# Sedimentological and Architectural Characteristics of a Rift Initiation Package: Middle-Upper Jurassic, North Sea*

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## Abstract

In the Danish Central Graben (DCG) the Middle Jurassic pre-rift succession consists of laterally extensive, fluvial and lacustrine deposits. In most of the DCG the syn-rift succession is erosively overlain by a package of estuarine sediments that form the lower part of the rift initiation succession. The erosion surface is the pre-rift/syn-rift boundary. In the study area the rift initiation package is subdivided into three tiers, each the result of a rotational event at the nearby main boundary fault.

The lower tier (tier 1) consists mainly of stacked estuarine sandstone capped by a thick coal bed. The estuary deposits developed as a response to the first rotational movements of the rift initiation phase. With the basin floor close to sea level, even a limited rotation caused incision into the uplifted parts of the hanging-wall slope, and infilling by estuarine deposits. The coal bed at the top of tier 1 shows that a low gradient coastal plain was re-established after the initial rotational event.

The two upper tiers (2 and 3) both consist of a lower wedge of paralic deposits thickening up-dip, and an upper wedge of mainly shoreface deposits thickening down-dip. Renewed rotational movement and associated flooding terminated peat growth in the coastal plain swamps that are represented by the thick coal beds separating tiers 1 and 2. Transgression caused onlap of paralic deposits on the hanging-wall dip slope, forming the westward thickening paralic wedge. When transgression stopped, remaining accommodation in the paralic wedge was rapidly filled and sediments shed further seawards, where they formed the eastward thickening shallow marine wedge. A thin but extensive coal bed on top of the shallow marine wedge shows that a low energy coastal plain was re-established, before renewed rotation caused a repetition of the events that led to the development of tier 2. Tier 3 is essentially developed as tier 2.

Deposition of the rift initiation package was terminated by marine flooding and a shift to fully marine conditions and deposition of mainly marine mudstone. This change was associated with acceleration of the rotational movements and the transition from rift initiation to rift climax.

Coeval rift initiation packages in the Viking Graben show similar developments. Outside the rift basin in neighboring Danish-Norwegian Basin, contemporaneous successions exhibit the same facies tracts but not the characteristic architecture of the rift-related successions.

# Sedimentological and Architectural Characteristics of a Rift Initiation Package

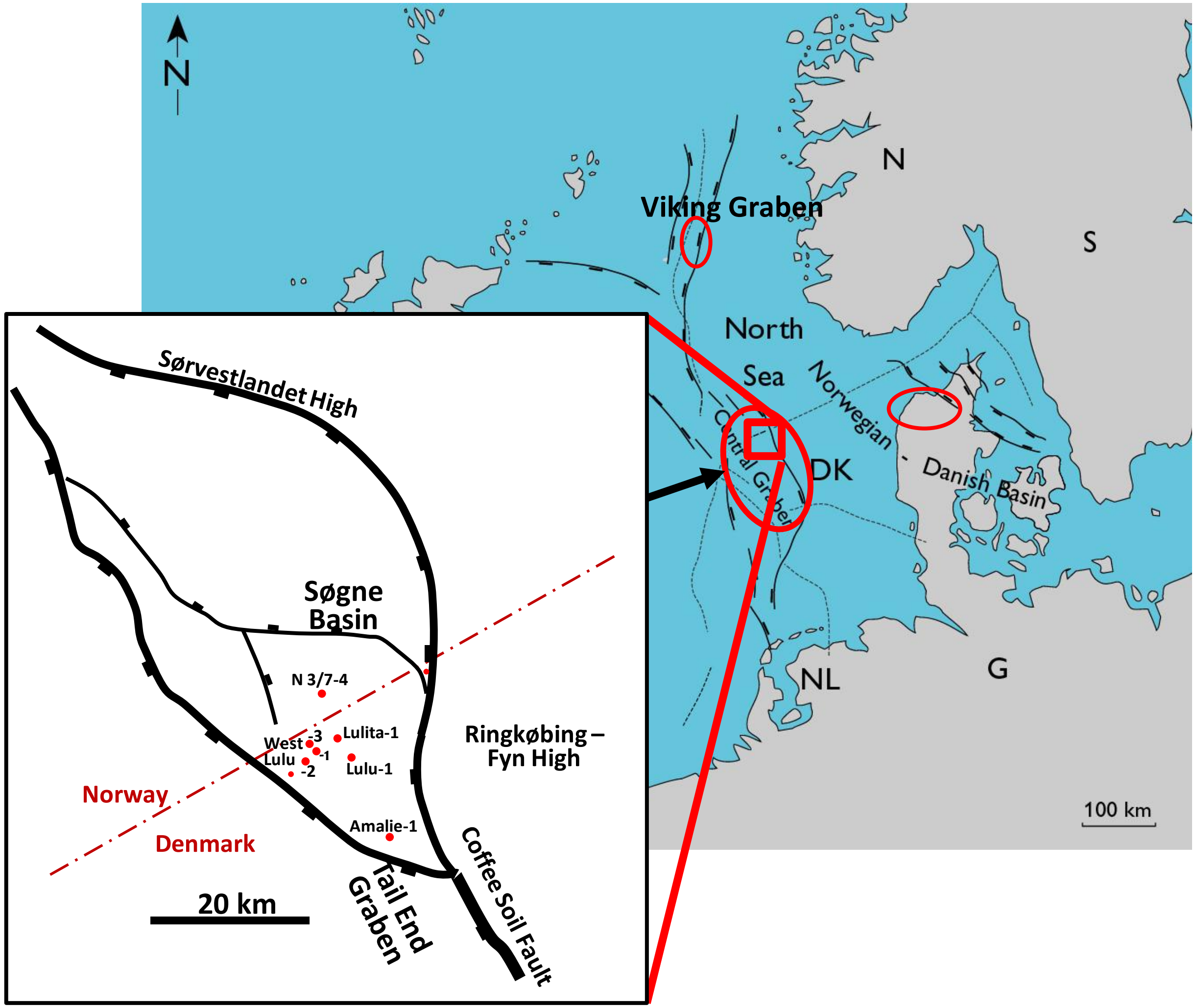
Middle – Upper Jurassic, North Sea

Jan Andsbjerg

# Outline of presentation

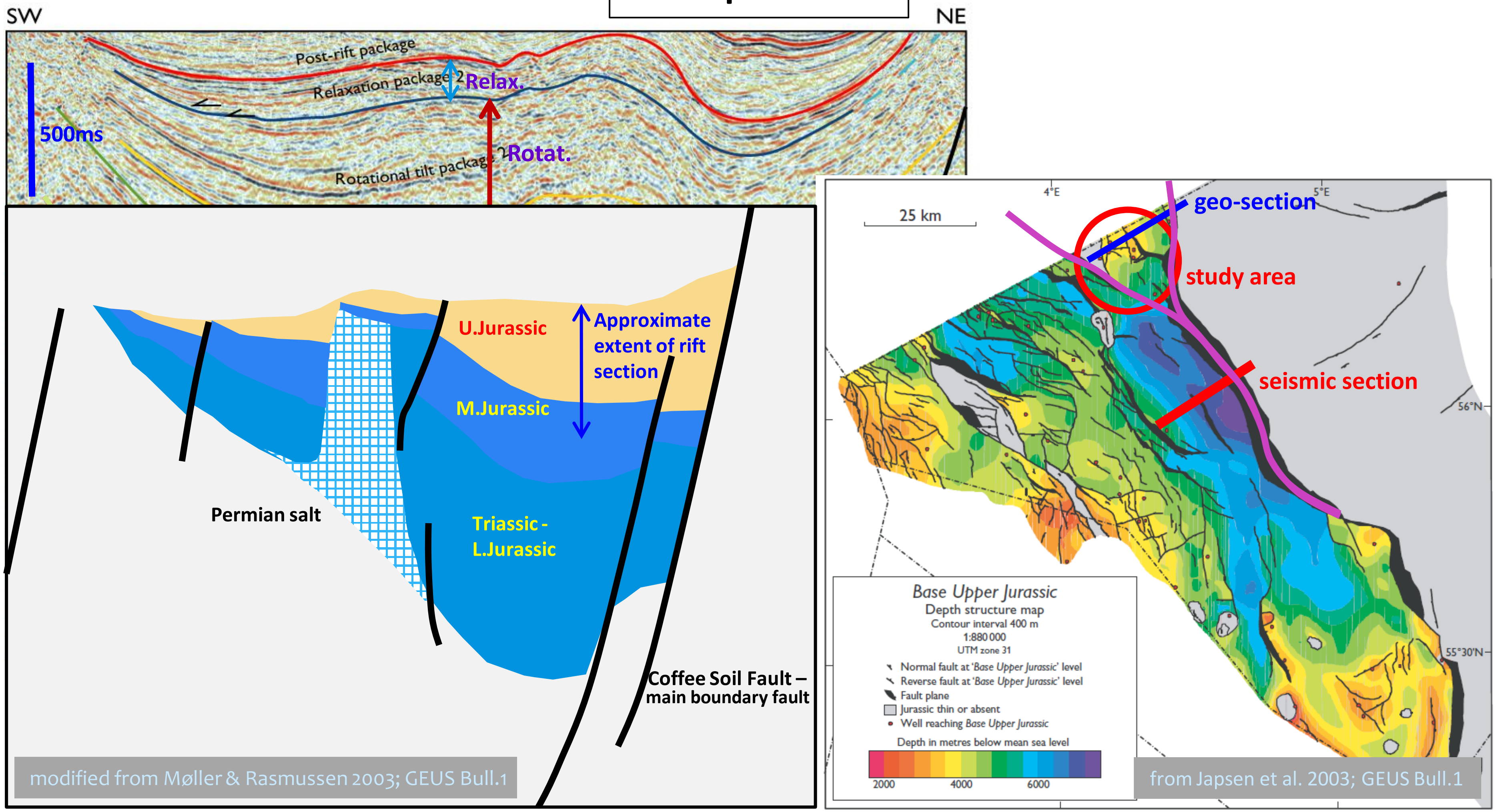
- The Jurassic North Sea Rift, Danish Central Graben.
- Facies associations of the late Middle Jurassic.
- Depositional geometry outlined by key surfaces.
- How geometry and rotational events connect.
- Coeval deposits from neighbouring basins.
- Conclusions

# The North Sea with the Middle – Upper Jurassic graben system




- The study area in the Central Graben.
- Comparisons to neighbouring basins.
- A rift basin - the Viking Graben.
- An epicontimental basin - the Norwegian – Danish Basin.
- Studied wells are located in the Søgne Basin – a minor subbasin of the Central Graben

