



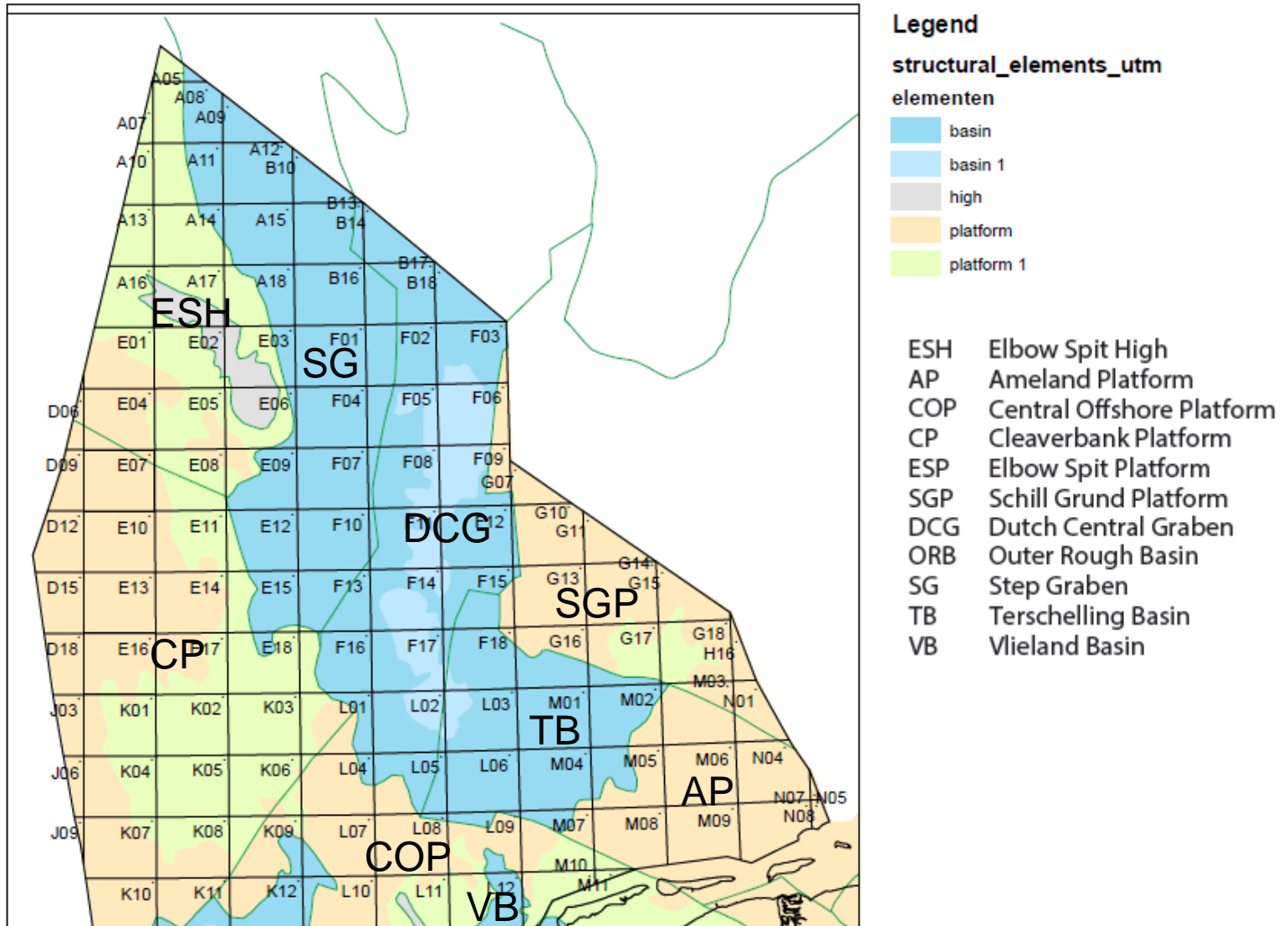
## Munsterman et al., 2012

**Revision and update of the Callovian-Ryazanian  
Stratigraphic Nomenclature in the northern Dutch offshore,  
i.e. Central Graben Subgroup and Scruff Group**





## Map showing the Mesozoic structural elements of the northern part of the Dutch Offshore





# Callovian-Ryazanian on the GTS 2012

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP	
Phanerozoic	Cenozoic	Quaternary	Holocene				
			Pleistocene	Upper	0.0117		
				"Ionian"	0.126		
				Calabrian	0.781		
				Gelasian	1.806		
		Neogene	Pliocene	Piacenzian	2.588		
				Zanclean	3.600		
			Miocene	Messinian	5.332		
				Tortonian	7.246		
				Serravallian	11.608		
				Langhian	13.82		
				Burdigalian	15.97		
				Aquitanian	20.43		
				Oligocene	Chattian	23.03	
	Rupelian				28.4 ± 0.1		
	Eocene	Priabonian	33.9 ± 0.1				
		Bartonian	37.2 ± 0.1				
		Lutetian	40.4 ± 0.2				
		Ypresian	48.6 ± 0.2				
	Paleocene	Thanetian	55.8 ± 0.2				
		Selandian	58.7 ± 0.2				
		Danian	~ 61.1				
		Mesozoic	Cretaceous	Upper	Maastrichtian	65.5 ± 0.3	
					Campanian	70.6 ± 0.6	
					Santonian	83.5 ± 0.7	
	Coniacian				85.8 ± 0.7		
	Turonian				~ 88.6		
	Lower			Cenomanian	93.6 ± 0.8		
				Albian	99.6 ± 0.9		
				Aptian	112.0 ± 1.0		
Barremian				125.0 ± 1.0			
Hauterivian				130.0 ± 1.5			
Paleozoic	Carboniferous		Varangian	~ 133.9			
			Berriasian	140.2 ± 3.0			
				145.5 ± 4.0			

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	145.5 ± 4.0	
				Kimmeridgian	150.8 ± 4.0	
				Oxfordian	~ 155.6	
				Callovian	161.2 ± 4.0	
				164.7 ± 4.0		
		Middle		Bathonian	167.7 ± 3.5	
				Bajocian	171.6 ± 3.0	
				Aalenian	175.6 ± 2.0	
		Lower	Toarcian	183.0 ± 1.5		
			Pliensbachian	189.6 ± 1.5		
			Sinemurian	196.5 ± 1.0		
			Hettangian	199.6 ± 0.6		
			Triassic	Upper	Rhaetian	203.6 ± 1.5
		Norian			216.5 ± 2.0	
	Carnian	~ 228.7				
	Middle	Ladinian		237.0 ± 2.0		
		Anisian		~ 245.9		
	Lower	Olenekian	~ 249.5			
		Induan				
	Paleozoic	Permian	Lopingian	Changhsingian	251.0 ± 0.4	
				Wuchiapingian	253.6 ± 0.7	
			Guadalupian	Capitanian	260.4 ± 0.7	
				Wordian	265.6 ± 0.7	
				Roadian	268.0 ± 0.7	
				Kungurian	270.6 ± 0.7	
		Cisuralian	Artinskian	275.6 ± 0.7		
			Sakmarian	284.4 ± 0.7		
			Asselian	294.6 ± 0.8		
				299.0 ± 0.8		
		Carboniferous	Pennsylvanian	Upper	Gzhelian	303.4 ± 0.9
Kasimovian				307.2 ± 1.0		
Mississippian			Middle	Moscovian	311.7 ± 1.1	
			Lower	Bashkirian	318.1 ± 1.3	
			Upper	Serpukhovian	328.3 ± 1.6	
			Middle	Visean	345.3 ± 2.1	
Lower	Tournaisian	359.2 ± 2.5				

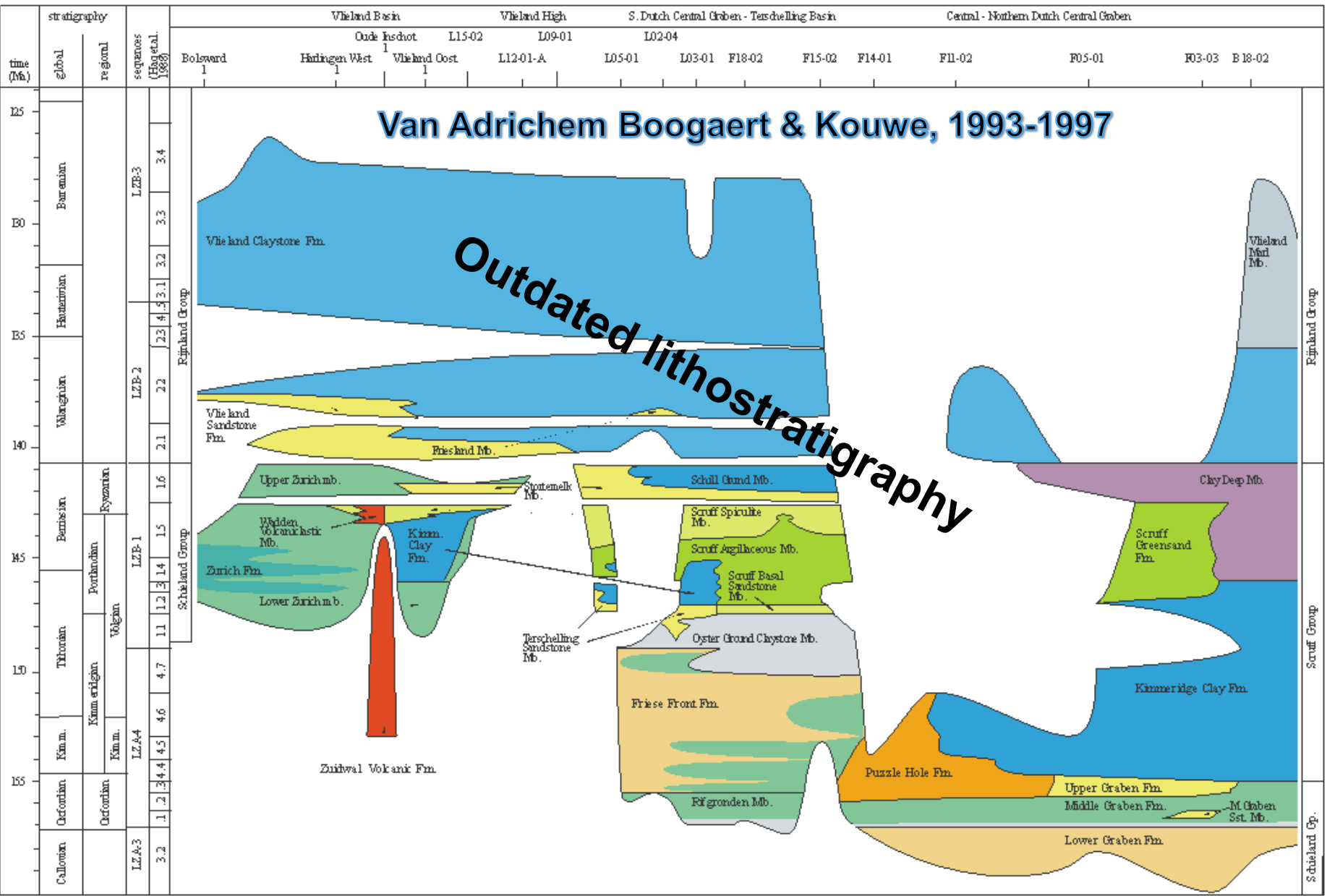


# Munsterman et al., 2012: new and revised lithostratigraphy in the Central Graben Subgroup and Scruff Group

**TNO** innovation for life

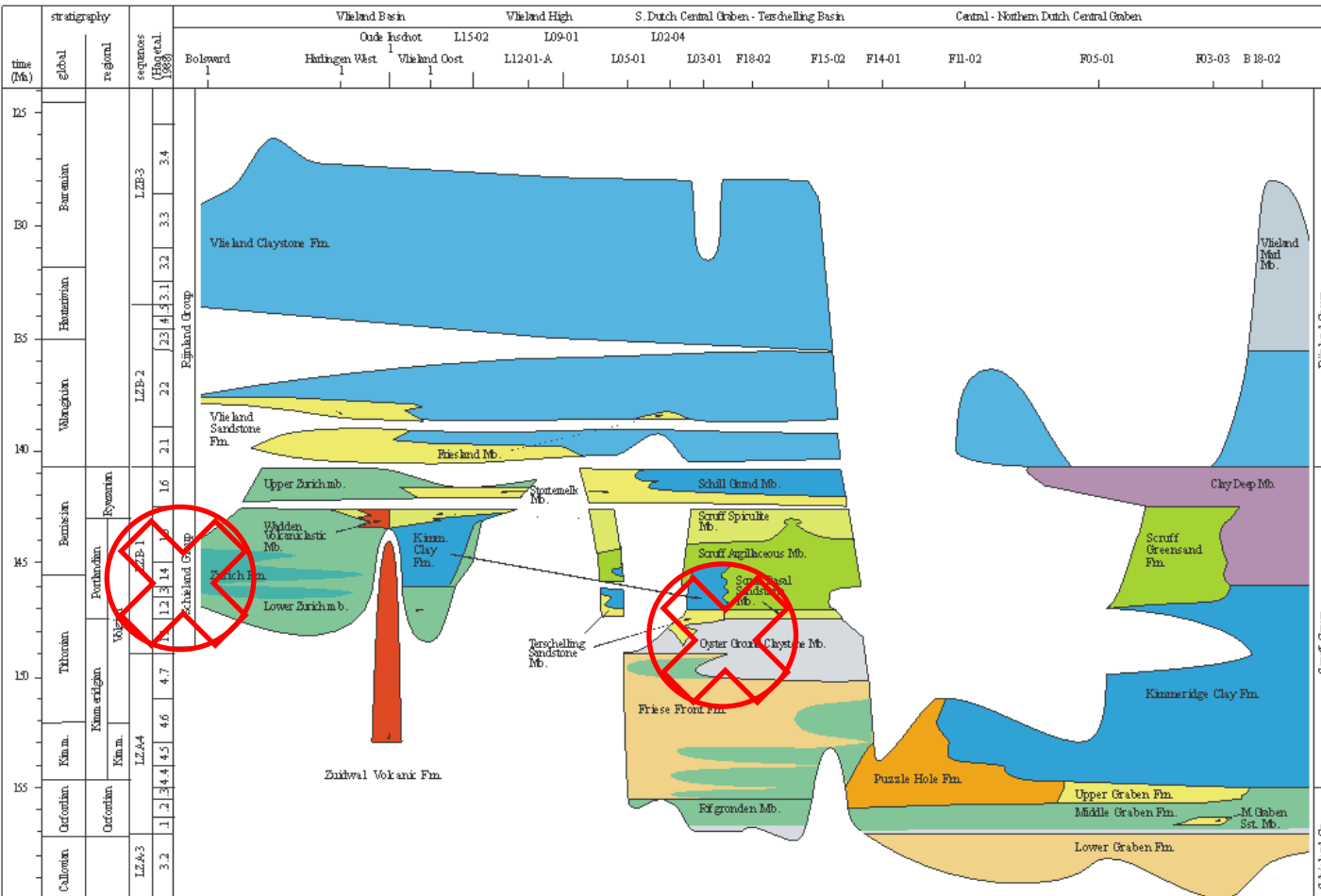
Van Adrichem Boogaert & Kouwe, 1993-1997

Outdated lithostratigraphy

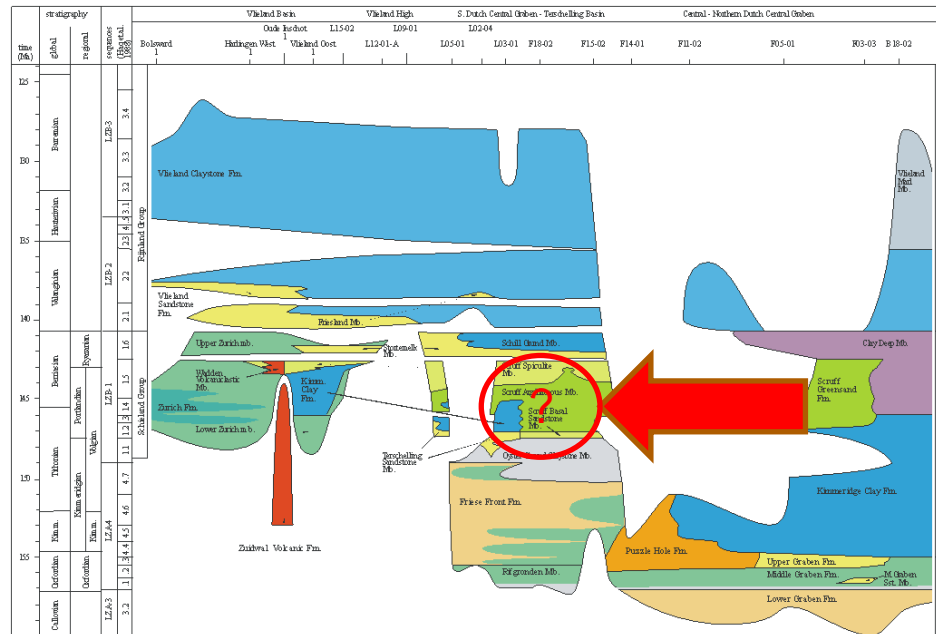




# Statement of lithostratigraphic problems (1)



The inclusion of the lagoonal to restricted marine Oyster Ground Claystone Member and the marginal to shallow marine barrier Terschelling Sandstone Member in the non-marine Friese Front Formation is inconsistent. The Friese Front Formation is part of the continental Schieland Group



