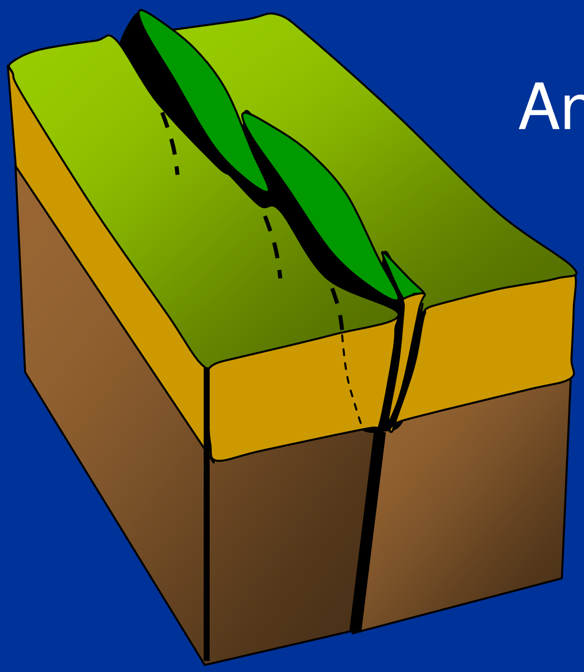
Characteristics of large-scale NW-SE trending faults along the Broad Fourteens Basin



And their influence on Downthrown & Pop-Up development

Herald Ligtenberg
NAM Exploration

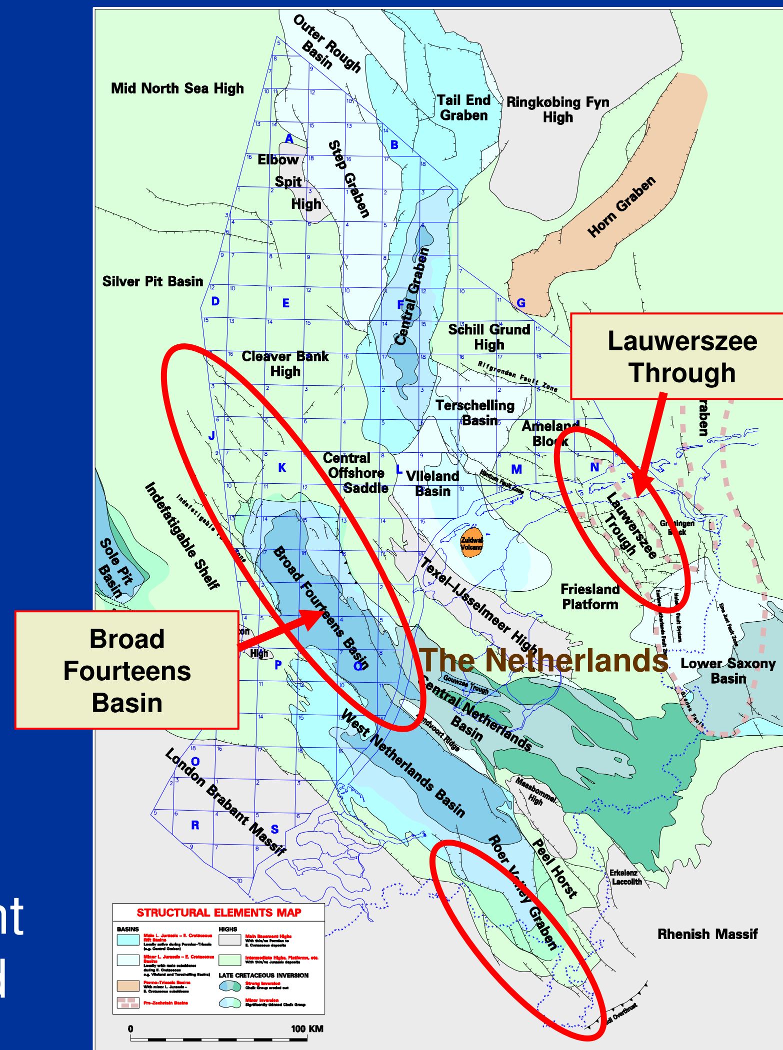
NAM

EBN-TNO Workshop on 'Rifting systems and its significance for hydrocarbon exploration in the Netherlands'

Utrecht, 5 June 2008

Introduction

- Large-scale & deep-seated faults.
  (Pre-Carboniferous)
- Crossing NL & UK area (100s km).
- Orientation NW-SE strike.
- Development of flower structures; containing downthrown & pop-up structures.
- Main regional structural grain; reactivated at most/ all subsequent tectonic events.
- These faults have played a dominant role in the development of the Broad Fourteens Basin.