# Rift profile

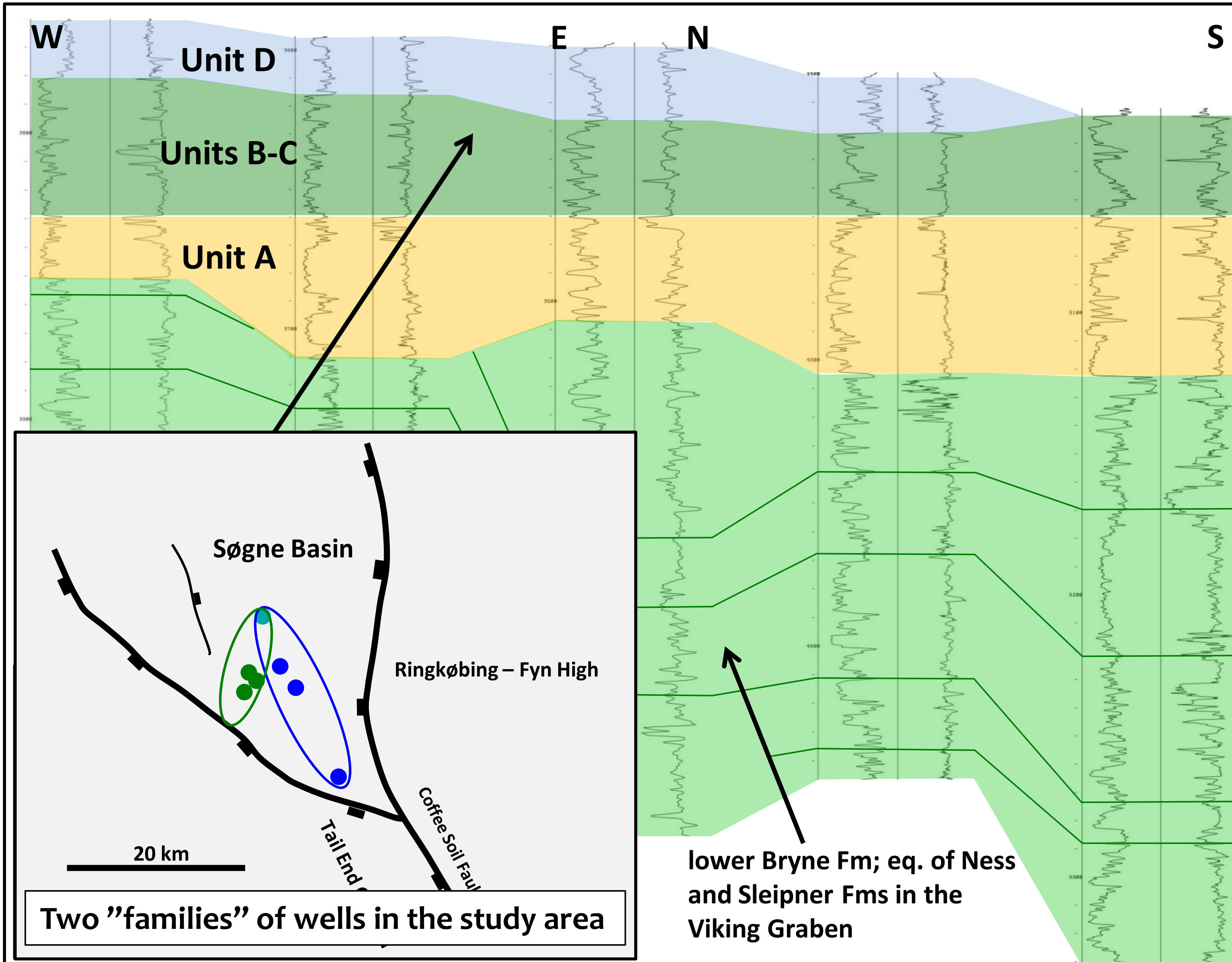



- In the main basin rift intiation package is located deeper than 6000m. No well data.
- In the Study area in the Søgne Basin the rift initiation package is generally located at depths of 3000m to 4000m. Data from exploration wells are available.

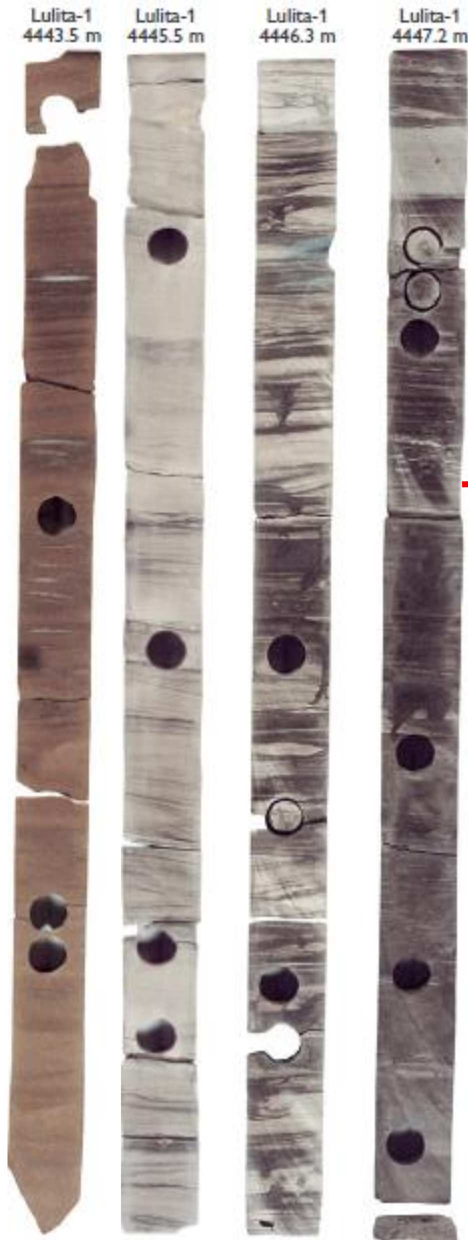
# Facies associations of the late Middle Jurassic of the Danish Central Graben

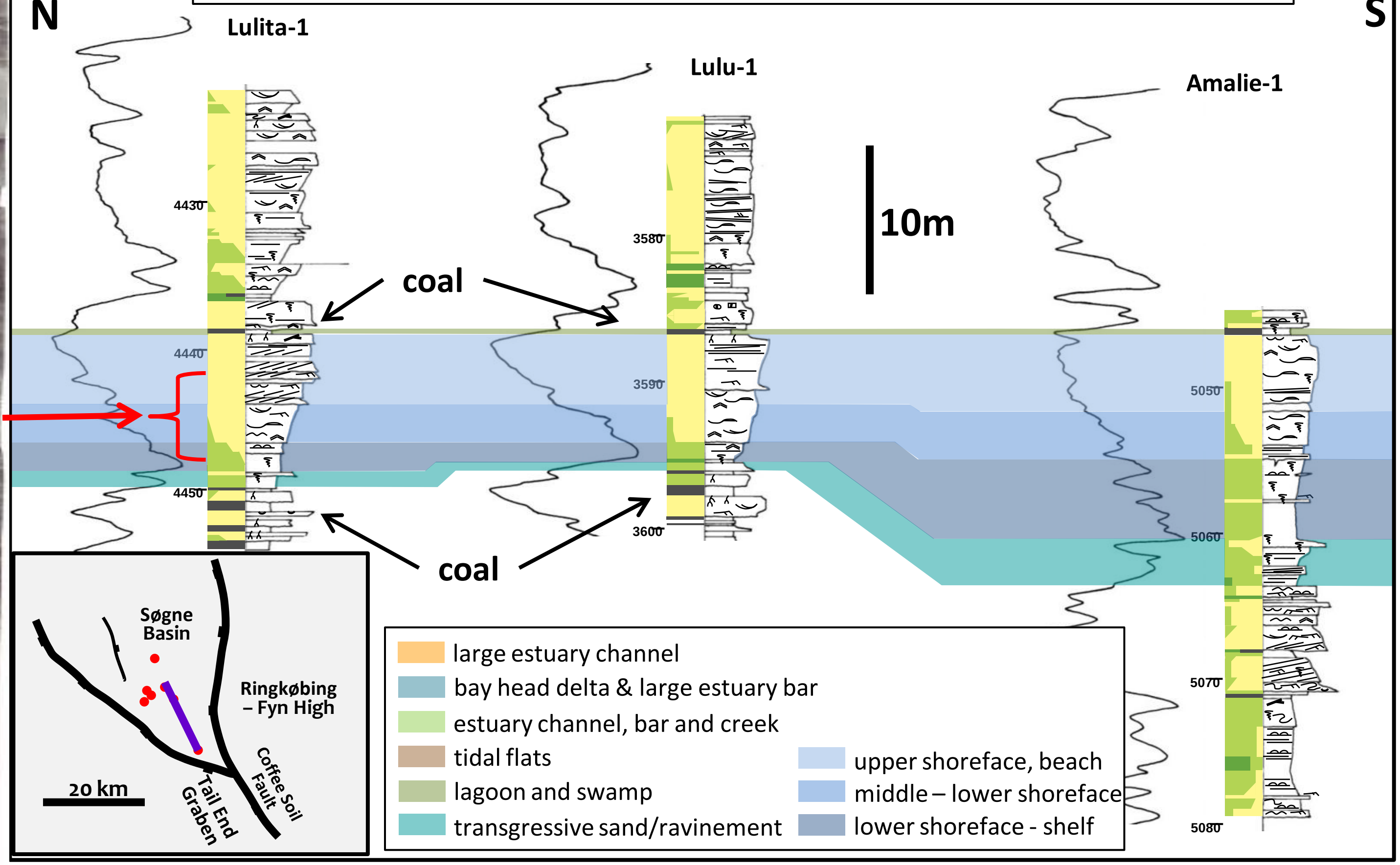
- Deposition in the late Middle Jurassic during initial stages of transgression of the Central Graben rift.
- Coastal plain transgressions occurred repeatedly throughout the Jurassic in the North Sea area.
- Facies associations similar to those described here are observed both in rift basins and basins undergoing thermal subsidence