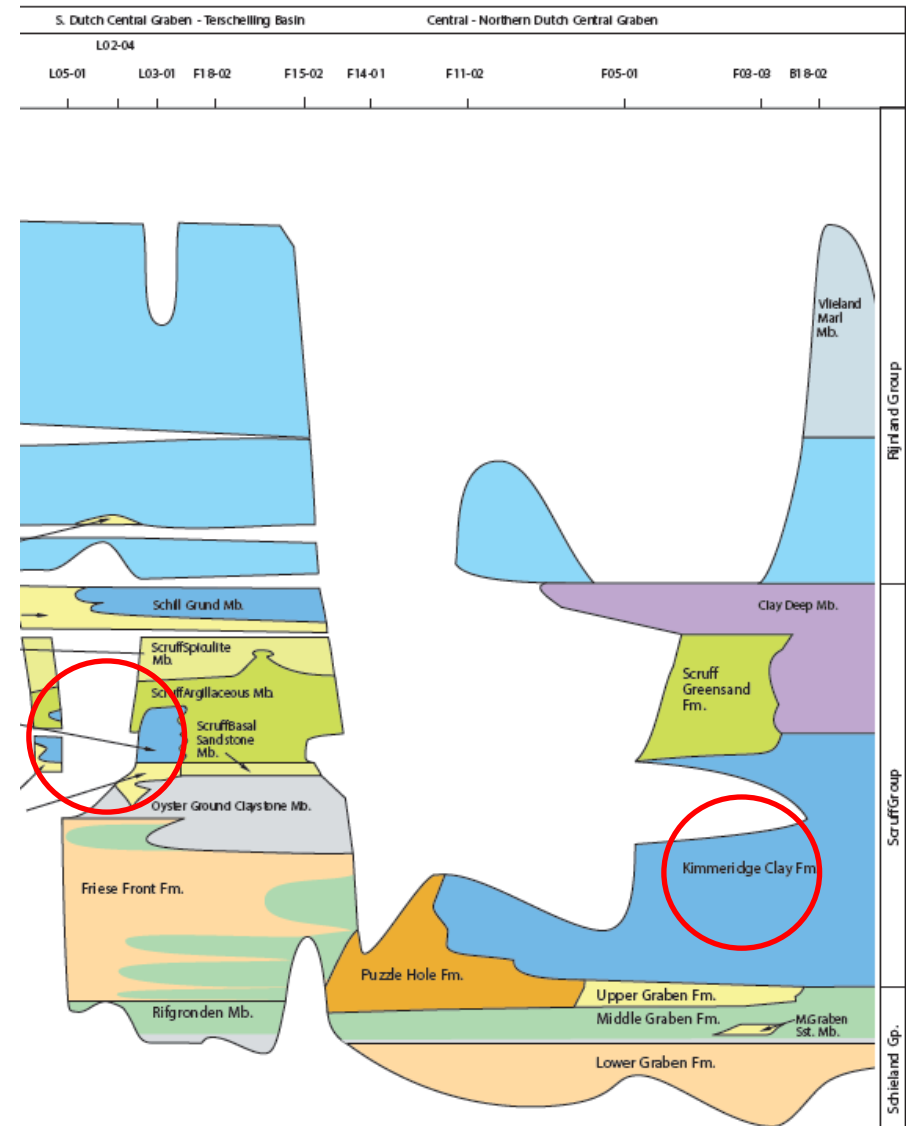
There is persistent lithostratigraphic confusion in the Terschelling Basin about where the clayey to sandy intervals below the Scruff Spiculite Member should be placed in the lithostratigraphic framework. Sometimes the clayey to sandy intervals are assigned to the Kimmeridge Clay Formation, sometimes to the Scruff Argillaceous Member (Scruff Greensand Formation) or sometimes to both. Biostratigraphic work revealed that the sandy Scruff Argillaceous Member in the north of the basin gradually changes into clays to the south, posing an additional complication.





## Statement of lithostratigraphic problems (3)

The Kimmeridge Clay Formation in the northern Central Graben exhibits significant differences from the same formation in the Terschelling Basin. The Kimmeridge Clay Formation in the northern Central Graben is older (Late Oxfordian and younger), has a different depositional setting (open marine conditions) and shows organic rich deposition in contrast to the Terschelling Basin. The palaeoenvironment of the Kimmeridge Clay Formation in the Terschelling Basin is shallow marine and is dated as late Late Kimmeridgian and younger.

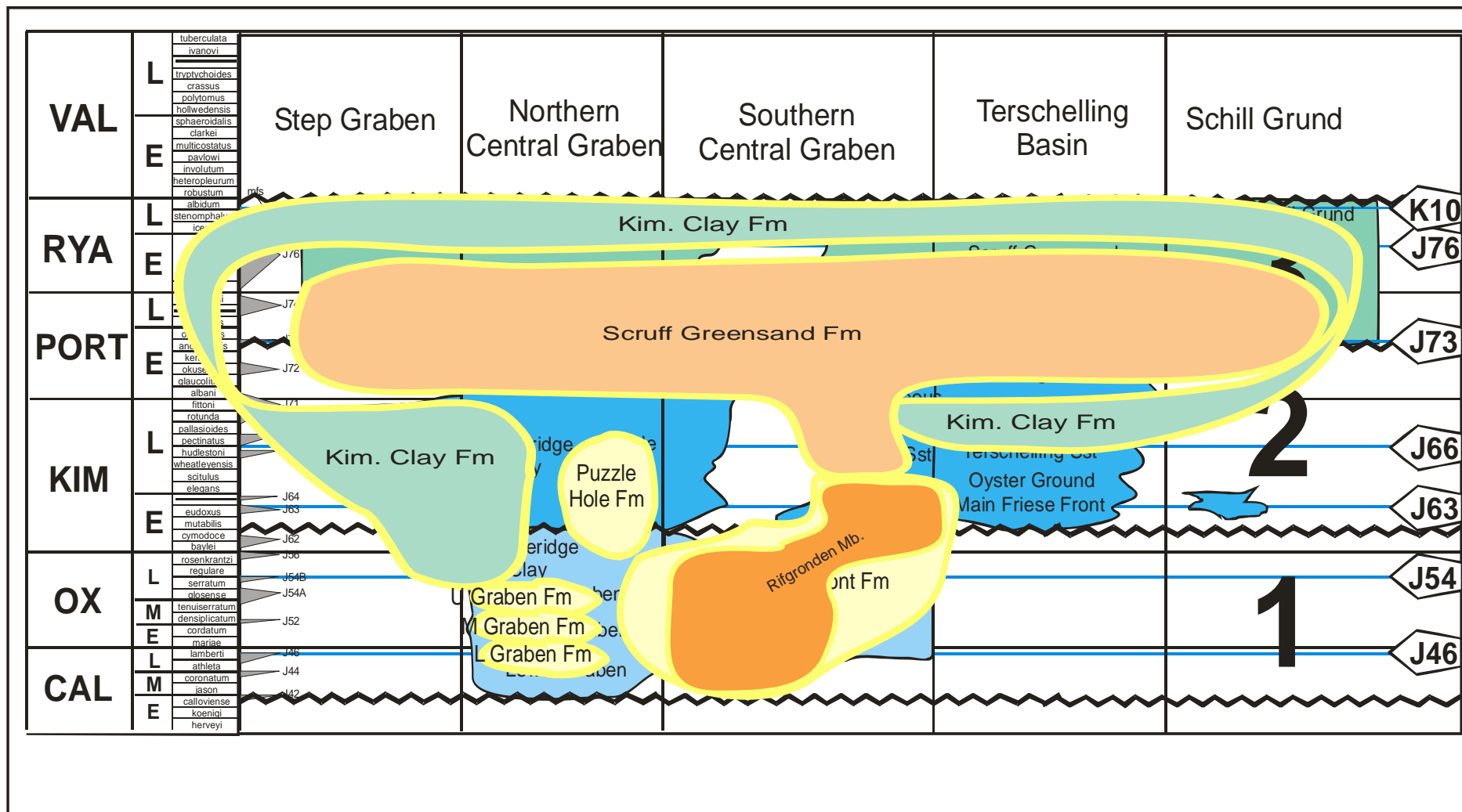




## Statement of lithostratigraphic problems (4)

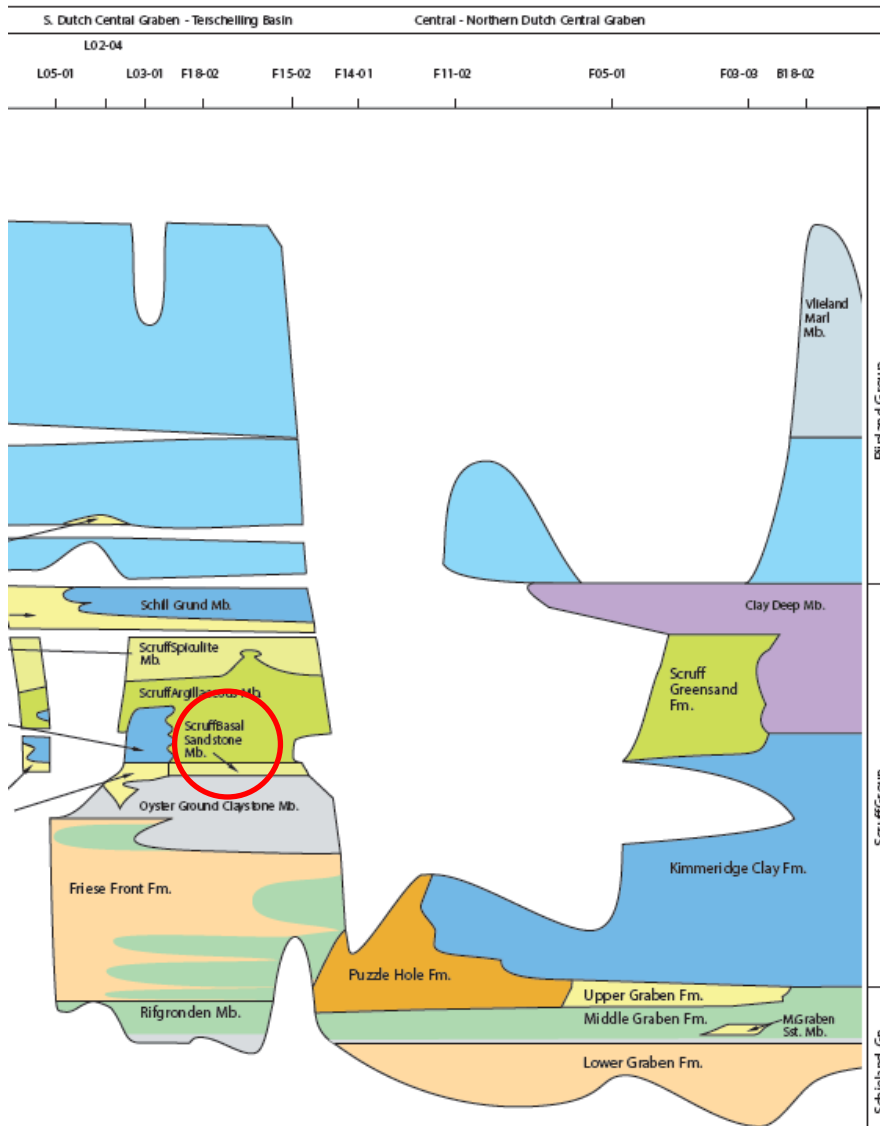
Another inconsistency in the Kimmeridge Clay Formation following the Nomenclature of Van Adrichem Boogaert & Kouwe (1993) is the chronostratigraphical divergence between its Clay Deep and Schill Grund members and the rest of the formation. This is particularly evident in the northern Central Graben (e.g. well B18-02) where the Clay Deep Member is split from the main Kimmeridge Clay by the Scruff Greensand Formation. In this area the Kimmeridge Clay Formation has an age from the Late Oxfordian to Early Portlandian, while the Clay Deep Member is dated as Ryazanian (*runctoni-albidum* Ammonite zones). In addition the lithology and depositional environment of the Clay Deep Member are different in comparison with the Main Kimmeridge Clay Member. In the Terschelling Basin (e.g. well L06-02) the same inconsistency is encountered with the shallow marine Schill Grund Member which ranges from the latest Early to Late Ryazanian (*kochi-albidum* Ammonite zones) in relation to the rest of the older and open marine Kimmeridge Clay Formation in the northern Central Graben.







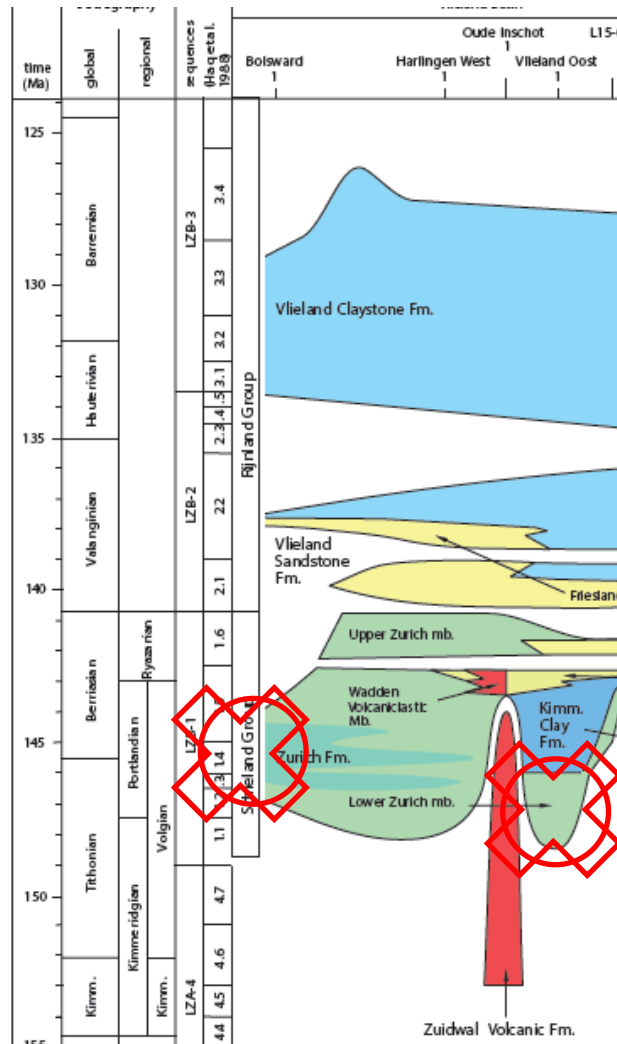
## Statement of lithostratigraphic problems (5)



In terms of lithology and log character, the predominantly sandy part of the Scruff Argillaceous Member is difficult to distinguish from the underlying Scruff Basal Sandstone Member in the NW part of the Terschelling Basin, Blocks F15, F17, F18 and G16.



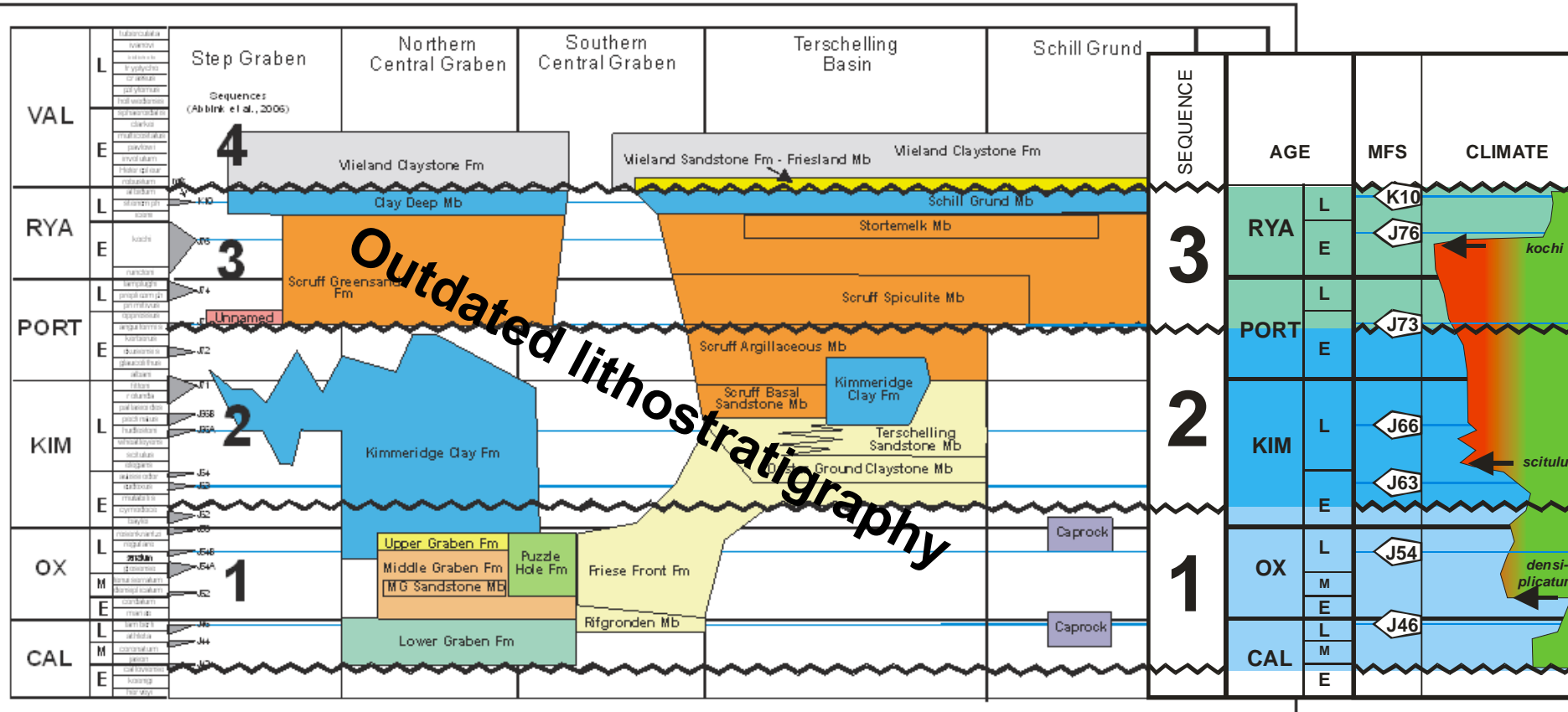
## Statement of lithostratigraphic problems (6)



Siliciclastic successions of Sequence 2 sensu Abbink et al. (2006) from the northern Vlieland Basin (situated north of the Wadden Islands and south of the Central Offshore Platform) are either considered to be absent or, when occasionally present, associated with the Lower Zurich Member, Zurich Formation. The Zurich Formation is classified in the mainly continental Schieland Group. Recent studies however show a restricted to shallow marine setting.