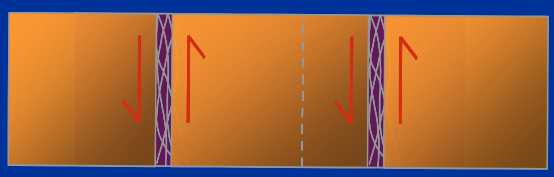


Important to evaluate and understand the structural development of this fault system to obtain better insight in Rotliegend structures.

NAM

Observations – in cross-section

Wedge-shaped fault zones containing folded and faulted, broken up zones in between stable, undeformed blocks.



Local zones of deformation, accommodating main displacement.

Observations – in top view

NW-SE faults cross-cutting Netherlands & UK area.

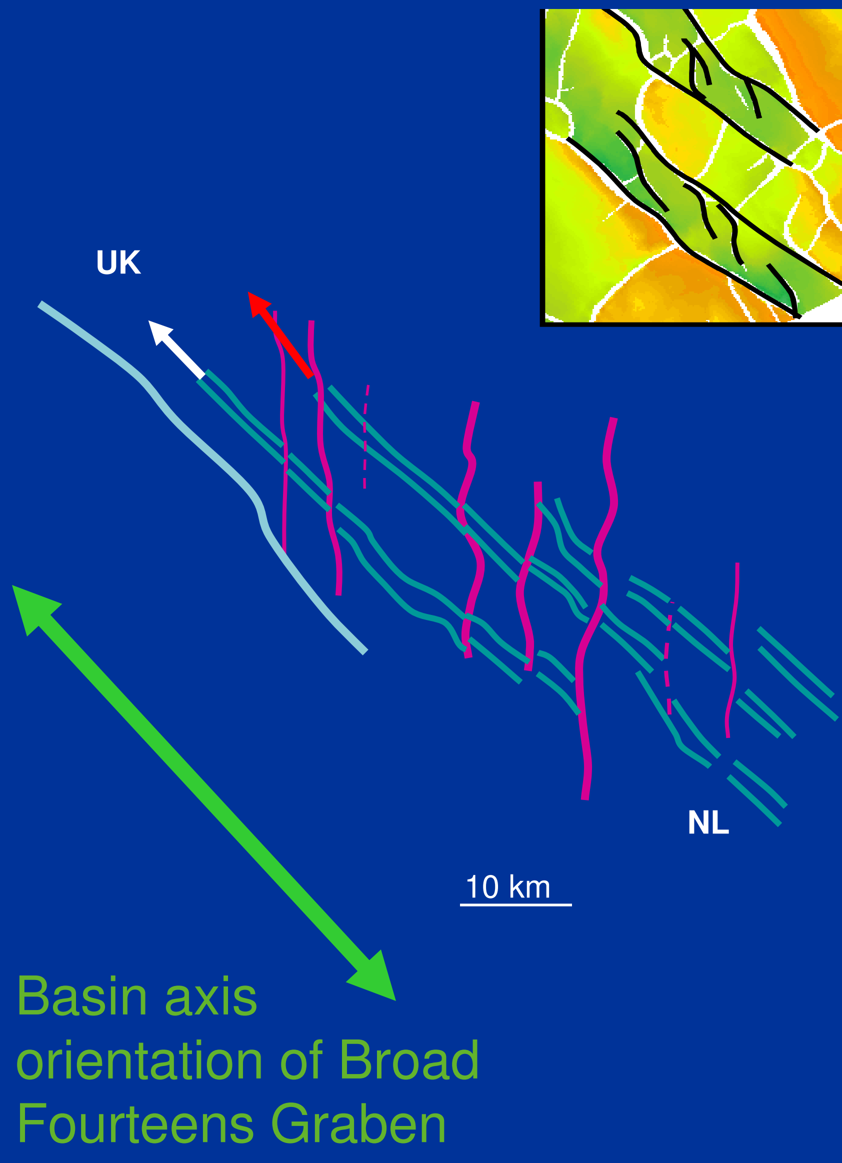
Their extend is hundreds of kilometres.

Faults run parallel to the basin axis of Broad Fourteens Basin.