# M. Jurassic of the Søgne Basin including informal units A - D



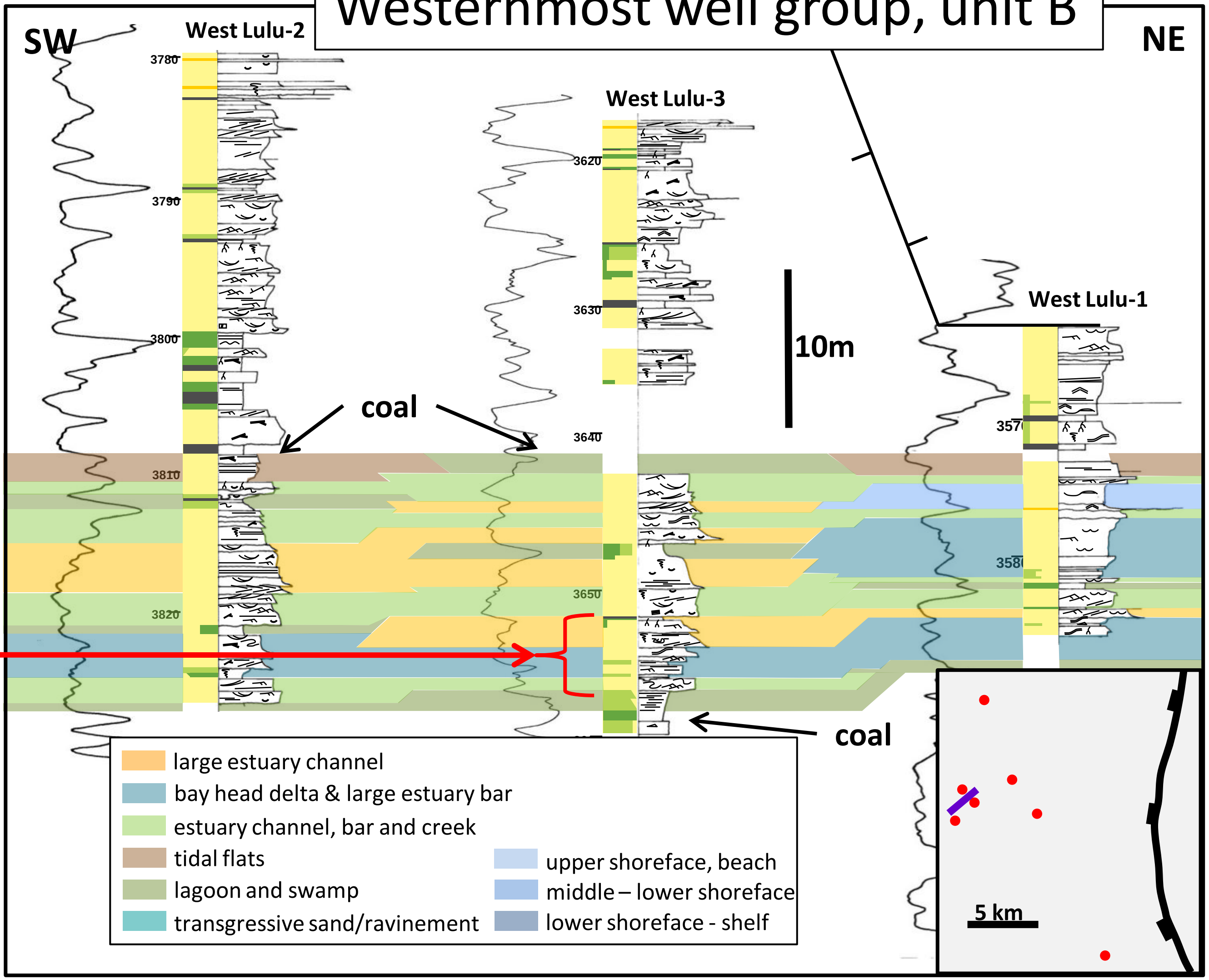
# Easternmost well group, unit B; strike line



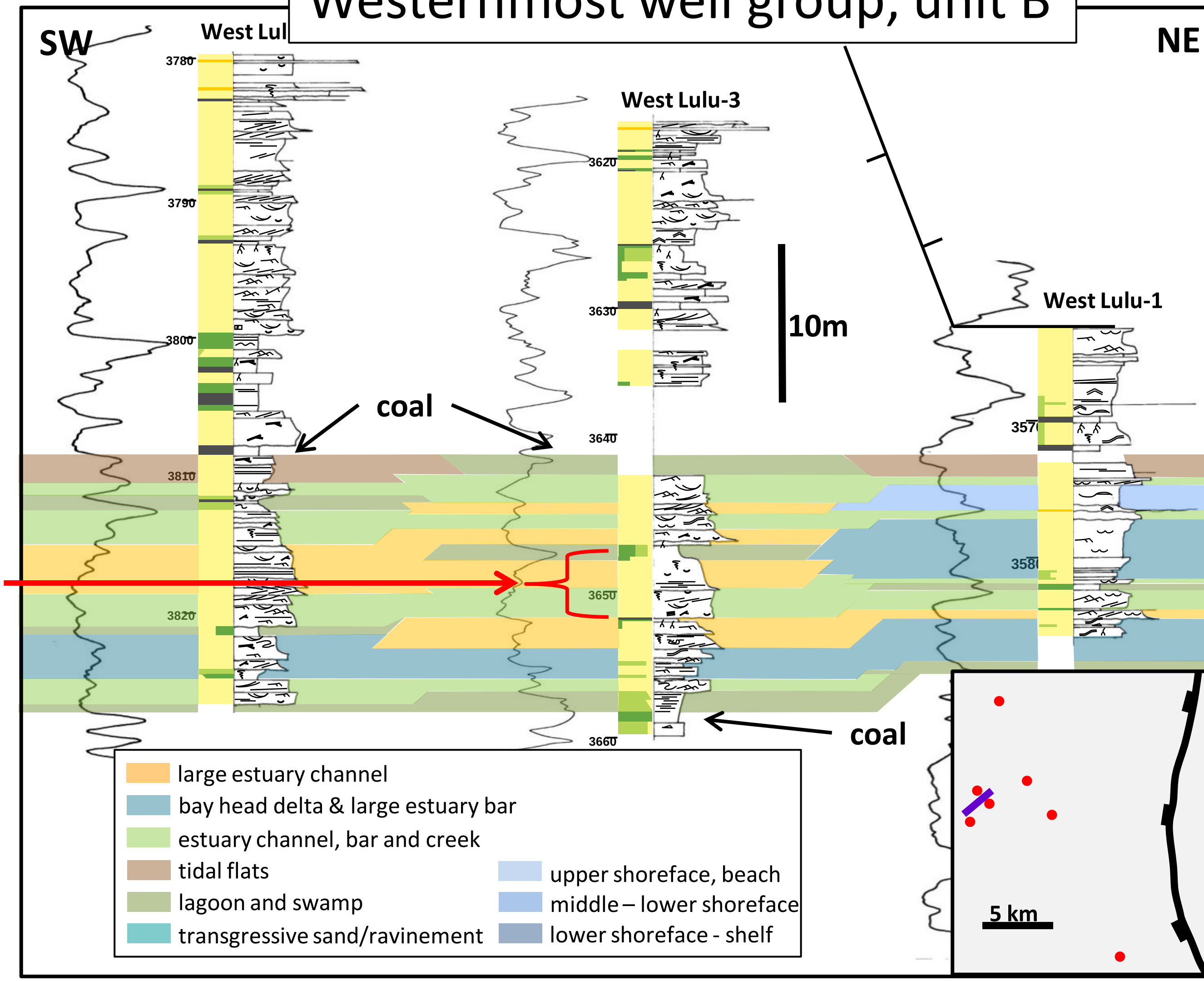

- Unit B; shelf to shoreface succession in Lulita-1 well.
- Upward coarsening succession from heterolithic, bioturbated siltstone in lower part to heterolith and sandstone with HCS, SCS and cross bedding in upper part.
- Succession is bracketed by wide spread coal beds.

# Westernmost well group, unit B

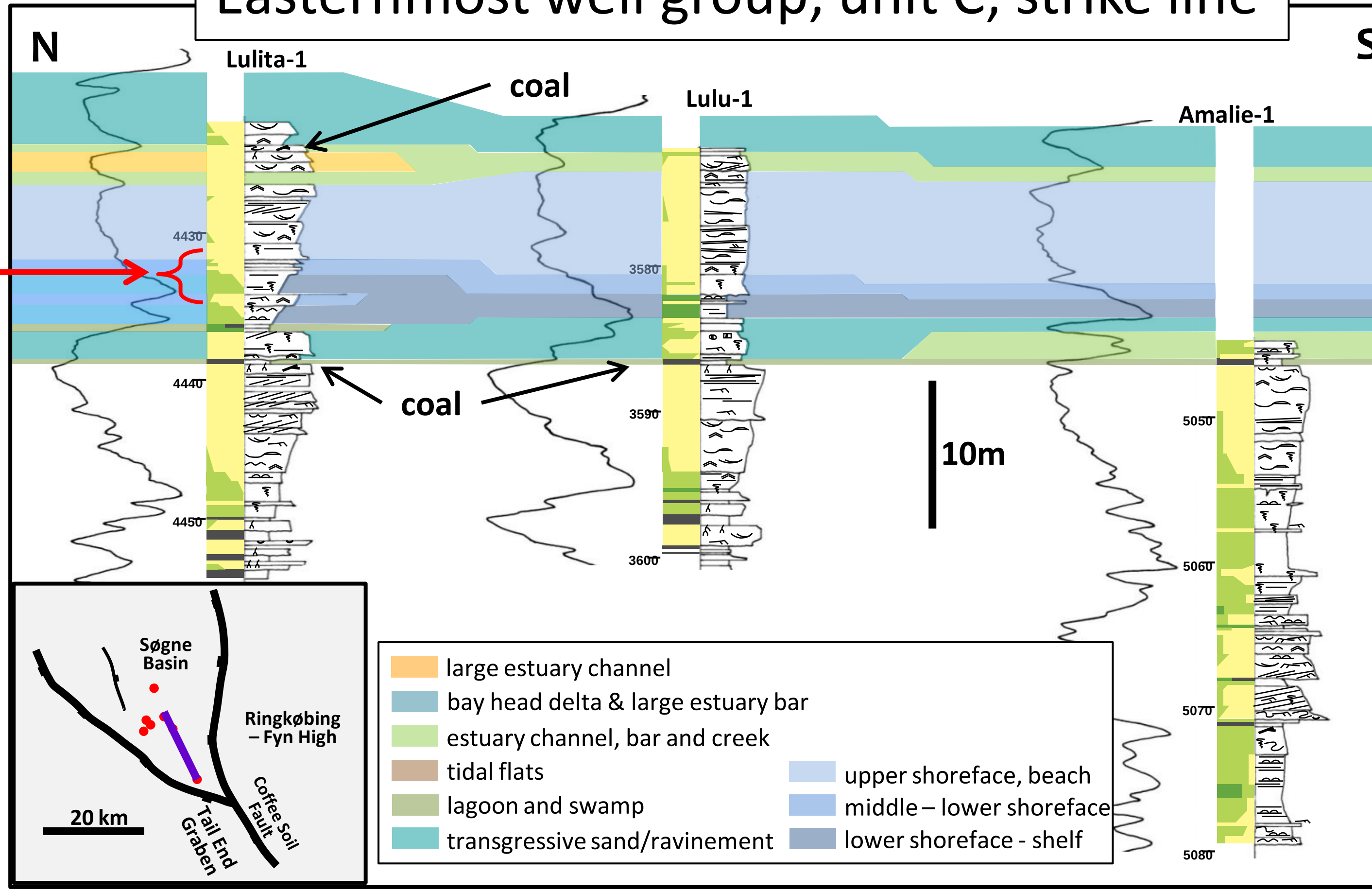

- Unit B; bay head delta or estuary bar (West Lulu-3)
- Erosive surface to underlying lagoonal deposits, flaser lamination and double mud drapes.
- well developed roots under coal at top of section.

