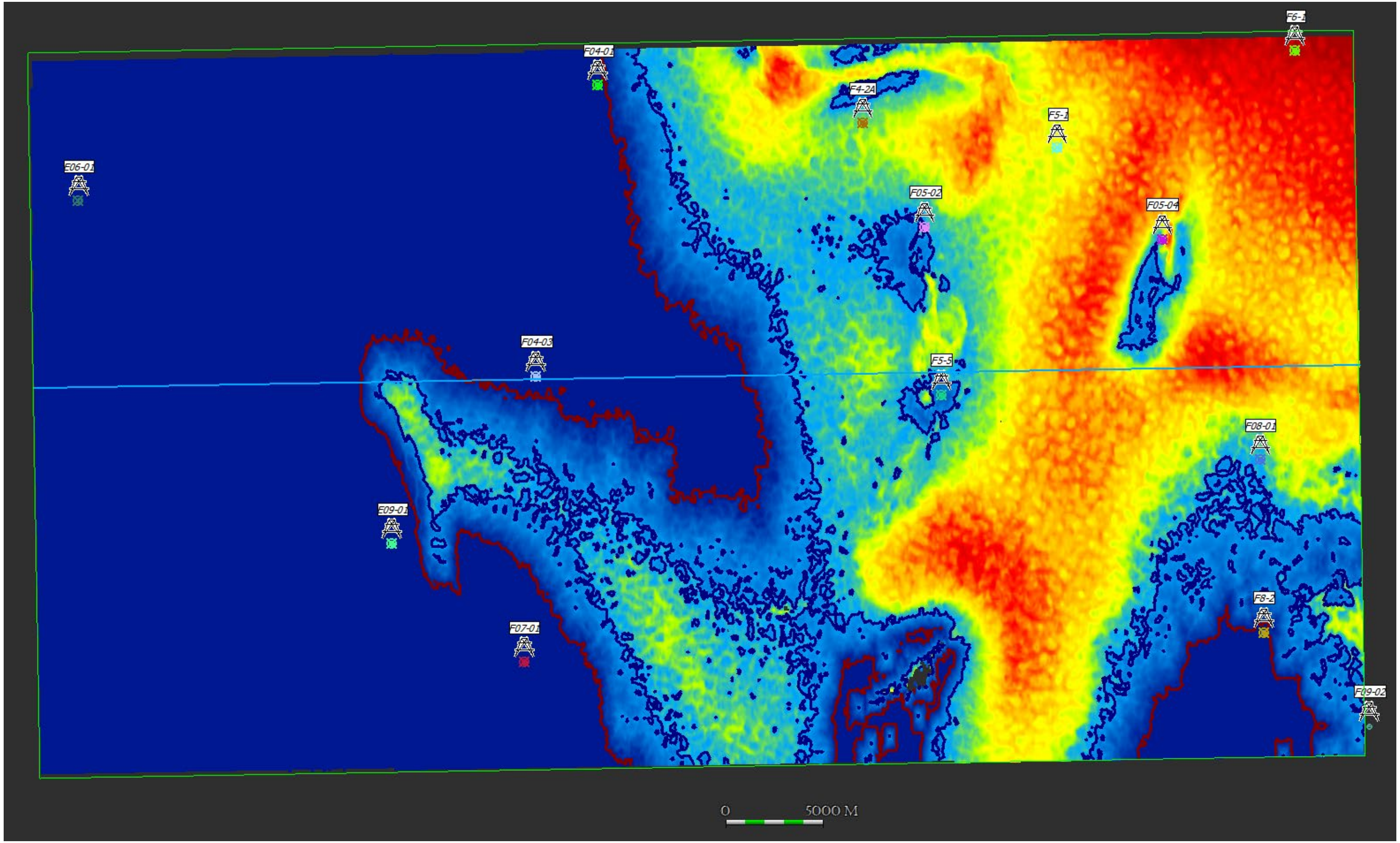


SEQ. MODEL TRUNCATED: HORIZON BASE S2

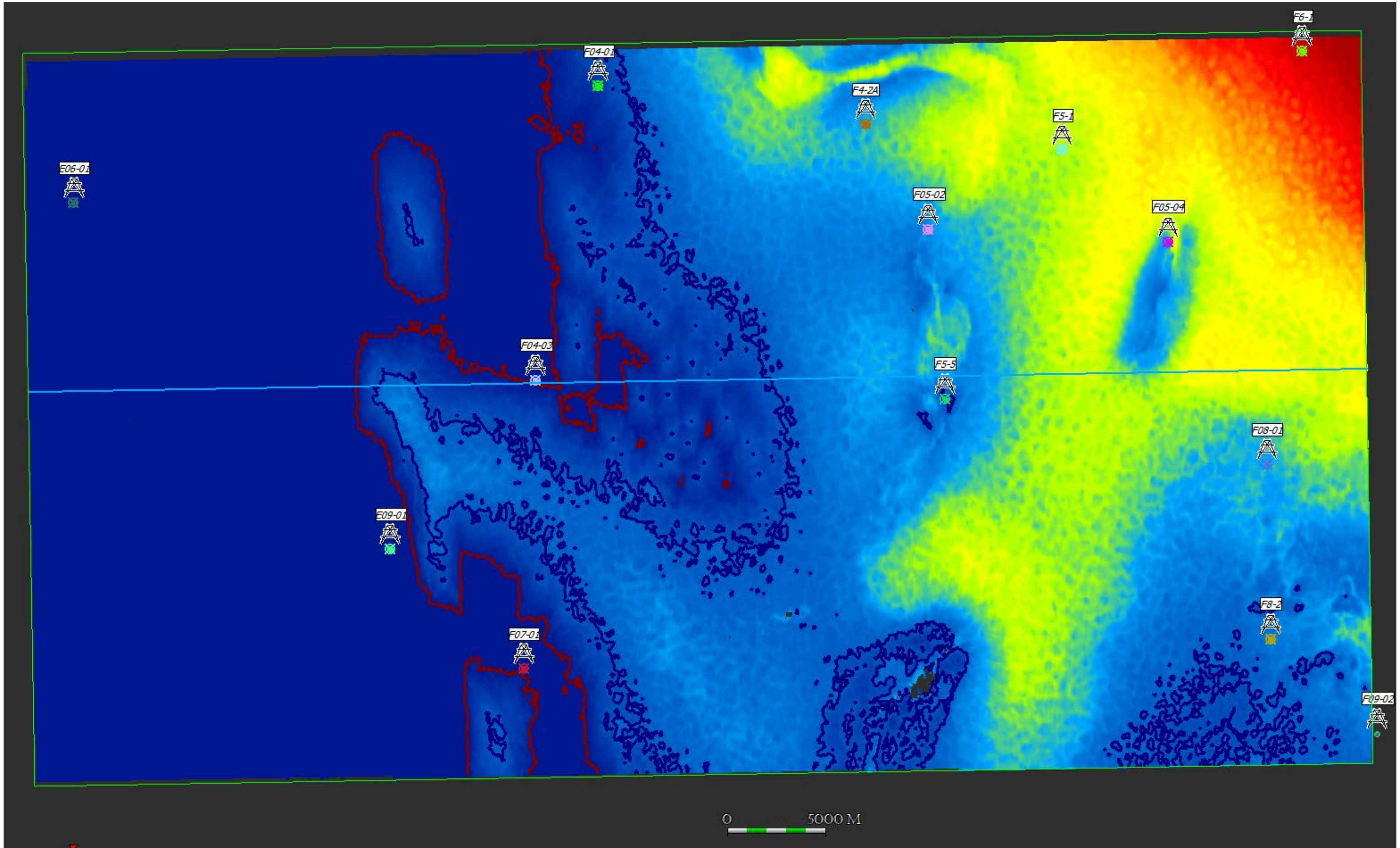
TNO innovation for life



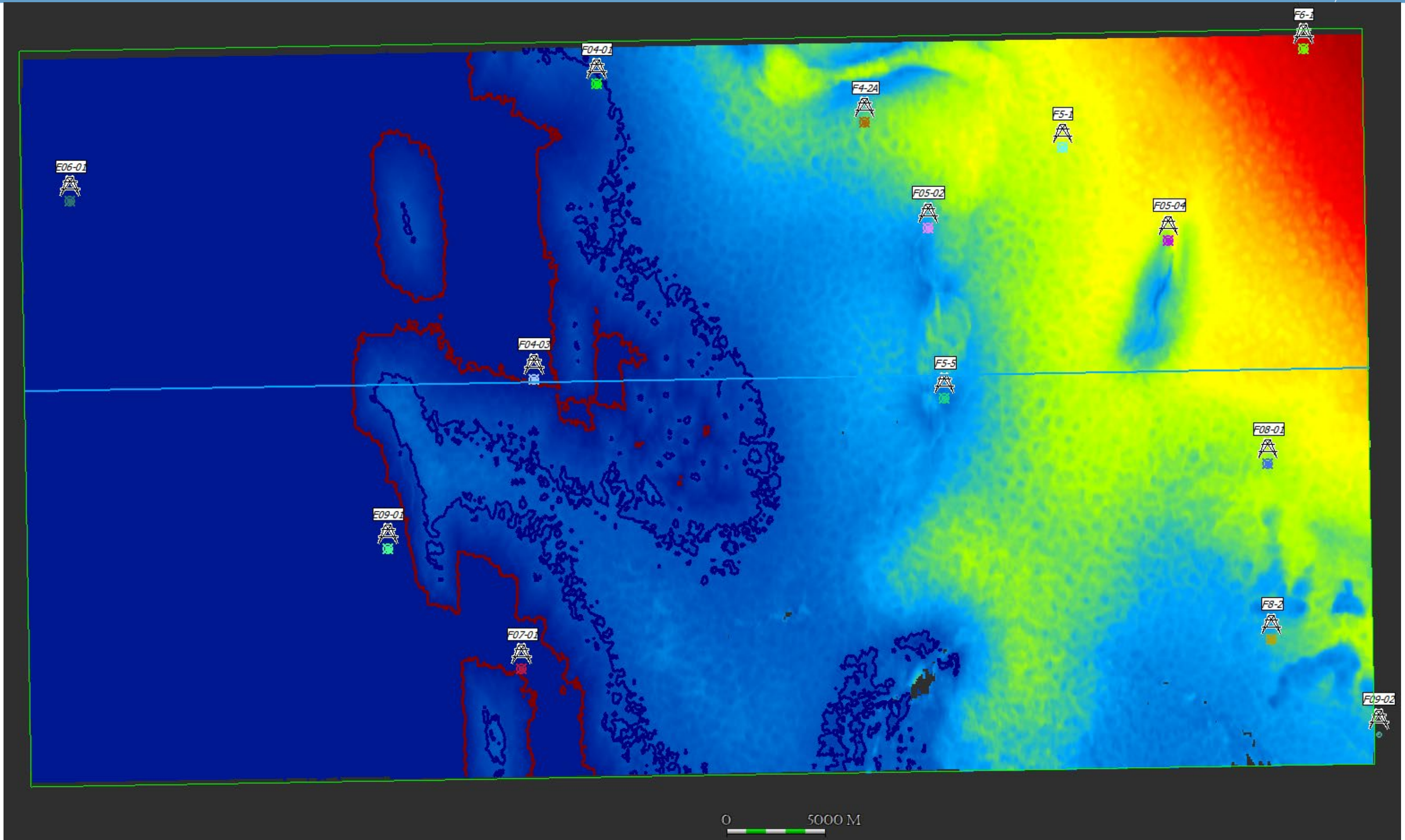
SEQ. MODEL TRUNCATED: HORIZON BASE S3



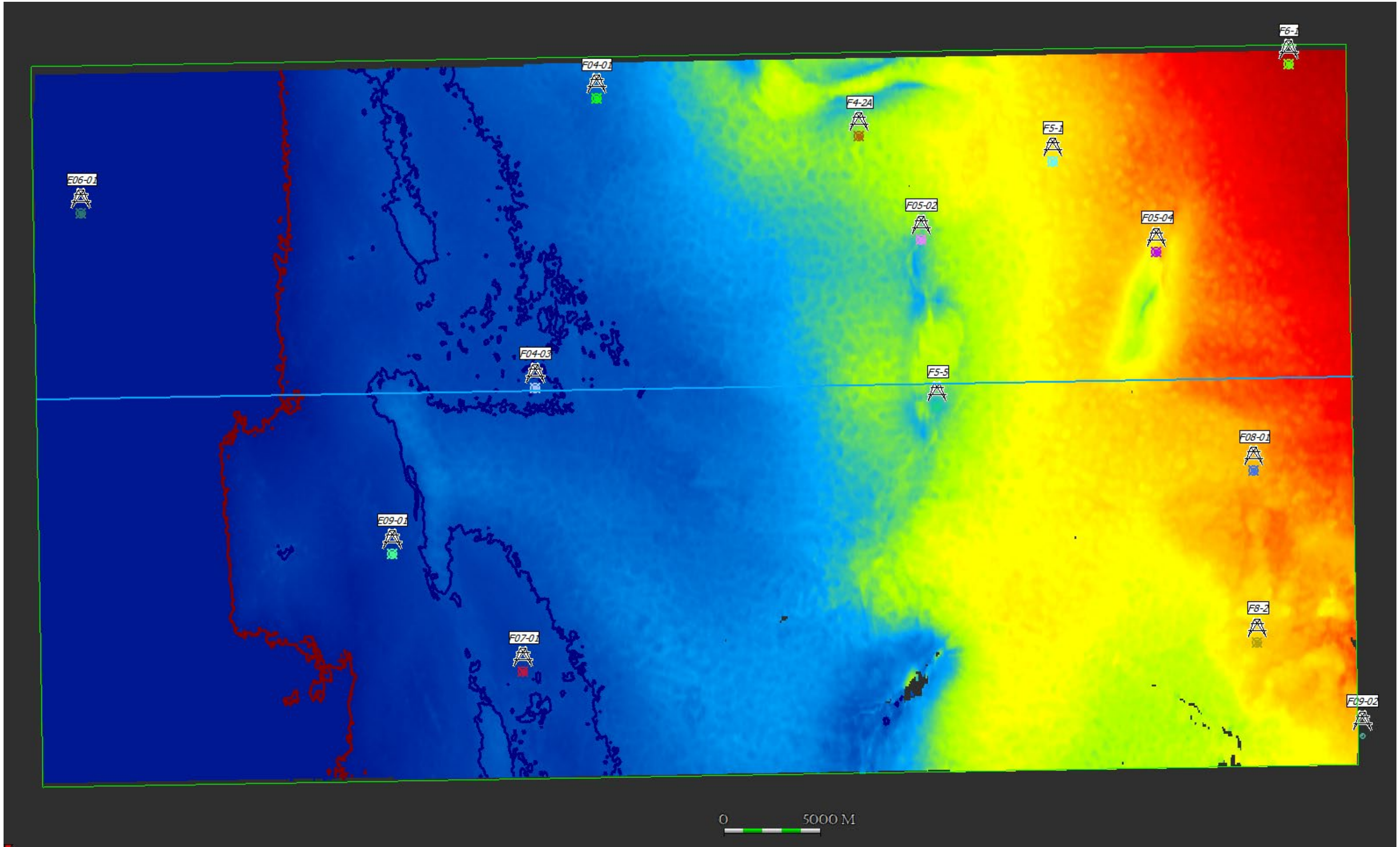
SEQ. MODEL TRUNCATED: HORIZON BASE S4



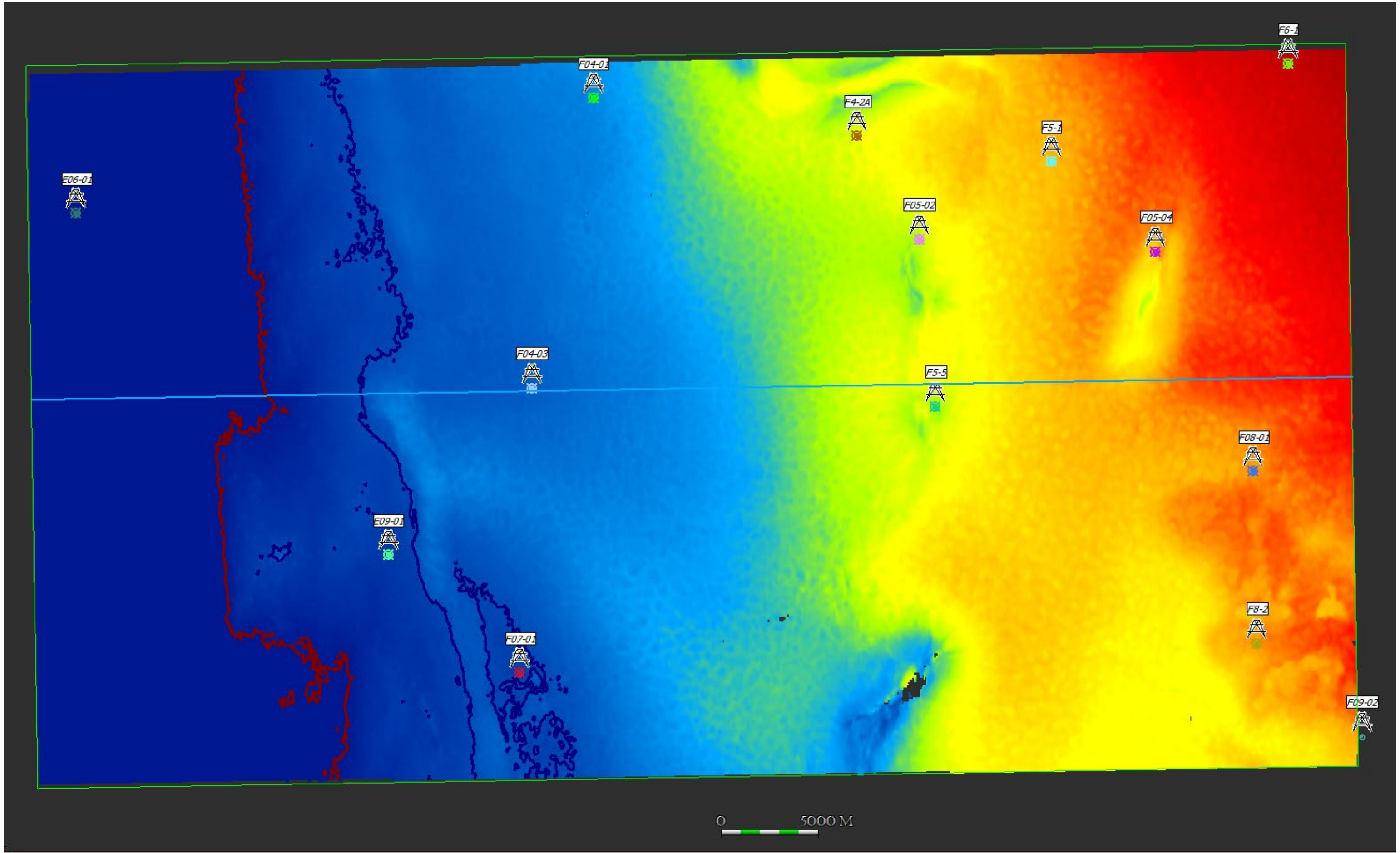
SEQ. MODEL TRUNCATED: HORIZON BASE S5



SEQ. MODEL TRUNCATED: HORIZON S5 TOP103-SAND

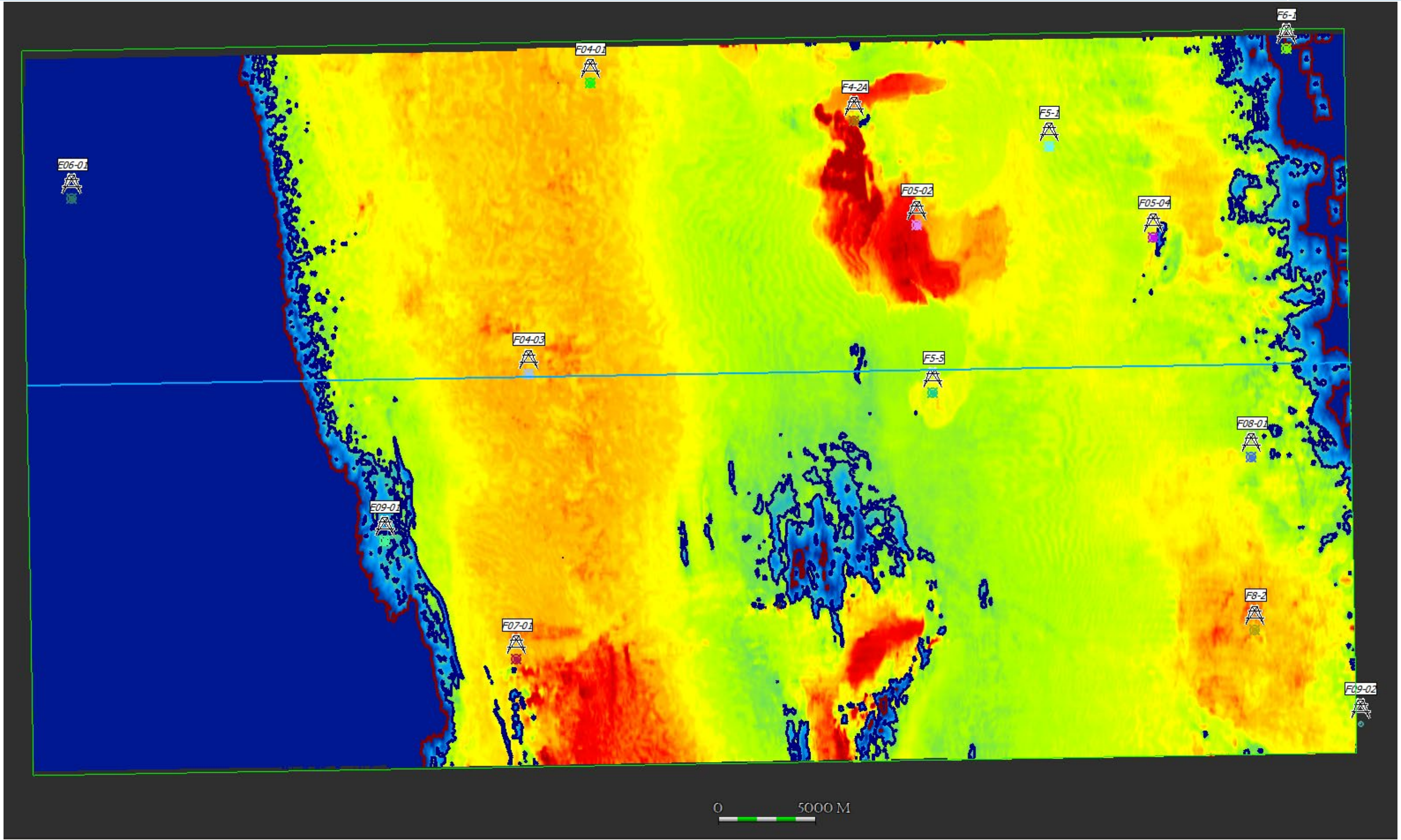


SEQ. MODEL TRUNCATED: HORIZON S5 TOP101