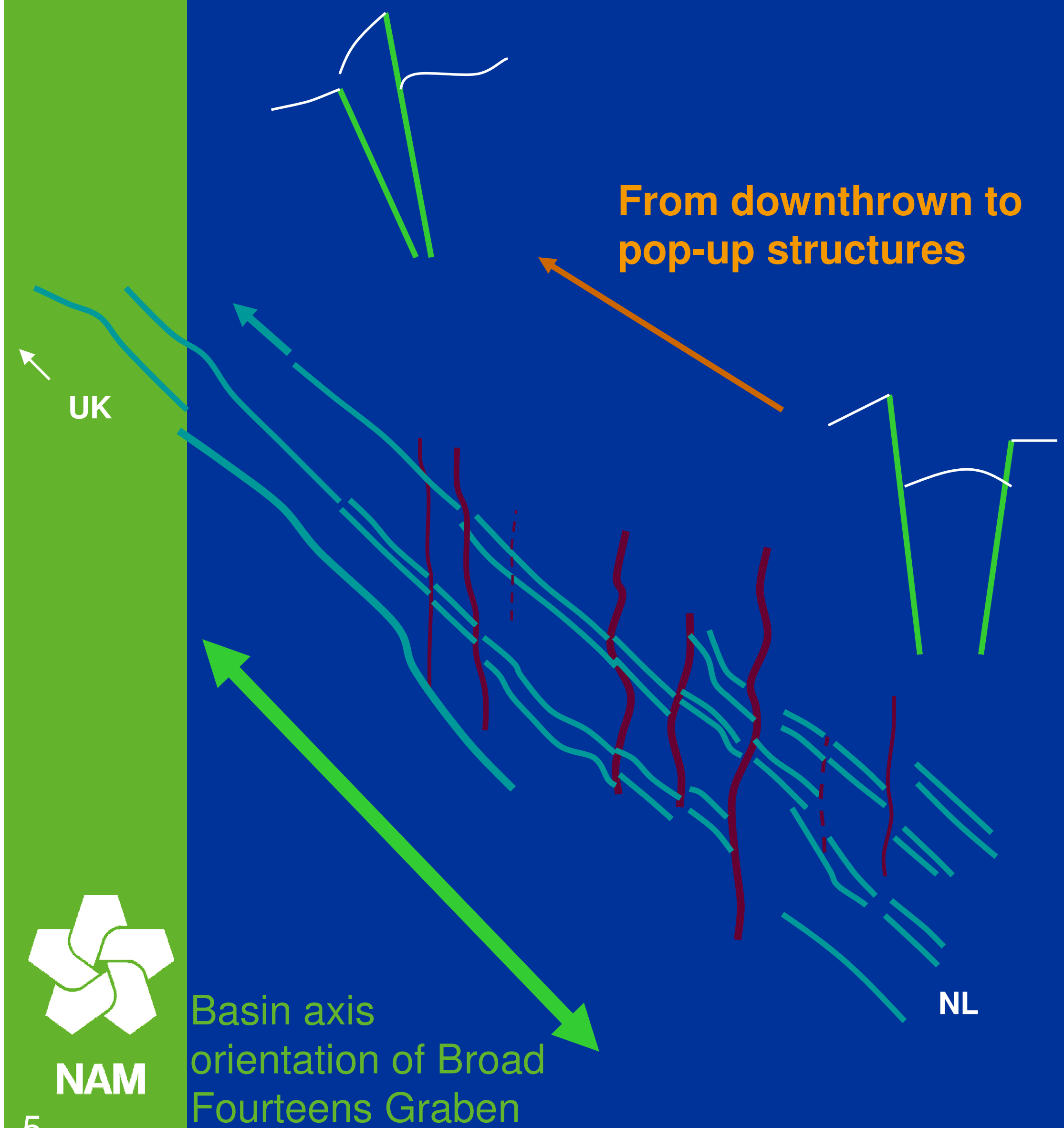
Internal fault character shows *en echelon* fault pattern.

NW-SE faults are offset by North-South trending faults.

Not always continuous; faults may die out and/or step over.