# Westernmost well group, unit B

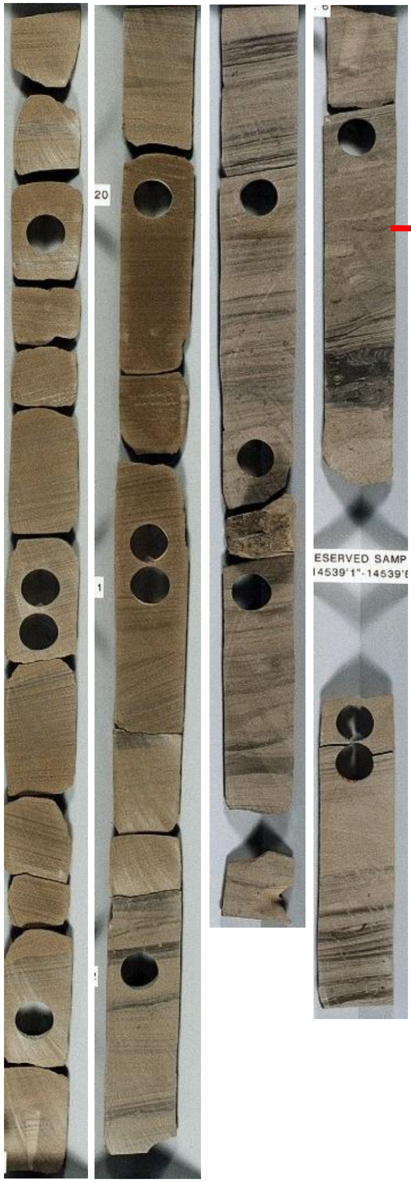

- Unit B; estuary channel and bar deposit (West Lulu-3).
- large scale cross stratification in lower part, strongly bioturbated (mainly Teichichnus) in upper fine-grained part (flooding event?).

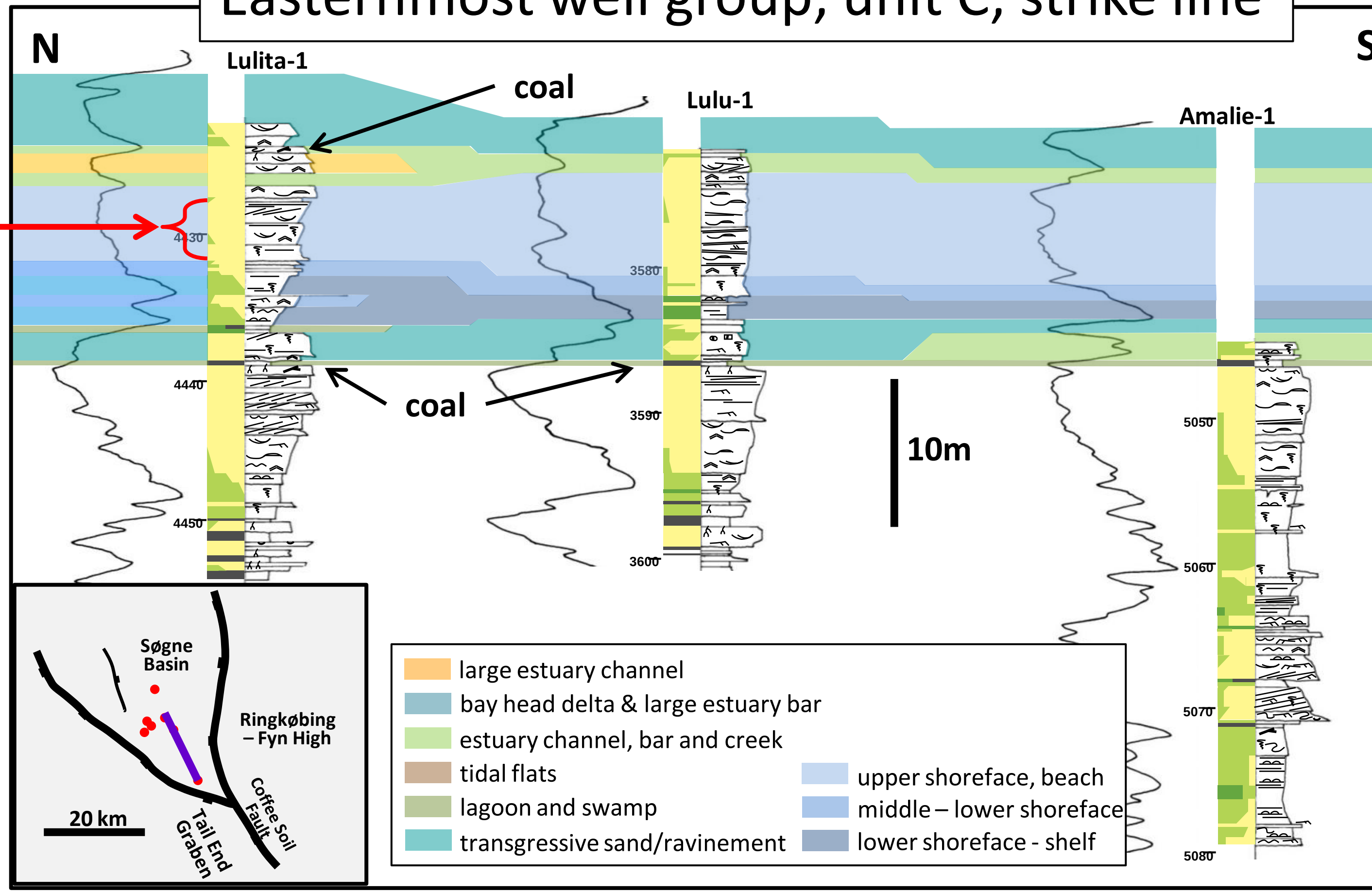
# Easternmost well group, unit C; strike line




- Unit C; cored section from lower part of progradational shelf/shoreface succession in Lulita-1 well.
- Shelf mudstone and siltstone becomes heterolithic upwards with HCS heterolithic sandstone in upper part.
- Unit is bracketed by coal beds.

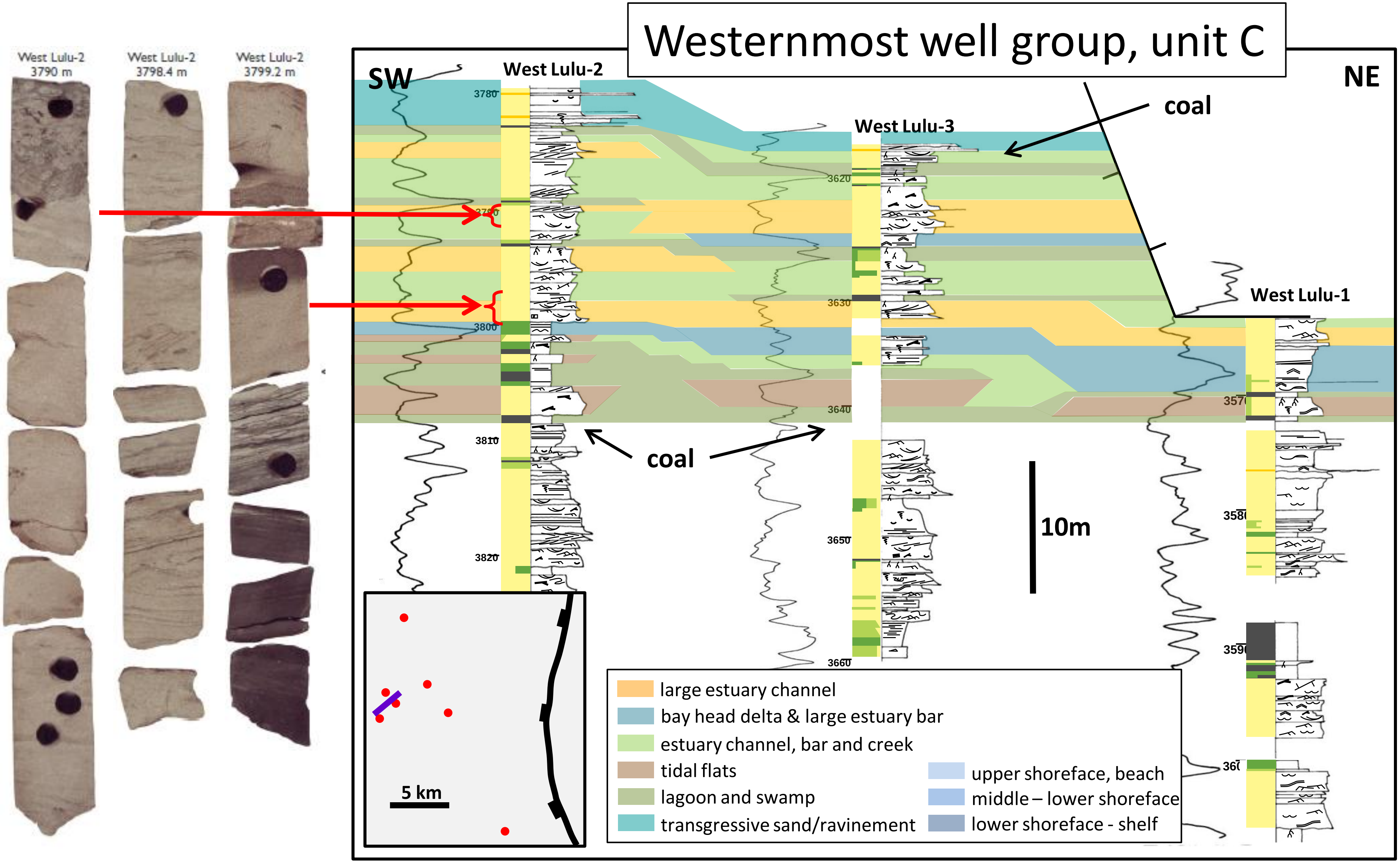
# Easternmost well group, unit C; strike line





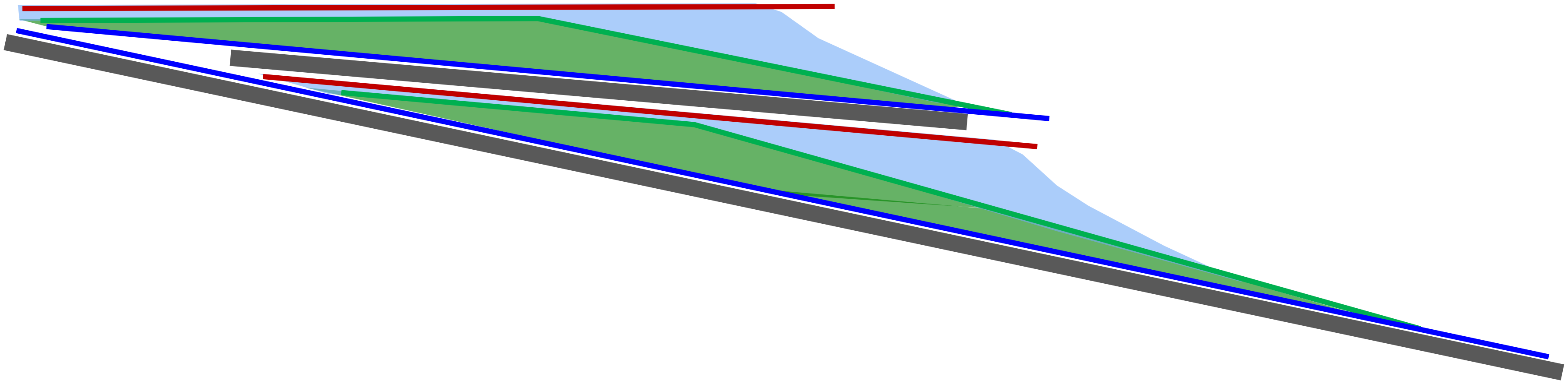

- Unit C; cored section from upper part of progradational shelf/shoreface succession in Lulita-1 well.
- Transition from HCS and wave-rippled, heterolithic sandstone upwards through SCS sandstone to large scale cross stratified sandstone.
- Thin coals and root horizons at top.