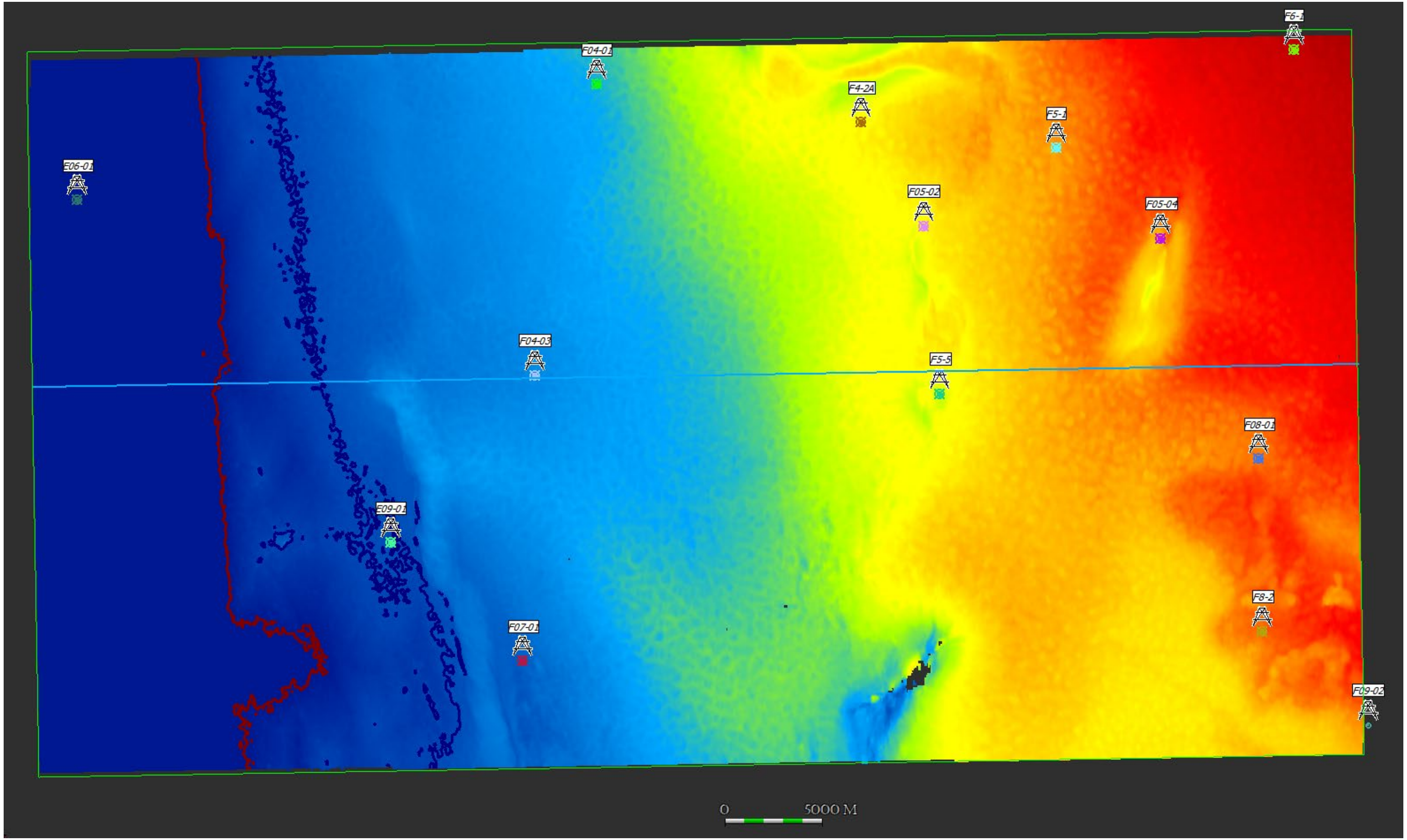


SEQ. MODEL TRUNCATED: HORIZON S5-BASE99-S

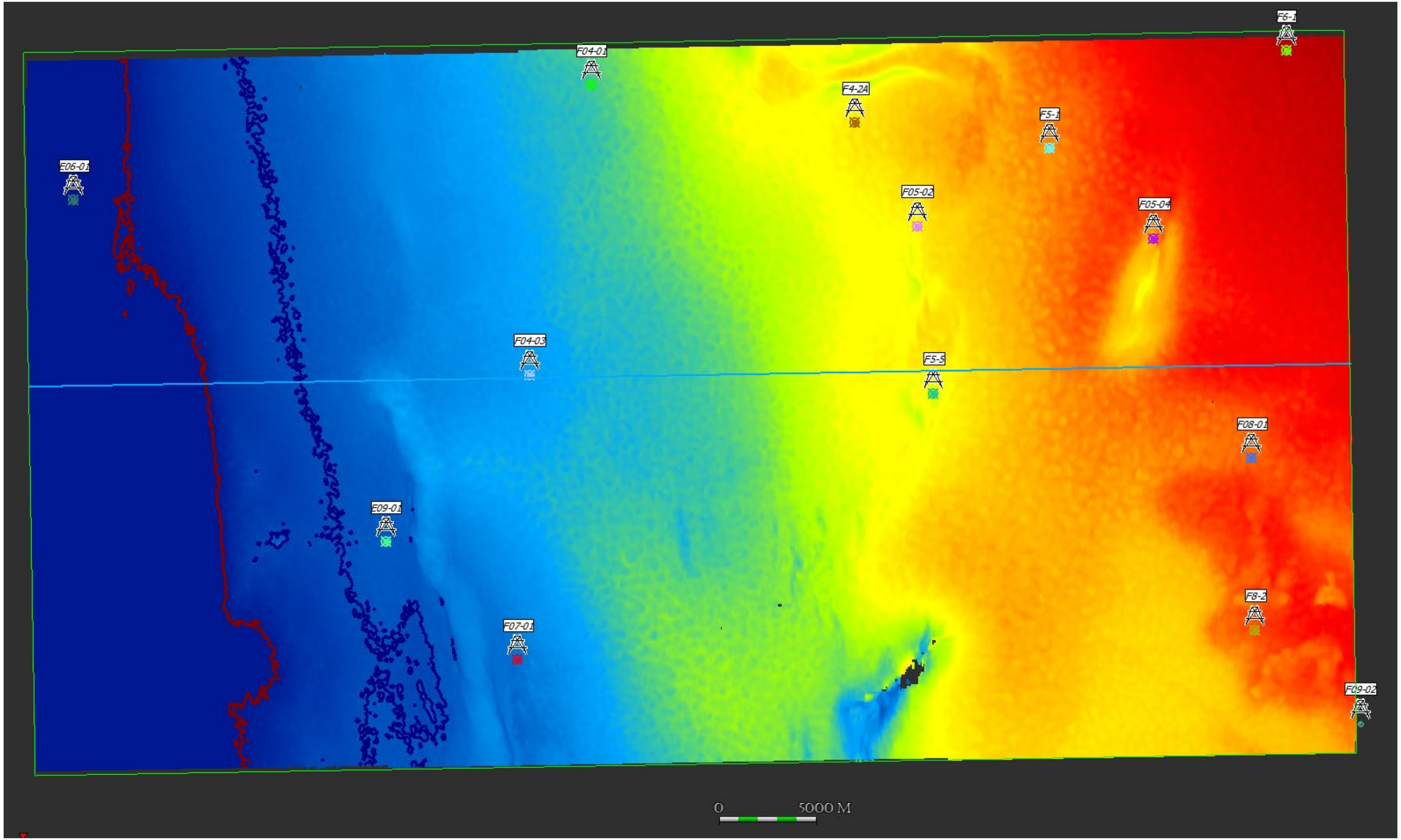
innovation for life



SEQ. MODEL TRUNCATED: HORIZON S5-TOP99-S



SEQ. MODEL TRUNCATED: HORIZON S5-BASE97-S



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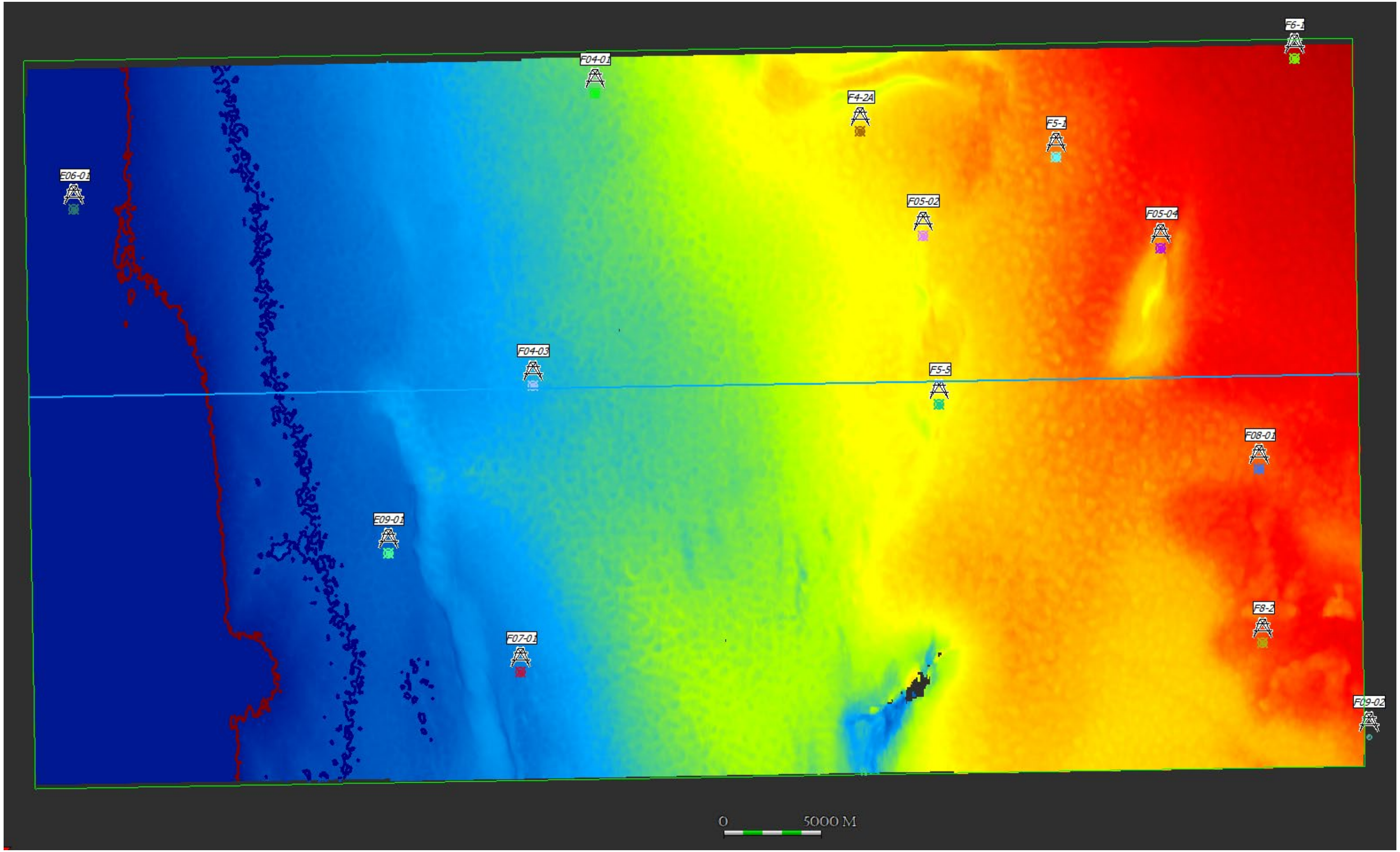
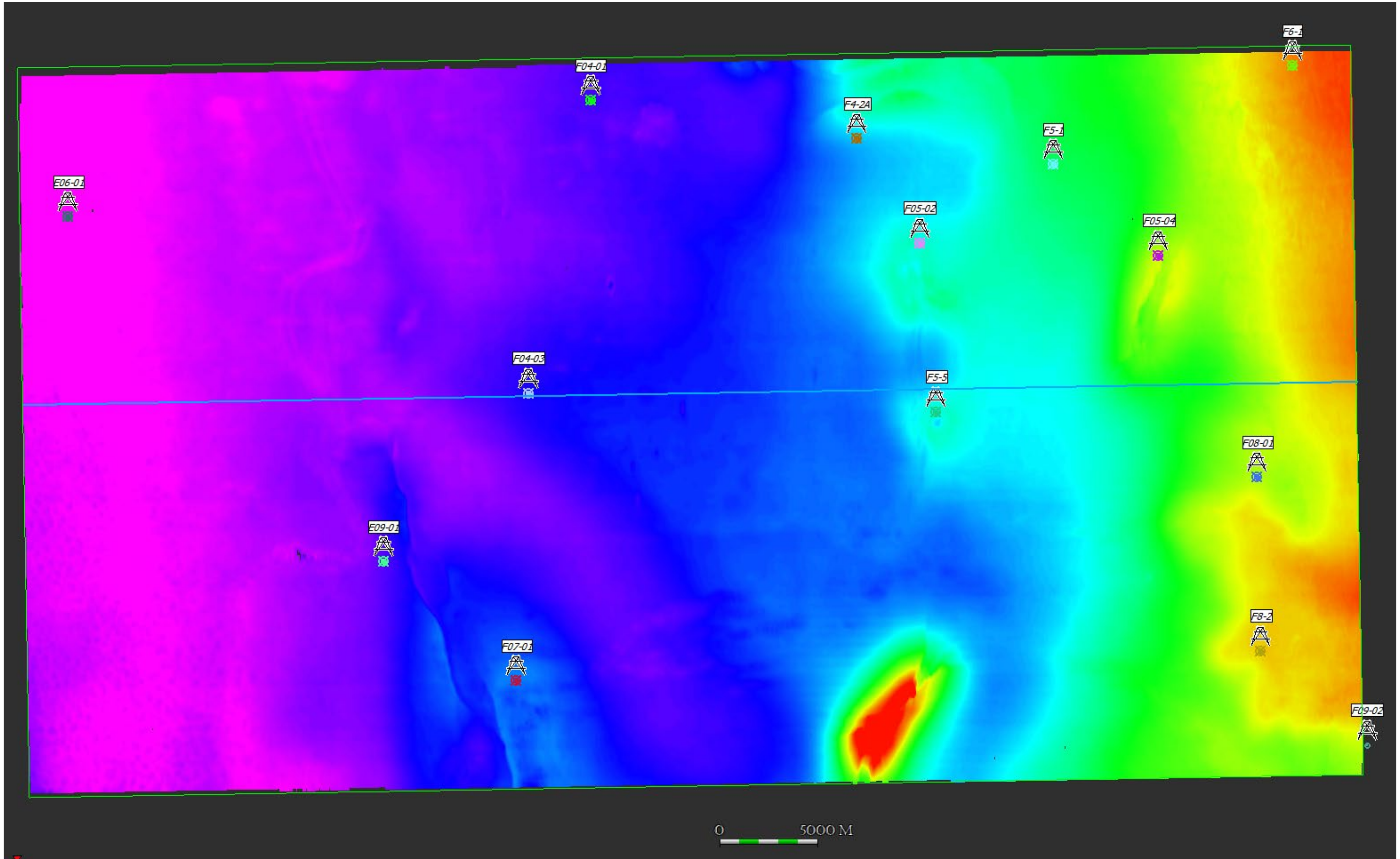
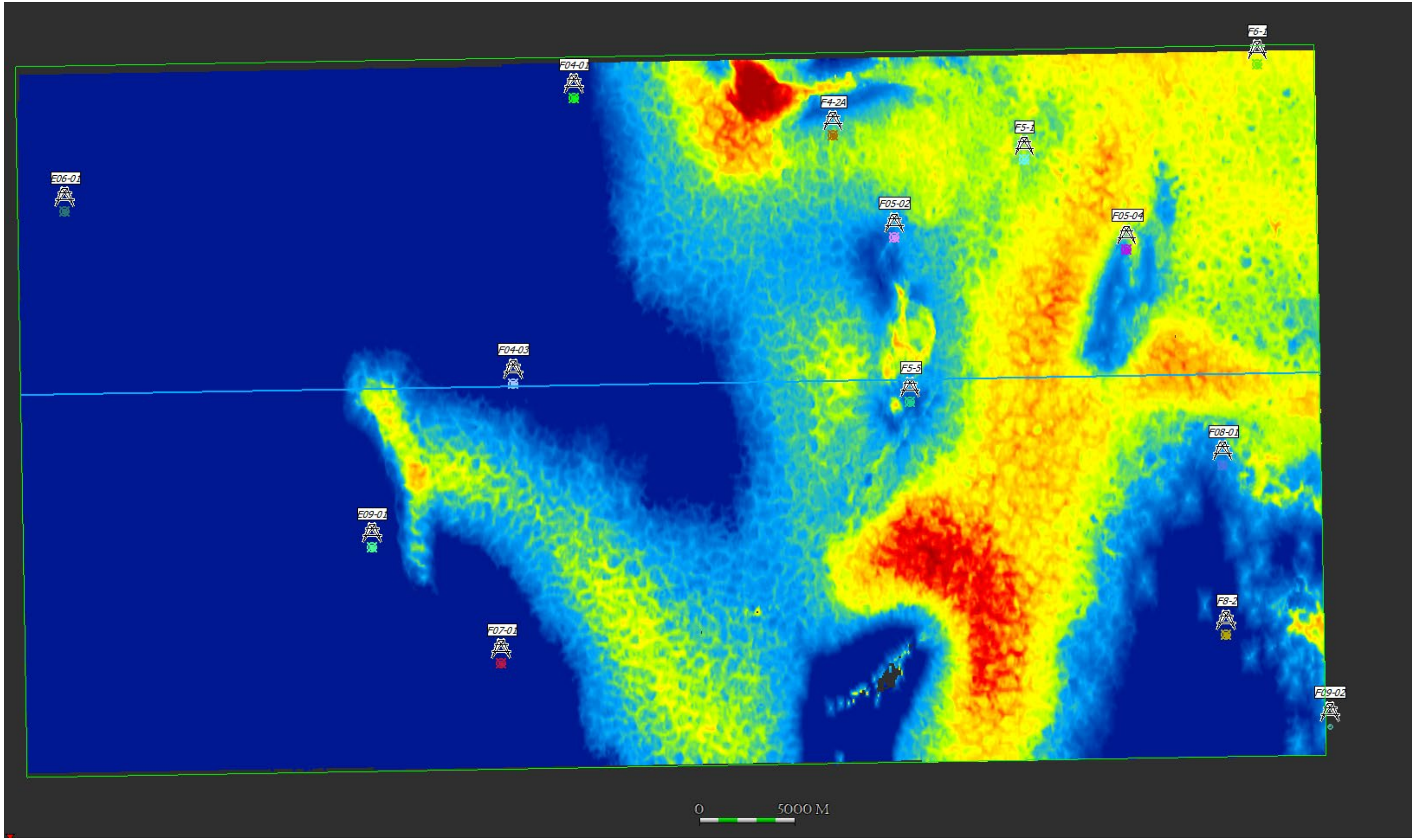


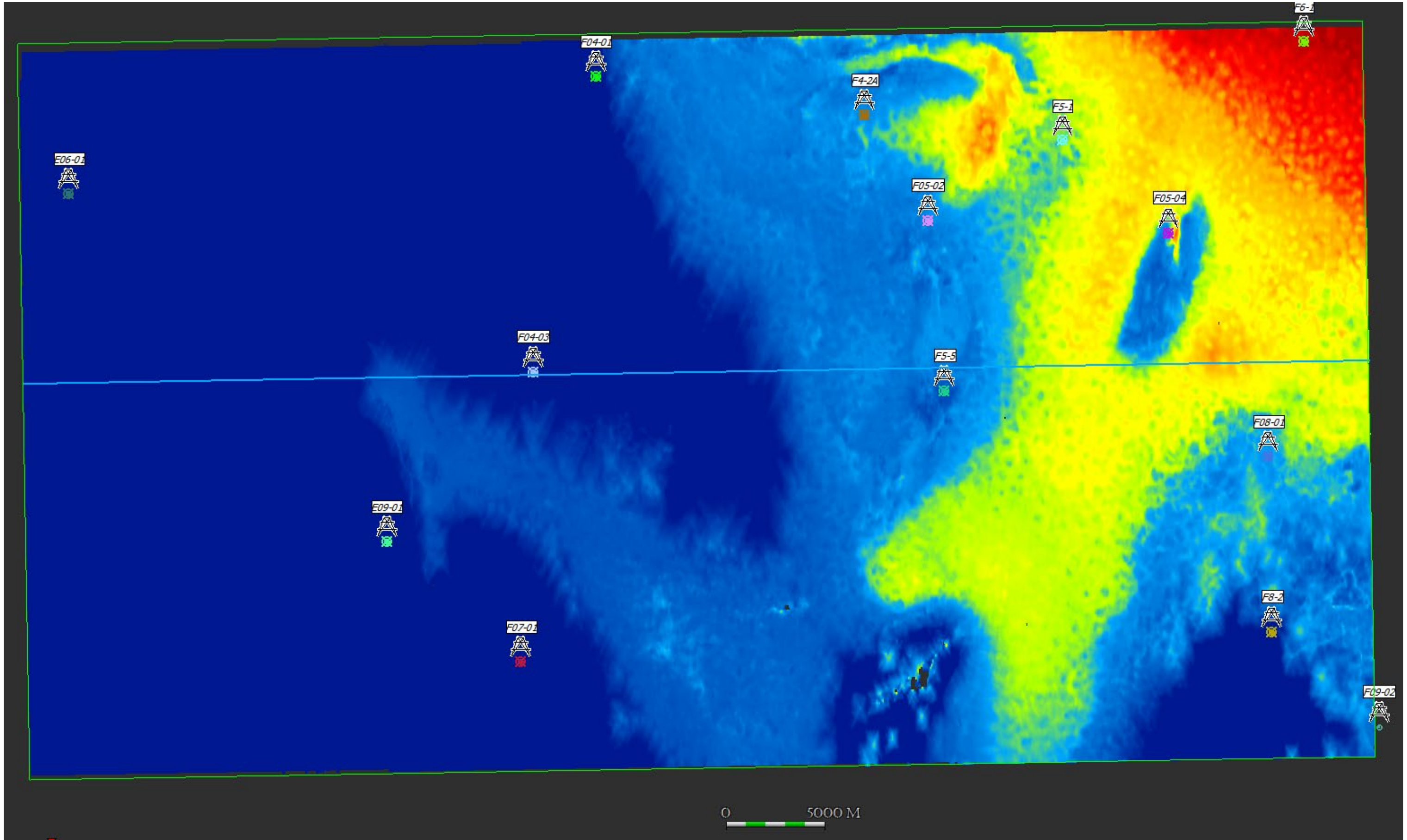
SEQ. MODEL TRUNCATED: HORIZON S6-BASE95-S