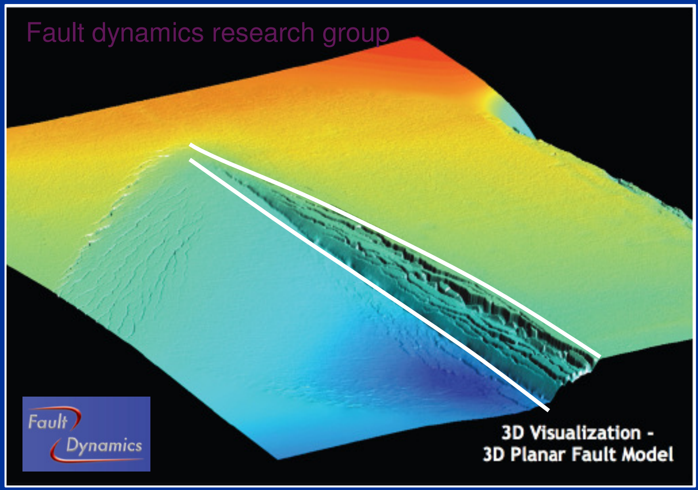


Extension of faults



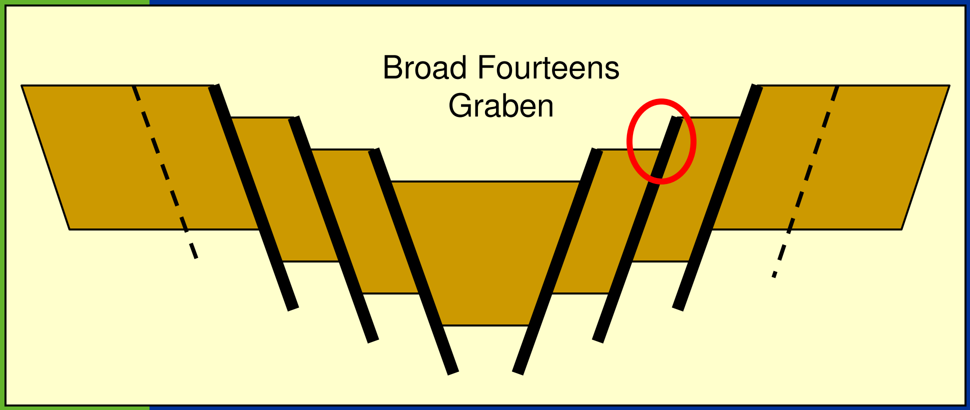
Trends towards the northwest:

1) Smaller fault zone width due to termination of BFB.
2) Possibly more compression towards the northwest.



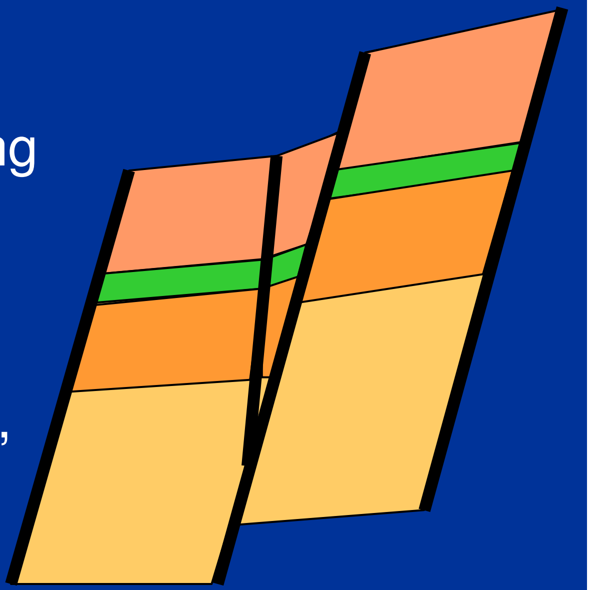
NAM

Structural tectonic setting



NW-SE fault zones have played a dominant role in the development of the Broad Fourteens Basin.