# Westernmost well group, unit C

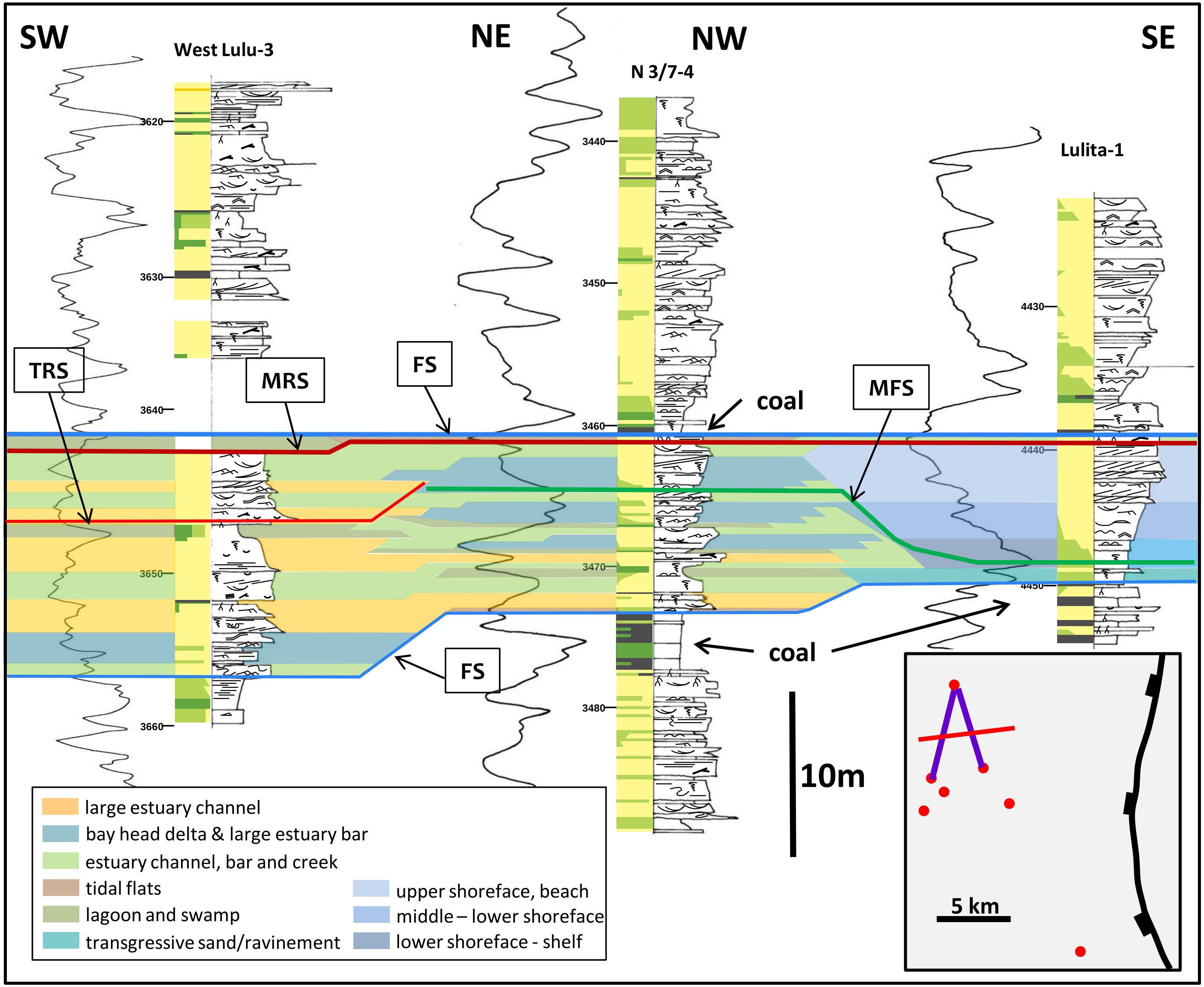



- Unit C; estuary channel and bar deposits.
- In lower cored section cross stratified and ripple laminated sandstone showing double mud drapes and flaser lamination sits erosively on lagoonal mudstone.
- In upper cored section cross bedded sandstone is extensively bioturbated right below mudstone bed (marine flooding?) (West Lulu-2 well).

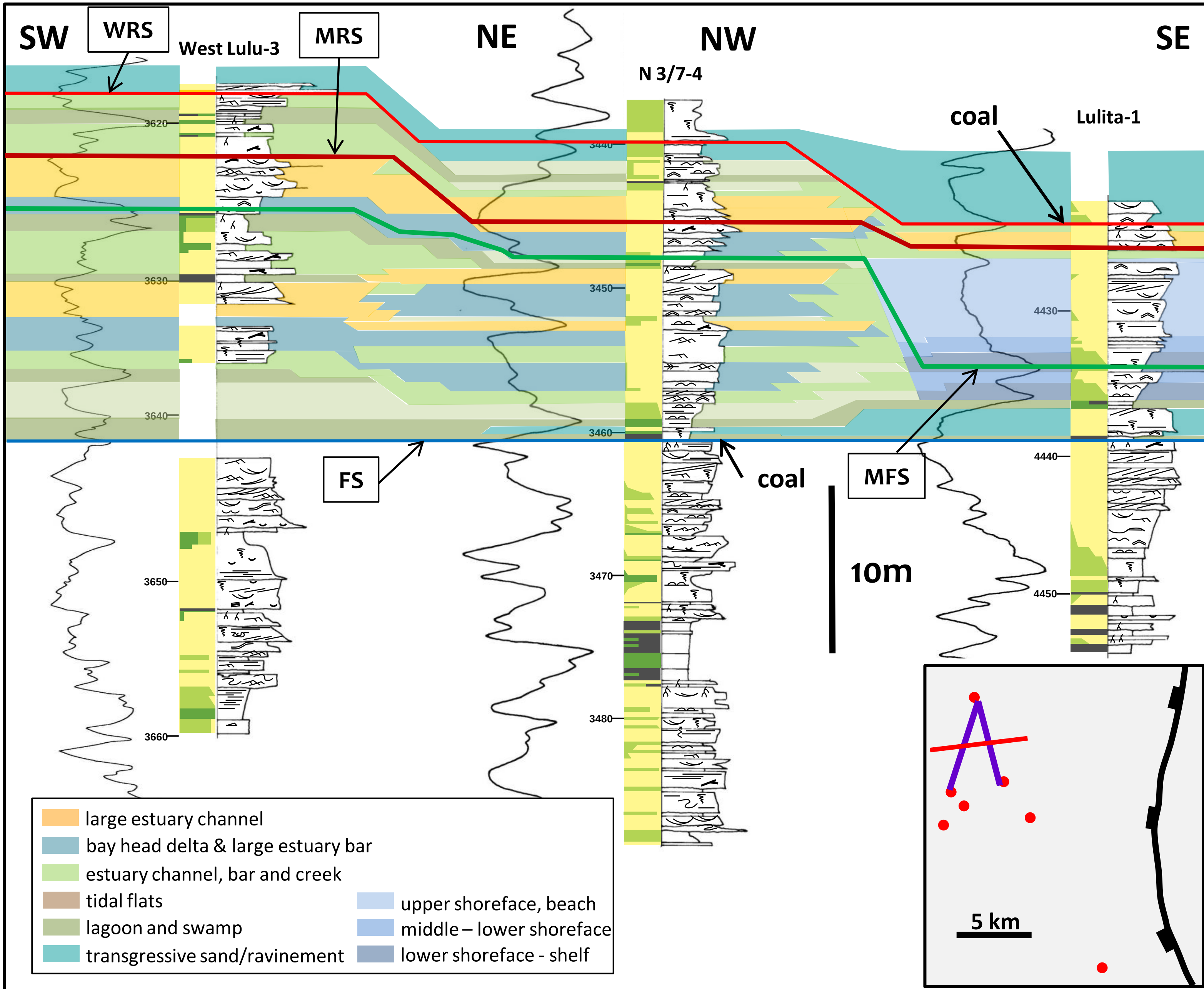
# Key surfaces and depositional geometry