SEQ. MODEL TRUNCATED: ISOCHORE S1

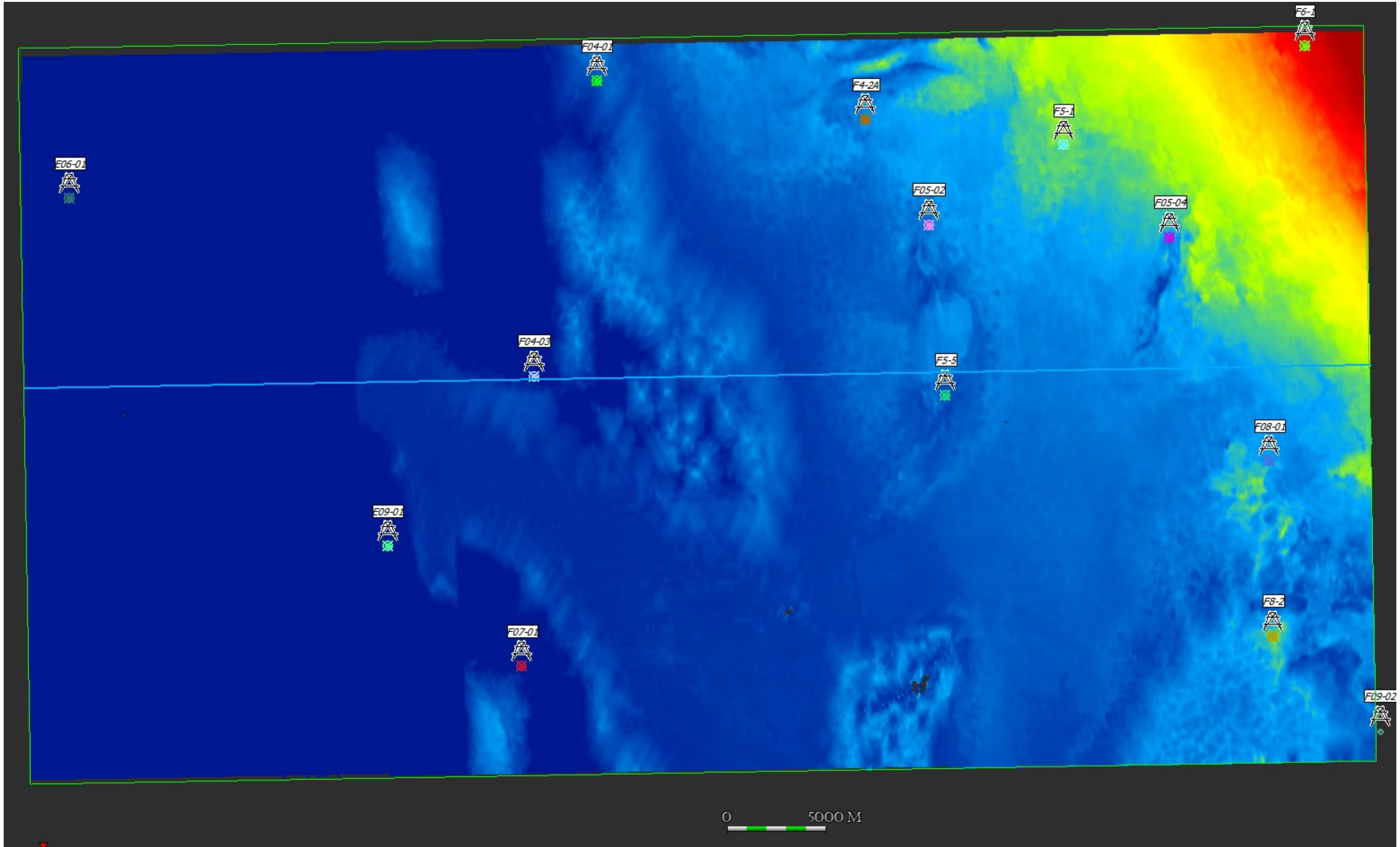


SEQ. MODEL TRUNCATED: ISOCHORE S2



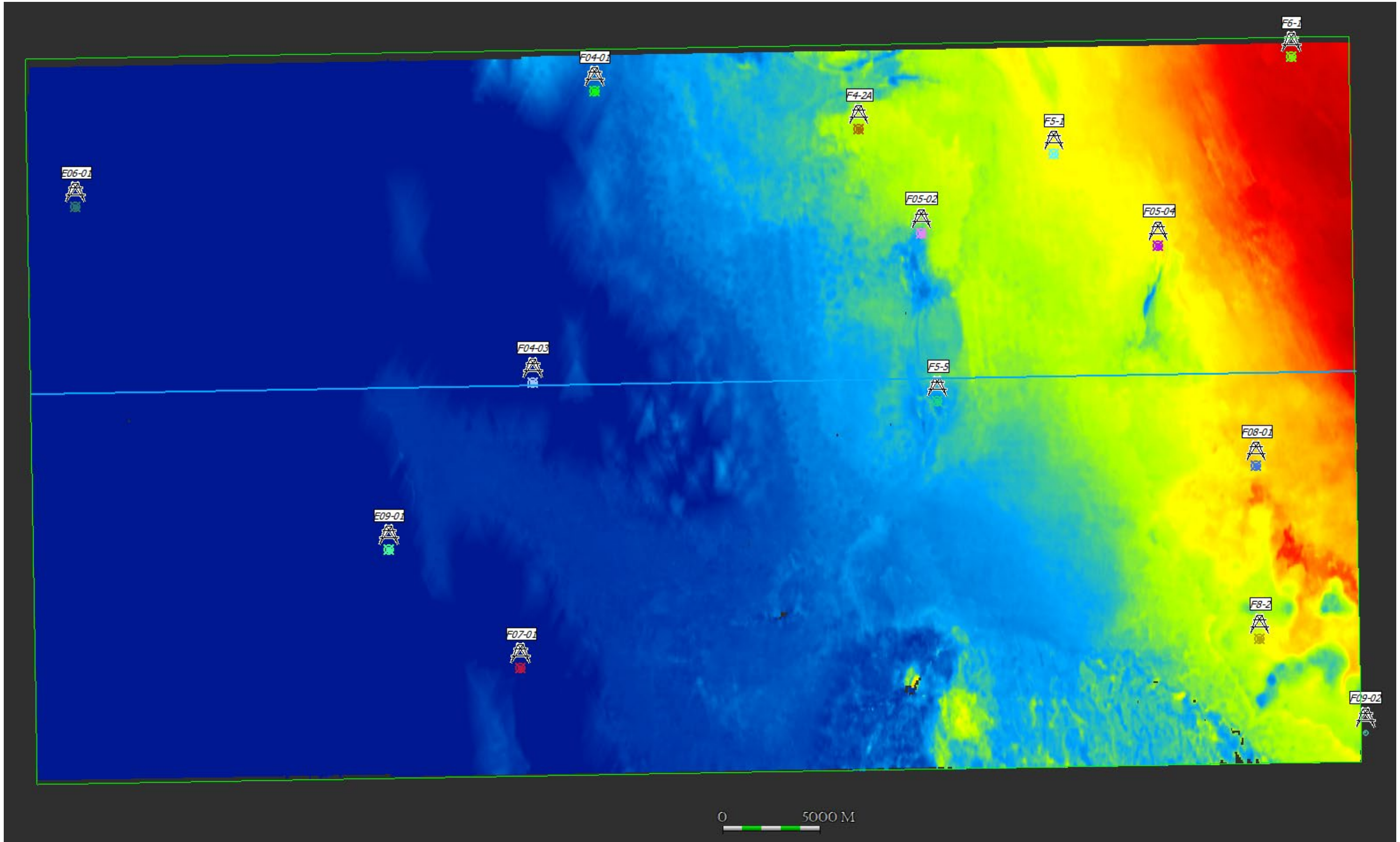
SEQ. MODEL TRUNCATED: ISOCHORE S3

innovation for life

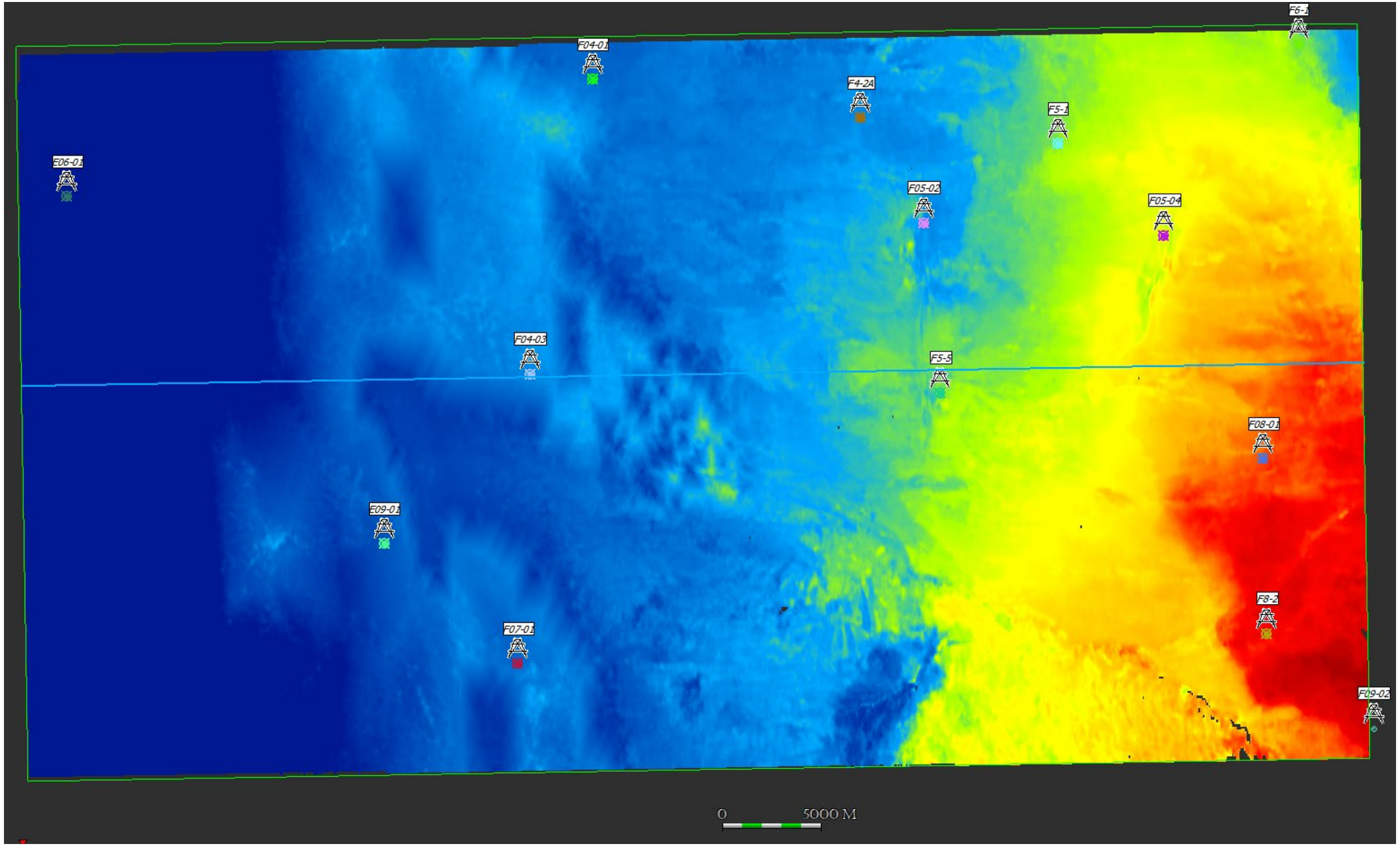


SEQ. MODEL TRUNCATED: ISOCHORE S4

TNO innovation for life

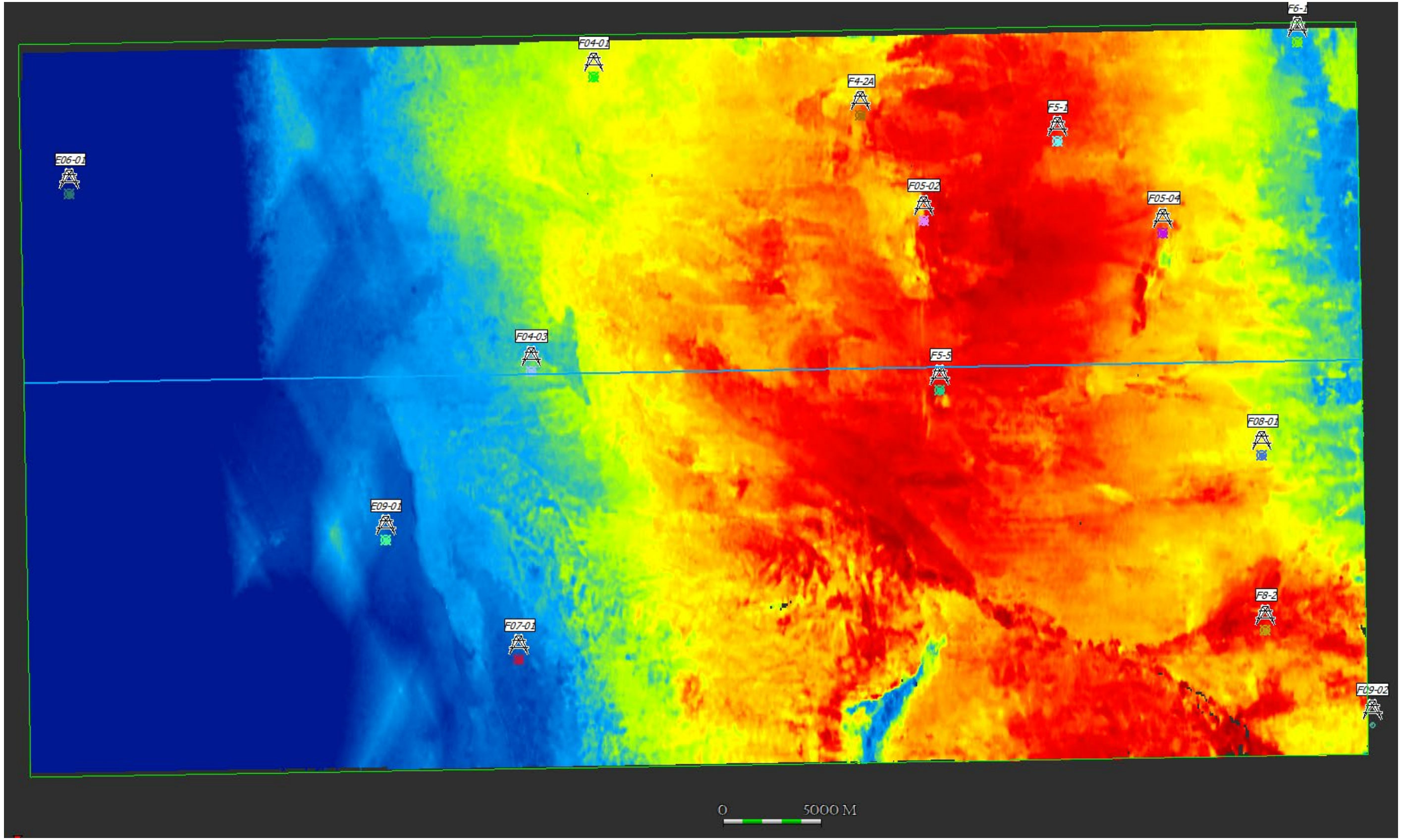


SEQ. MODEL TRUNCATED: ISOCHORE S5-103

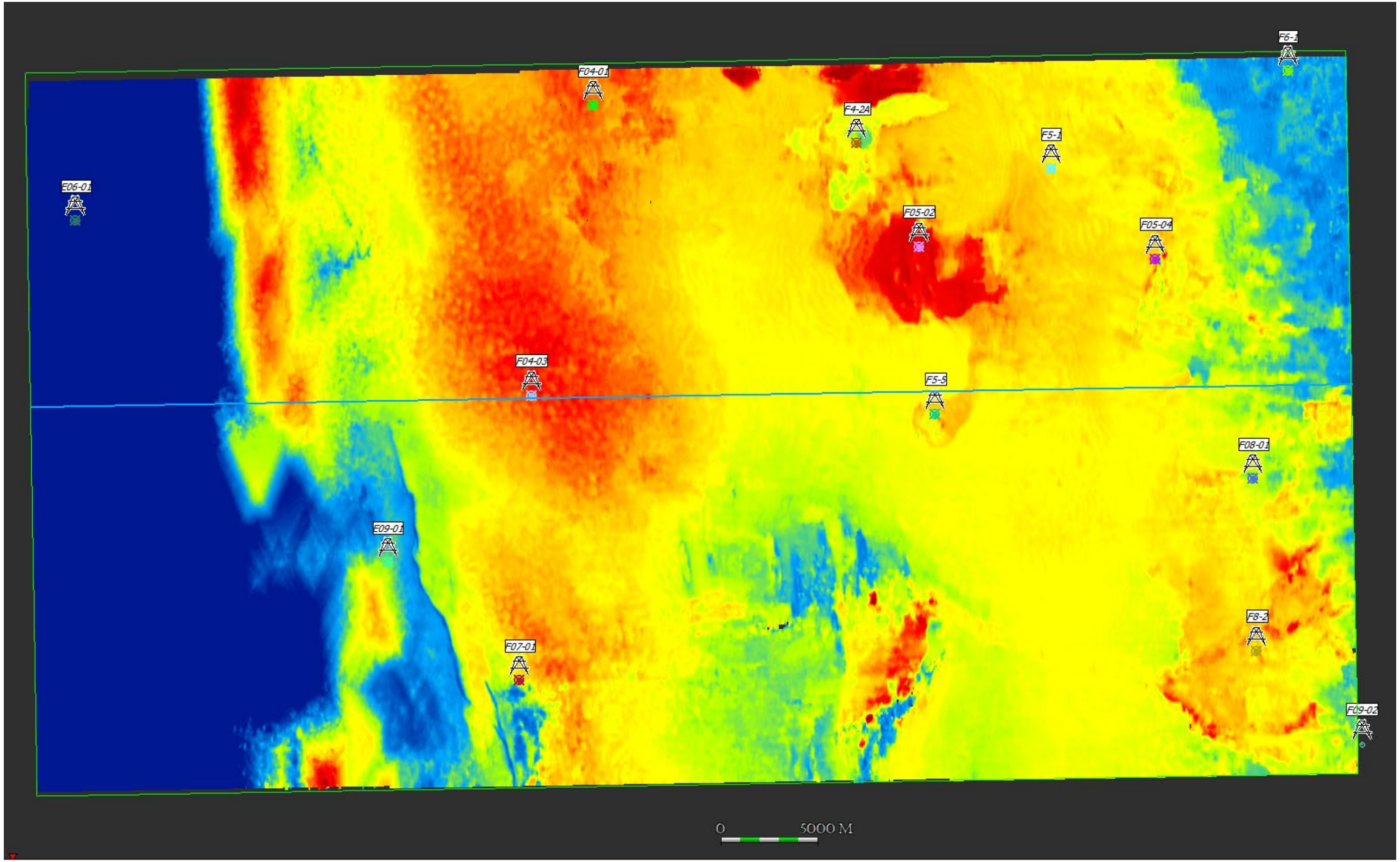


SEQ. MODEL TRUNCATED: ISOCHORE S5-1010-102

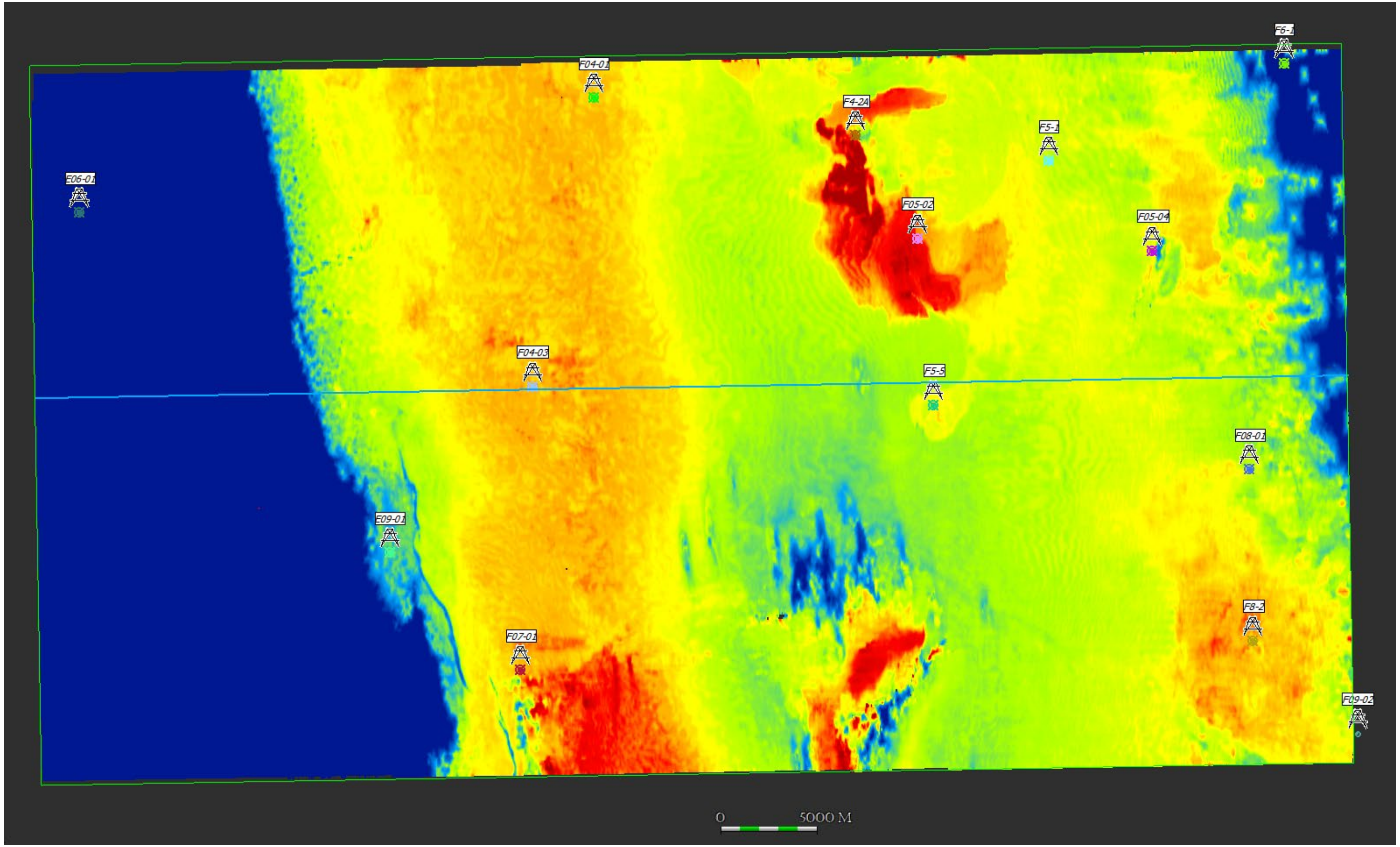
TNO innovation for life



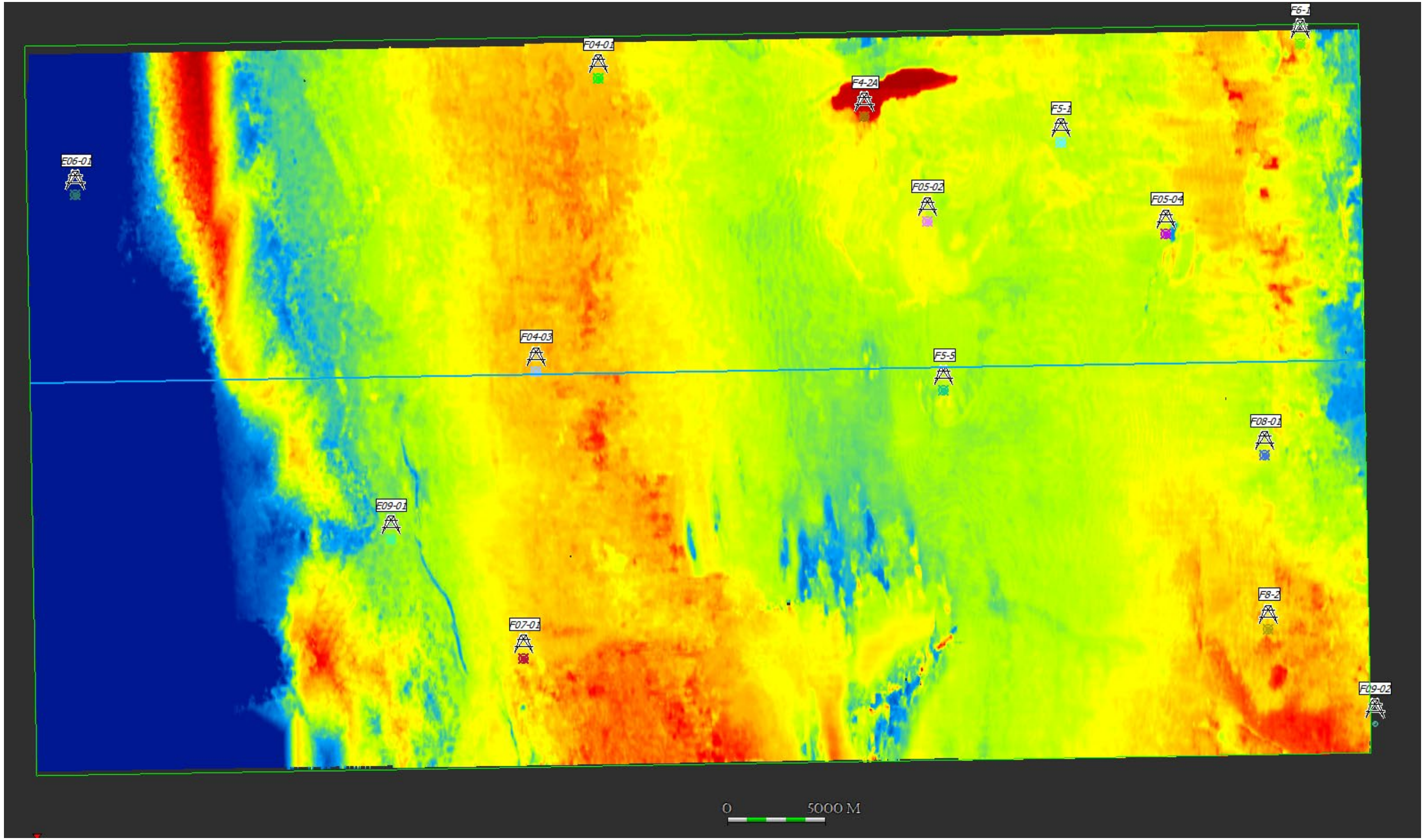
SEQ. MODEL TRUNCATED: ISOCHORE S5-100



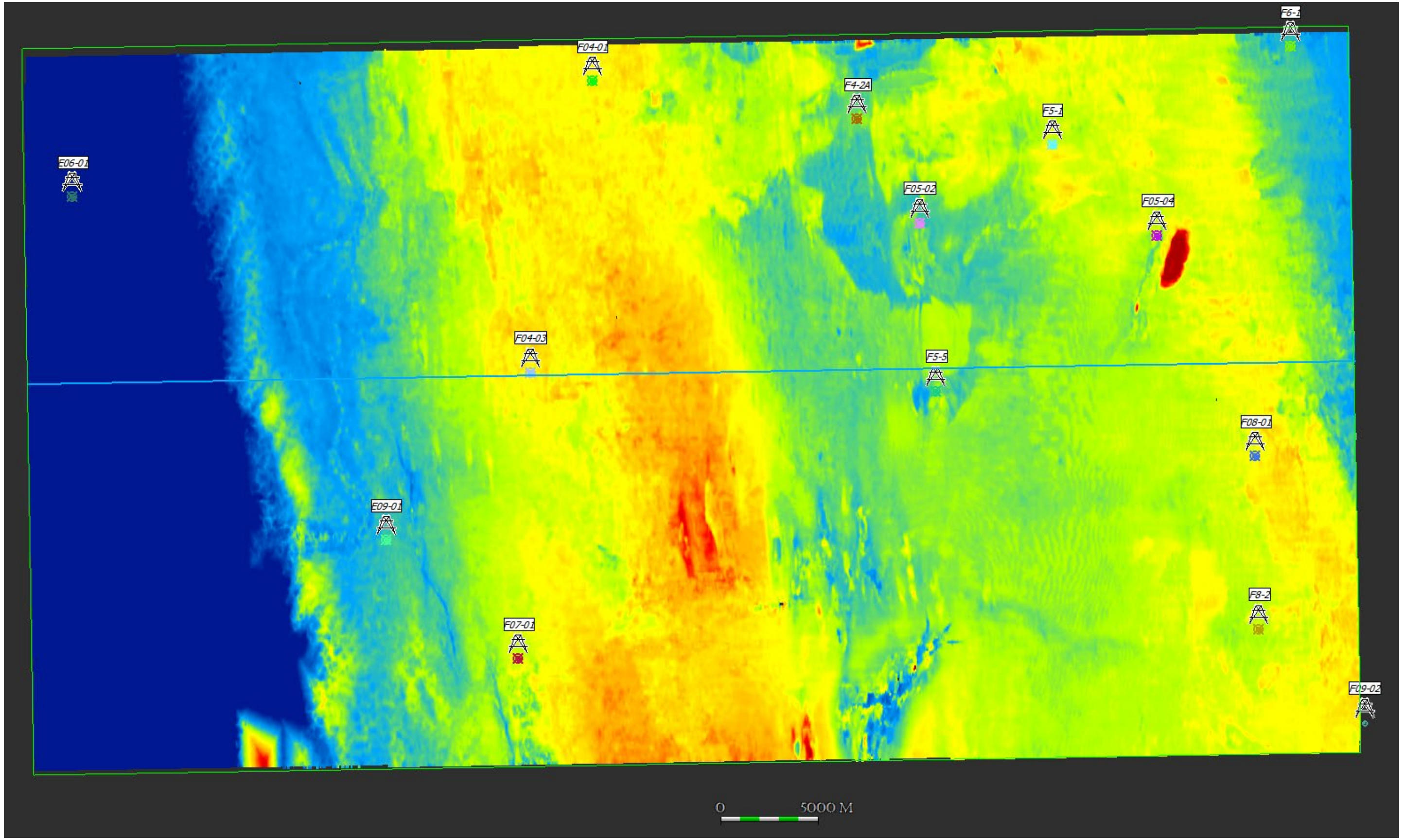
SEQ. MODEL TRUNCATED: ISOCHORE S5-99S