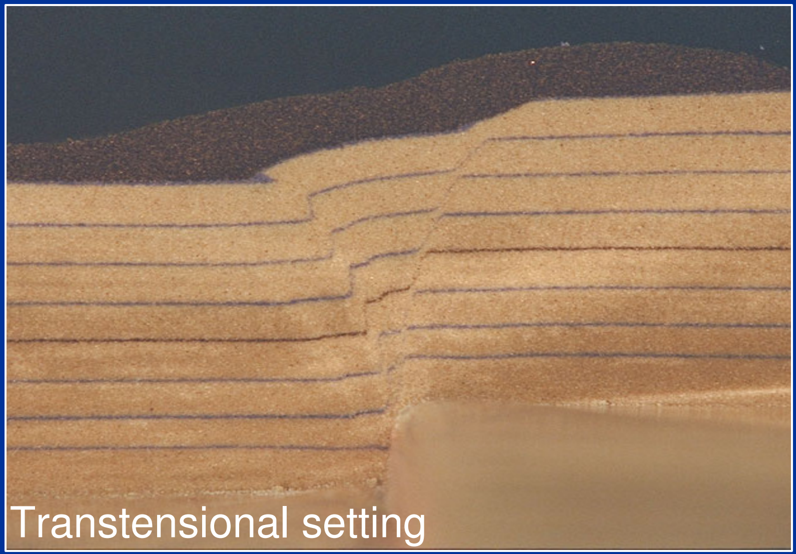
- Faults run parallel to basin axis and interpreted to be 'sister' faults of main graben faults.
- Faults underwent significant movement during rifting and inversion.
- Development of fault zone wedges occurs predominantly in hanging wall of overburden, above deep-seated basement faults.



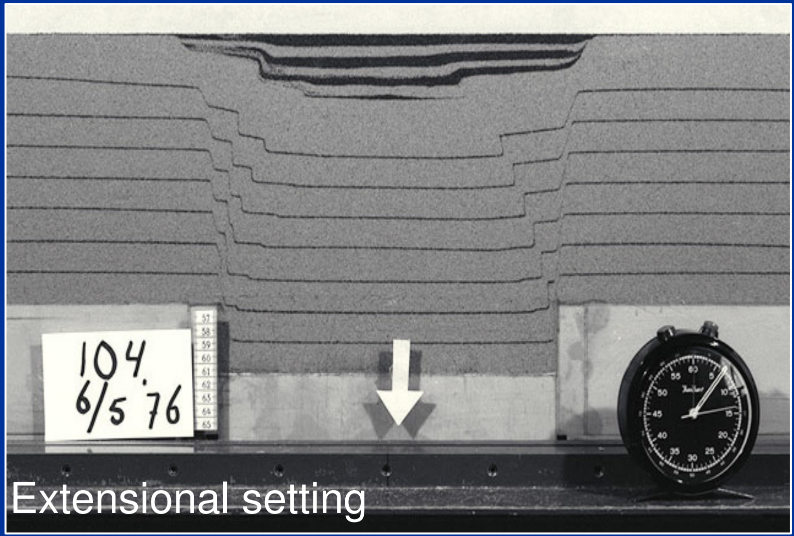
NAM

Development of fault wedge

Sandbox modelling analogues



Transtensional setting

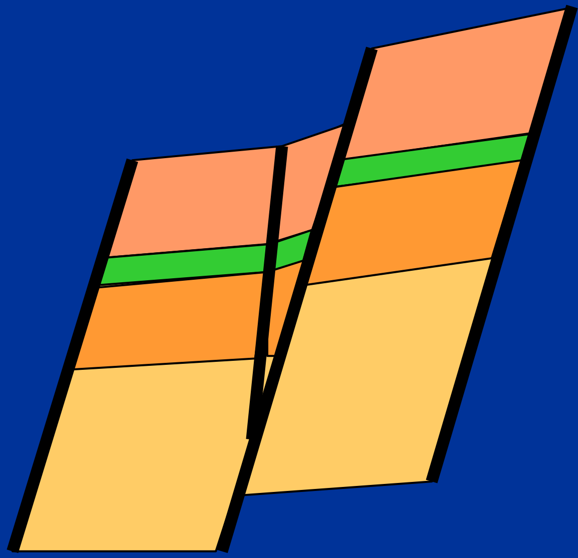


Extensional setting

In extensional setting, hanging wall is often more faulted/ broken up.

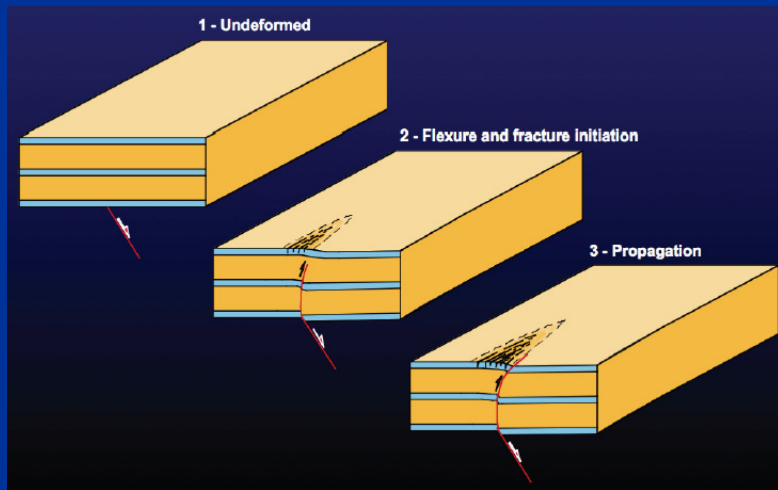
→ development of fault zone wedge.