## Abbink et al., 2006: introduction to sequences



SL	Schiland Group
SLC	Central Graben Subgroup
SLCU	Upper Graben Formation
SLCM	Middle Graben Formation
SLCUM	Upper claystone member
SLCMS	Middle Graben Sandstone Member
SLCML	Lower claystone member
SLCL	Lower Graben Formation
SLCP	Puzzle Hole Formation
SLCF	Friesse Front Formation
SLCFM	Main Friesse Front member
SLCFR	Rifgronden Member
SLCFO	Oyster Ground Claystone Member
SLCFT	Terschelling Sandstone Member

SG	Scruff Group
SGKI	Kimmeridge Clay Formation
SGKIM	Main Kimmeridge Clay member
SGKIC	Clay Deep Member
SGKIS	Schill Grund Member
SGGS	Scruff Greensand Formation
SGGSB	Scruff Basal Sandstone Member
SGGSA	Scruff Argillaceous Member
SGGSP	Scruff Spiculite Member
SGGSS	Stortemelk Member

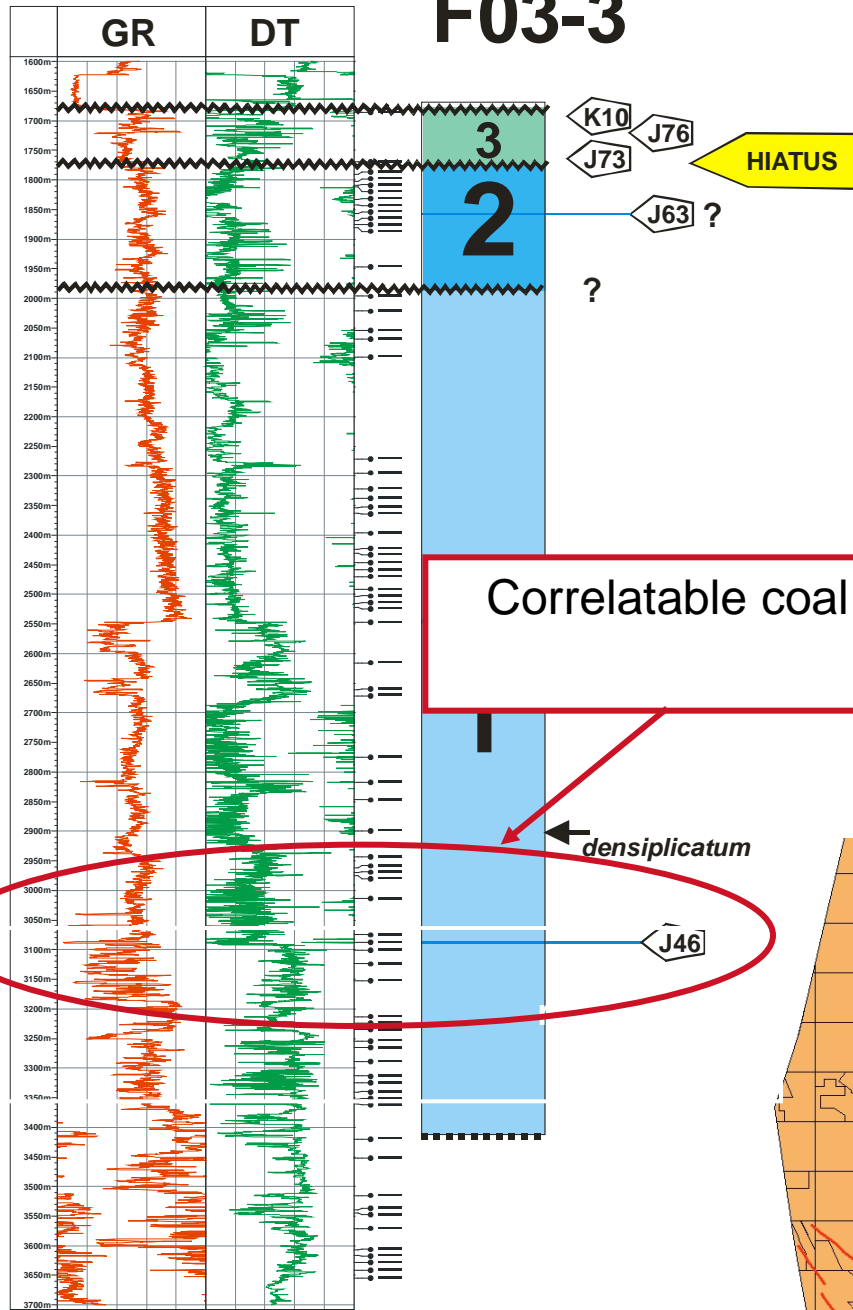
Fig. 1a Huidige lithostratigrafie Boven Jura



# Late Jurassic basin evolution: 3 sequences

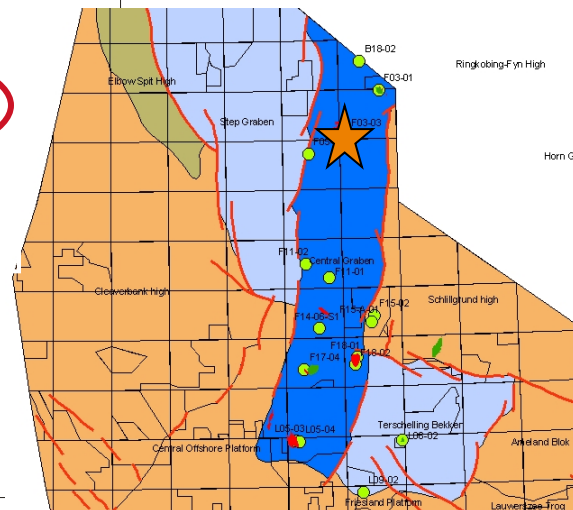
- › **Sequence 1: Graben axis development**
- › Sequence 2: Change in structural style, peripheral basins develop
- › Compressional features in Graben axis: reverse faulting and halokinesis
- ›
- › Sequence 3: Deceleration of faulting and flooding of platform areas
- › Thermal sag, fault locking and the Cretaceous transgression

# F03-3



## Sequence 1 NL

- Opening DCG (rift initiation)
- Transgressive trend
  - Non-marine (Lower Graben)
  - Lacustrine/estuarine (Middle Graben)
  - Barrier (Upper Graben)
  - Offshore marine (Kimmeridge Clay)



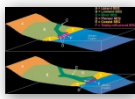
SEQUENCE	AGE	MFS	CLIMATE
3	RYA	L E	K10 J76 ← <i>kochi</i>
	PORT	L E	J73
2	KIM	L E	J66 J63 ← <i>scitulus</i>
	OX	L M E	J54 J46 ← <i>densiplicatum</i>
1	CAL	L M E	J46



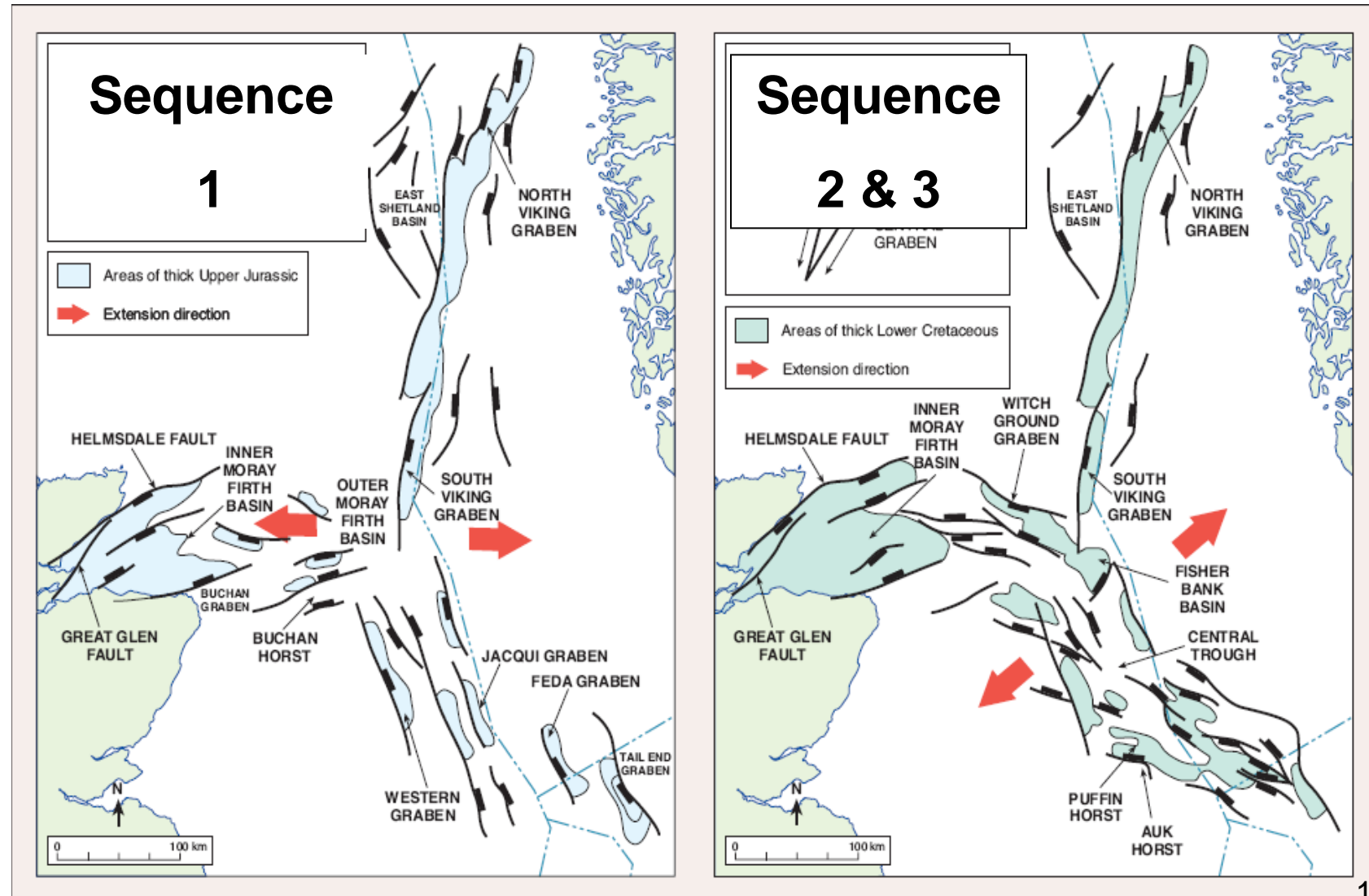
# Late Jurassic basin evolution: 3 sequences

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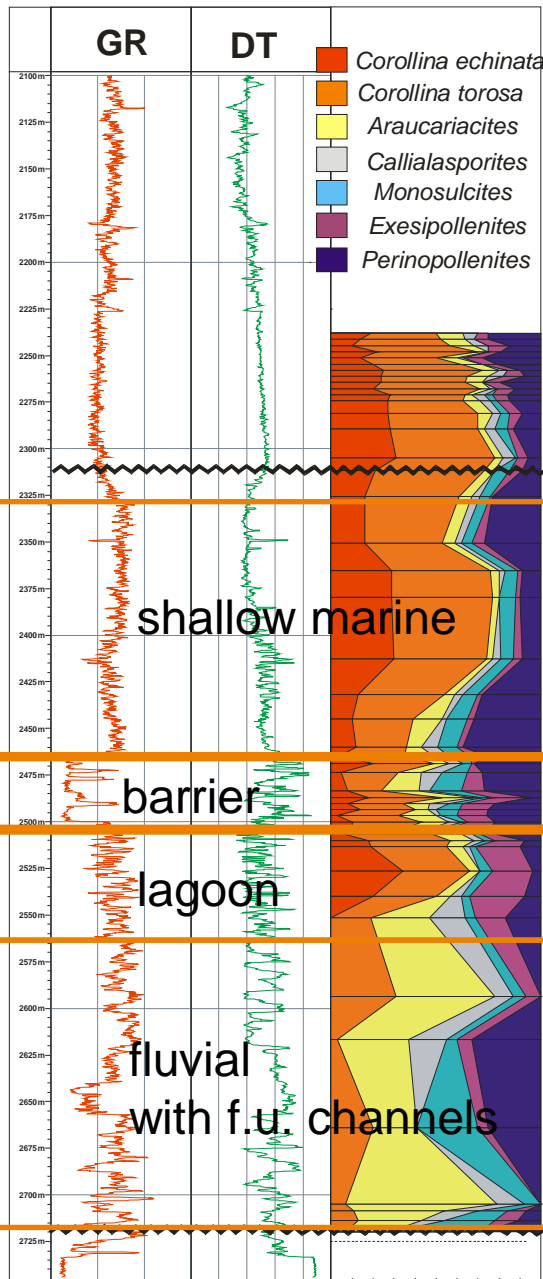




# Driving mechanism: change extension direction



# L06-2



3

K10 ?

J76 ← *kochi*

J73

2

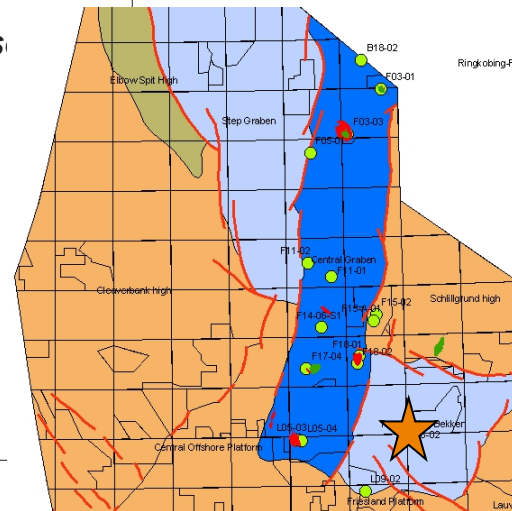
J66

← s

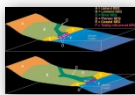
J63

## Sequence 2 NL

- opening Terschelling Basin
- transgressive trend:
  - Fluvial (Frieze Front Fm)
  - Lagoonal (Oyster Ground Mb)
  - Barrier/shoreface (Terschelling Sandstone Mb)
  - Shallow Marine (Lies Mb)
- reactivation paleozoic faults
- start of arid phase



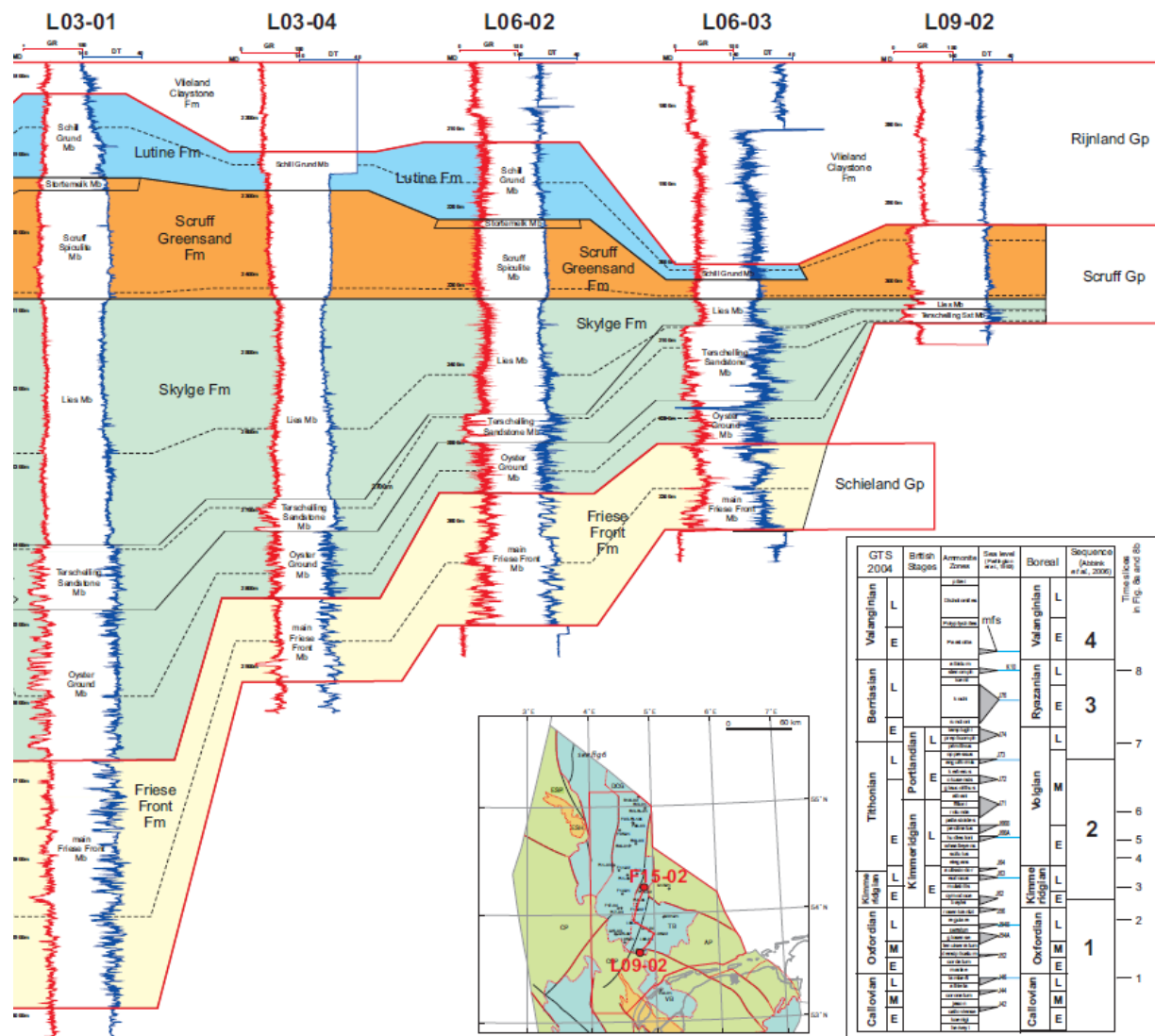
SEQUENCE	AGE	MFS	CLIMATE
3	RYA	L E	K10 J76 ← <i>kochi</i>
	PORT	L E	J73
2	KIM	L E	J66 J63 ← <i>scitulus</i>
	OX	L M E	J54 J46 ← <i>densiplicatum</i>
1	CAL	L M E	J46