SEQ. MODEL TRUNCATED: ISOCHORE S5-98

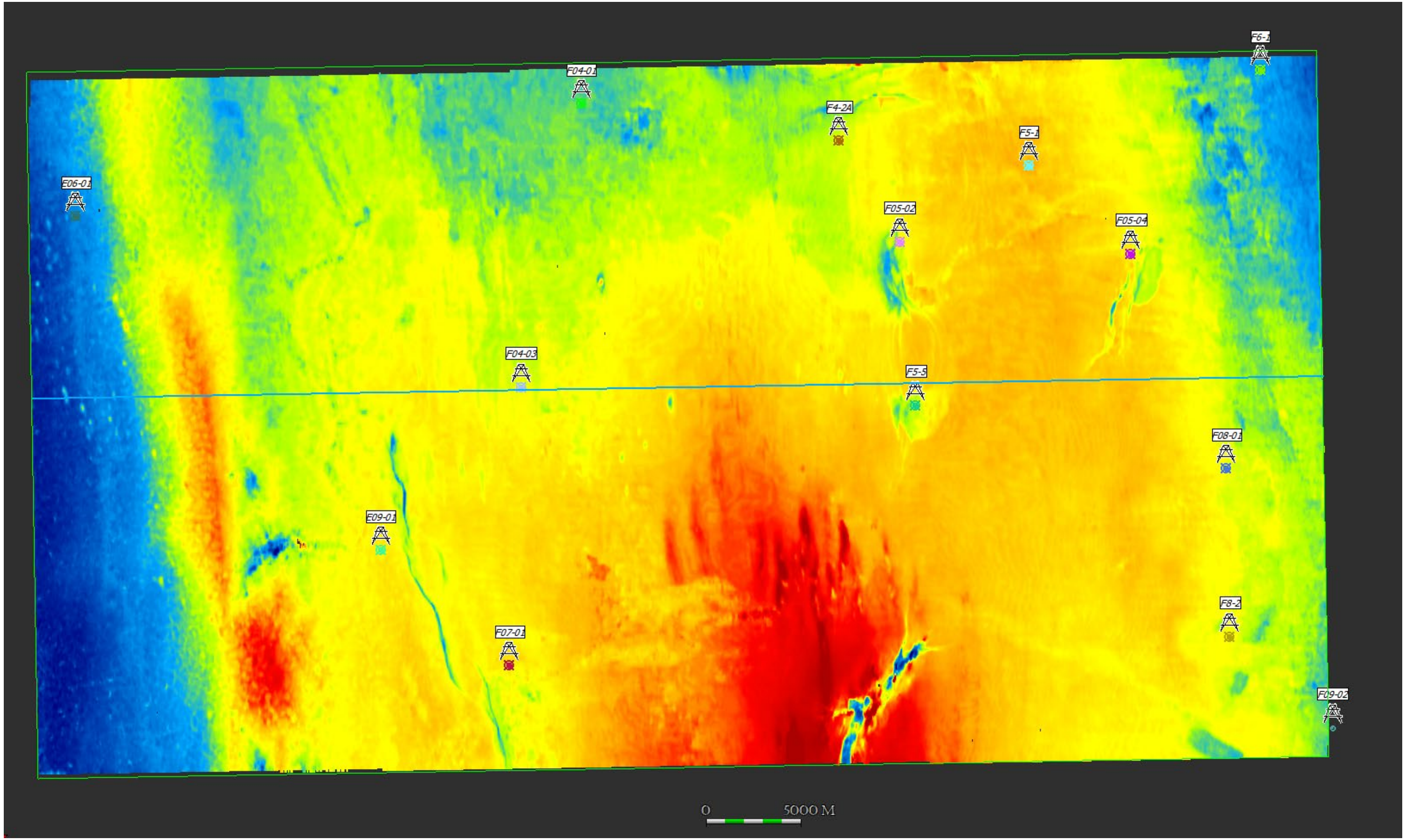


SEQ. MODEL TRUNCATED: ISOCHORE S5-97S

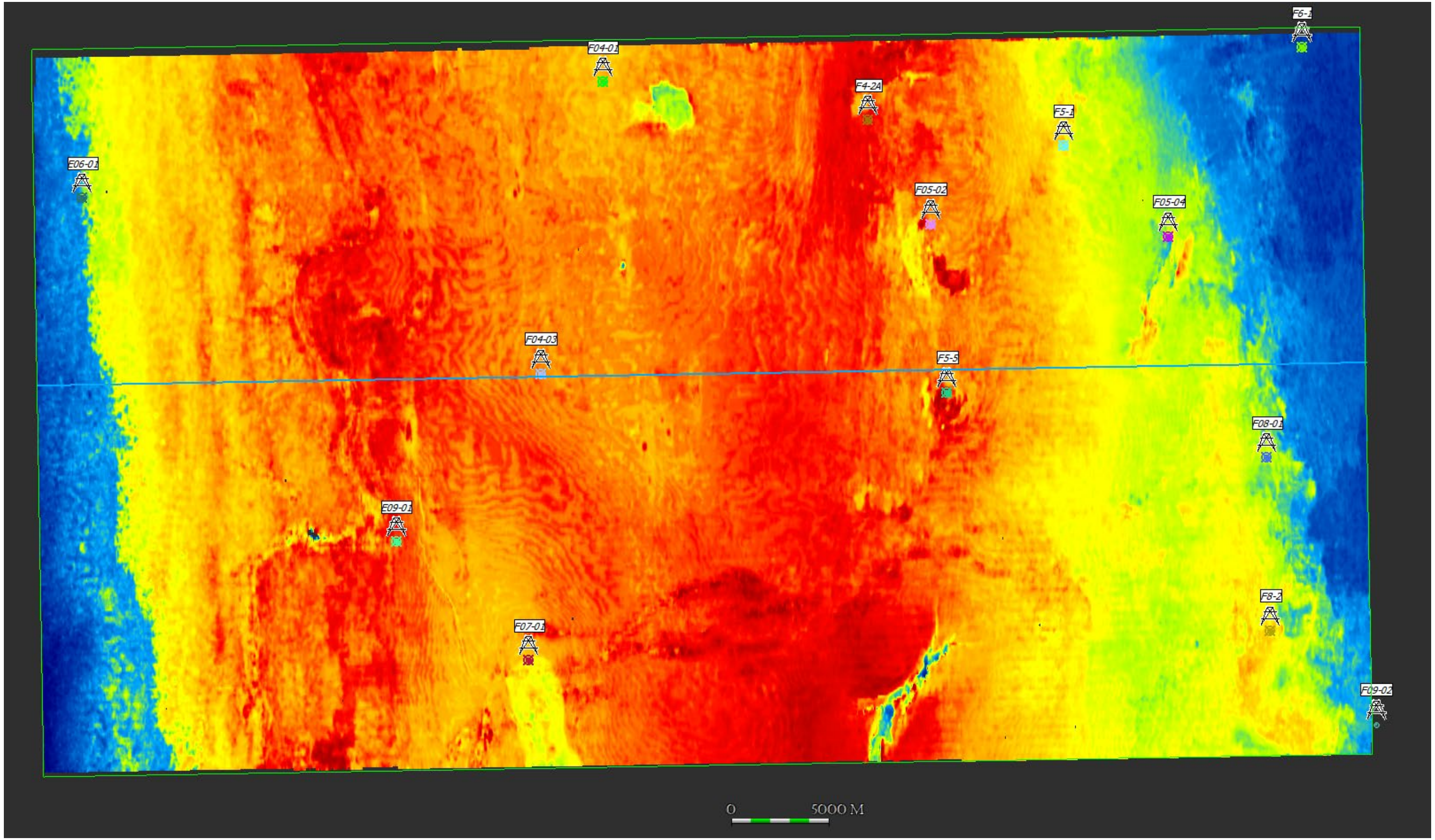


SEQ. MODEL TRUNCATED: ISOCHORE S5-96

innovation for life



SEQ. MODEL TRUNCATED: ISOCHORE S6-95S



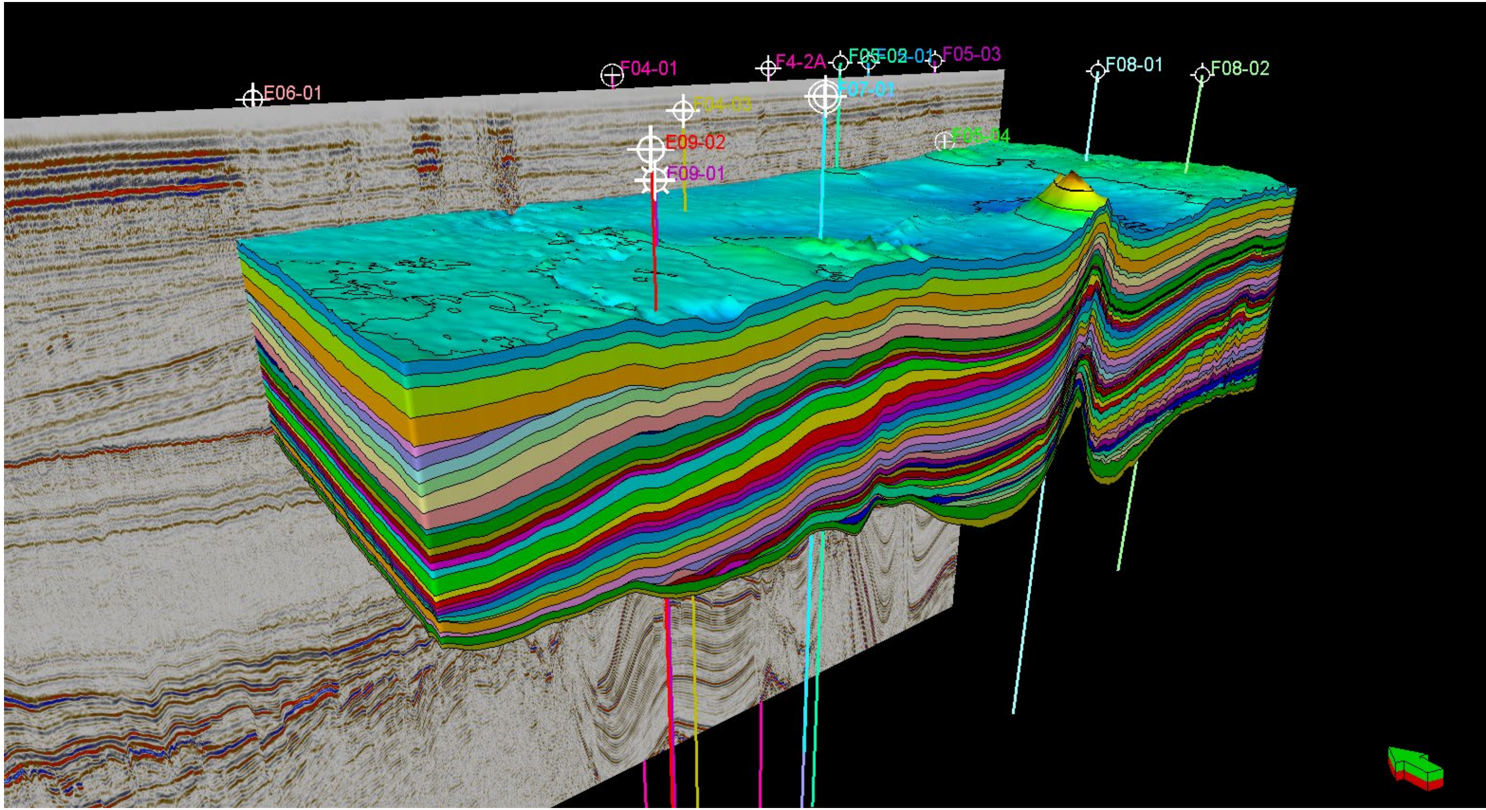
WP3 – PROPERTY MODEL

- Construction of 3D model (Sequence- and Geocellular modelling in Paleoscan)
- Property/reservoir modelling
  - Enhancement, correction and petrophysical evaluation of available well logs
  - 3D interpolation techniques
- Evaluation of sediment properties of brightspots

GEOMETRY

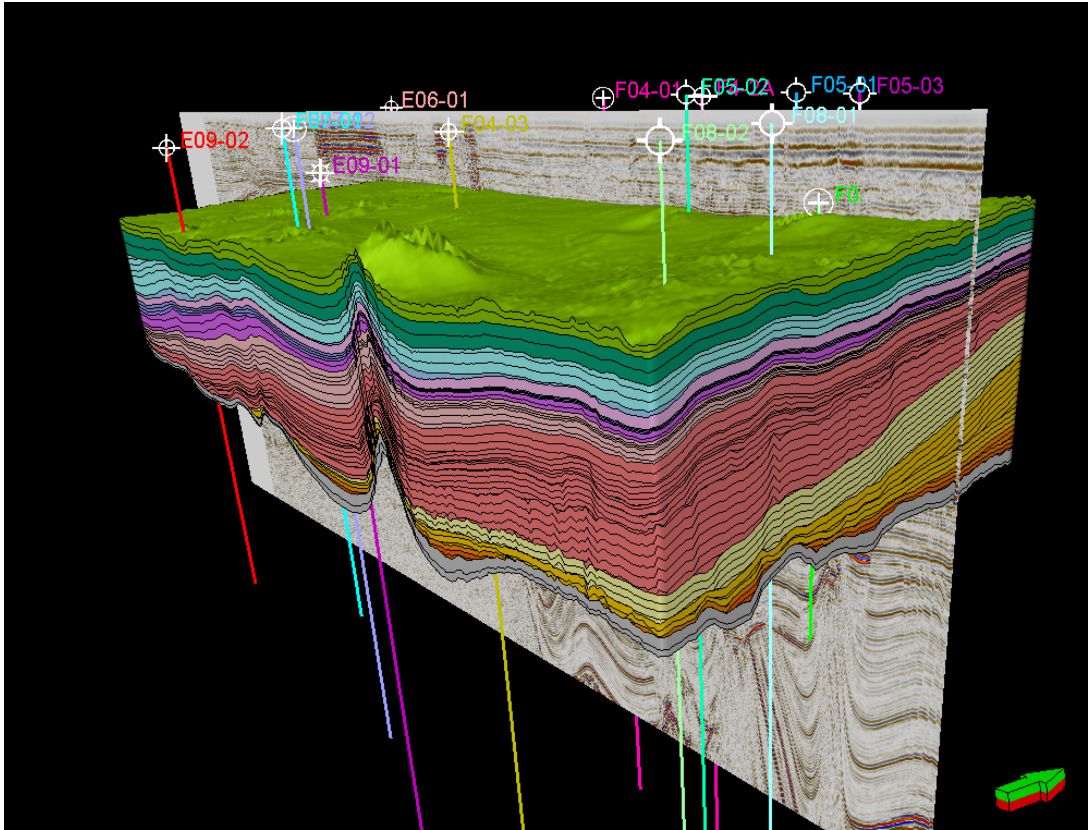
- Geometry was exported from PaleoScan as an Eclipse corner point grid, and imported in Petrel.