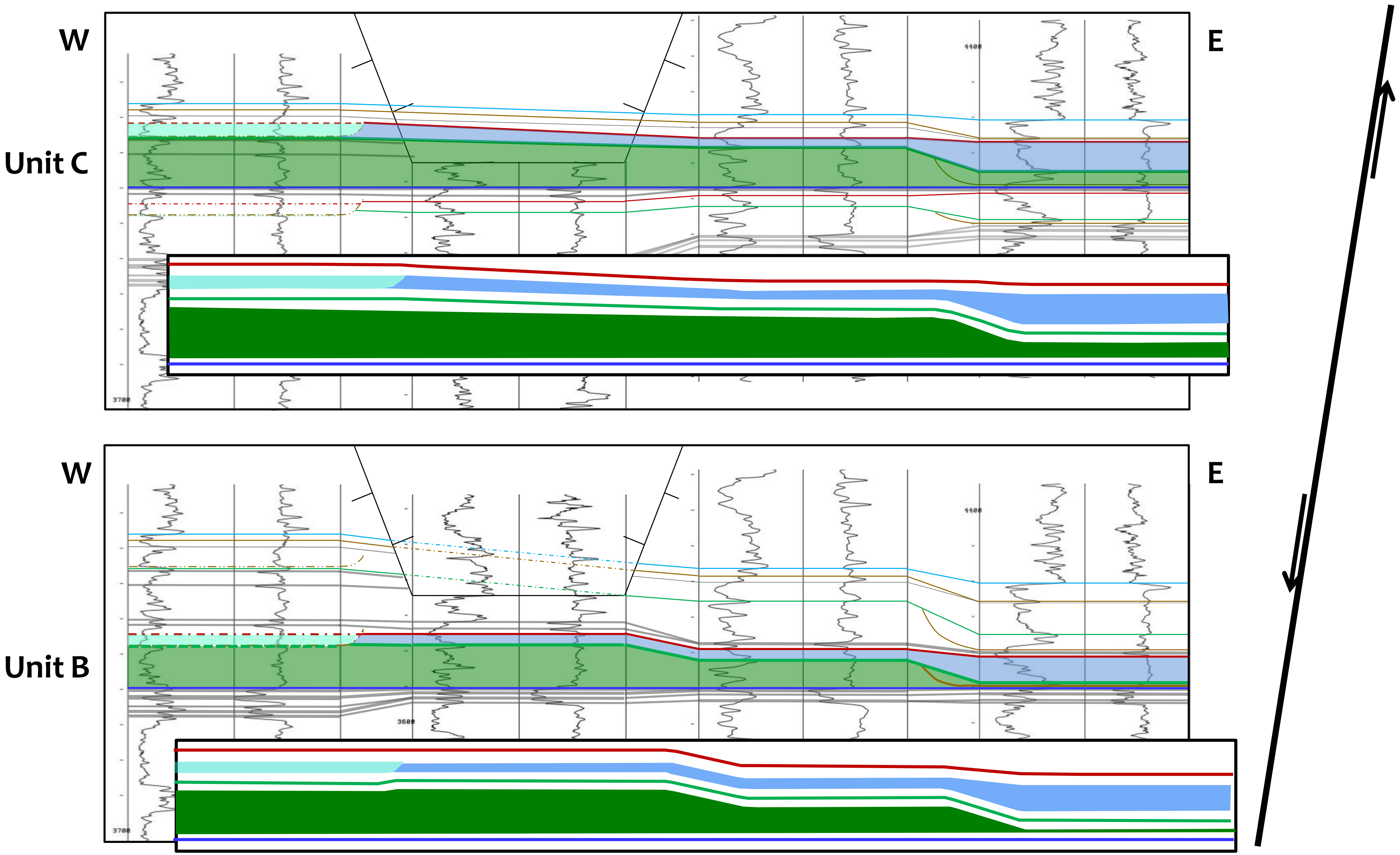
# Wells projected to strike line, unit B



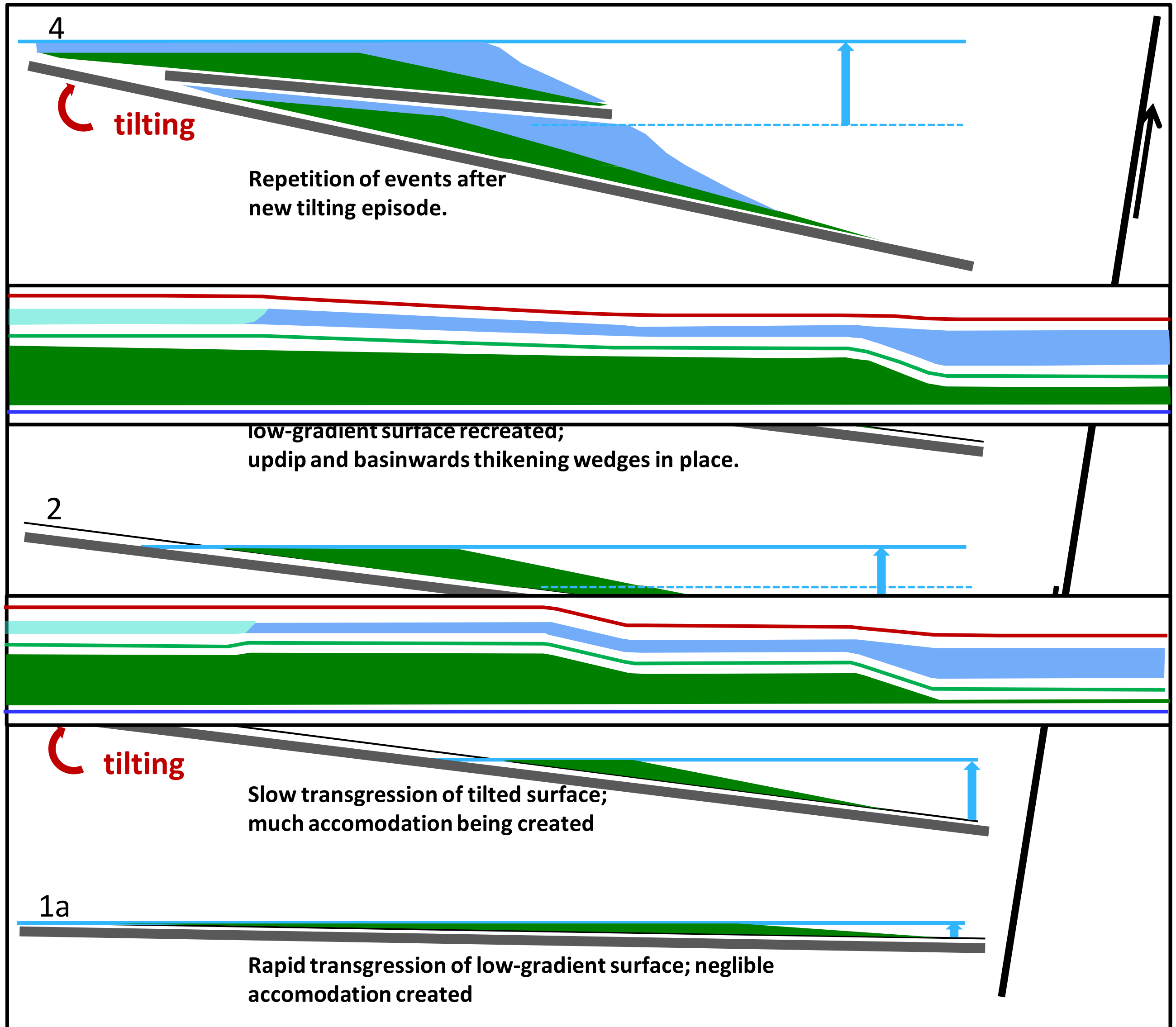
# Wells projected strike to line, unit C



# Schematic wedge geometry



# Schematic depiction of wedge forming events




Subsequent rotational events may cause repetition of the events until accellerating fault movements outpaces sediment supply.

↑

Remaining accomodation is being filled by prograding RST with sufficient sediment supply. When rise of sea level stops (rotational hinge line?) a new low-gradient surface is created.

↑

Up-dip accomodation space is filled by TST deposits until relative sea level rise stops.

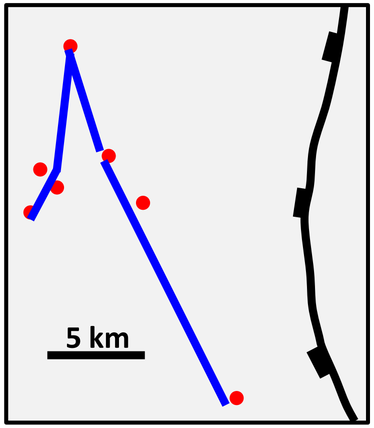
↑

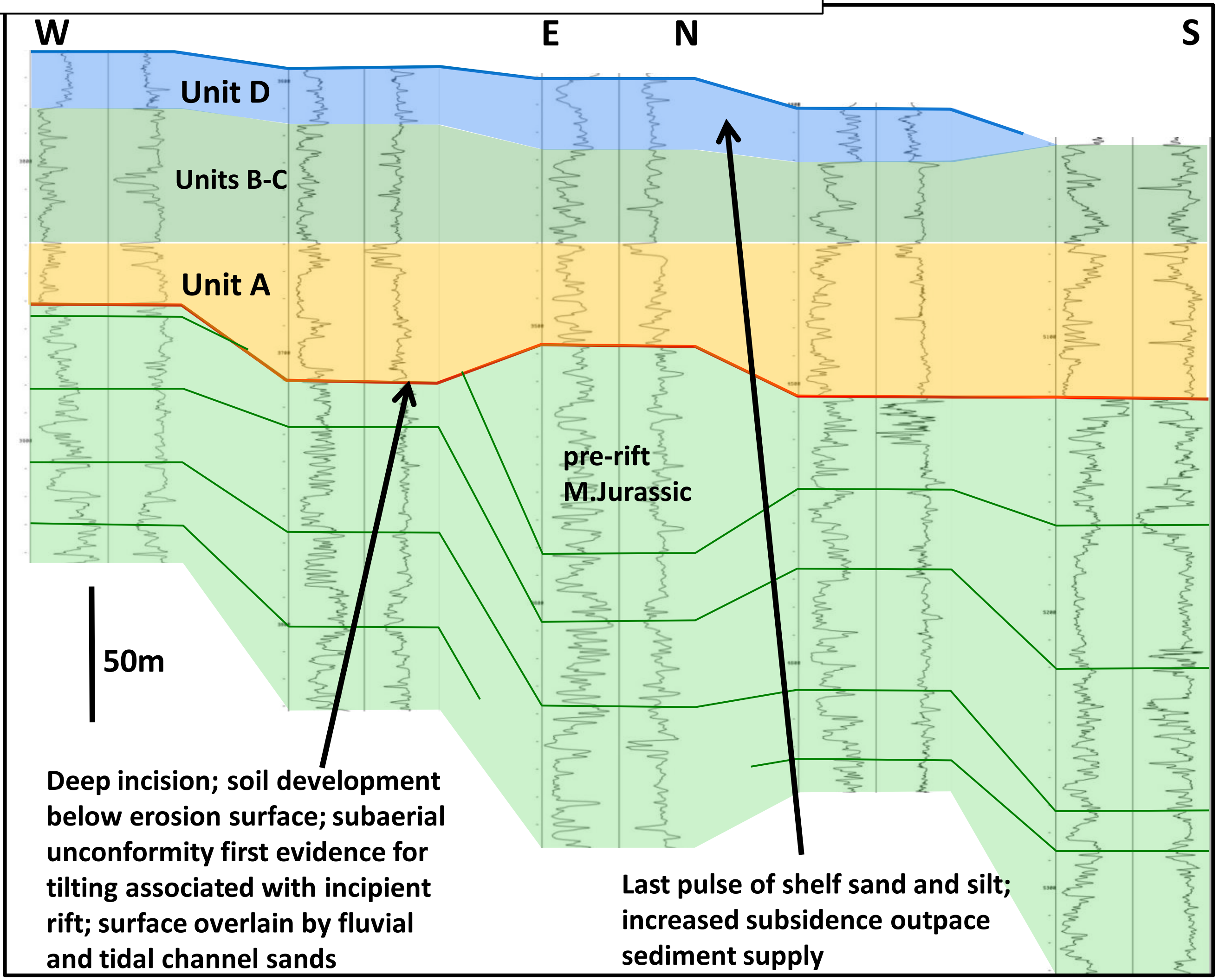
A sloping or stepped basin floor is a precondition for creation of accomodation for the thick TST seen in the westernmost wells.