## Barrier-sandstone units amalgamate towards southern basin margin

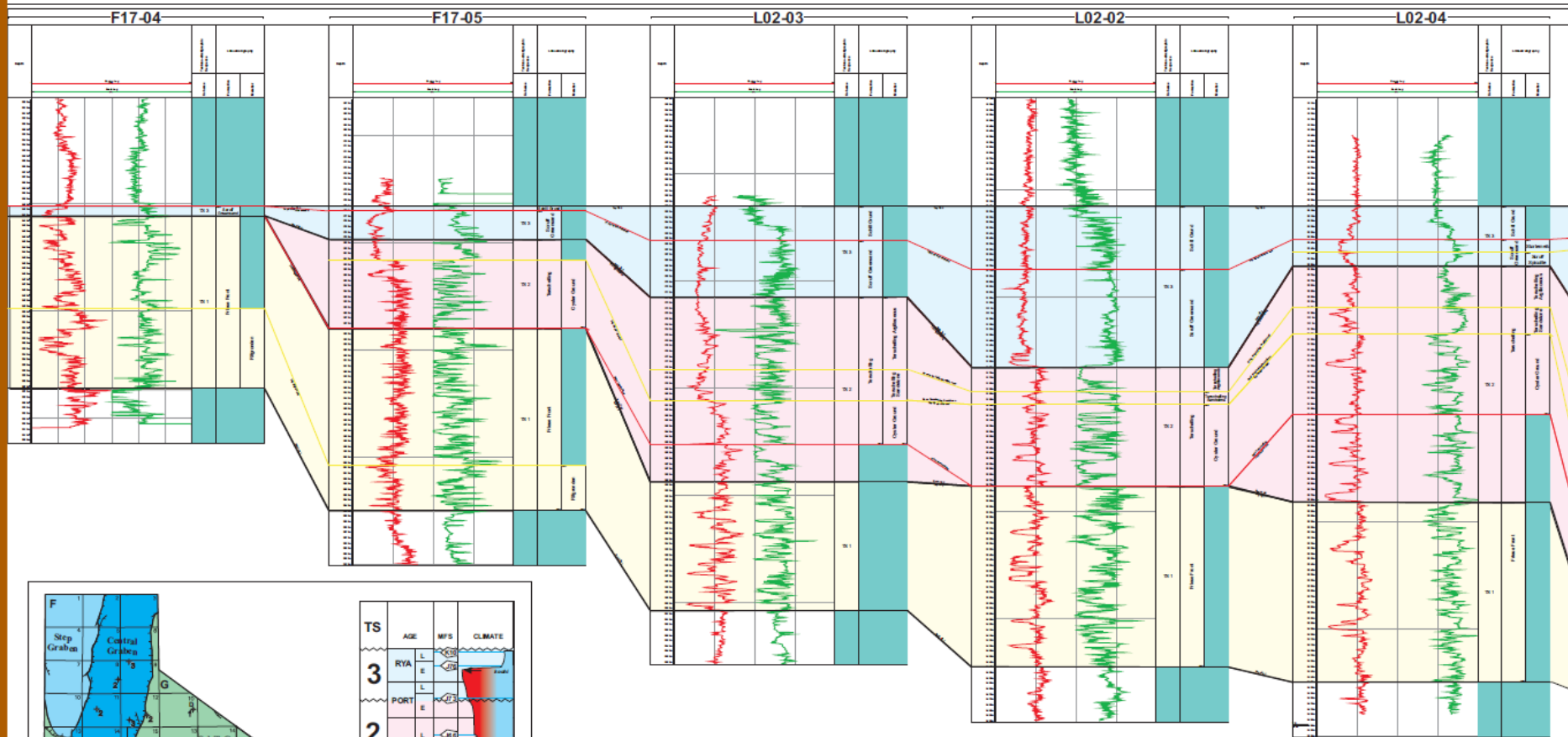
NW

SE



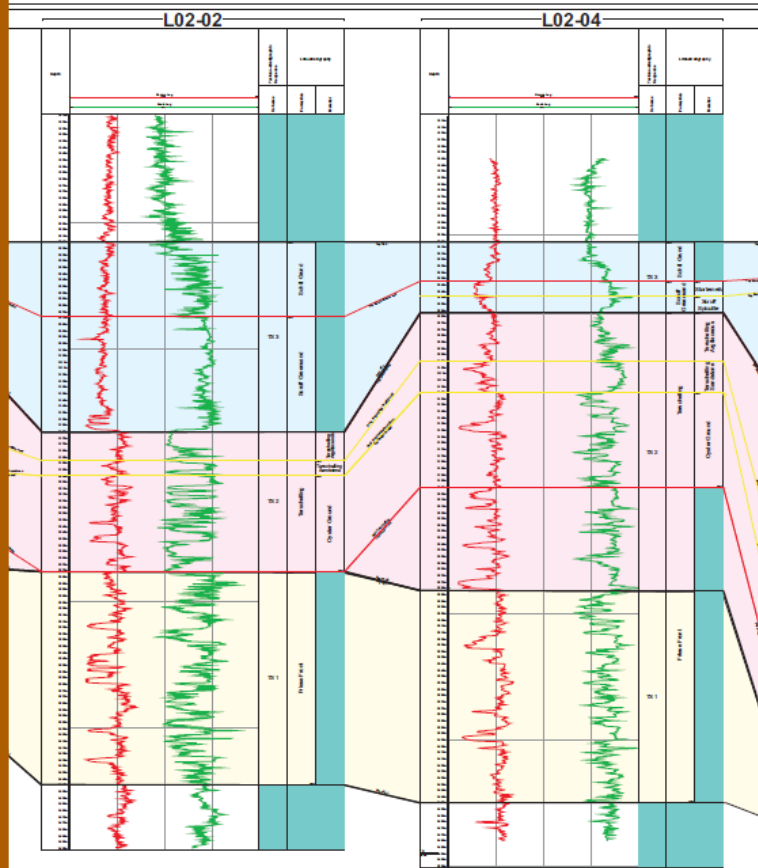
GTS 2004	British Stages	Ammonite Zones	Sea level (m, 1000)	Boreal	Sequence (Antony et al., 2005)	Time scale in Fig. 6a and 6b
Valanginian	L			Valanginian	L	4
	m				m	
Berriasian	L			Ryazanian	L	3
	m				m	
Titonian	L			Volgian	L	2
	m				m	
Kimmeridgian	L				L	1
	m				m	
Oxfordian	L				L	
	m				m	
Callovian	L				L	
	m				m	

# Central Graben



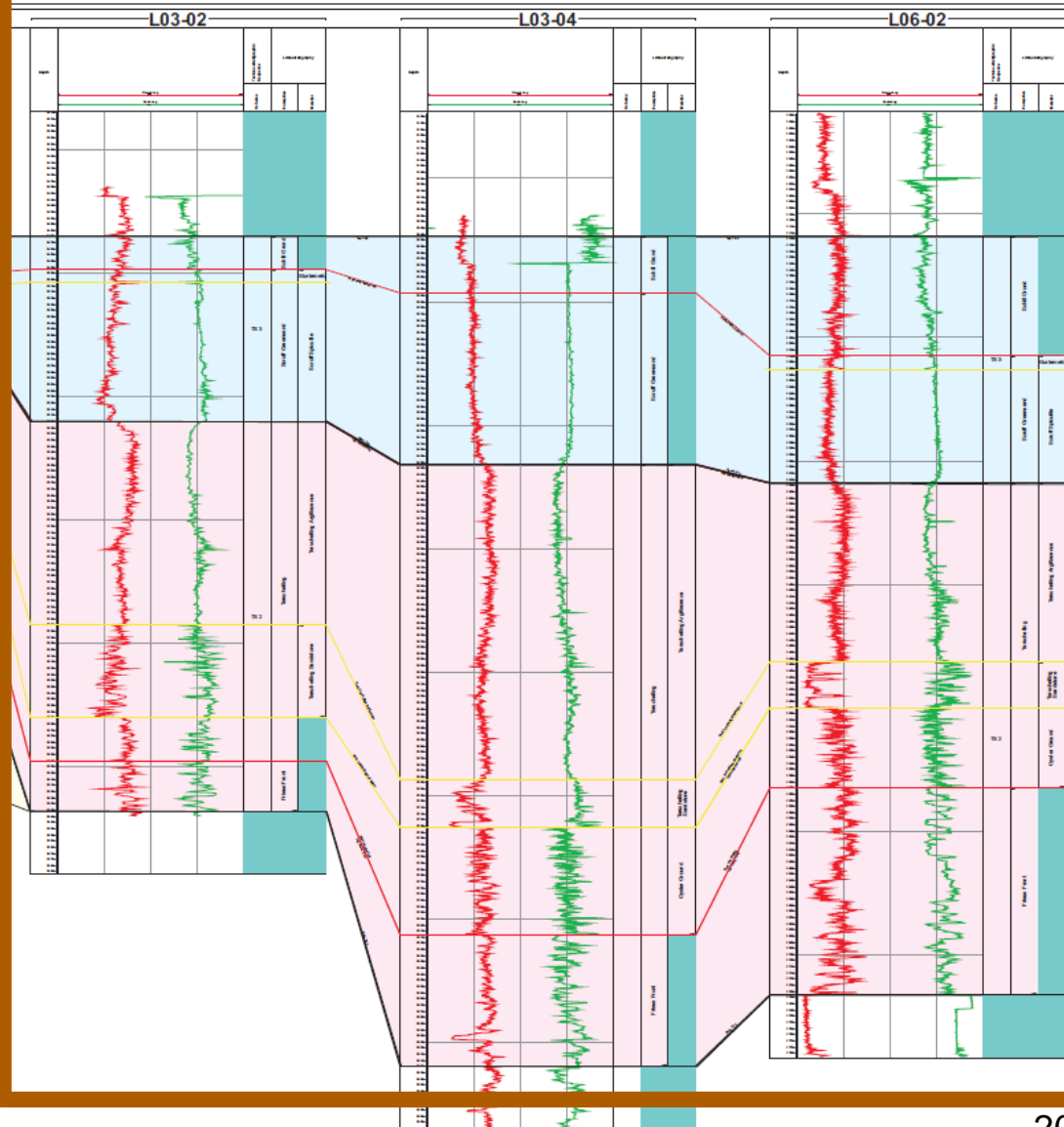
Blue = Mega Sequence 3  
 Pink = Mega Sequence 2  
 Yellow = Mega Sequence 1

# Central Graben

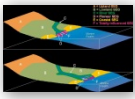


Blue = Mega Sequence 3  
 Pink = Mega Sequence 2  
 Yellow = Mega Sequence 1

# Terschelling Basin







## Compressional features in NL major: Dominated by halokinesis: salt withdrawal and push-up

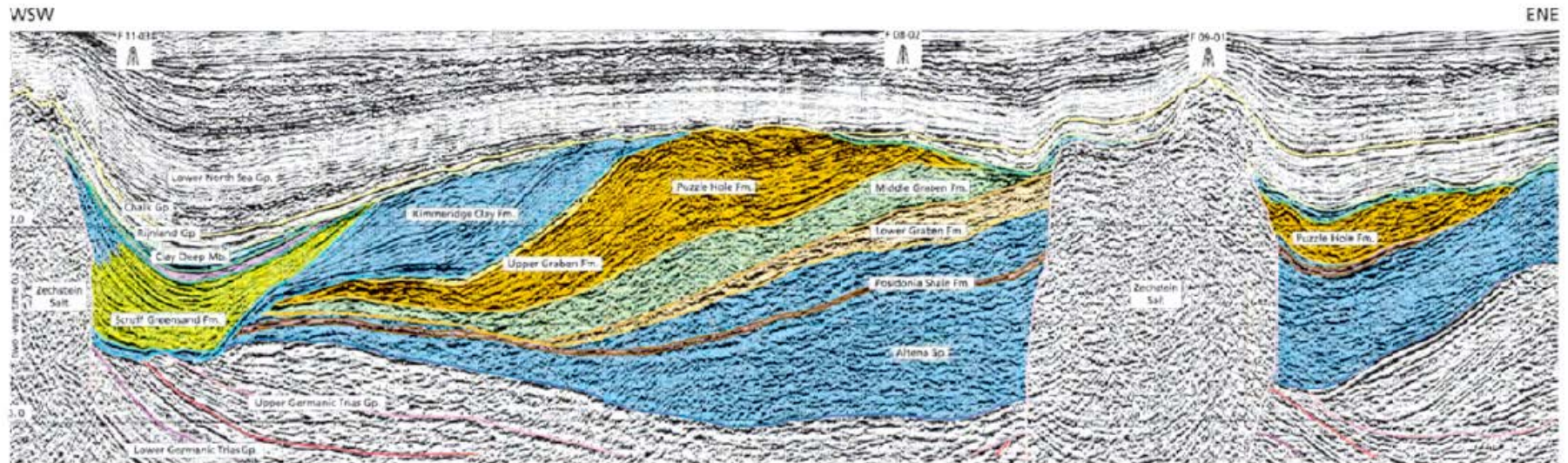
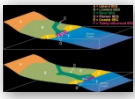


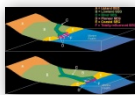
Figure 2.15 Seismic section across the northern part of the Dutch Central Graben. The lower blue is the Altens group with the Posidonia source unit indicated. Note the distribution and thickness of the Scruff Greensand Fm (yellow in the western part of the figure), which is controlled by withdrawal of underlying Zechstein salt. (Figure from Wong, 2007)



# Late Jurassic basin evolution: 3 sequences

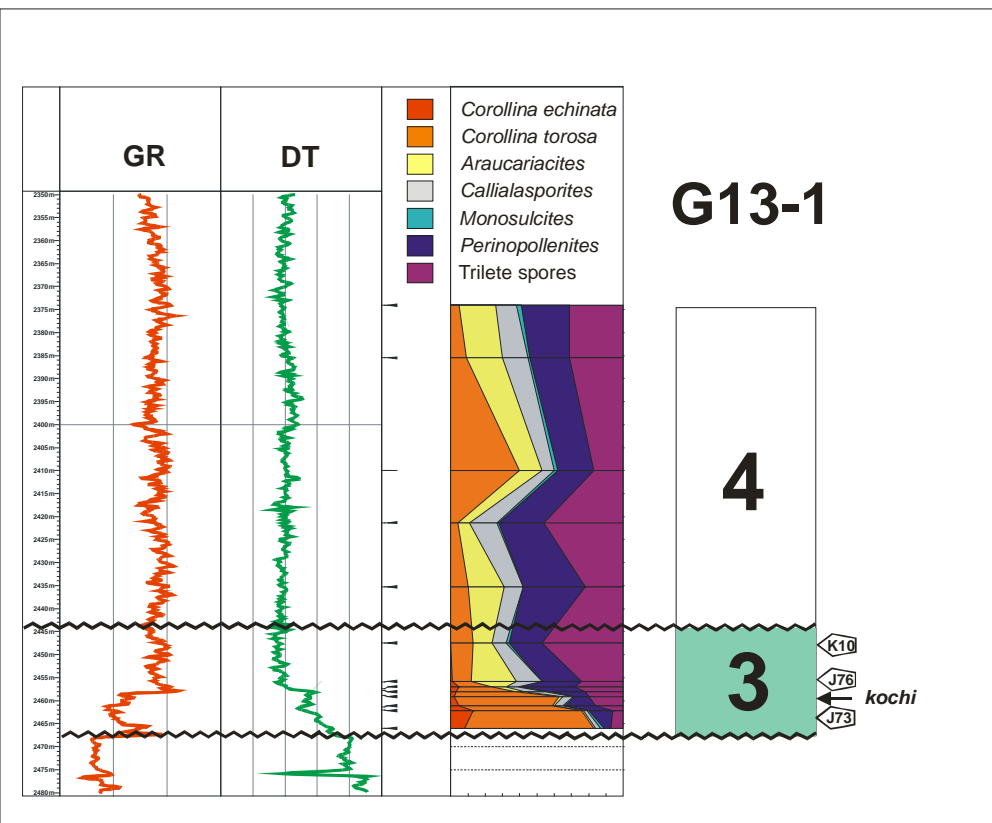
- › Sequence 1: Graben axis development
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- ›
- › **Sequence 3: Deceleration of faulting and flooding of platform areas**
- › Thermal sag, fault locking and the Cretaceous transgression





## Sequence 3

- sediments step over on adjacent platform areas
- widespread sand deposition
- erosion in DCG
- end of arid phase; beginning of Wealden facies