- 87 layers
- 272x74*87 cells =
- 1.75 million cells



GEOMETRY

- Colours were adjusted to match colour coding from A15-03

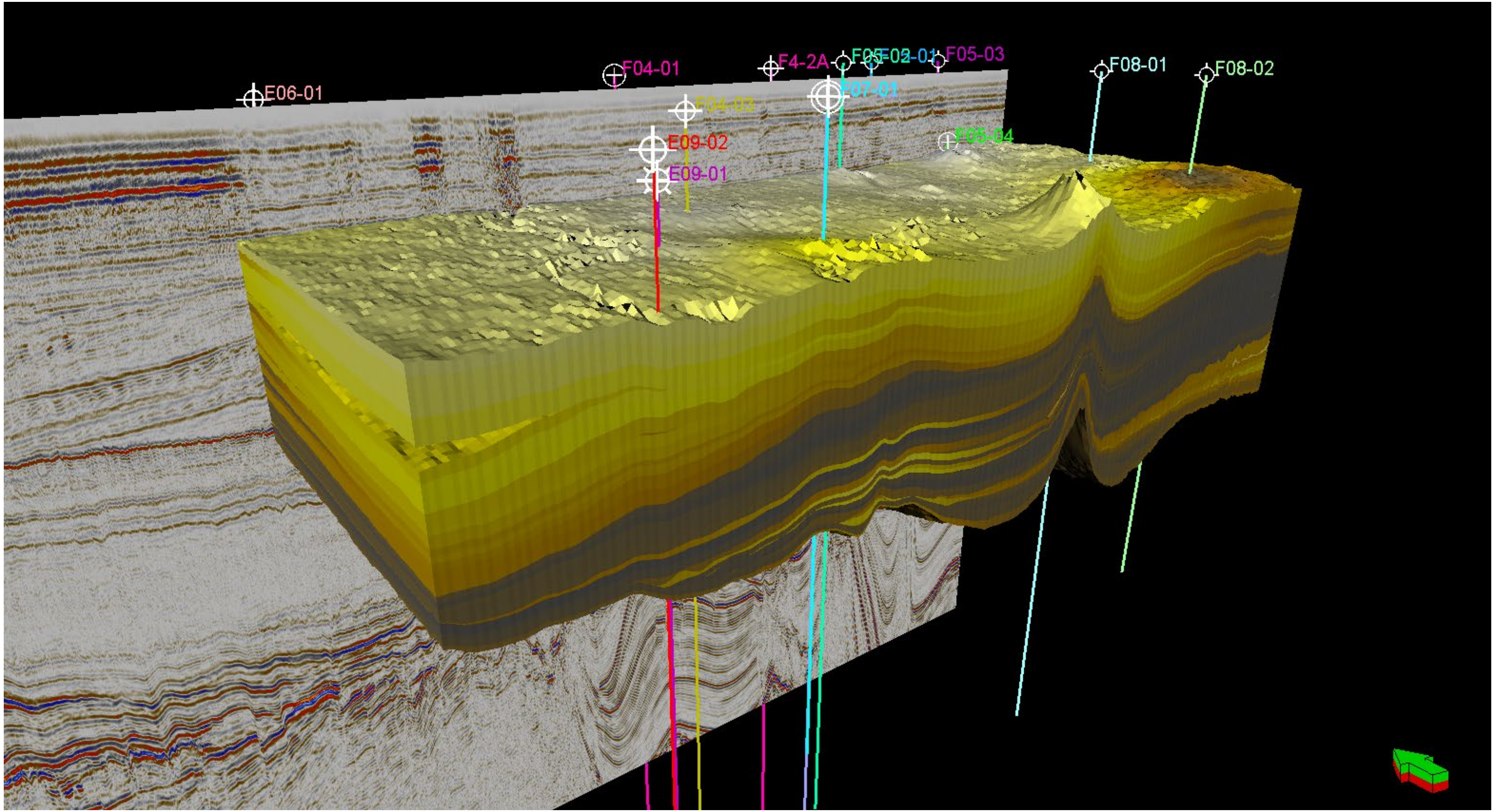


PROPERTY MODELLING

- Attempts were made to model the sand distribution in the 87 layers, from Top S13 to LMU-MMU-EMU.
- First a Vsand logs was created through the global well log calculator:
  - Vshale = (GR – Grmin) / (Grmax – Grmin); Clamp between 0 and 1; VSand = (1 – Vshale)

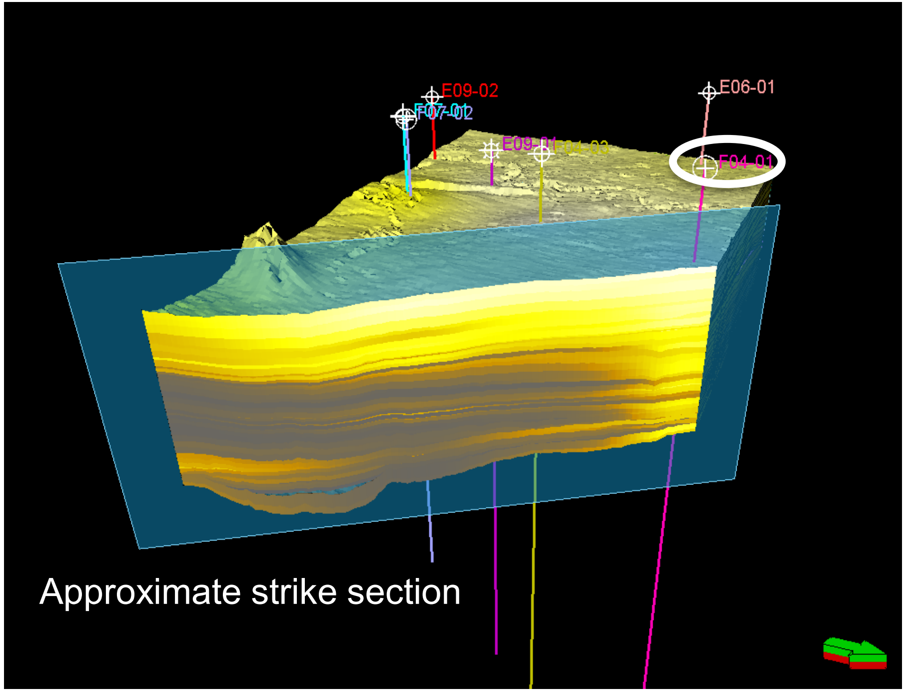
- The Vsand log was upscaled to the imported PaleoScan reservoir model
- Vsand was distributed in the model using various methods
  - 1) Inverse Distance Squared. Just to have a look at the data
  - 2) Kriging with experimentally determined variograms
  - 3) Co-Kriging with the RMS cube

1) VSAND WELLS ONLY, INV DIST SQ

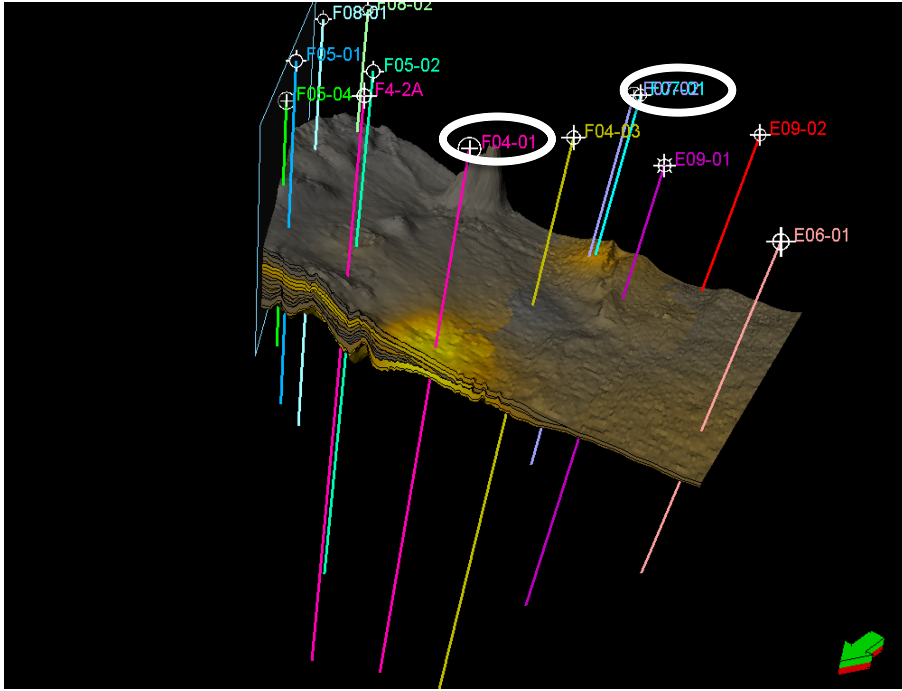


BULL'S EYES...

› Wells F07-01 and especially F04-01 are very sandy, in all zones, giving rise to bull's eyes. Bug or feature?

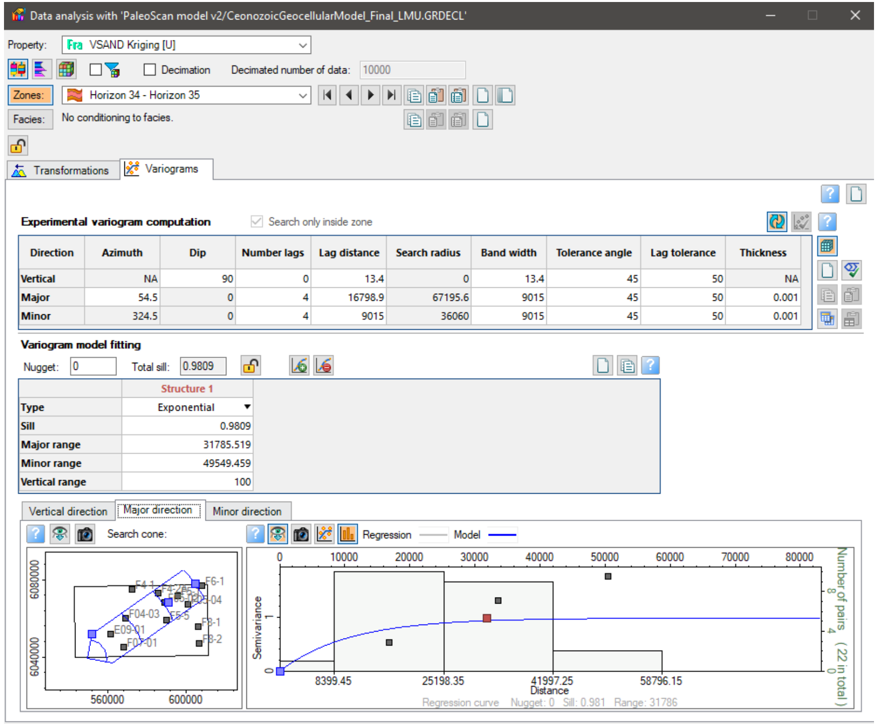


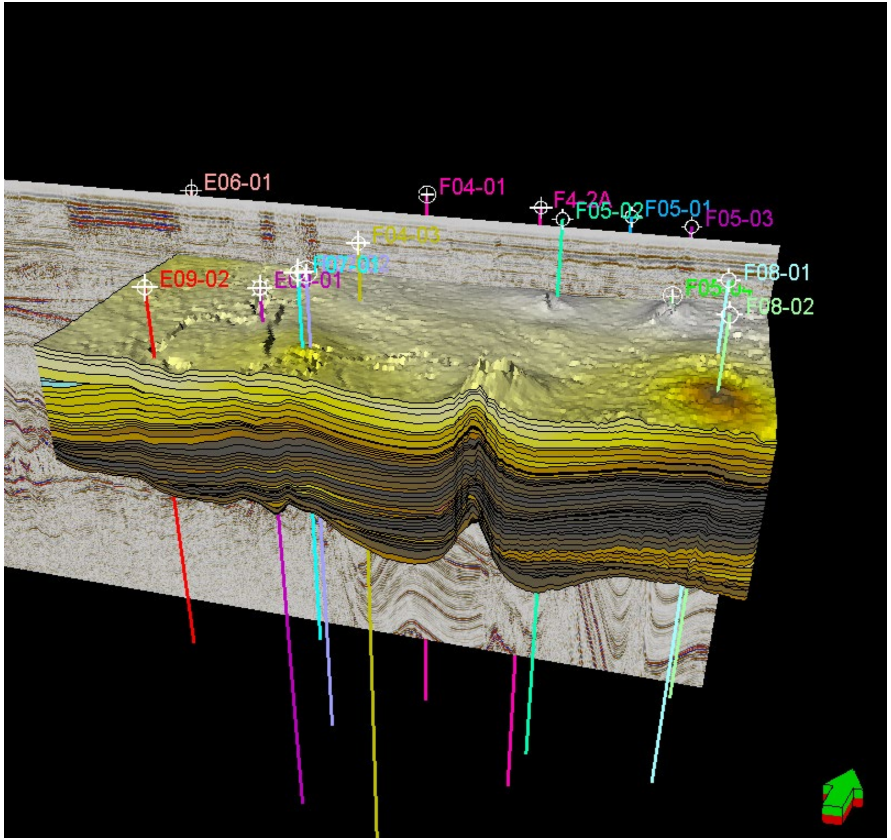
Approximate strike section



2) VSAND WELLS ONLY, KRIGING

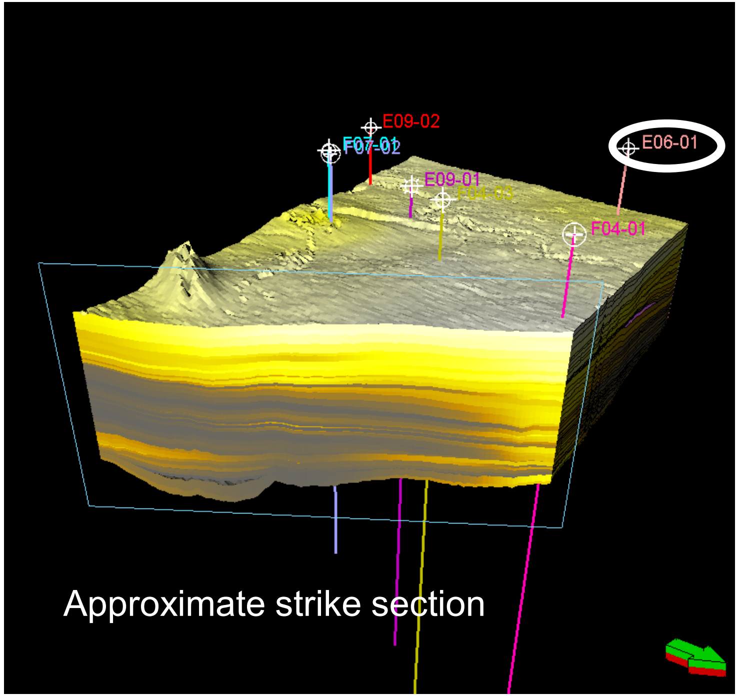
Variograms NE-SW and NW-SE; ranges 39 and 50 km

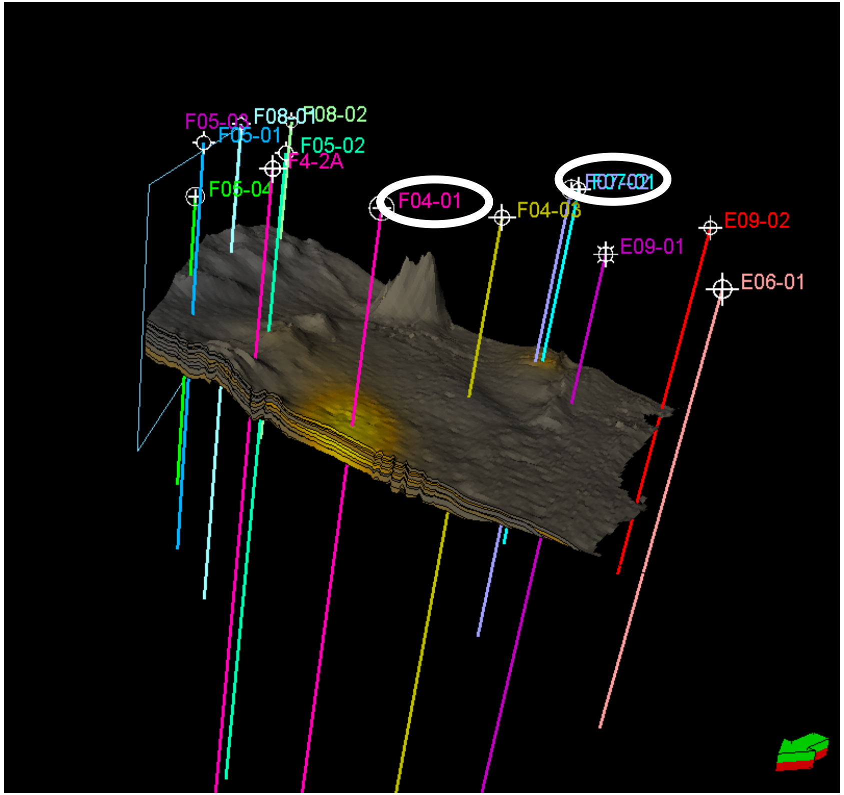




BULLSEYES…

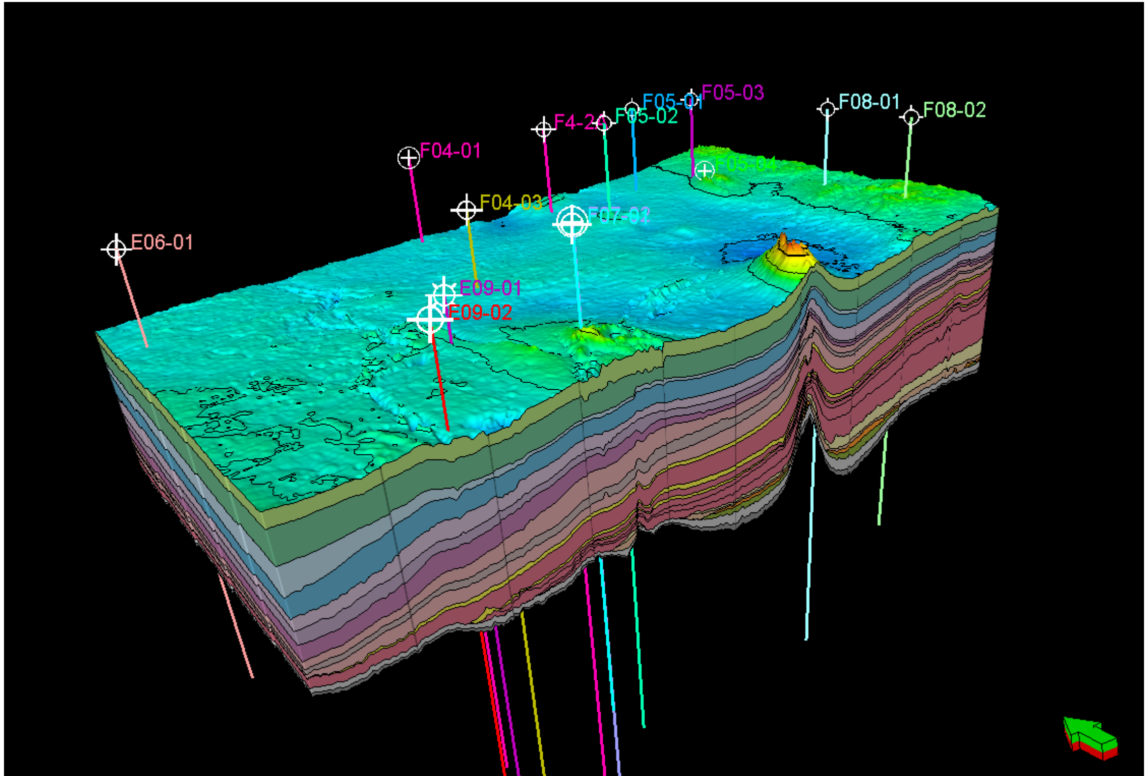
› Wells F07-01 and especially F04-01 are very sandy, in all zones, giving rise to bull's eyes. Bug or feature?