↑

Flooding of a low gradient basin floor would cause deposition of an extensive but thin transgressive sand.

# Units A and D, a very short version

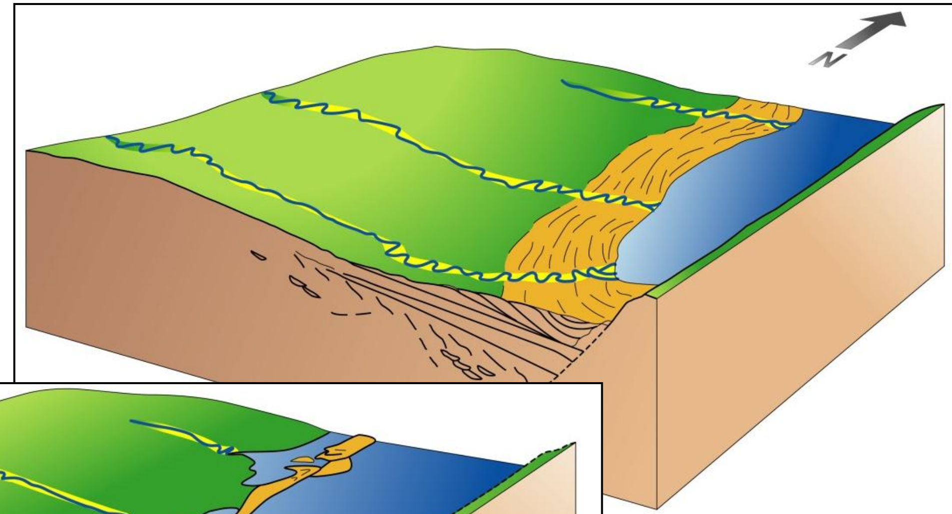


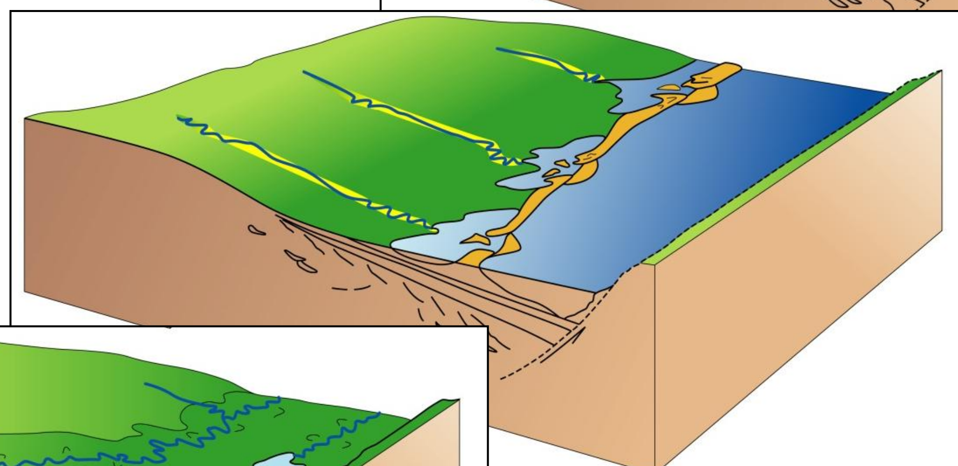

- Unit A; stacked channel sandstones in most wells, lower boundary unconformably on pre-rift Middle Jurassic. Oldest date above boundary is Late Bathonian.
- Unit D; strongly bioturbated shelf silt and vf sandstone; top of unit coincides with top Callovian.

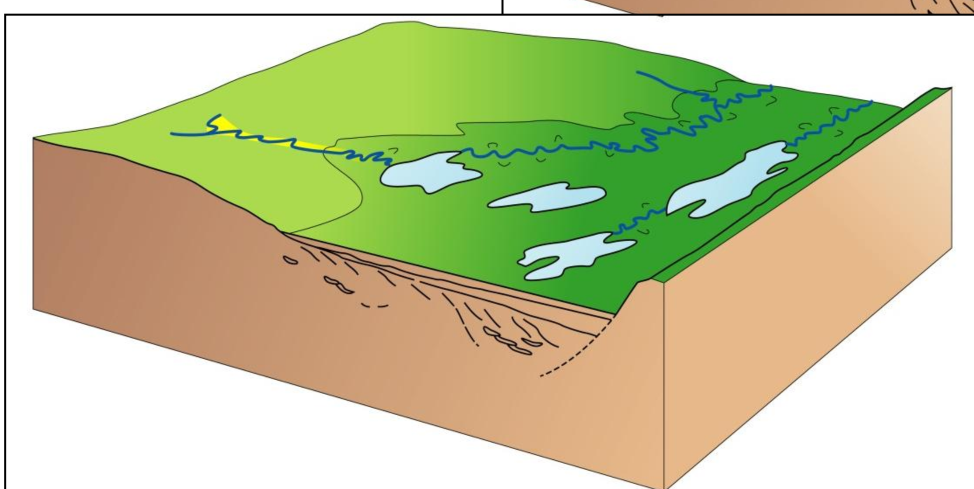
# 3–step development of landward and basinward thickening wedges

**3. tectonic quiescense; regressive phase;
prograding shoreface/delta; low-gradient surface re-established;
formation of RST wedge**