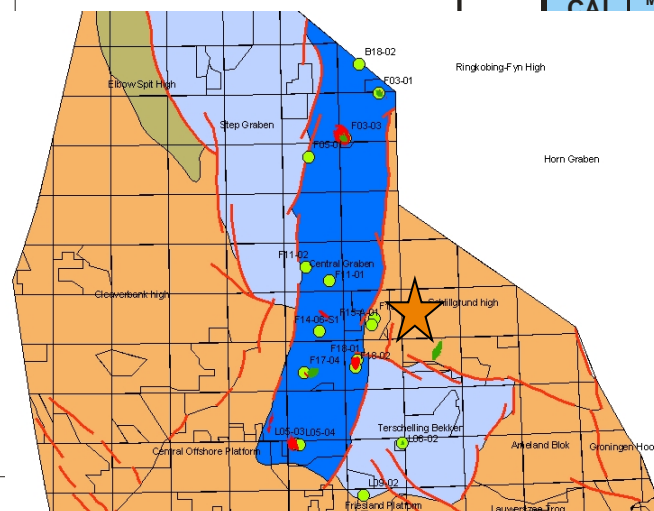


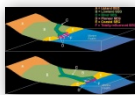
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	CAI	L M	

*kochi*

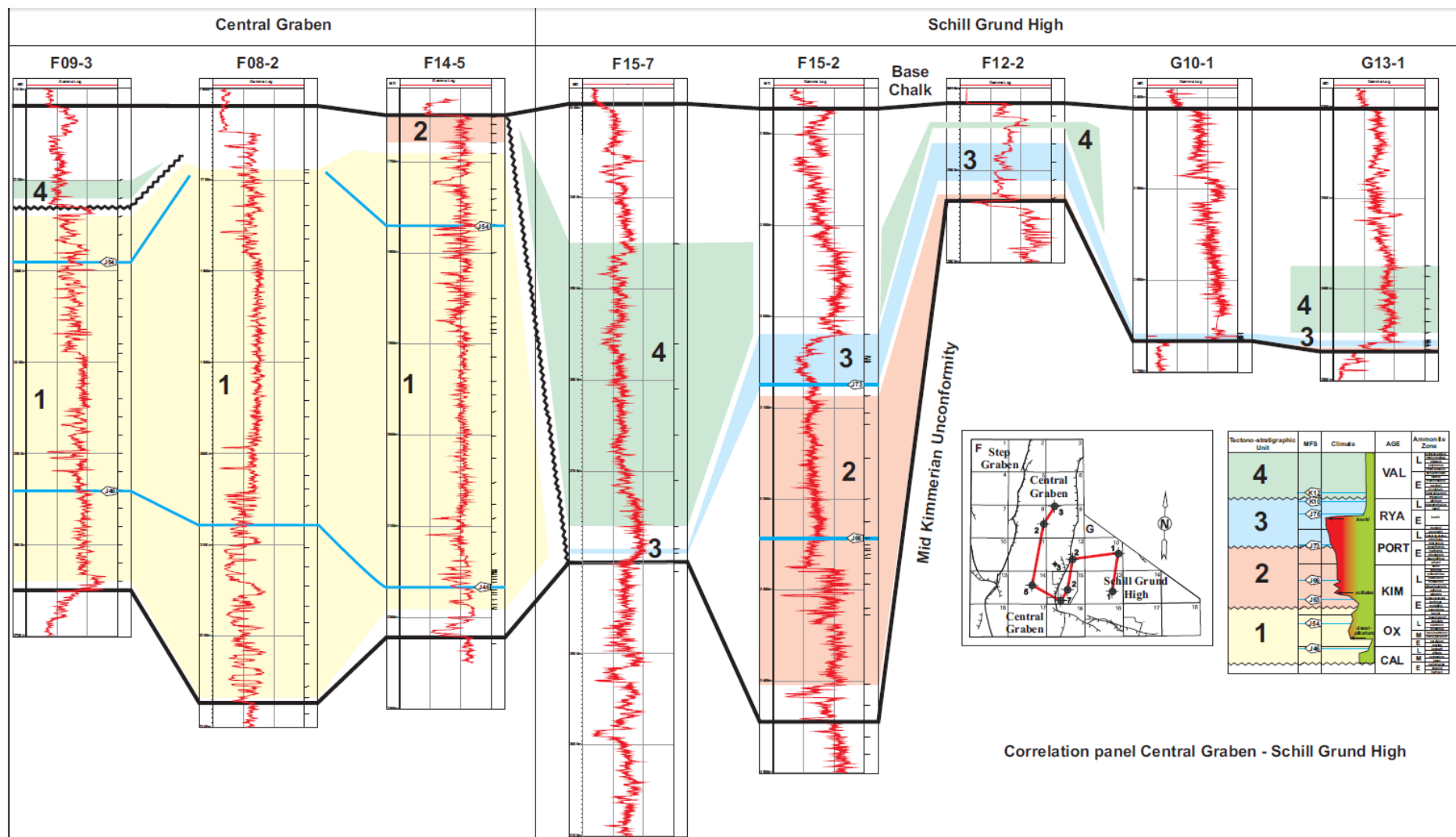
*scitulus*

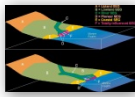
*densiplicatum*





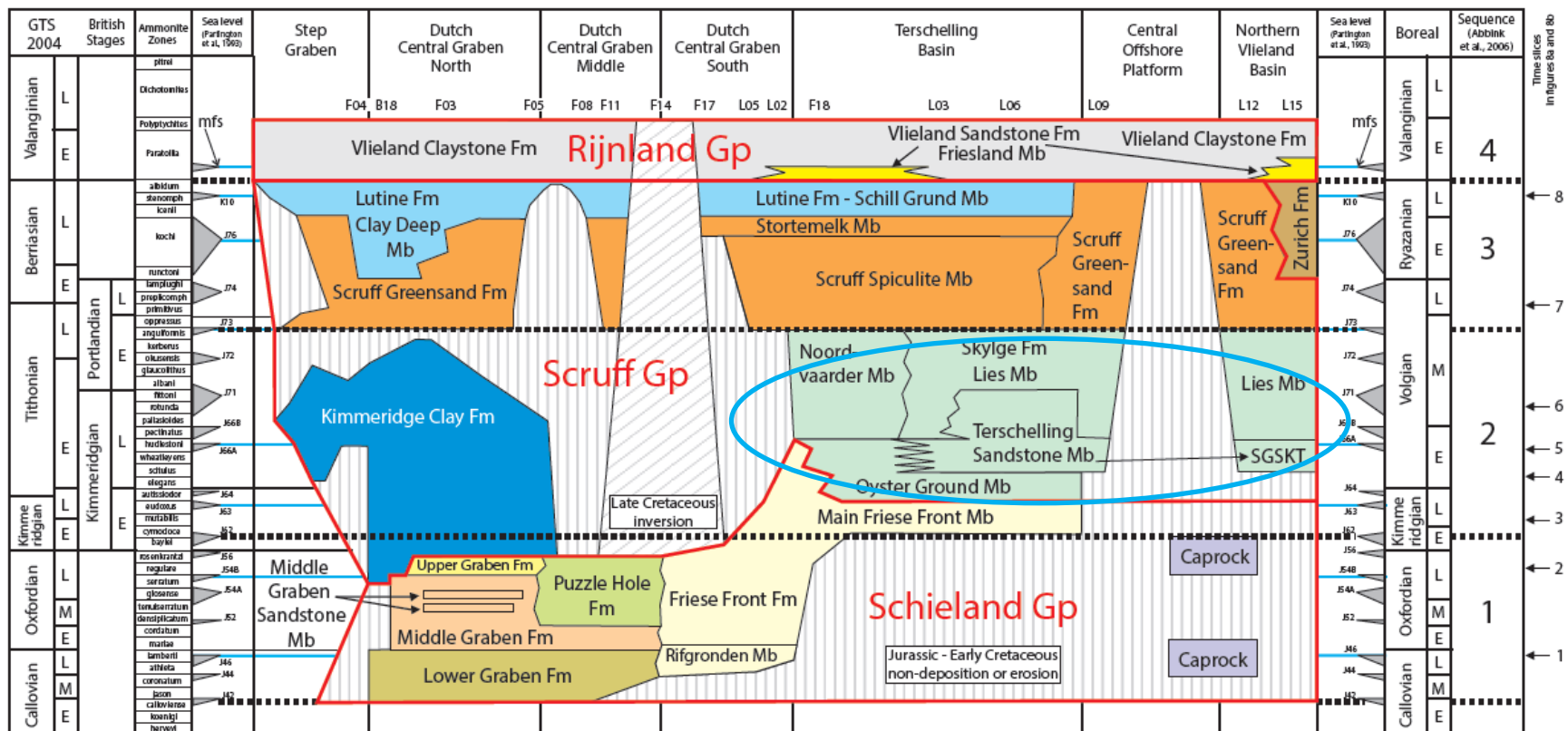
## Evidence for intra-Jurassic erosion in the Central Graben

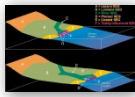




# Lithostratigraphic revision and update (1)

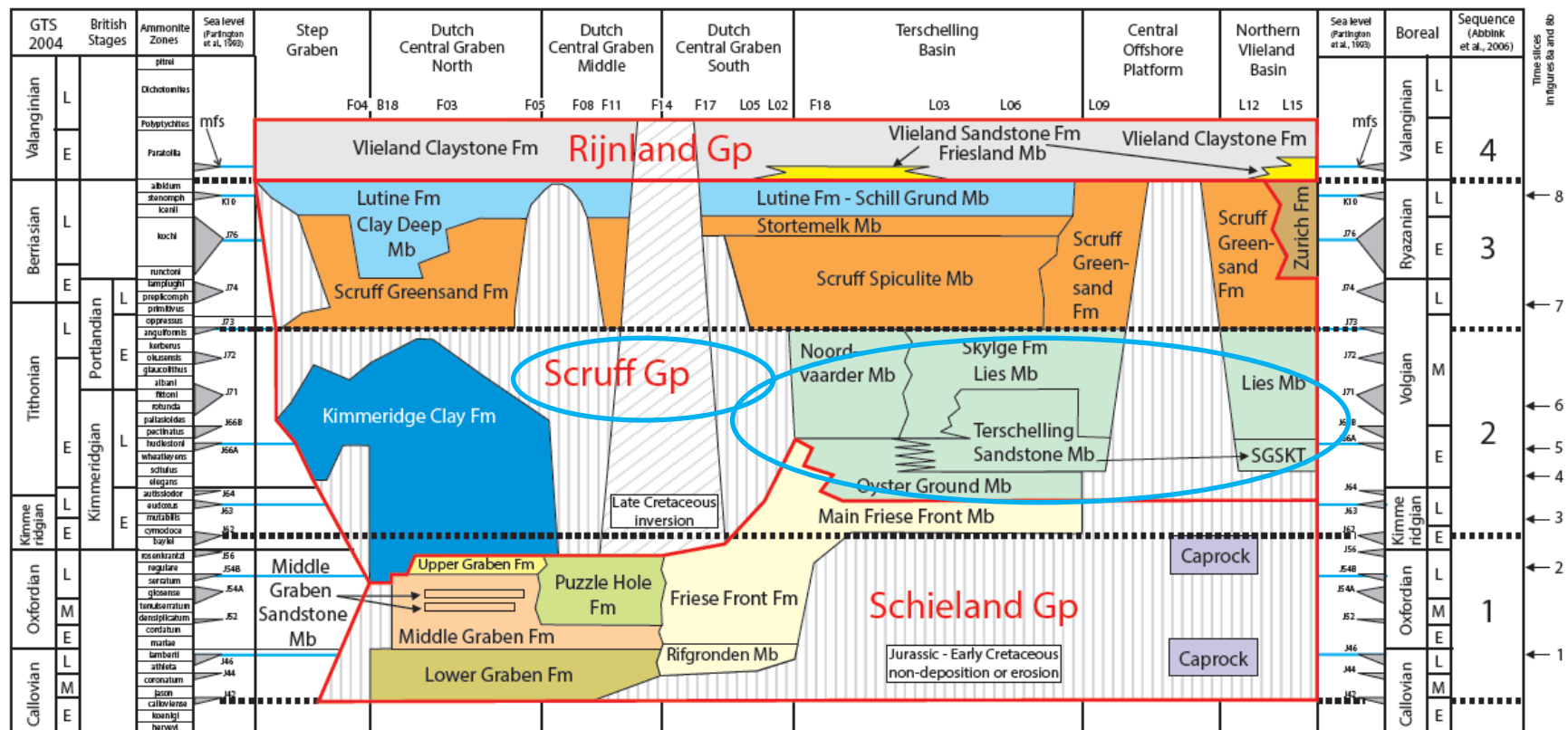
The establishment of a new formation, the Skylge Formation, comprising all restricted to shallow marine Late Jurassic successions from Sequence 2 sensu Abbink et al. (2006) along the fringes of the Central Graben, Terschelling Basin and northern part of the Vlieland Basin

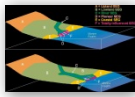




## Lithostratigraphic revision and update (2)

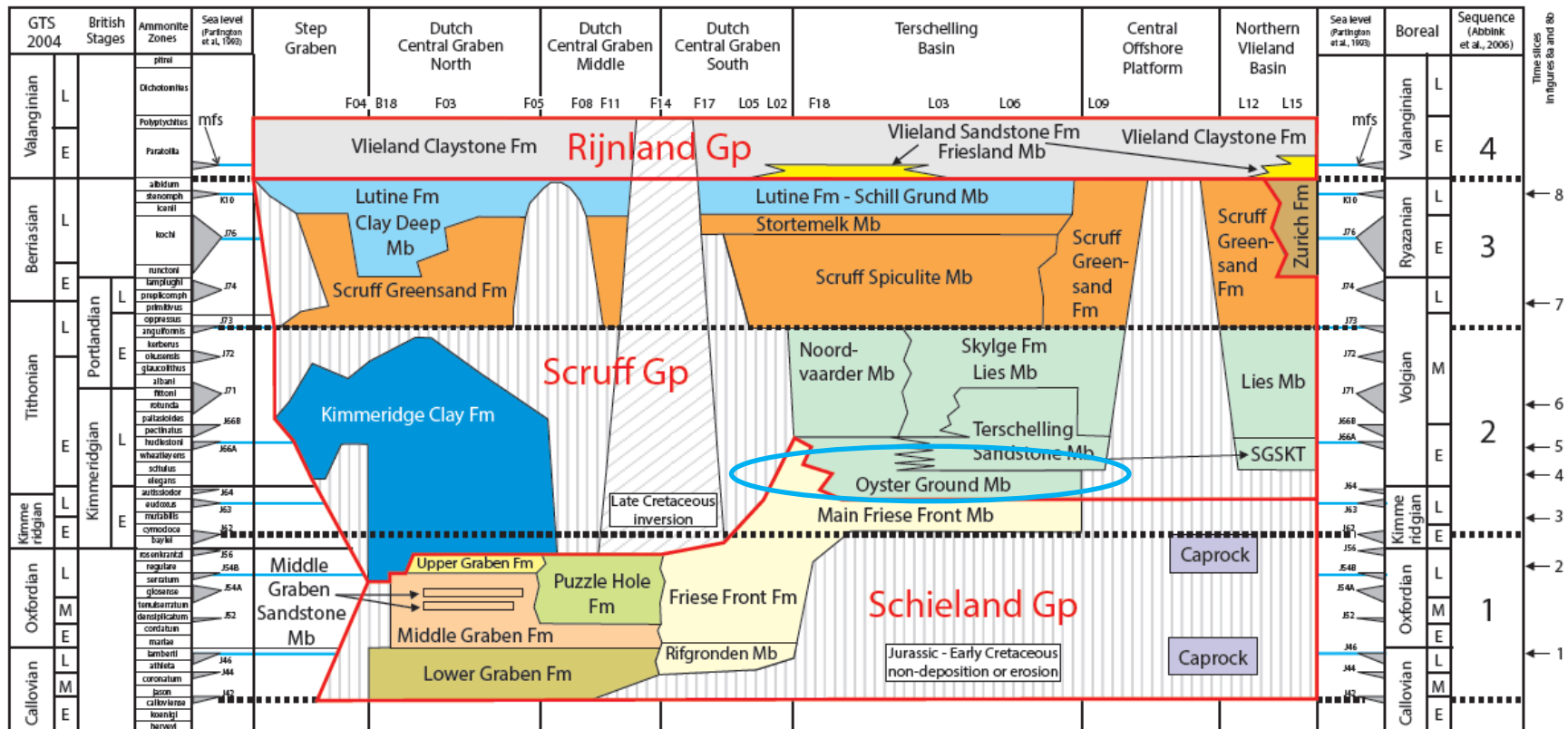
The Skylge Formation will be classified in the Scruff Group. This group encompasses all predominantly marine formations (Van Adrichem Boogaert & Kouwe, 1993).