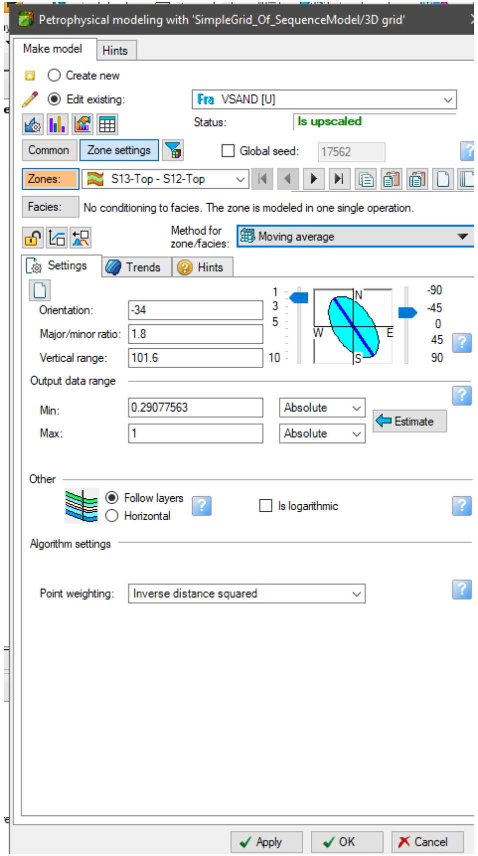
NEW MODEL: FROM DIRECT LINK PALEOSCAN → PETREL

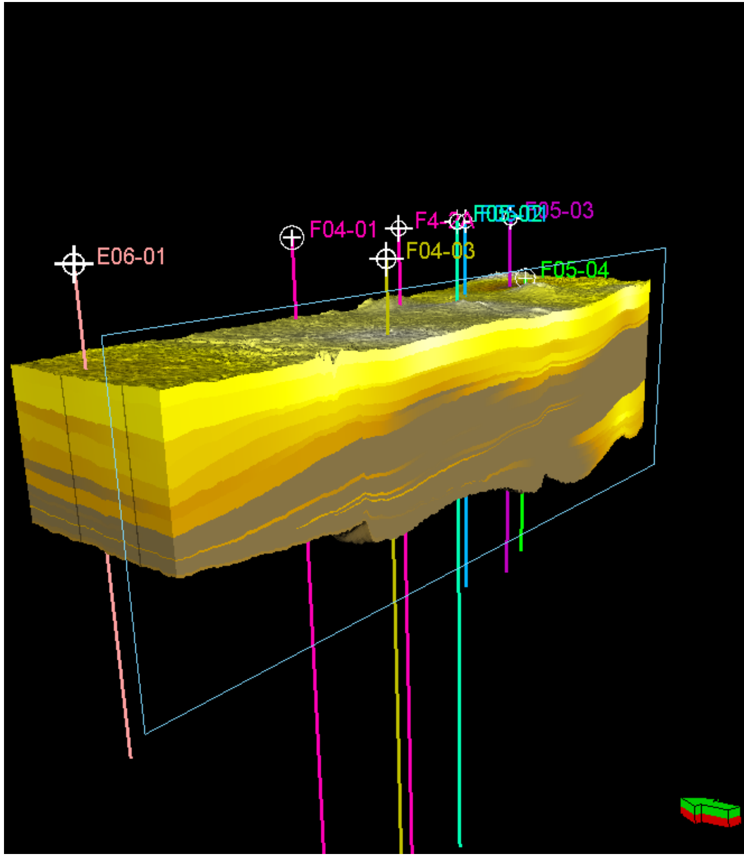
- 684 x 378 x 24 grid cells (6.2 million)
- 100 x 100 m x ~37 m



NEW MODEL: MORE CELLS (AREALLY)

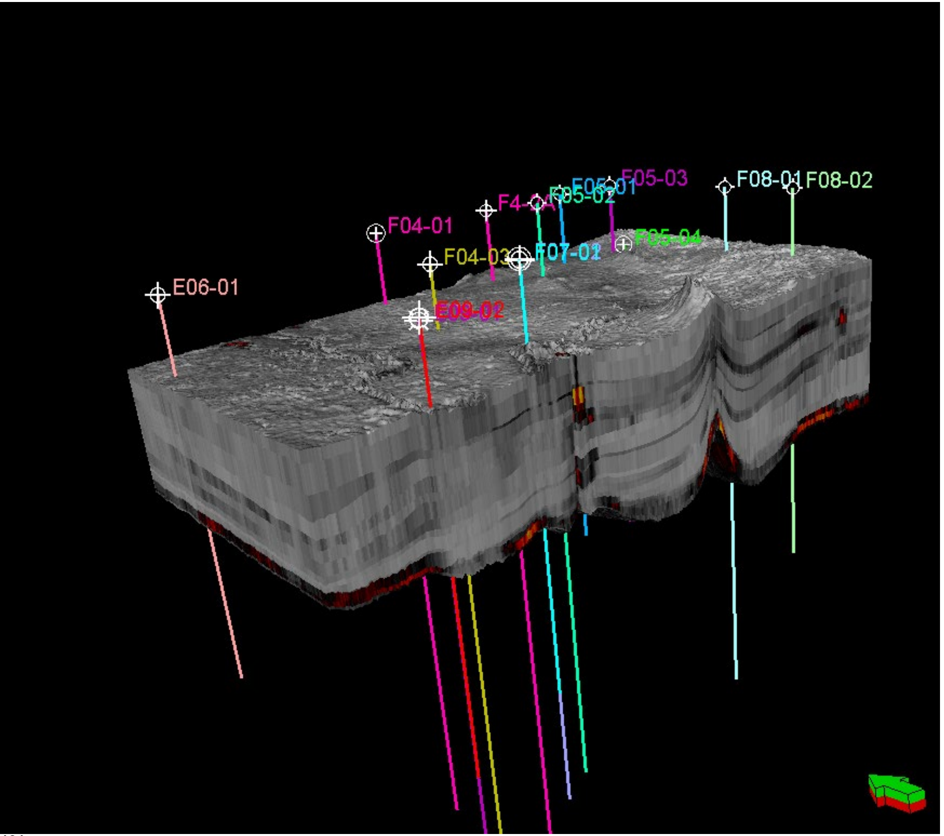
- Vsand modelling

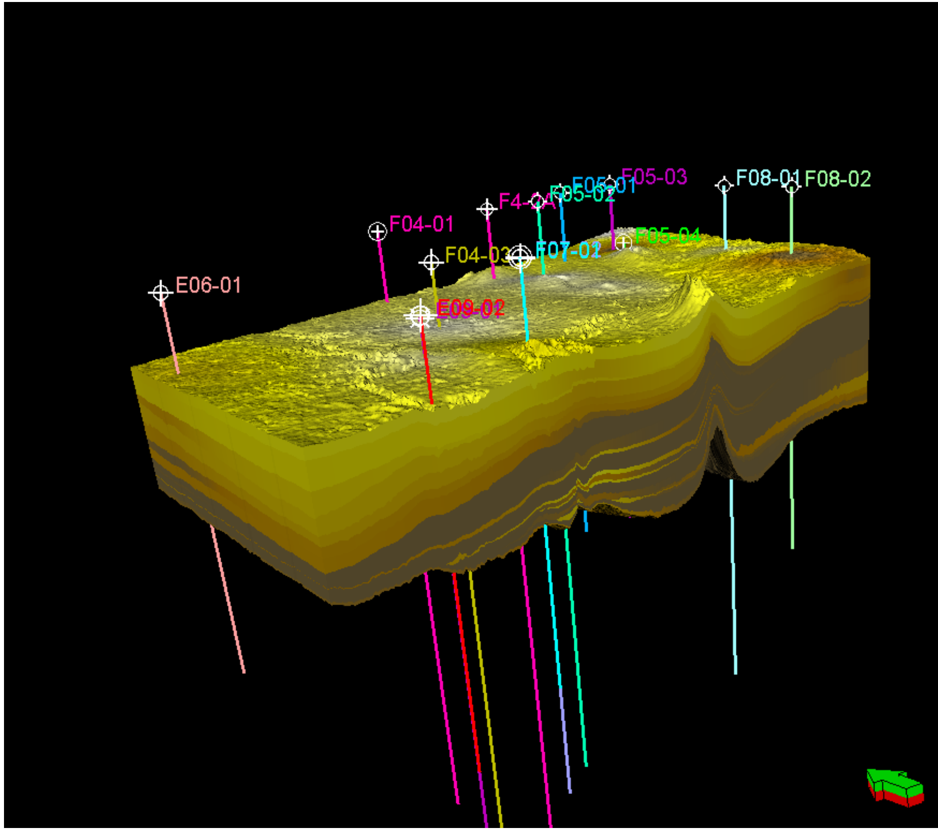




RMS VS. VSAND

- Does not look very promising…

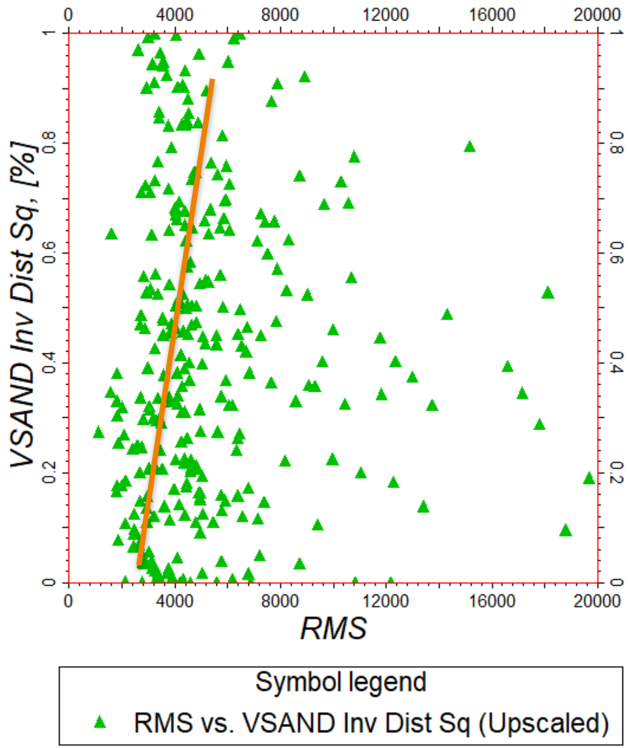




VSAND VS RMS (ALL ZONES)

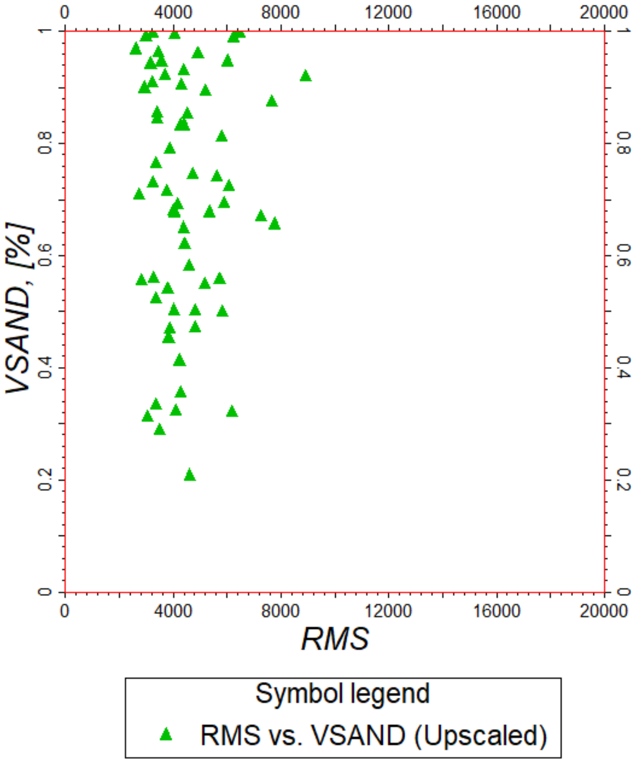
TNO innovation for life

- Cross-plot does not look very promising either.
- A very weak correlation seems to be present overall, but with quite a lot of scatter

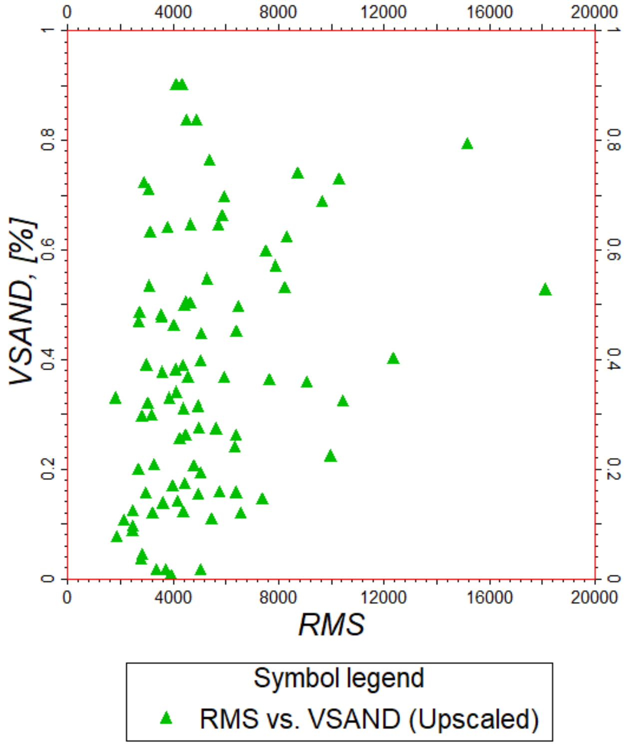


VSAND VS RMS (S13 – S6)

S13-S9

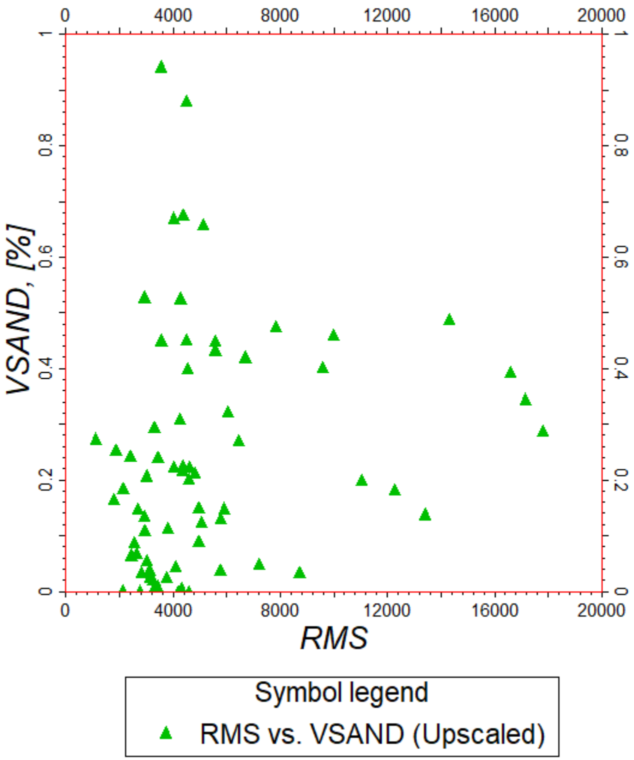


S8-S6

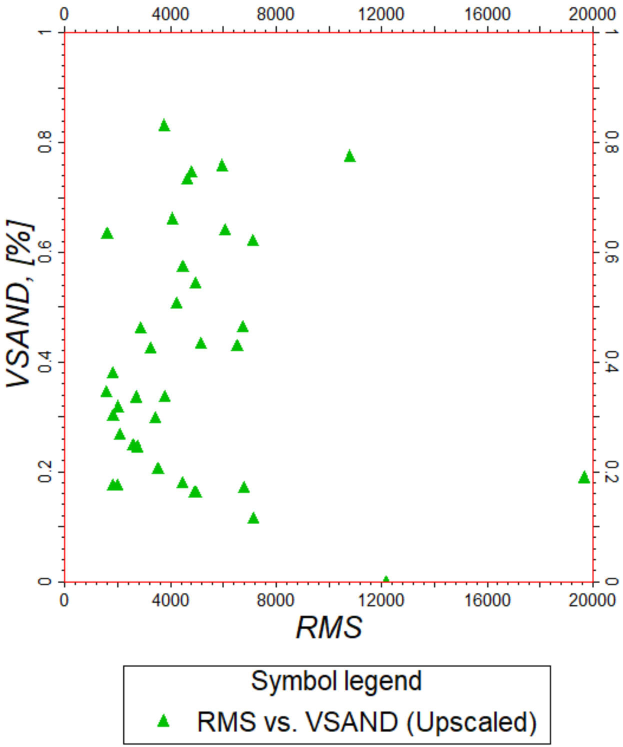


VSAND VS RMS (S5 AND S4-S1)