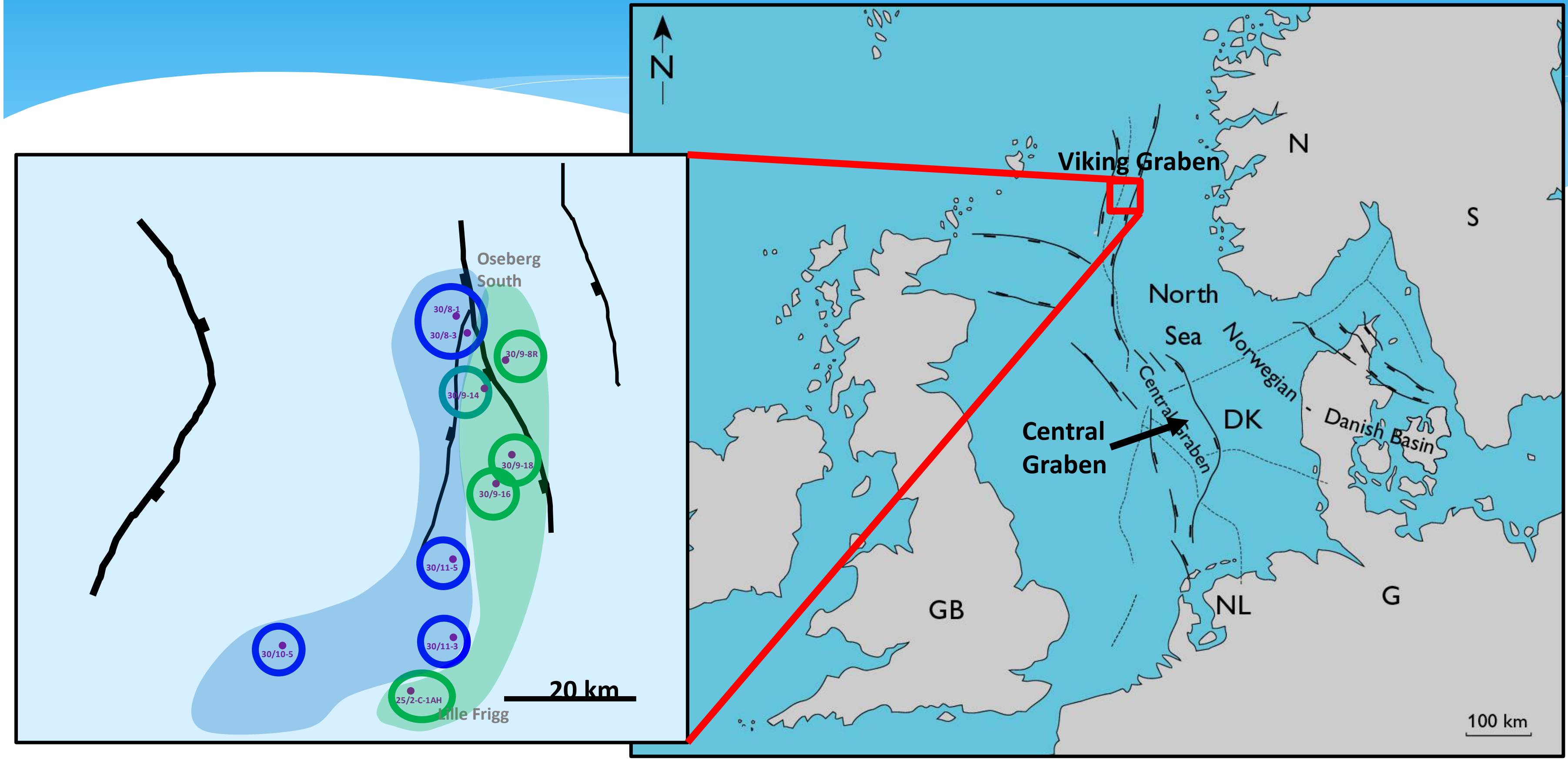

**2. after rotational event;
transgressive phase;
backstepping tidally dominated coast;
formation of TST wedge**





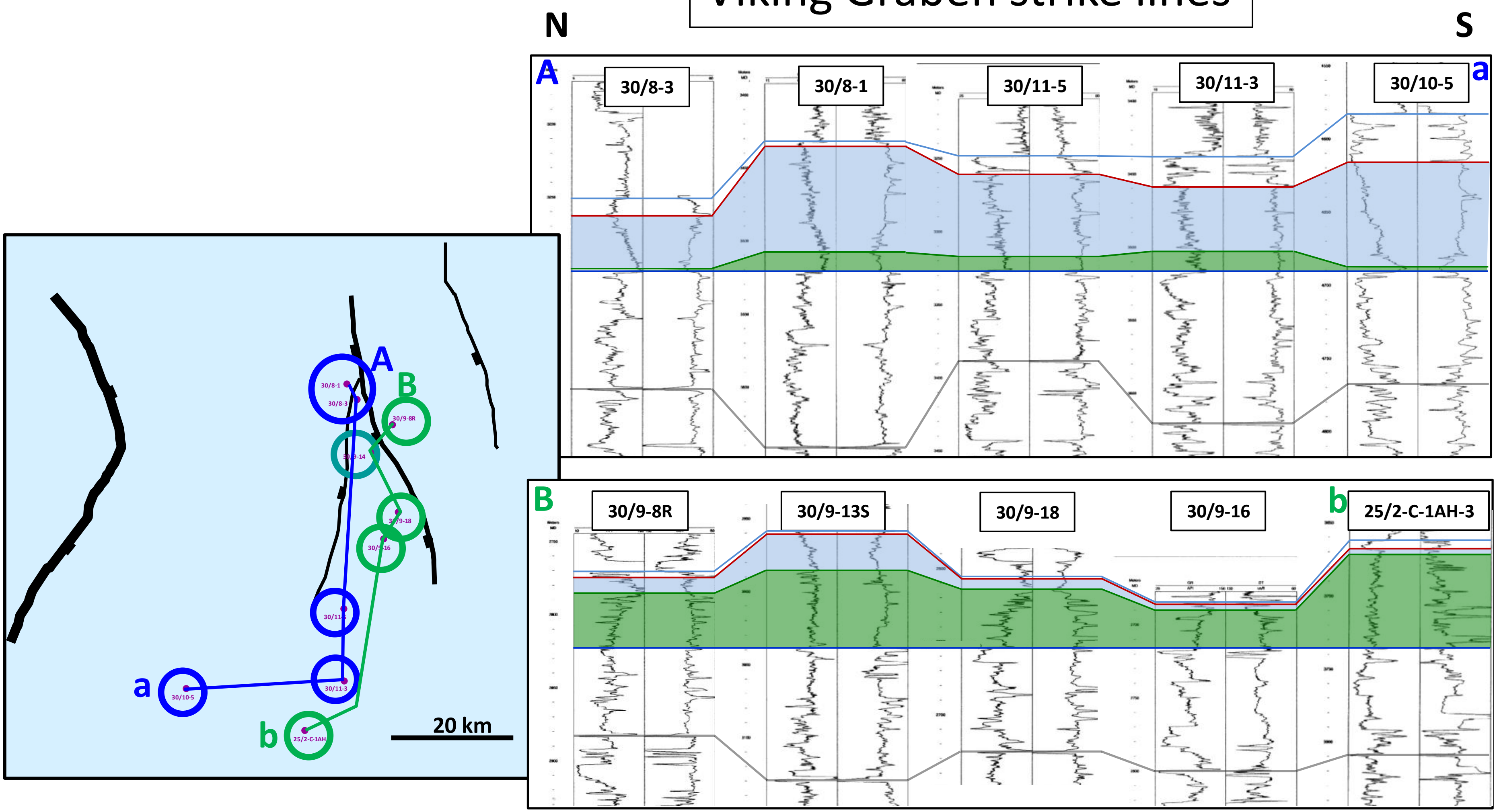
**1. tectonic quiescence; basin-wide peat swamps on low-gradient basin floor; slowly rising sea-level. Pre- unit A, end unit A, end unit B.**

# Contemporaneous deposits in neighbouring basins




- The wells are located in the Viking Graben from Oseberg South to Lille Frigg Fields.
- Two groups of wells can be separated on log character.
- Each group of wells is concentrated in an arch shaped area

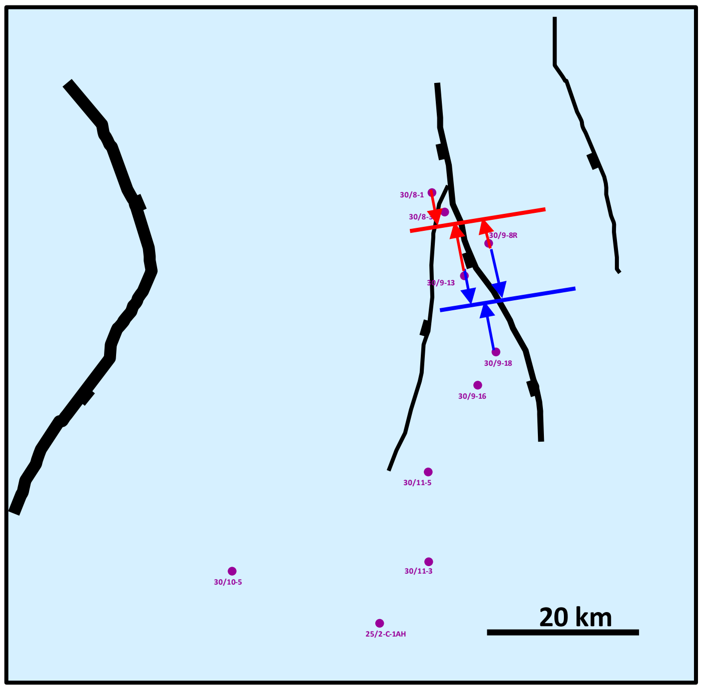
# Viking Graben strike lines

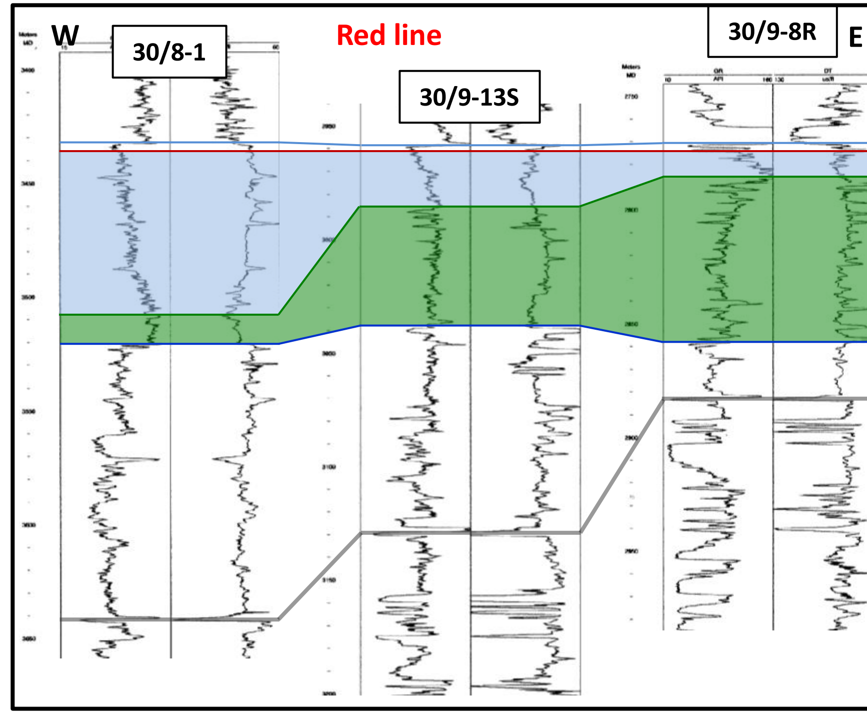


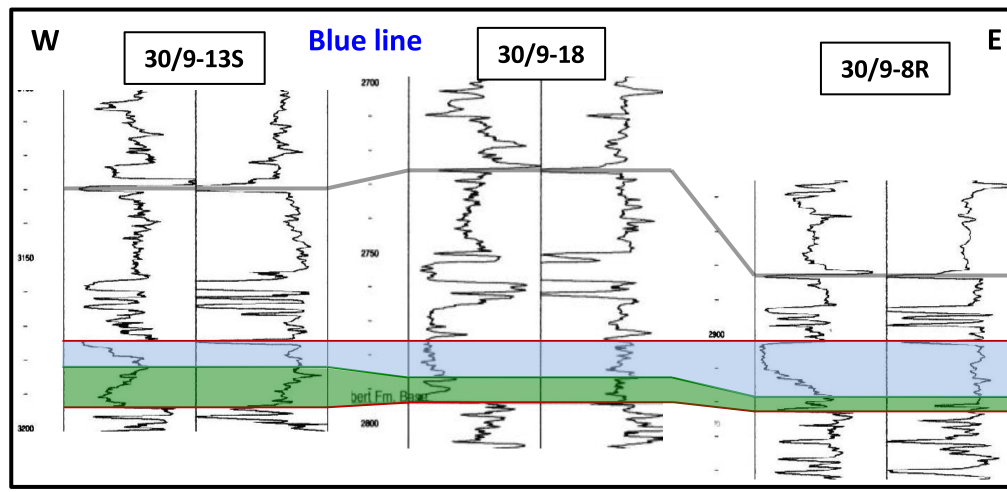

- The depicted unit straddles the TarbertFm. – Heather Fm. Boundary.
- In the easternmost wells (line B – b) the unit is dominated by a lower upward fining section of shallow marine, bioturbated sandstone and siltstone (TST).
- In the westernmost wells (line A – a) the unit is dominated by an upward coarsening succession of shelf to shoreface siltstone and sandstone with abundant wave generated structures (RST).

# Two Viking Graben dip lines

- Two dip lines with strike-projected wells are shown.
- The red line is the Tarbert-Heather transitional unit from the previous slide.
- The TST wedge is thickening to the east.
- The RST wedge is thickening to the west.

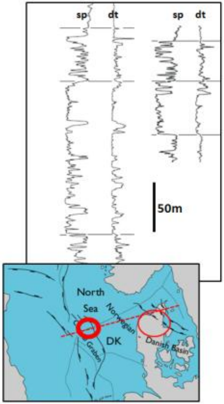


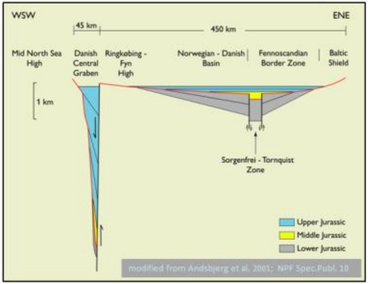




- The blue line is a lower Tarbert unit also showing a wedge shaped pattern.
- The TST wedge thickens to the west, the RST wedge thickens to the east !
- A more complex structural history

## Contemporaneous deposits in neighbouring basins




- The Norwegian – Danish Basin is an epicontinental basin that formed the eastern part of a greater North Sea Basin until rifting started.
- Middle Jurassic sedimentary facies and their log expression are very similar to Central Graben wells.
- The wedge shape geometry has not been described from this area.



Presenter's notes: The DCG contains more than 4 km of U.Jurassic syn-rift deposits and max. 300 m of M.Jurassic
The M.Jurassic consists of Aalenian - Callovian representing rift intiation to early rift climax phases
The M.Jurassic is subdivided into 3 units each representing a stage in the rift development
The M.Jurassic succession is bounded below by E.Aalenian unconformity formed by L-Toarcian - E.Aalenian uplift

# Conclusions

- Rift initiation leaves a distinct, often sub-seismic signature on the geometry of paralic – shallow marine deposits.
- A detailed study may help understanding of even complex structural history of the early rift phase.
- Analysis of the rift initiation - depositional geometry connection may have a predictional potential for distribution of reservoir rocks.

**Thanks to Statoil for access to, and permission to use, well data from the Norwegian shelf**

**Thanks to GEUS, the Geological Survey of Denmark and Greenland for generous support and data access during work with the Jurassic of the Danish Central Graben**