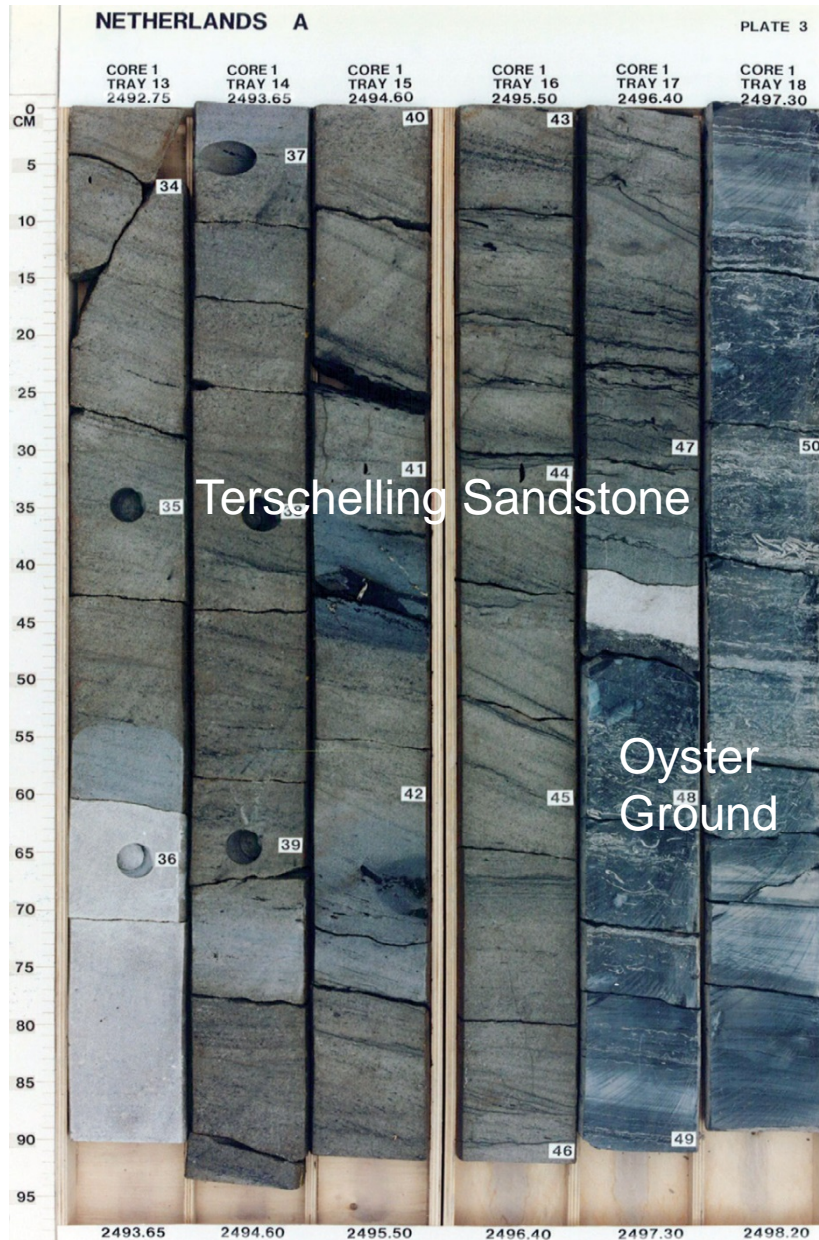
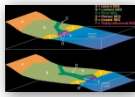
## Lithostratigraphic revision and update (3)

The lagoonal to restricted marine Oyster Ground Claystone Member represents the first transgressive phase in the southern part of the Dutch Central Graben and the Terschelling Basin and will be incorporated in the Skylge Formation. It becomes the basal member of the Skylge Formation. In the Nomenclature of Van Adrichem Boogaert & Kouwe (1993) the Oyster Ground Claystone Member was part of the non-marine Friese Front Formation



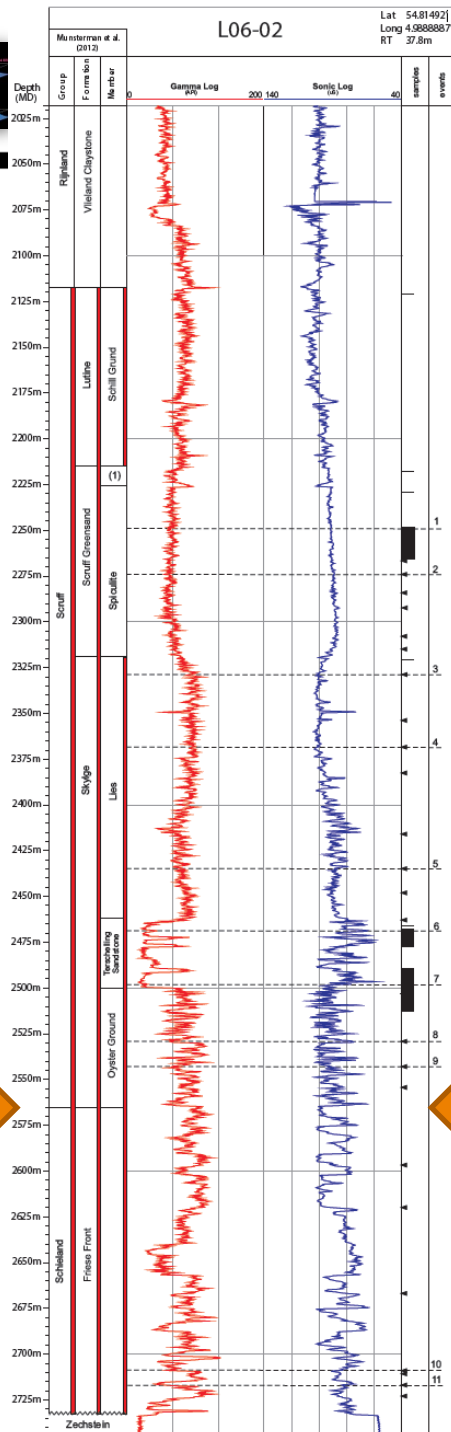
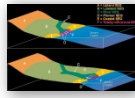






*Photograph of the core section over the lithostratigraphic boundary of the Terschelling Sandstone Member and the Oyster Ground Mbr. The Terschelling Sandstone Mbr is characterised by fine to medium grained sandstones which are horizontally, low angle and cross laminated sandstone beds. Burrows are present. Note the common occurrence of coal clasts. The true thickness of this member may be reduced by faulting. The lithostratigraphic boundary is visible at 2496.95m at the abrupt change from the sandstone to black claystone in a downward direction. The claystone is subtly laminated. Remarkable are the interbedded bioclastic layers of monotypical shell hash (cf. Neomiodon Oyster).*



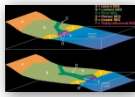


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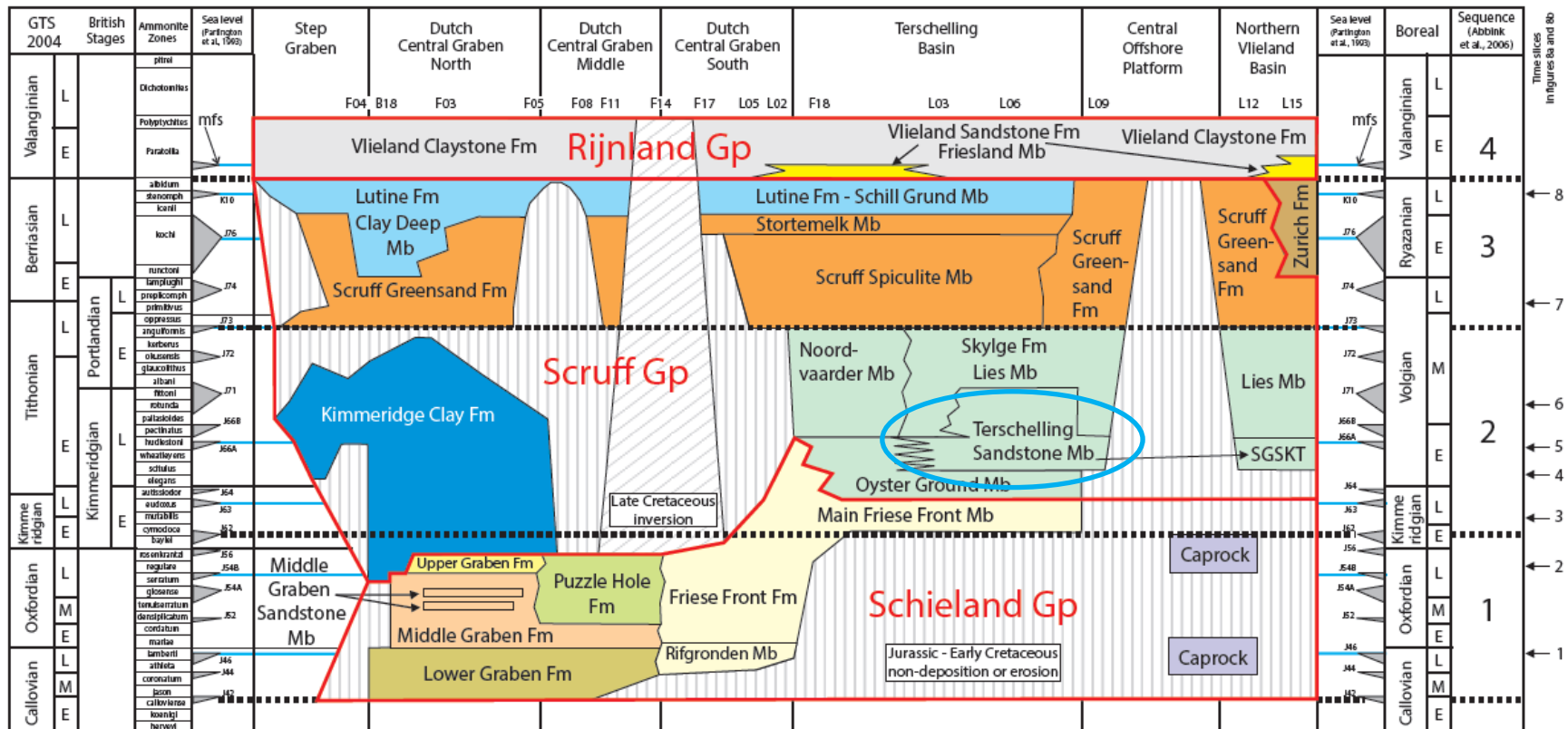
## Lithostratigraphic revision and update (5)

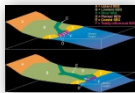
The new base of the Scruff Group in the Terschelling Basin is lithologically easy to distinguish from the underlying continental to coastal/delta plain deposits of the Friesse Front Formation. This can be seen for instance in well L06-02 at depth 2565 m. The boundary fits with the transition to the Schielland Group, which is defined by all predominantly continental Late Jurassic and Early Cretaceous successions.



## Lithostratigraphic revision and update (6)

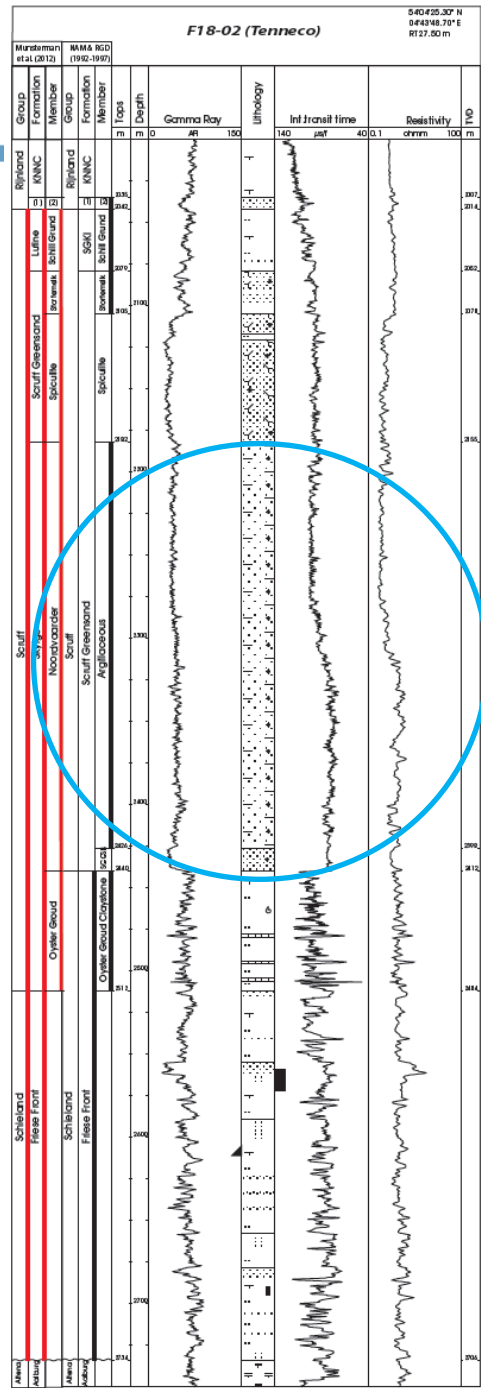
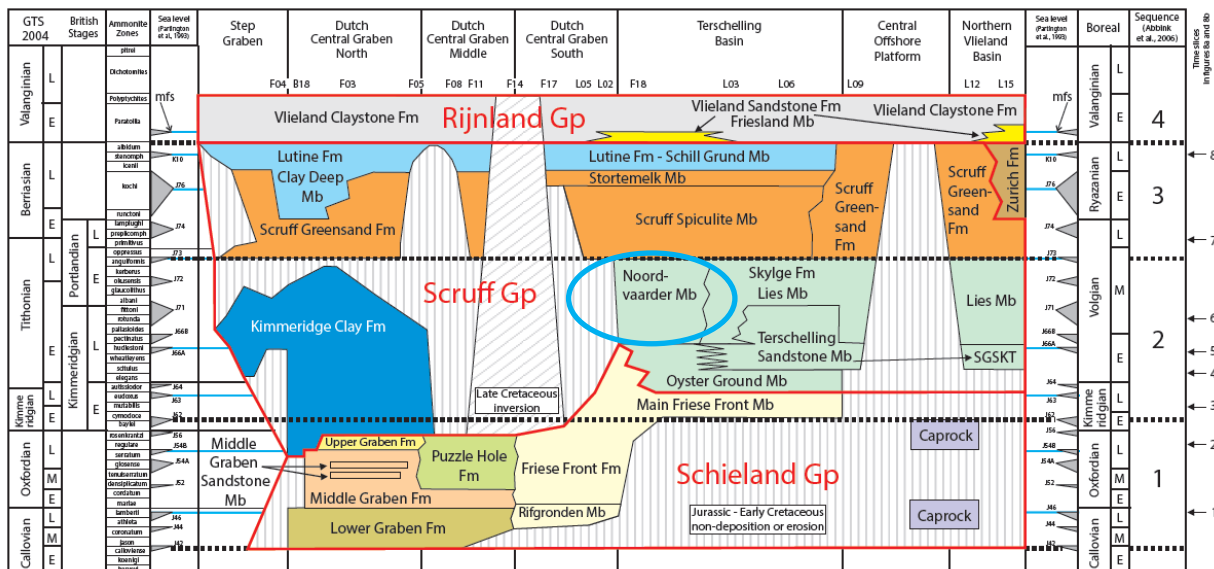
The marginal to shallow marine Terschelling Sandstone Member will also be transferred to the Skylge Formation of the marine Scruff Group. In the Nomenclature of Van Adrichem Boogaert & Kouwe (1993), the Terschelling Sandstone Member was also part of the mainly terrestrial Friese Front Formation (Schieland Group). The new classification is obviously more consistent with reference to the depositional setting and sequence.

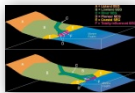




# Lithostratigraphic revision and update (7)

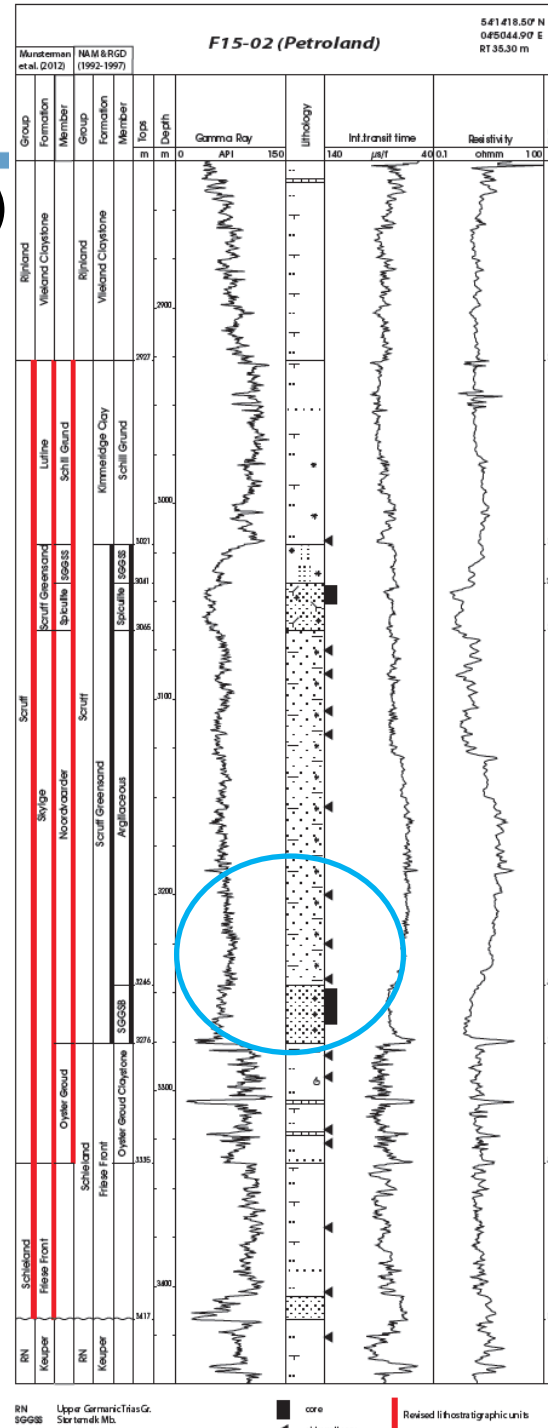
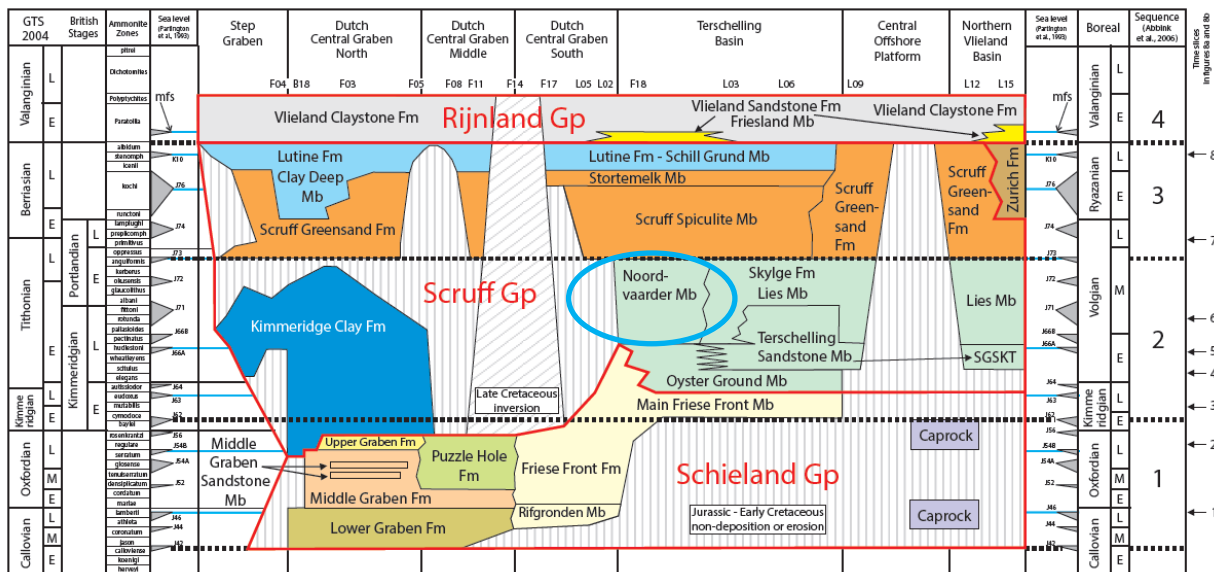
The present Scruff Argillaceous Member is replaced by two new members, both accommodated in the Skylge Formation. The sandy facies in the northwestern part of the Terschelling Basin is classified as the new Noordvaarder Member (well F15-02: interval 3065-3276 m; well F18-02: interval 2182-2440 m).