S5

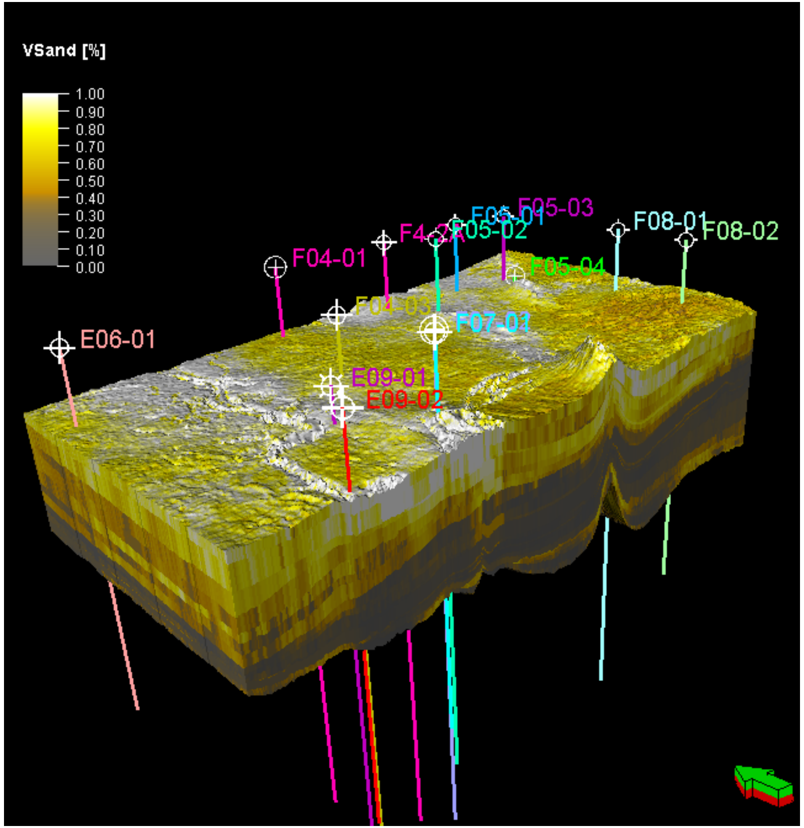


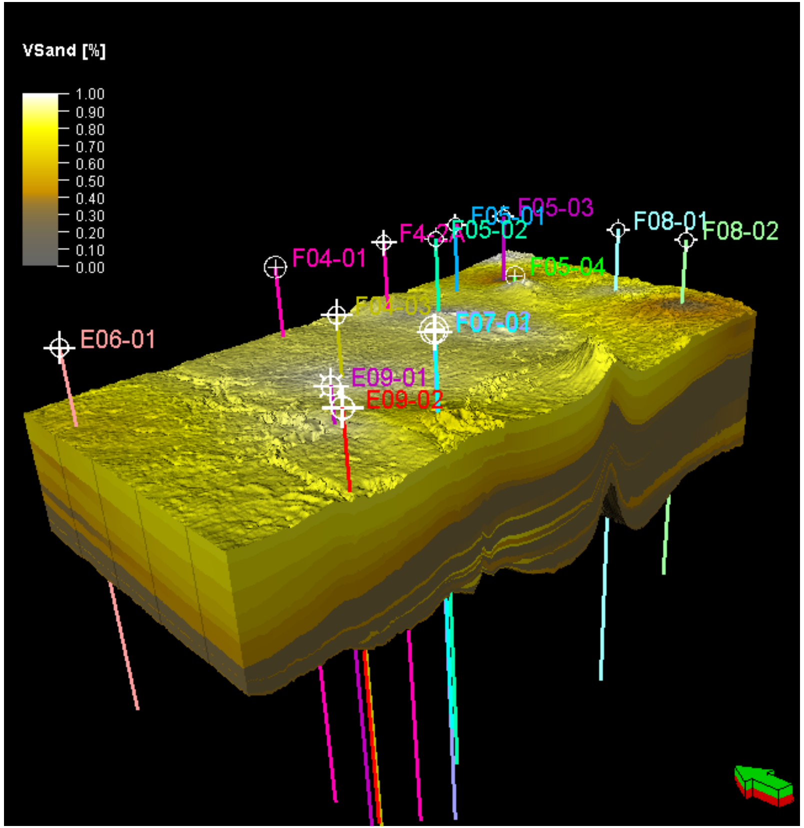
S4-S1

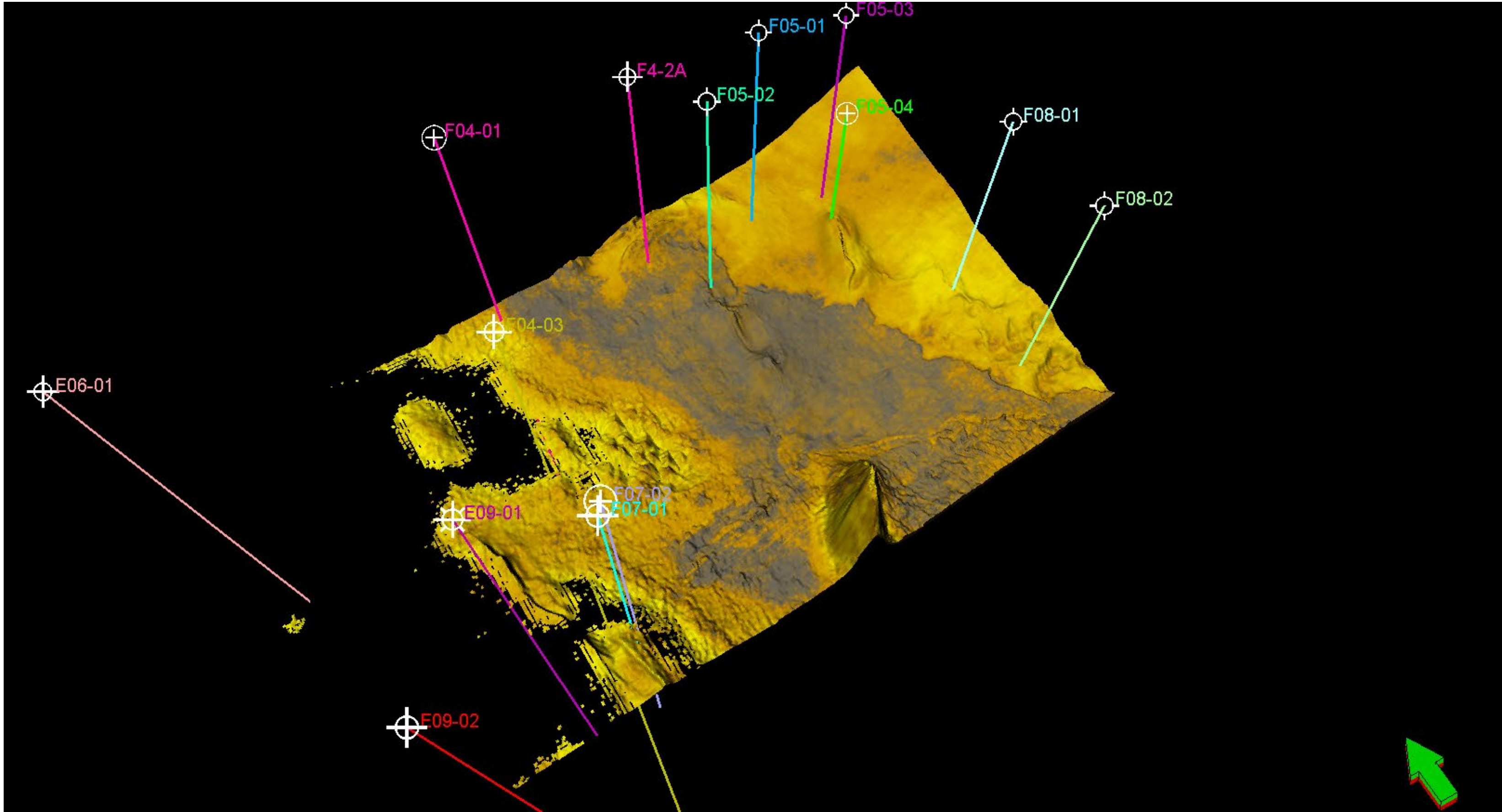


KRIGING VSAND, CO-KRIGING WITH RMS CUBE

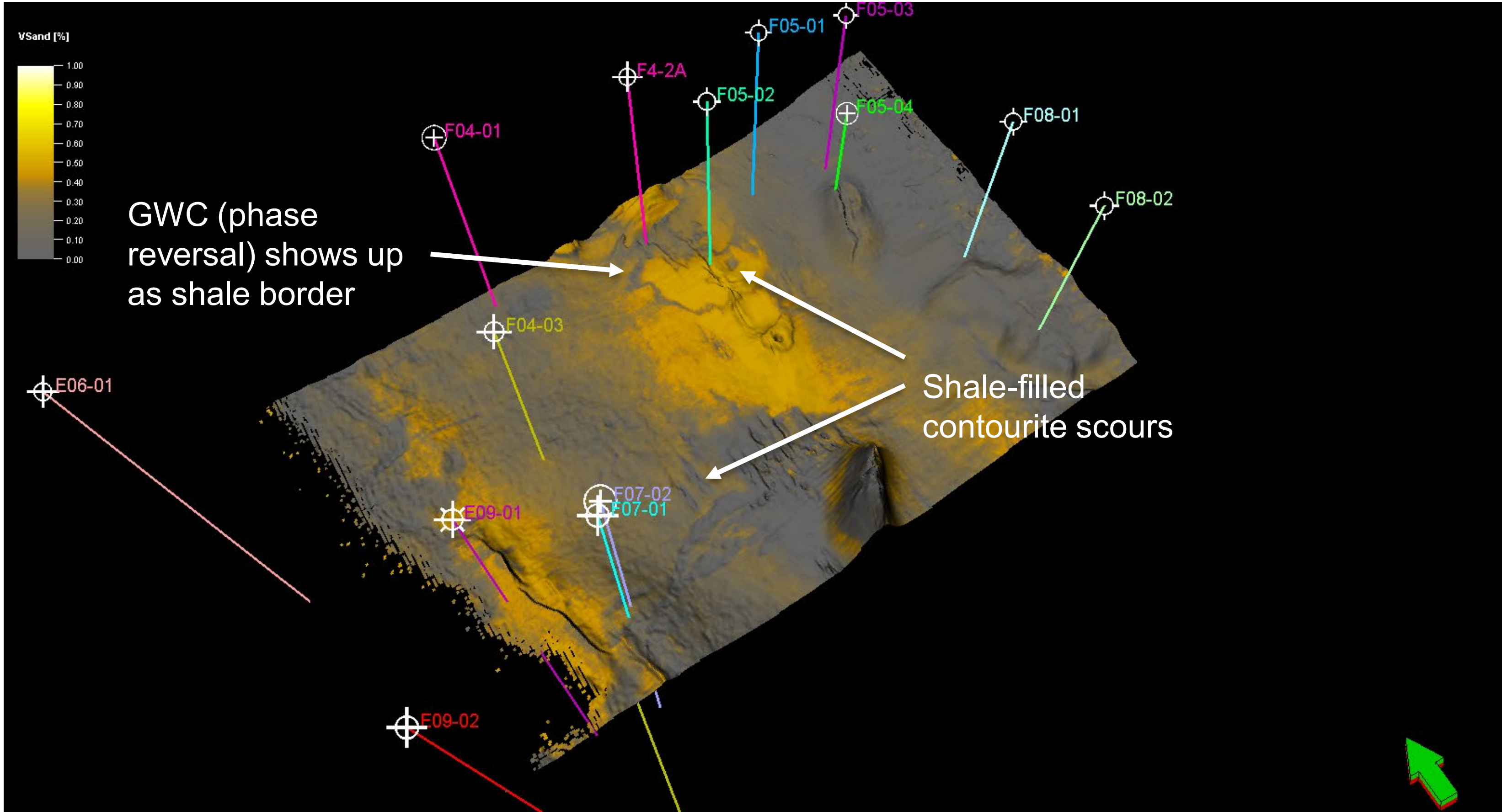
TNO innovation for life





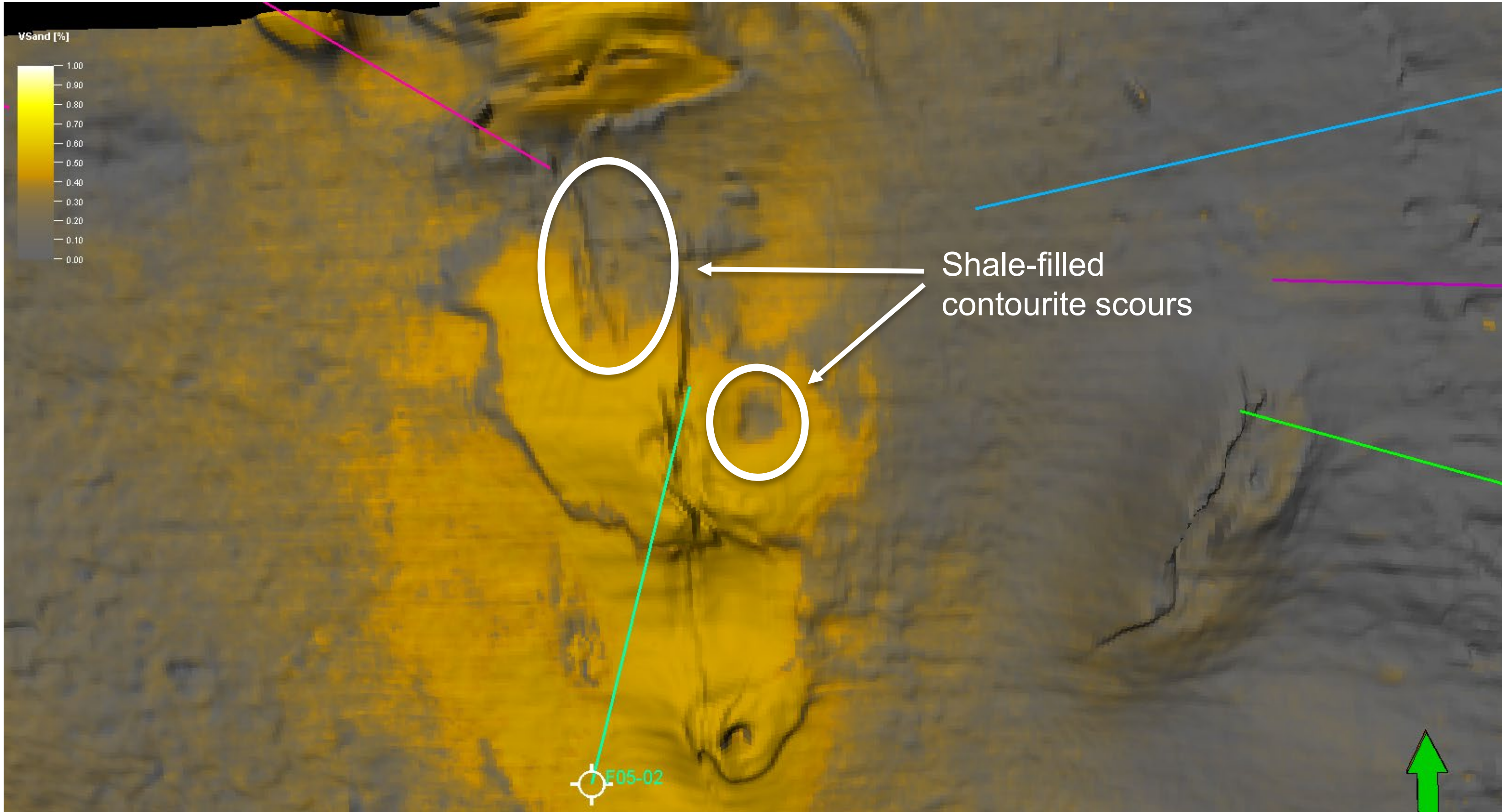

F05-03
F05-01
F4-2A
F05-02
F05-04
F08-01
F04-01
F08-02
F04-03
E06-01
F07-02
F07-01
E09-01
E09-02

S5 – SAND 99

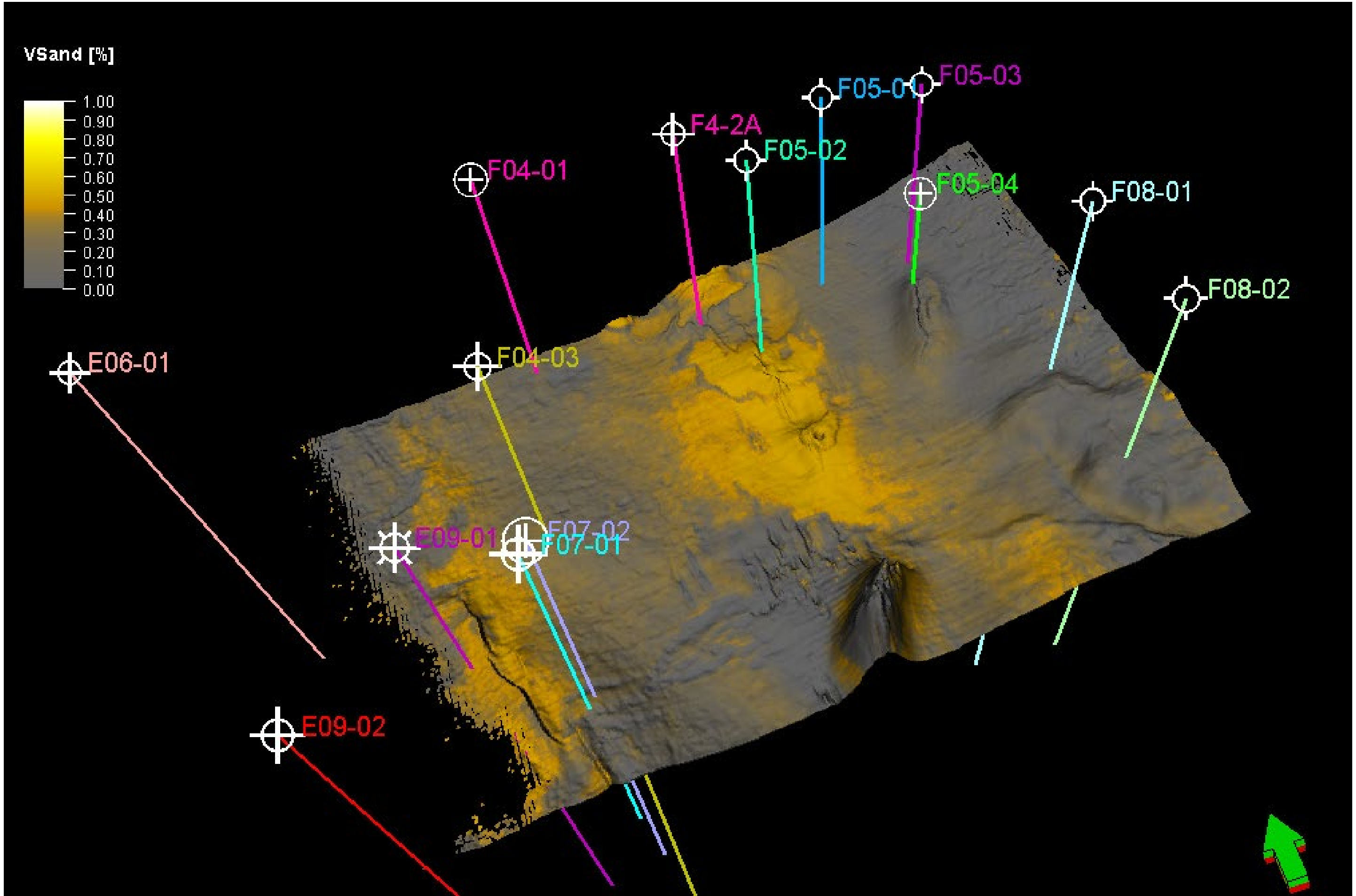


VSand [%]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
F05-03
F05-01
F4-2A
F05-02
F05-04
F04-01
F08-01
F08-02
GWC (phase reversal) shows up as shale border
F04-03
E06-01
Shale-filled contourite scours
F07-02
F07-01
E09-01
E09-02

S5 – SAND 99 – CLOSE-UP AROUND F05-02

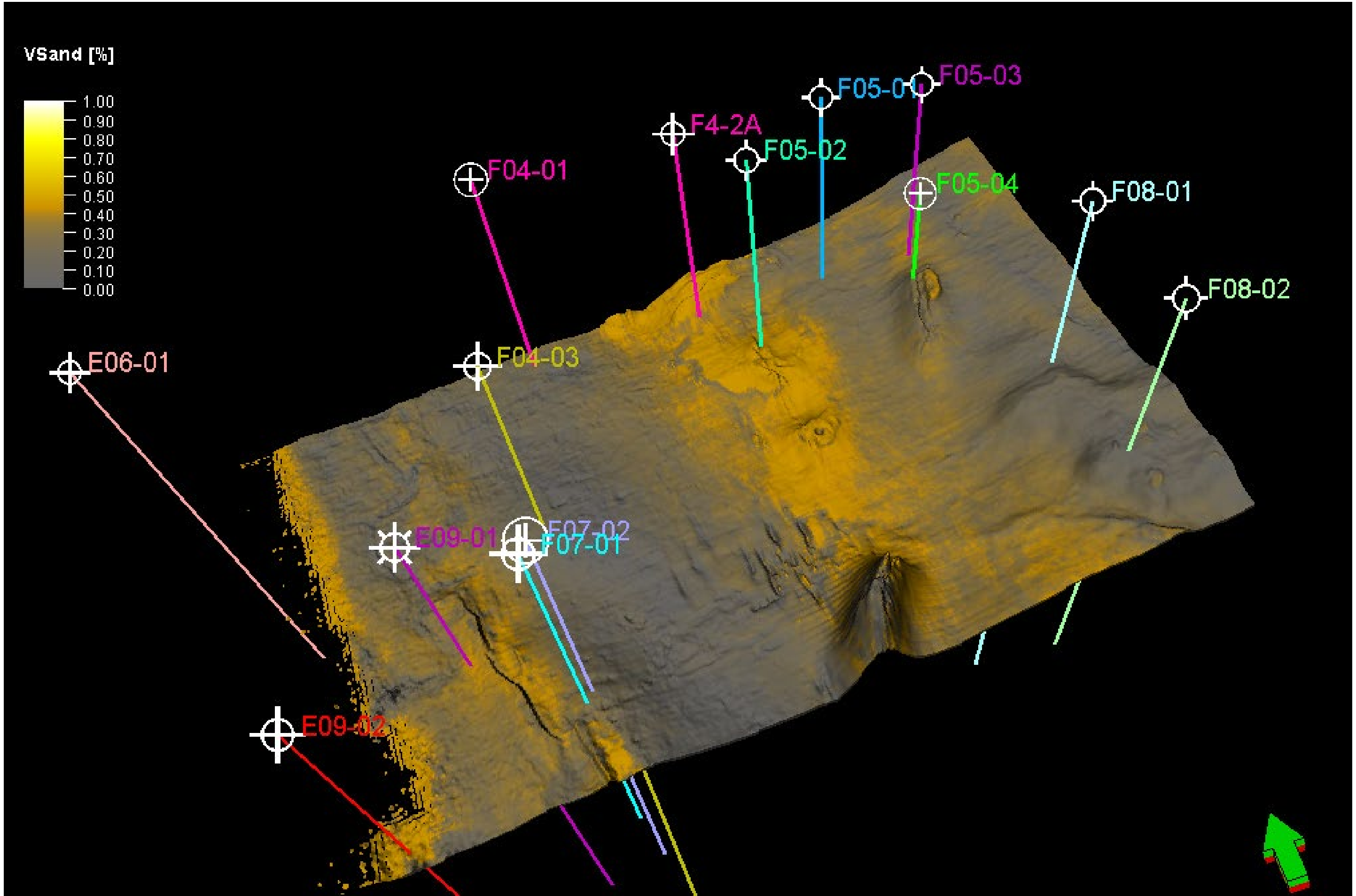


S5 – SAND 99

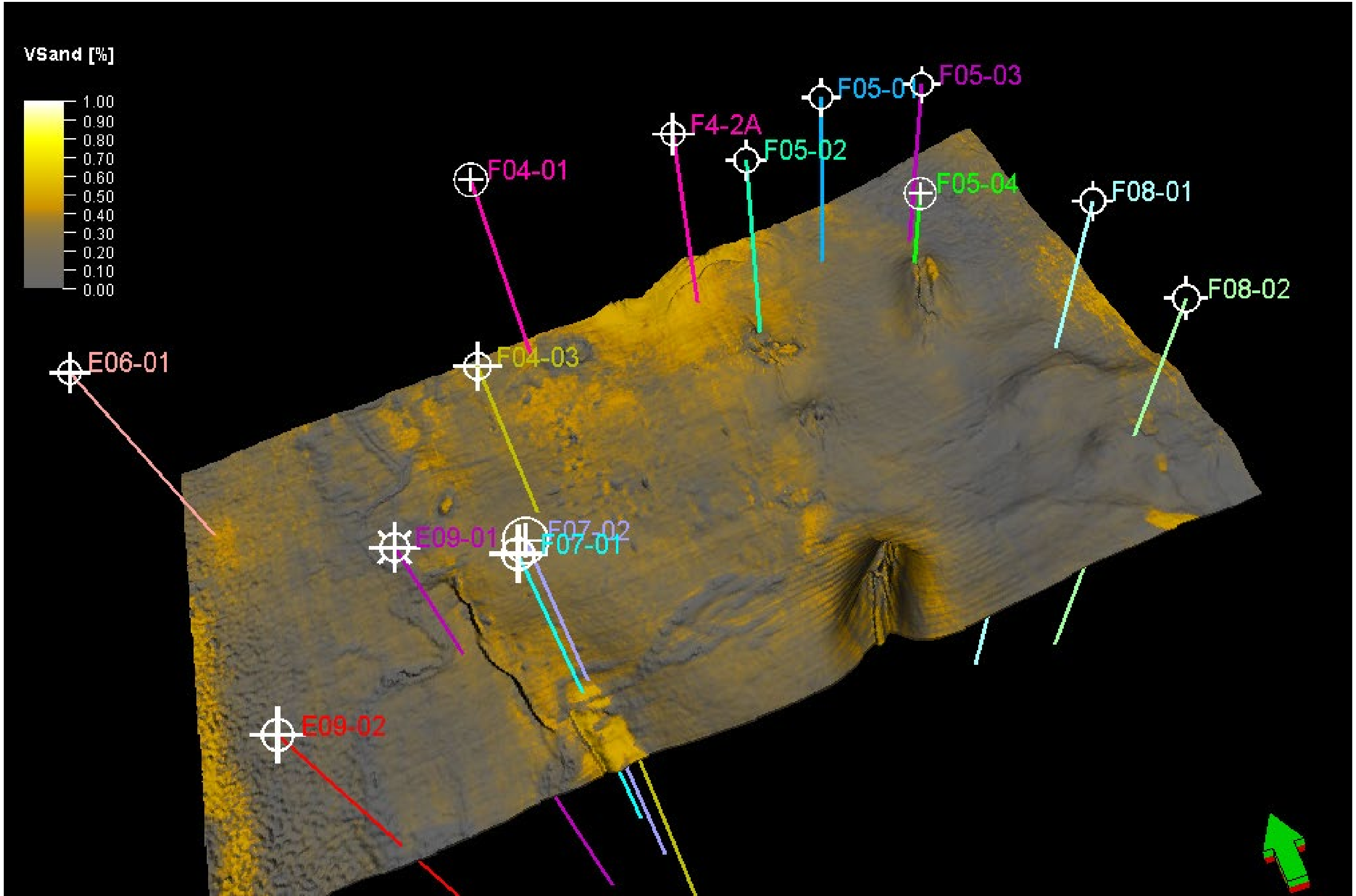


VSand [%]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
F05-01
F05-03
F4-2A
F05-02
F04-01
F05-04
F08-01
F08-02
E06-01
F04-03
E09-01
F07-02
F07-01
E09-02

S5 – SAND 97

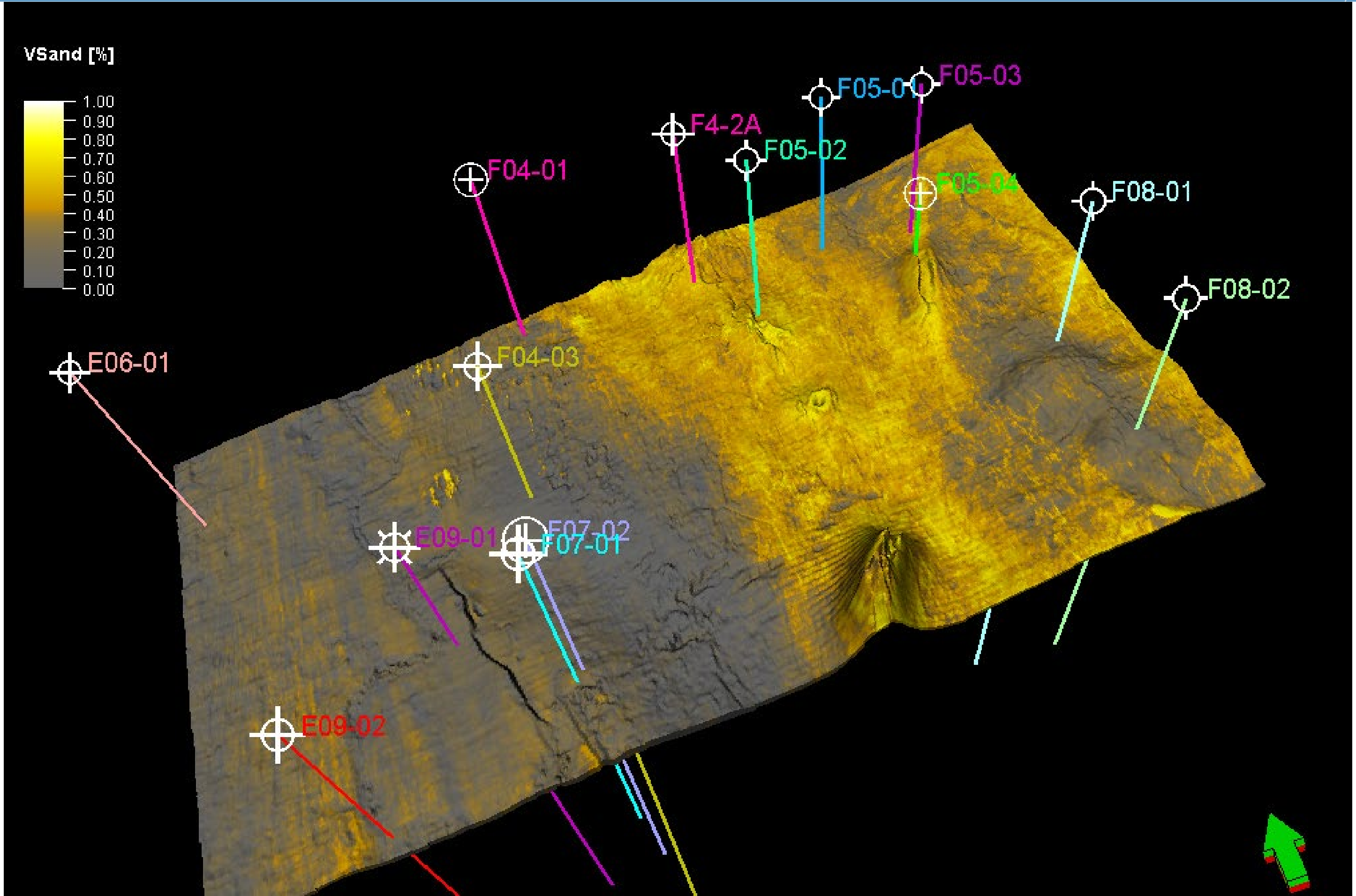

VSand [%]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
F05-01
F05-03
F4-2A
F05-02
F04-01
F05-04
F08-01
F08-02
E06-01
F04-03
E09-01
F07-02
F07-01
E09-02