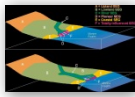




# Lithostratigraphic revision and update (8)

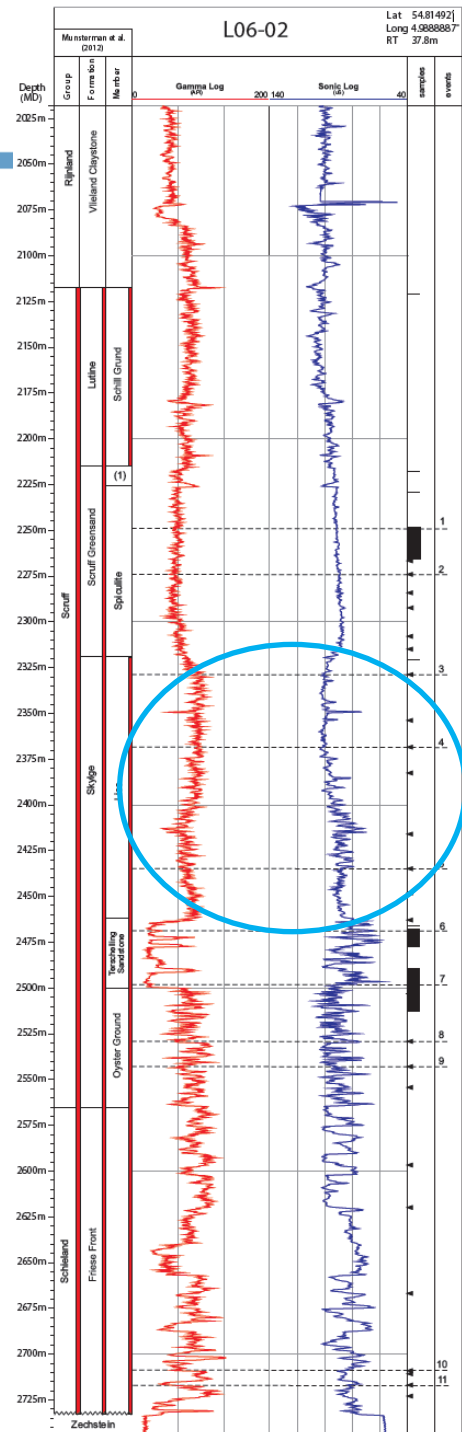
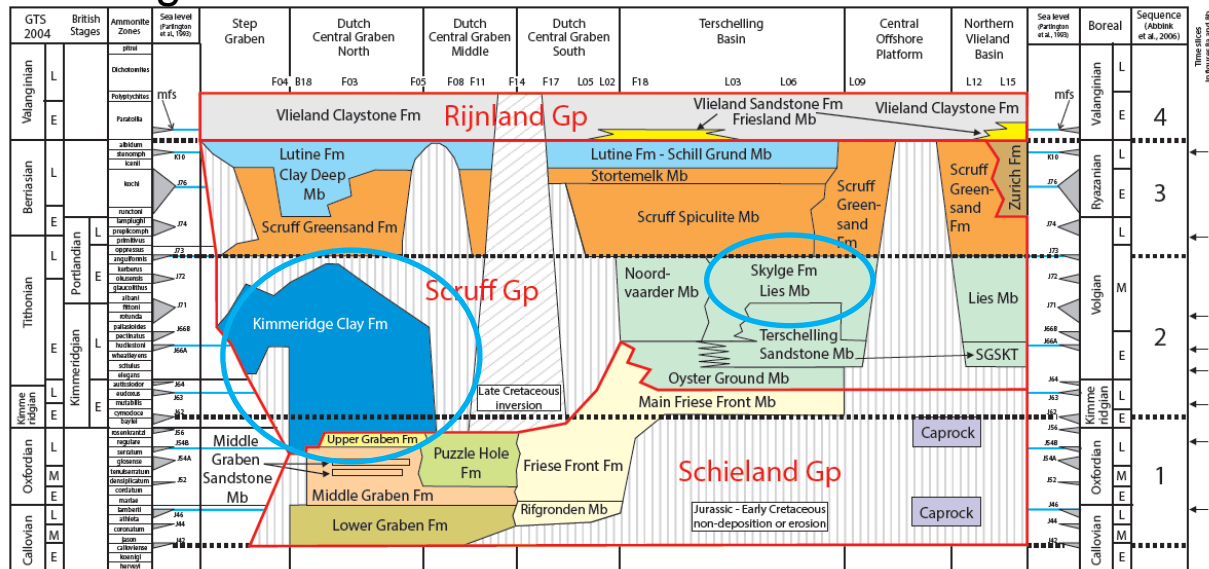
The locally distributed Scruff Basal Sandstone Member was difficult to differentiate from the overlying sandy succession of the Scruff Argillaceous Member and has therefore been incorporated into the Noordvaarder Member (see well F15-02: interval 3246-3276 m).





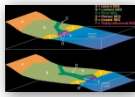
# Lithostratigraphic revision and update (9)

The clayey facies of Sequence 2 sensu Abbink et al. (2006) in the southern part of the Terschelling Basin is attributed to the new Lies Member (well L06-02: interval 2318-2463 m). Formerly these successions were classified in the Scruff Argillaceous Member (now abandoned) and/or in the Kimmeridge Clay Formation. The Kimmeridge Clay Formation will be amended and restricted to the northern part of the Central Graben, Step Graben and Outer Rough Basin. Differences in age, depositional setting and lithology justify this limitation. Problems regarding the interfingering of lithologies are now overcome.



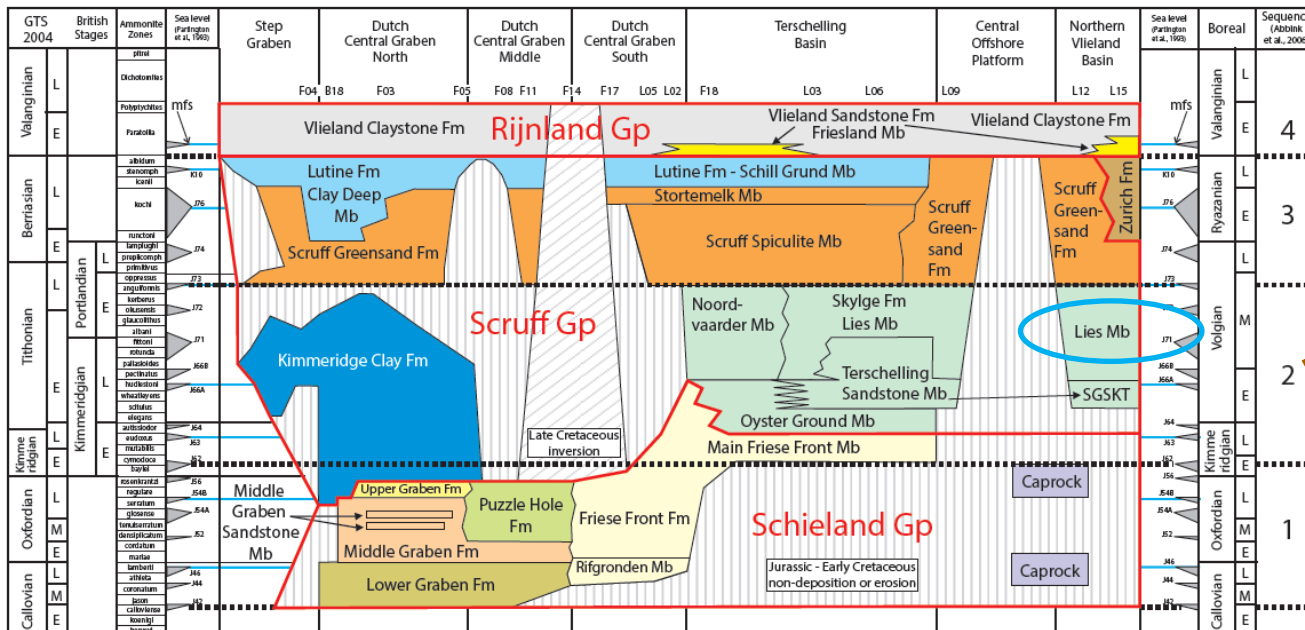
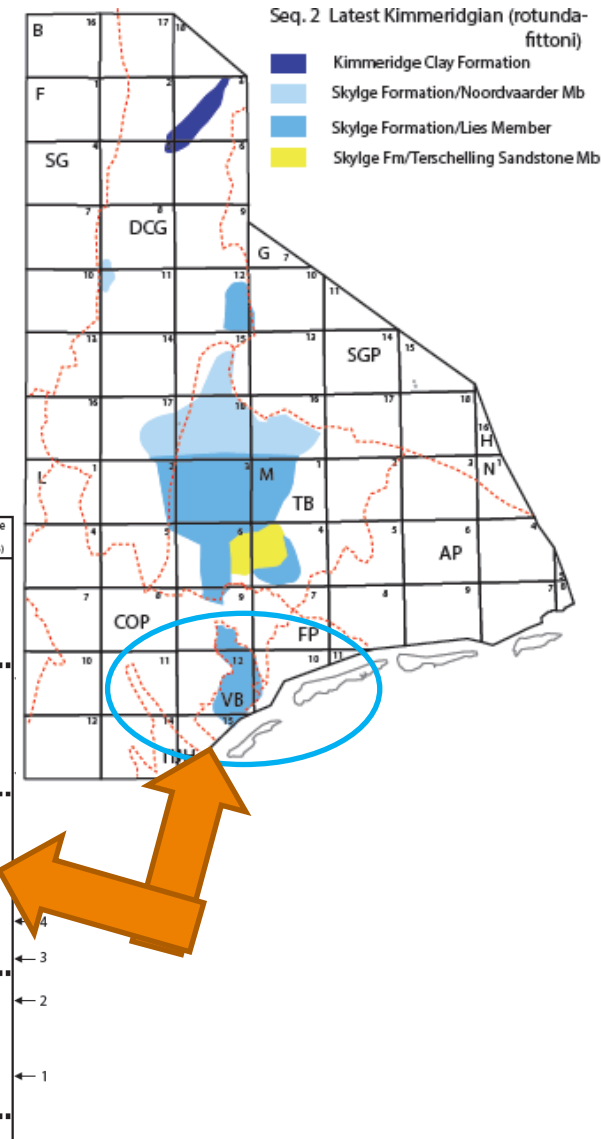




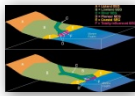


# Lithostratigraphic revision and update (10)

In the northern Vlieland Basin the clayey facies of Sequence 2 sensu Abbink et al. (2006) may, occasionally, be erroneously associated with the Lower Zurich Member, Zurich Formation (Schieland Group) or with the Scruff Argillaceous Member and/or Kimmeridge Clay Formation. These restricted to shallow marine successions also belong to the new Lies Member (e.g. in well L12-03 & well L15-03)

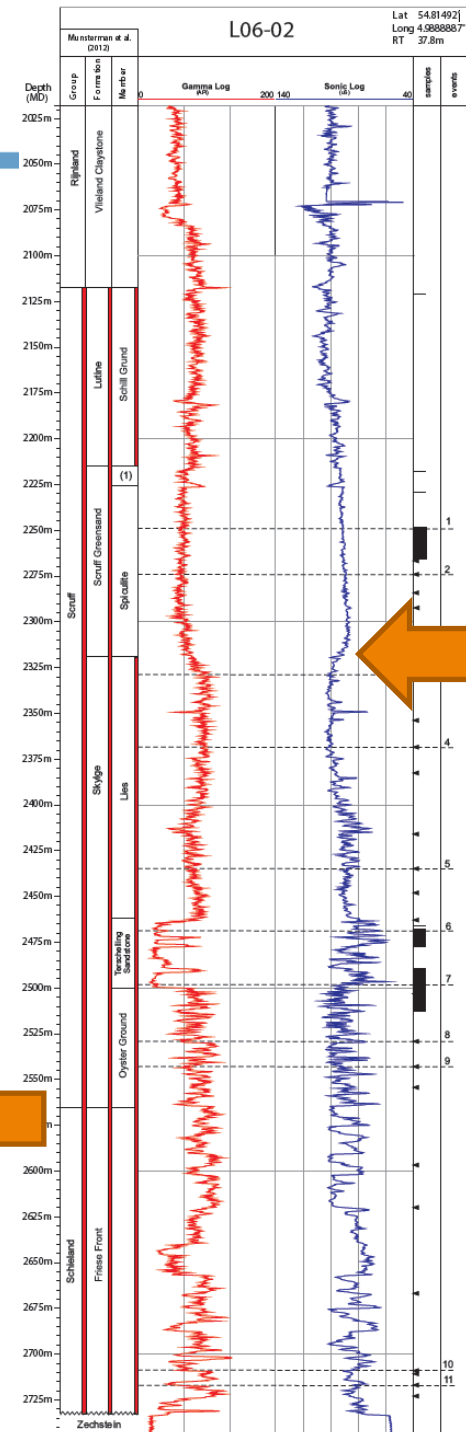
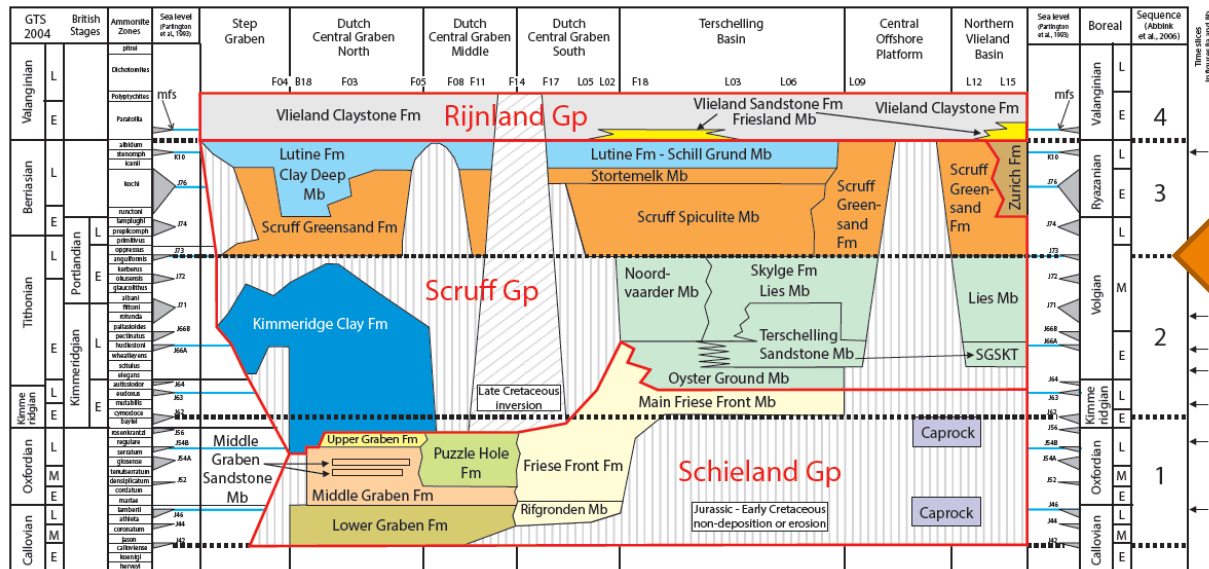


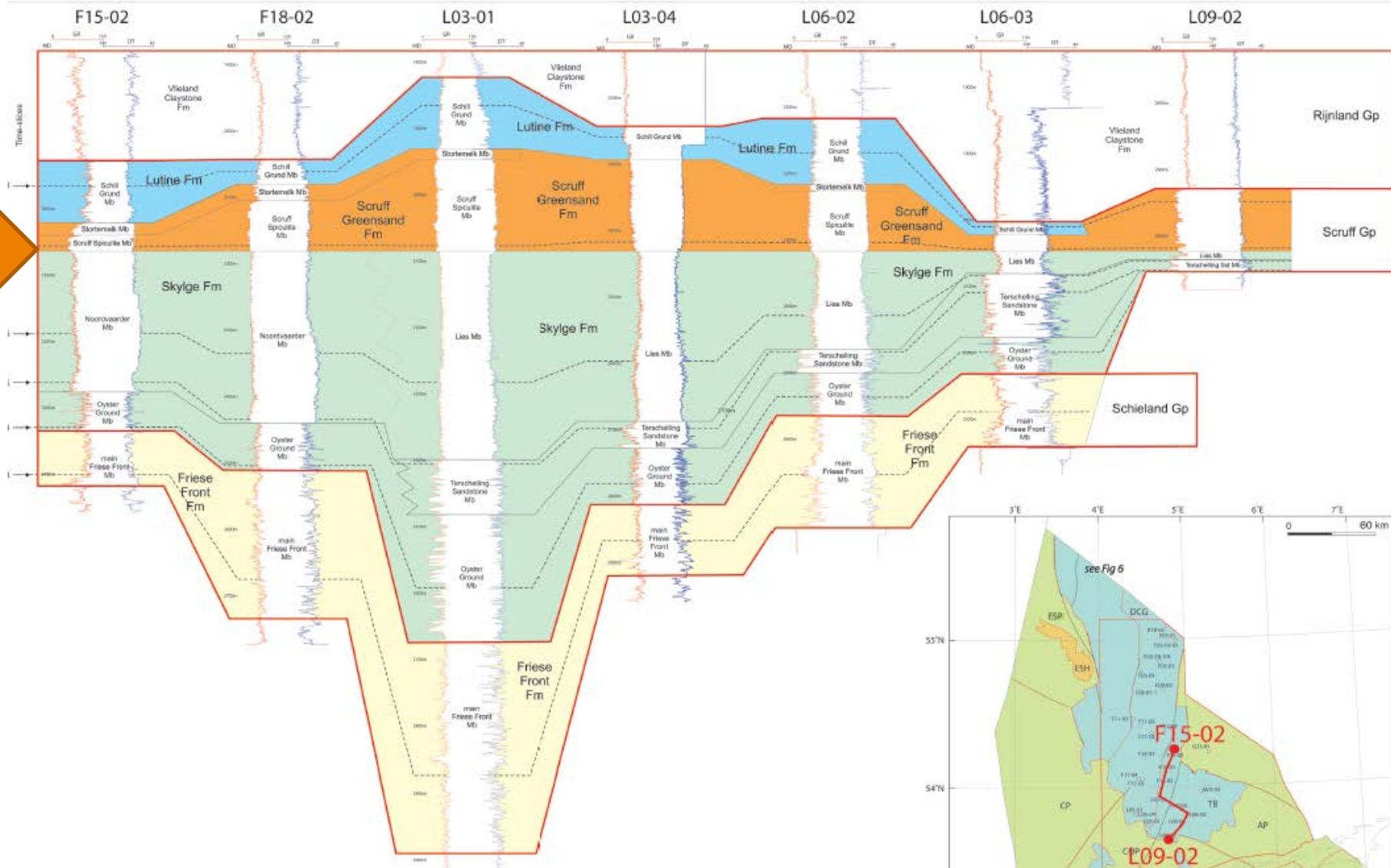
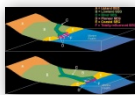


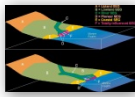


# Lithostratigraphic revision and update (11)

Based on lithology, seismics and log characteristics, the top of the Skylge Formation can clearly be distinguished from the overlying Scruff Greensand Formation (see, e.g. L06-02: depth 2318 m along hole, Fig. 9). The transition from the Skylge Formation to the Scruff Greensand Formation coincides with the boundary between Sequence 2 and Sequence 3 sensu Abbink et al. (2006).

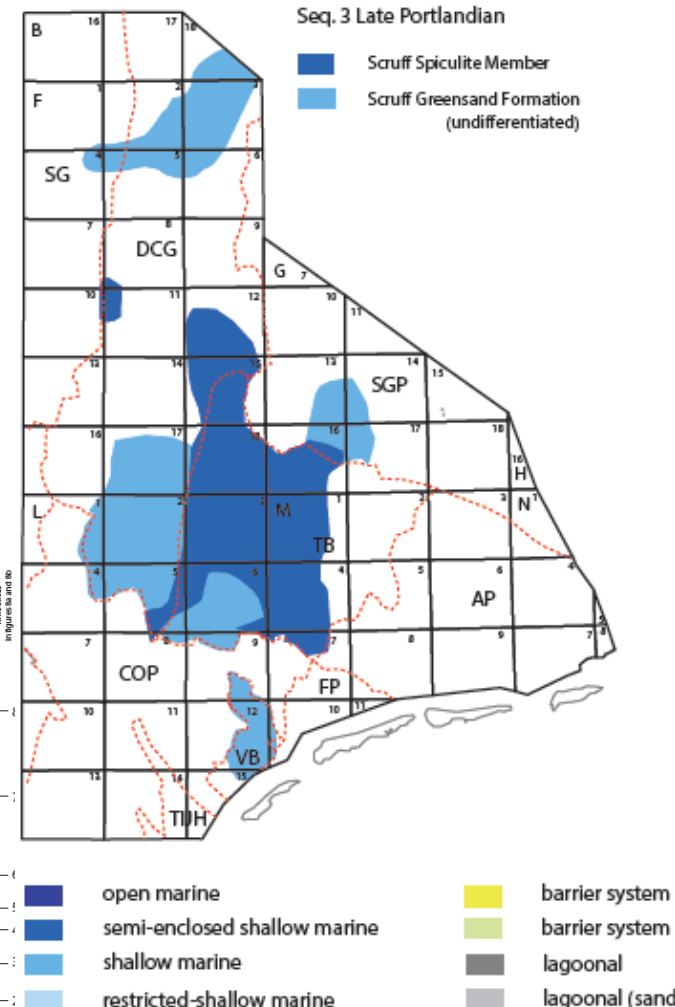
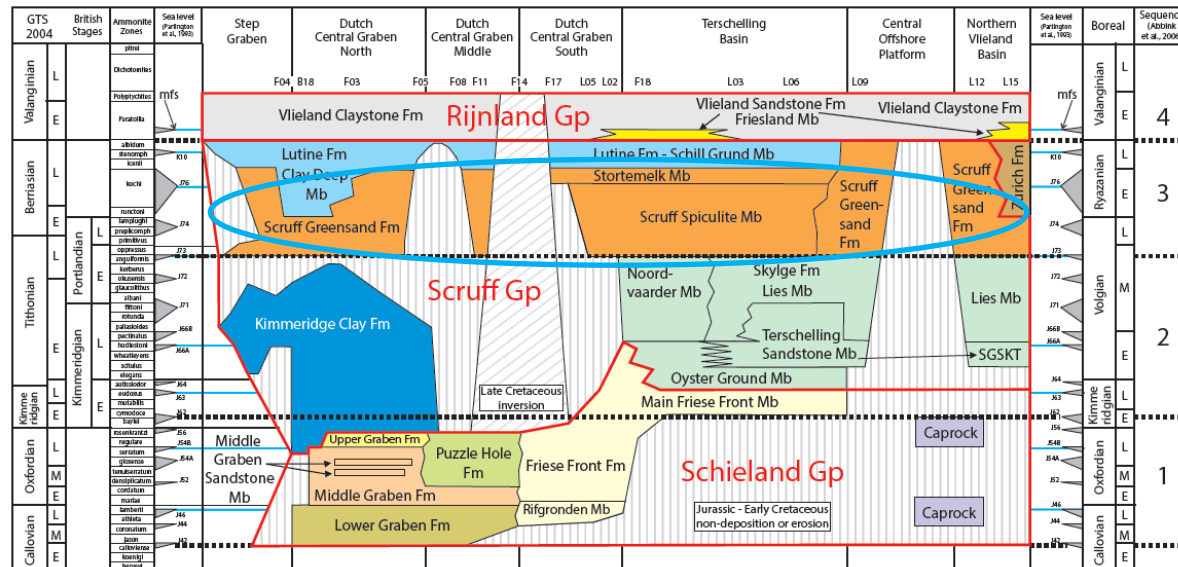


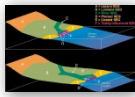




# Lithostratigraphic revision and update (12)

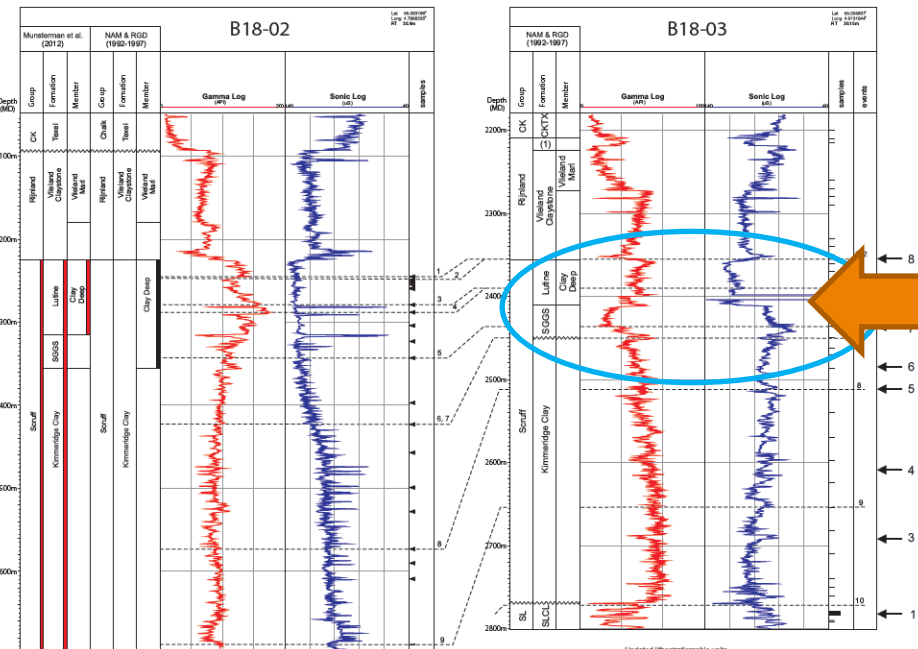
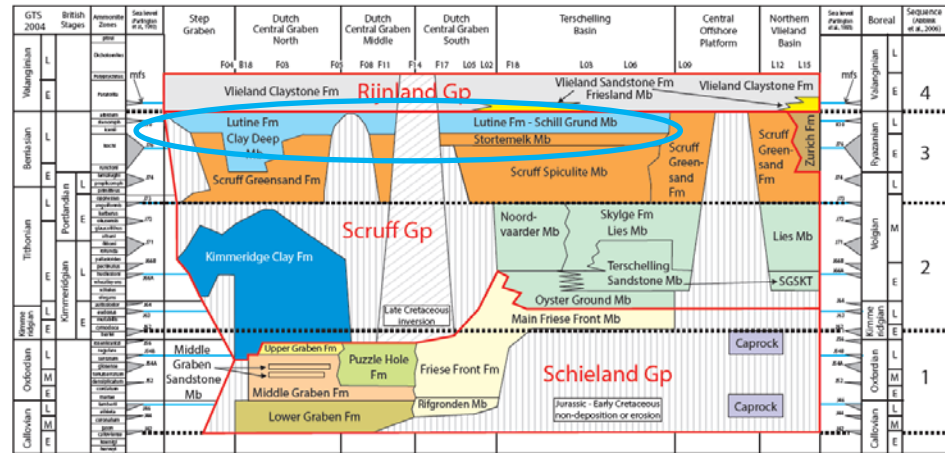
The Scruff Greensand Formation is amended to comprise all shallow marine glauconitic sandstones of the Central Graben, Step Graben, Schill Grund Platform, Terschelling and northern Vlieland basins in Sequence 3 sensu Abbink et al. (2006). Two members are recognised in the Scruff Greensand Formation: the Scruff Spiculite and Stortemelk members. The Scruff Basal Sandstone and Scruff Argillaceous members are abandoned.



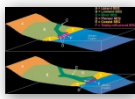


# Lithostratigraphic revision and update (13)

The Clay Deep Member and the Schill Grund Member are part of the Kimmeridge Clay Formation in the Nomenclature of Van Adrichem Boogaert & Kouwe (1993). However, these units are separated from the Kimmeridge Clay Formation by the Scruff Greensand Formation. In addition, it is mentioned that the main Kimmeridge Clay Member is older (Late Oxfordian-Early Portlandian) than the Clay Deep and Schill Grund members, which are dated as Late Portlandian (post-*anguiformis* Ammonite Zone) - Ryazanian. Hence both members are given formation status; the Lutine Formation. As noted, the Kimmeridge Clay Formation is now geographically limited to the northern part of the Dutch Central Graben and adjacent basins.



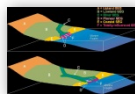




## Overview showing the changes and adaptations from the existing to the new and revised lithostratigraphy. All revisions are indicated in red

Current Lithostratigraphy (Van Adrichem Boogaert & Kouwe, 1993)		Revised Lithostratigraphy	
SL	Schieland Group	SL	Schieland Group
SLC	Central Graben Subgroup	SLC	Central Graben Subgroup
SLCL	Lower Graben Formation	SLCL	Lower Graben Formation
SLCM	Middle Graben Formation	SLCM	Middle Graben Formation
SLCMS	Middle Graben Sandstone Member	SLCMS	Middle Graben Sandstone Member
SLCU	Upper Graben Formation	SLCU	Upper Graben Formation
SLCP	Puzzle Hole Formation	SLCP	Puzzle Hole Formation
SLCF	Friese Front Formation	SLCF (amend.)	Friese Front Formation
SLCFR	Rifgronden Member	SLCFR	Rifgronden Member
SLCFM	main Friese Front member	SLCFM	main Friese Front member
SLCFO	Oyster Ground Claystone Member	transferred to Scruff Group*	
SLCFT	Terschelling Sandstone Member	transferred to Scruff Group**	
SG	Scruff Group	SG	Scruff Group
SGKI	Kimmeridge Clay Formation	SGKI (amend.)	Kimmeridge Clay Formation
SGKIM	main Kimmeridge Clay member		
		SGSK	Skylge Formation (new)
		*SGSKO	Oyster Ground Member (revised name and classification)
		**SGSKT	Terschelling Sandstone Member (revised classification)
		SGSKN	Noordvaarder Member (new)
		SGSKL	Lies Member (new)
SGGS	Scruff Greensand Formation	SGGS (amend.)	Scruff Greensand Formation
SGGSB	Scruff Basal Sandstone Member	abandoned	see Skylge Formation
SGGSA	Scruff Argillaceous Member	abandoned	see Skylge Formation
SGGSP	Scruff Spiculite Member	SGGSP	Scruff Spiculite Member
SGGSS	Stortemelk Member	SGGSS	Stortemelk Member
		SGLU	Lutine Formation (new)
SGKIC	Clay Deep Member	SGLUC	Clay Deep Member (revised classification)
SGKIS	Schill Grund Member	SGLUS	Schill Grund Member (revised classification)





## Hierarchical subdivision of the new and revised lithostratigraphy of the Rijnland Group (pars.), Scruff Group and the Central Graben Subgroup of the Schieland Group

Lithostratigraphic units				Type section			
Group	Formation	Member	Code	Well	Interval MD (m)		Status
Rijnland Group			KN	VLO-01	1522	2246	
	Vlieland Claystone Fm		KNNC	VLO-01	1650	2200	
	Vlieland Sandstone Fm		KNNS	VLO-01	2200	2246	
		Friesland Mb	KNNSF	VLO-01	2200	2246	
Scruff Group			SG	F03-03	1682	2547	
	Scruff Greensand Fm		SGGS	F15-02	3021	3065	amend.
		Scruff Spiculite Mb	SGGSP	F15-02	3041	3065	
		Stortemelk Mb	SGGSS	F18-02	2079	2105	
	Kimmeridge Clay Fm		SGKI	F03-03	1780	2547	amend.
	Lutine Fm		SGLU	B18-02	2225	2315	new
		Clay Deep Mb	SGLUC	B18-02	2225	2315	amend.
		Schill Grund Mb	SGLUS	F18-02	2042	2079	amend.
	Skylge Fm		SGSK	L06-02	2318	2564	new
		Lies Mb	SGSKL	L06-02	2318	2463	new
		Noordvaarder	SGSKN	F15-02	3065	3276	new
		Oyster Ground Mb	SGSKO	L06-02	2500	2565	amend.
		Terschelling Sandstone Mb	SGSKT	L06-02	2463	2500	amend.
Schieland Group		SL	NKK-01	1052	1942		
Delfland Subgroup			SLD	NKK-01	2547	3652	
	Zurich Fm	SLDZ	ZUR-01	1773	2053		
Central Graben Subgroup			SLC	F03-03	2547	3652	
	Friese Front Fm	SLCF	F18-01	2422	2686	amend.	
		"Main Friese Front Mb"	SLCFM	no official status			
		Rifgronden Mb	SLCFR	F17-04	2497	2572	
	Puzzle Hole Fm		SLCP	F11-02	2175	2397	
	Upper Graben Fm		SLCU	F03-03	2547	2670	
	Middle Graben Fm		SLCM	F03-03	2670	3090	
		Middle Graben Sandstone Mb	SLCMS	F05-01	2628	2648	
	Lower Graben Fm		SLCL	F03-03	3090	3652	