S6 – SAND 95



VSand [%]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
F05-01
F05-03
F4-2A
F05-02
F04-01
F05-04
F08-01
F08-02
E06-01
F04-03
E09-01
F07-02
F07-01
E09-02

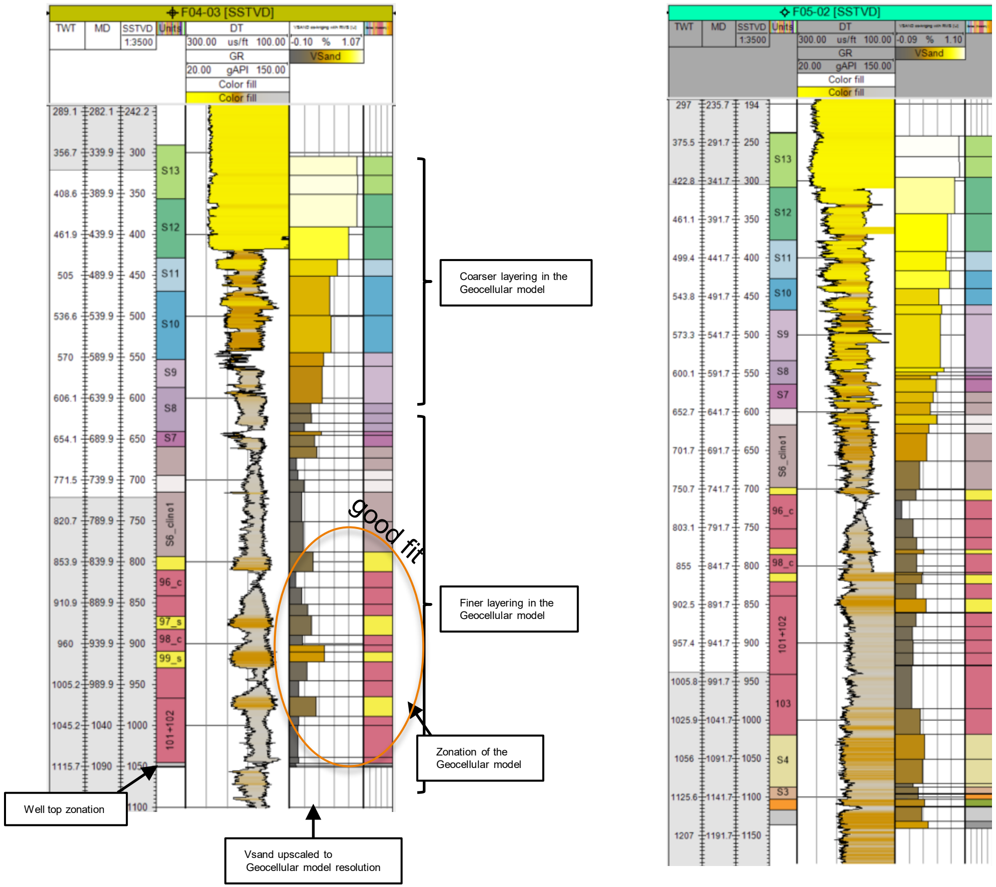
S6 - TOP UNC – S6 TOP CLINOFORM

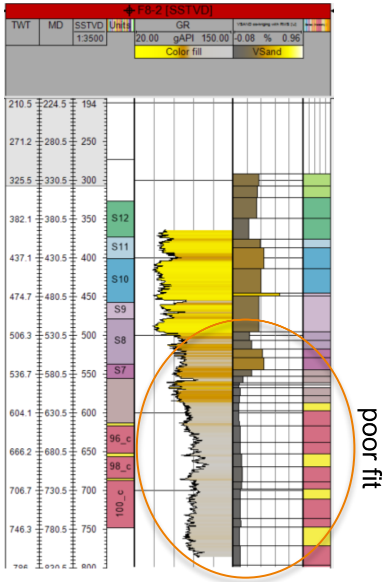


WP3 – PROPERTY MODEL

- Construction of 3D model (Sequence- and Geocellular modelling in Paleoscan)
- Property/reservoir modelling
  - Enhancement, correction and petrophysical evaluation of available well logs
  - 3D interpolation techniques
- Evaluation of sediment properties of brightspots

VSAND - CO-KRIGING WITH THE RMS CUBE





Observations:

- Good representation of the 99,97, and 95 sand layers (as one zone), consequently, one average Vsand
- top of S5-101 CU unit = 1 zone, S5-103 often not represented
- Geocellular model shows erroneous presence of thin downlapping beds in the base (S2, S3)
- Gas effects on properties hard to verify in the absence of RHOB/NPHI logs

..CONCLUSIONS

- Attempts were made to model the sand distribution in both models, from Top S13 to LMU-MMU-EMU.
- First a Vsand logs was created through the global well log calculator:
  - Vshale = (GR – Grmin) / (Grmax – Grmin); Clamp between 0 and 1; VSand = (1 – Vshale)

- The Vsand log was upscaled to the imported PaleoScan reservoir model
- Vsand was distributed in the model using various methods
  - 1) Inverse Distance Squared. Just to have a look at the data
  - 2) Kriging with experimentally determined variograms
  - 3) Co-Kriging with the RMS cube. Preliminary results look promising for prediction of sand (and shale cut-outs), but care must be taken with artefacts such as bright spots, glacial valleys, etc

EXECUTIVE SUMMARY

Project scope and objective

- DHI's (Bright spots) in the Cenozoic Eridanos shelf edge delta in the offshore blocks F4 and F5 s.l. (Area of Interest, AOI) were studied in the light of the well-established regional geologic understanding that is centered around a multiproxy (glacioeustatic, chronostratigraphic, and seismo-stratigraphic) depositional framework. Of main interest are the distribution (in time and space) of the DHI's near the Pliocene-Pleistocene part of the delta sequence (the so-called S4 and S5 sands), their link to depositional facies and the properties of the sediments they occur in.
- This had been achieved by summarizing the current knowledge to update of the multiproxy depositional model, regional seismic and well interpretation, detailed seismic interpretation within the AOI and the generation of 3D geological and property models.
-

The main conclusions are summarized below:

Seismic reflection character

- Seismically the tops of S5 water-saturated "sheet" sands produce a hard kick as they have higher densities than surrounding shales. At BS, i.e. where the sands become gas filled, density decreases to the extent an acoustic polarity reversal occurs.
- These reversals may coincide with a GWC, although we cannot exclude that multiple GWC's exist and that sealing faults within one accumulation may produce GWC's at different depths. Density and sonic logs sometimes show the presence of a gas "cap" which would imply the existence of a GW interface within the sand layer (probably too thin to be detectable in seismic).
- Lateral amplitude dimming (as confirmed with RMS maps) is produced by erosional features in the gas-filled sands.

EXECUTIVE SUMMARY

Seismostratigraphy:

- Detailed seismic interpretation is only performed in the AIO, other seismic interpretation supports the generation of regional seismic panel that are constructed in parallel with the interpretation of key wells.
- We use the Seismic Units (SU) of Kuhlmann (2004) and their correlation with log units as much as possible.
- For units S5 and S6 we adopt the concept that the sands (and/or coarser grained silts) are deposited during highstand shedding (e.g. ten Veen et al., 2013; Harding, 2016) and the clays (and/or finer-grained silts) represent the glacial minima during which sediment influx is low.
- Thus the fines demarcate the low-stand period and the major down drops (sequence boundaries) and associated features are to be found at the transition from sand to clay, i.e. at an in the top of the sands.
- Consequently the flooding surfaces (FS) occur below the sand.
- As the log units of Kuhlmann are rather arbitrarily chosen ("*Unit boundaries were placed at both trend reversals and distinct gamma-ray log breaks*"), we choose to adjust them (slightly) to the top sands as these levels correspond to the reservoir/seal transitions and are therefore more usable for demarcating the top of gas sands (i.e., bright spots). As such, there is also better correlation with marine isotopic stages (MIS).
- The gas sands of unit S5 and S6 are labelled according the MIS.

EXECUTIVE SUMMARY

Main seismic features observed within AOI:

- Good continuation of the S5 sands, where the top of these sands are discontinuous (erosive) and the occurrence of bright spots (BS) is high (e.g. A15-03/4 and F05-02).
- This section runs somewhat oblique to the paleo shelf trend and higher up the slope (right) individual S5 sand amalgamate or are truncated
- The presence of MTC's suggest major slope failure during early S5 time
- Stacked (X-mas tree) occur in the >S6 units in the north but are relatively absent in the F4/5 area with the exception of the near F04-01 BS's that reside in S7,S8 and S11, i.e., above the top S6 unconformity
- A large BS occurs at the transition of S4-S5 in a "dish-like" package interpreted as low-stand wedge (S5-LST). This may represent a stratigraphic trap bounded by both down- and onlap.
- The F03-02 gas accumulation in top S4 seems to be sealed by slightly younger onlapping shales in the base of S5 base (the MIS-103 highstand)
- The F02B gas accumulation in top S4 is stratigraphically similar to F03-02 (i.e. sealed by slightly younger onlapping shales in the base of S5 base). Here, the (salt dome related) structure is more prominent and faulted.

EXECUTIVE SUMMARY

Regional integration:

- Within the AOI mainly units S4-S13 are present
- Throughout the northern offshore, the correlatability of individual (reservoir) sands within units S5- S8 appears high, both in wells and in seismics.
- Compared to units below and above, S5 comprises very low angle clinoforms. No steep, coastal clinoforms are present.
- In the eastern part of the AOI (landward of the offshore) sands are truncated by younger units and individual sands amalgamate. This especially holds for the S5 sands.
- The base S6 forms a major unconformity. Steep, coastal clinoforms in unit S6 occur at least 70 km west compared to unit S5

Depositional Setting of the S5 sands:

- Based on the occurrence of depositional features (e.g. bottom currents, fluvial channel systems), it is often possible to gain understanding in the position of the paleo shelf edge and/or base of slope.
- The variety in interpreted sedimentary features (MTC's, fluvial systems, contourites, scour marks) within the unit S5 indicates that the relative sea level position strongly fluctuated between warmer and colder periods during unit S5 (see also figure below); Hence the position of the base of slope and shelf edge shifted several times within unit S5 by tens-, or possibly hundreds of kilometers, exhibiting an overall prograding trend.
- Contourites occur at the base of slope and are produced by tidal currents as presently active in the North Sea (and form similar sand waves). These currents account for continuous redistribution and homogenization of the sand. During glacioeustatic sea-level lowering the sandy contourites may become incised by channels (up to 60 m) that are (later) infilled by finer-grained glacial deposits. These may form local seals to the sand as can be seen around well F05-02 and are well-known features from the A15 block.

EXECUTIVE SUMMARY

Property modelling

- Attempts were made to model the sand distribution in both models, from Top S13 to LMU-MMU-EMU.
- First a Vsand logs was created through the global well log calculator:
  - Vshale = (GR – Grmin) / (Grmax – Grmin); Clamp between 0 and 1; VSand = (1 – Vshale)
  - The Vsand log was upscaled to the imported PaleoScan reservoir model
- Vsand was distributed in the model using various methods
  - 1) Inverse Distance Squared. Just to have a look at the data.
  - 2) Kriging with experimentally determined variograms.
  - 3) Co-Kriging with the RMS cube. Preliminary results look promising for prediction of sand (and shale cut-outs), but care must be taken with artefacts such as bright spots, glacial valleys, etc.

Applicability of the Vsand property model:

- Good representation of the 99,97, and 95 sand layers (as one zone), consequently, one average Vsand.
- top of S5-101 CU unit = 1 zone, S5-103 often not represented.
- Geocellular model shows erroneous presence of thin downlapping beds in the base (S2, S3).
- Gas effects on properties in the F4/F5 area hard to verify in the absence of RHOB/NPHI logs.

OVERVIEW OF DISSIMINATED PRODUCTS

- Petrel project with regional seismicp and well panels, Paleoscan results, and property model.
- Arc GIS project with all results as map products.
- Excel files with overview of data used.
- Powerpoint file with project results and explanation (this document).

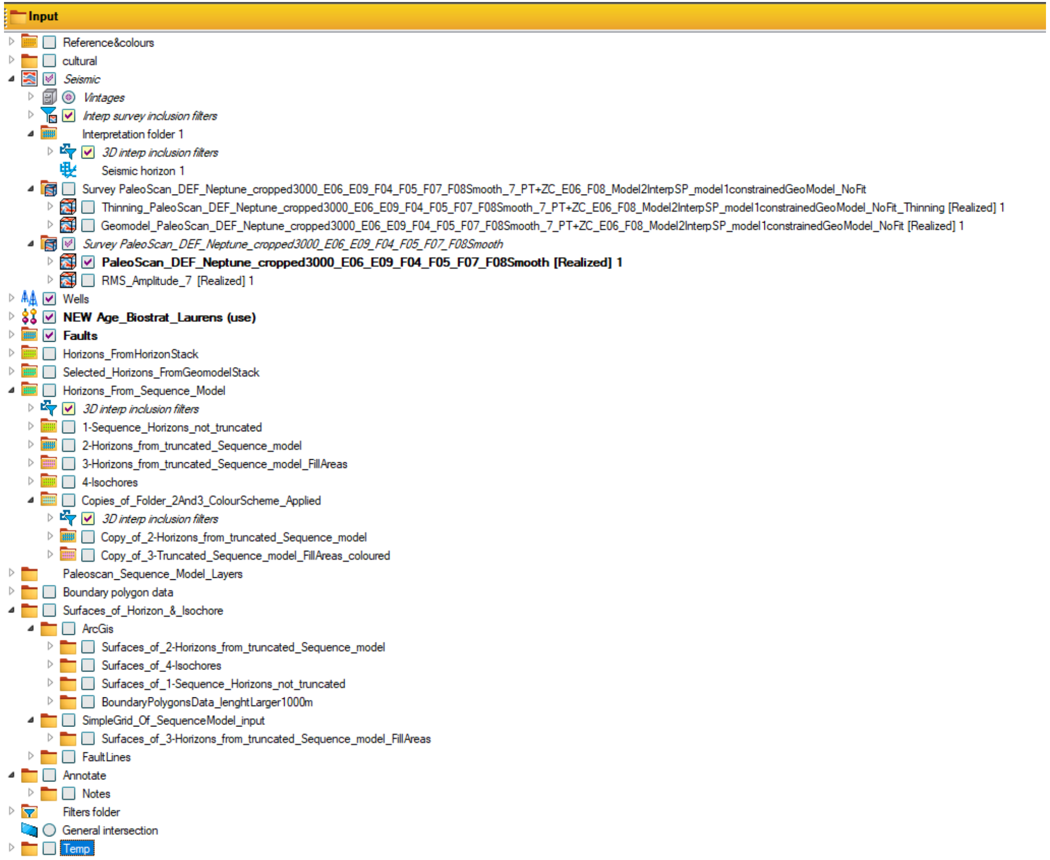
PETREL PROJECT (F4F5_STUDY.PET)

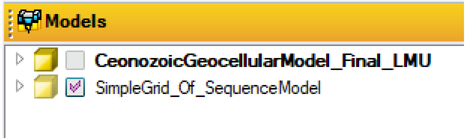
General project set up

- Geographical data
- Collection of wells from TNO and Neptune Energy
- Well tops based on TNO 2013 and adjusted
- Other well tops (consulted)
- Seismic according data structure of Neptune Energy, no actual data (expand)
- Lay out of the well panels
- Surfacers generated from new interpretation (to support regional correlelations, no detail)
- a.o. results from R. Harding thesis, DGM deep v5.0
- a.o. wavelets used for synthetics
- Reference objects for colour labelling (used in workflows)
- Interpreted faults in AOI
- Paleoscan results

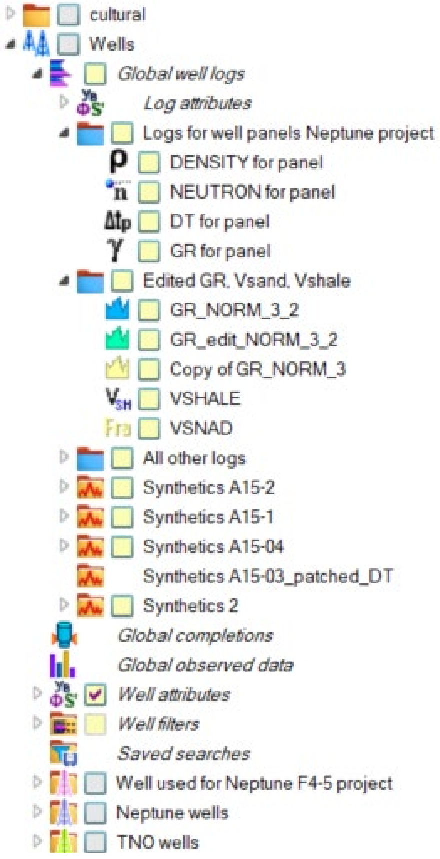
Use the hyperlinks for more explanation

PETREL PROJECT (F4F5_STUDY.PET)





WELL DATA



→ Log used in well panels

→ Normalized GR and calculated derivatives for property modelling

→ Numerous other logs from TNO 2013, Neptune Energy (most of them not used)

→ Seledction of wells from TNO 2013 and Neptunde Energy (well namesretained) See overview

→ Wells provided by Neptune Energy and not used in this project

→ Well from the TNO 2013 well not used in this project

SEISMIC DATA

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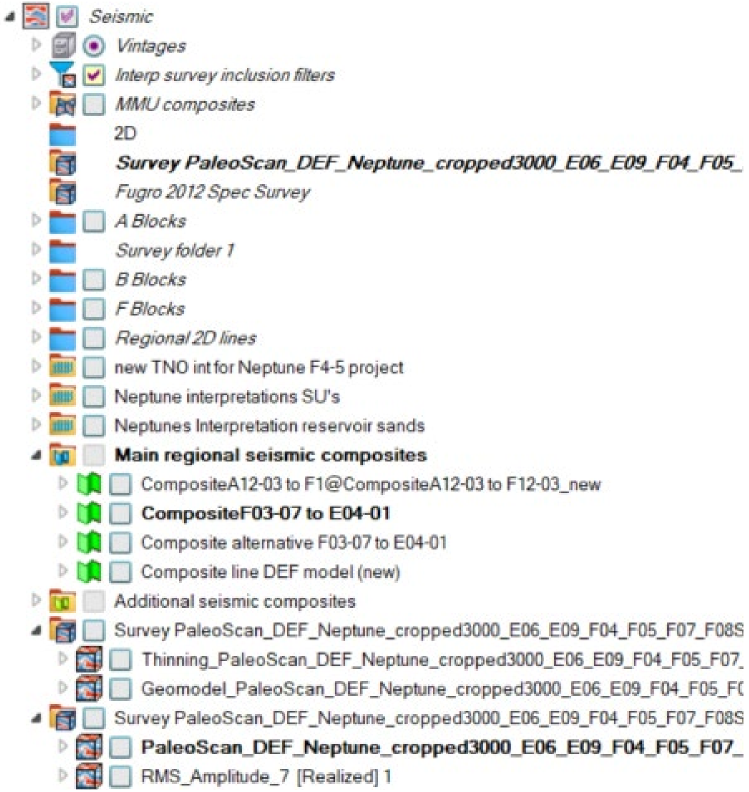


Surveys not provided

Interpretations to support regional seismic- and well correlation

Paleoscan surveys provided

Horizons_FromHorizonStack - Selection of horizons from the horizonstack, The horizon stack contains 1000 horizons extracted from the RTM model. For each horizon 2 attributes, TWT and RMS attribute, are included

Selected_Horizons_FromHorizonStack- Selected subset of horizons from the horizonstack, which were used for picking the horizon input to the sequence model. For each horizon 2 attributes, TWT and RMS attribute, are included

Horizons_From_Sequence_Model -

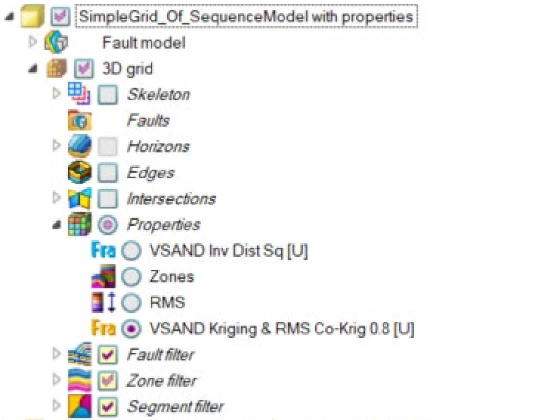
- 1-Sequence_Horizons_not_truncated
- 2-Horizons_from_truncated_Sequence_model
- 3-Horizons_from_truncated_Sequence_model_FillAreas – area is filled in truncated area
- 4-Isochores
- Copies_of_Folder_2And3_ColourScheme_Applied – subfolders 1 and 2 contain copies of the truncated horizons with the object colour adjusted to the colour scheme
    1. Copy_of_2-Horizons_from_truncated_Sequence_model
    2. Copy_of_3-Truncated_Sequence_model_FillAreas_coloured

Boundary polygon data – boundary data extracted from truncated horizons

Surfaces_of_Horizon_&_Isochore

- ArcGis – Surfaces created for ArcGis based on horizons listed in Horizons_From_Sequence_Model folder
    1. Surfaces_of_2-Horizons_from_truncated_Sequence_model
    2. Surfaces_of_4-Isochores
    3. Surfaces_of_1-Sequence_Horizons_not_truncated
    4. BoundaryPolygonsData_lenghtLarger1000m – copy of boundary data extracted from truncated horizons. Polylines with a length less than 1000m are excluded
- SimpleGrid_of_SequenceModel_input - Surfaces created for input in the simple model.
    1. Surfaces_of_3-Horizons_from_truncated_Sequence_model_FillAreas
- Faultlines - faultcenterlines calculated for each sequence model horizon using the quick scan fault interpretation set

PALEOSCAN MODELS AND PROPERTIES



→ Simple grid created in Petrel. Input to the model are the 100x100 grid increment surfaces based on the truncated horizons-truncated areas filled made in Paleoscan.

Properties from property modelling in Petrel

Zonation according seismostrat units (MMU-S13)

→ Geocellular model exported from Paleoscan (eclipse (GRDECL) format)

SimpleGrid_Of_SequenceModel - Simple grid created in Petrel. Input to the model are the 100x100 grid increment surfaces based on the truncated horizons-truncated areas filled

Properties from property modelling in Petrel

Detailed zonation according including individual sands layers