Support from sandbox models.



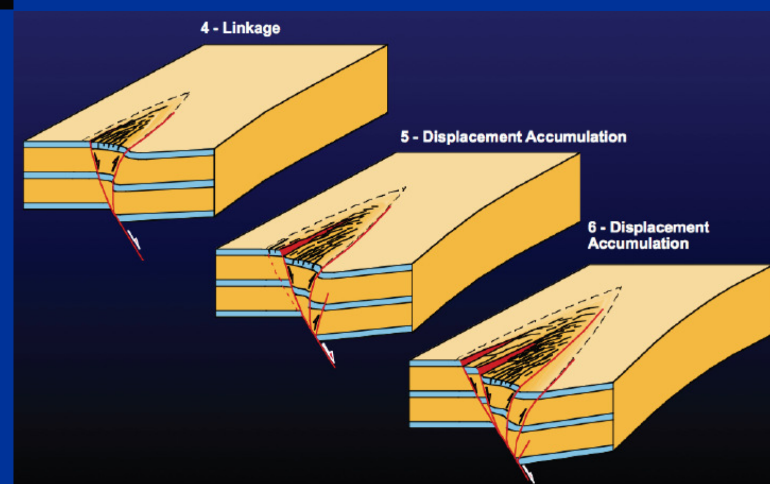
NAM

Fault & fracture system growth



Fault wedges in 3D

In ‘*real life’* it is likely to encounter more complex fault wedge development.



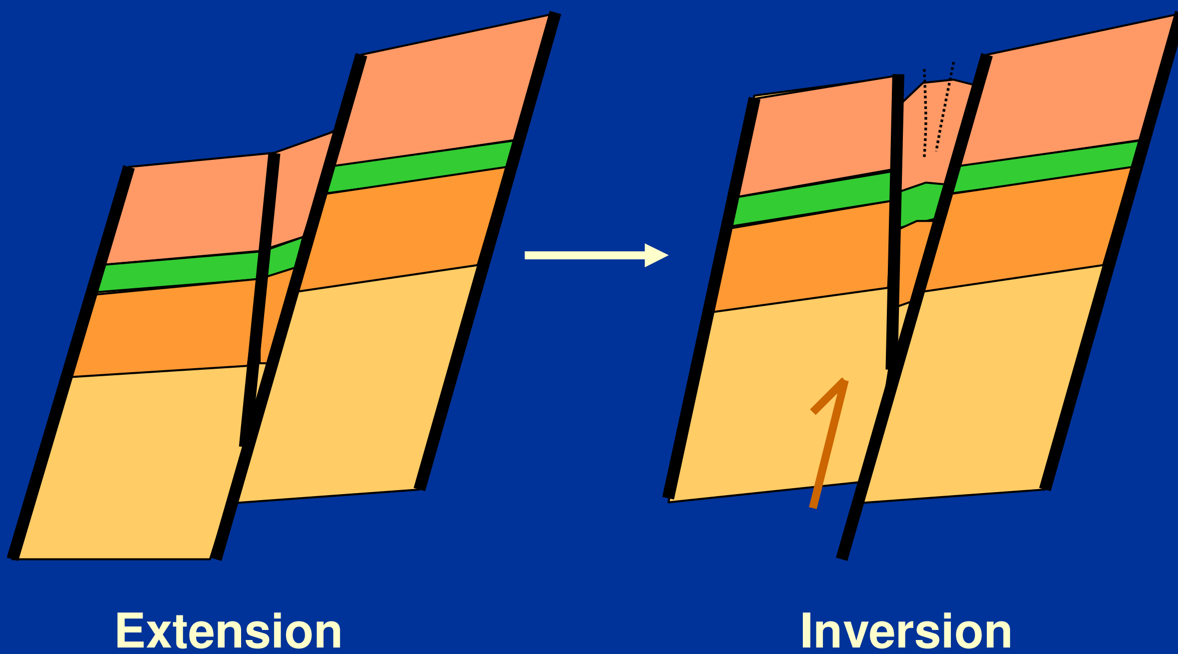
NAM

Fault Dynamics

Inversion effect

Alpine inversion (L. Cretaceous – Paleocene) took place under different main stress orientation compared to stress-regime at origin of faults:

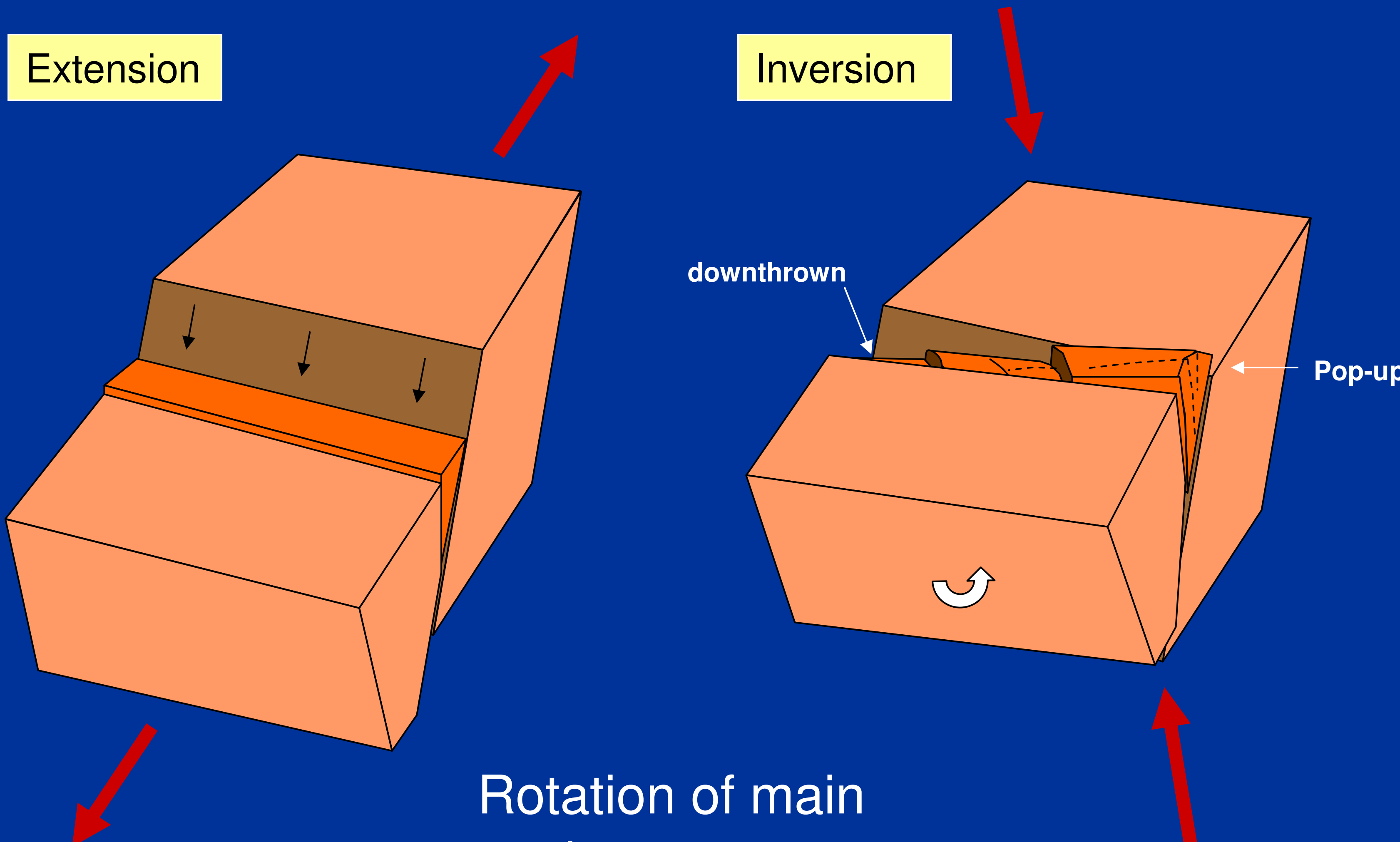
→ Oblique inversion, resulting in strike-slip and flower-structure development, with pop-ups and downthrown structures within the same fault zone.



Internal fault blocks are more deformed and likely to be more intensely faulted.

NAM

Oblique inversion in 3D



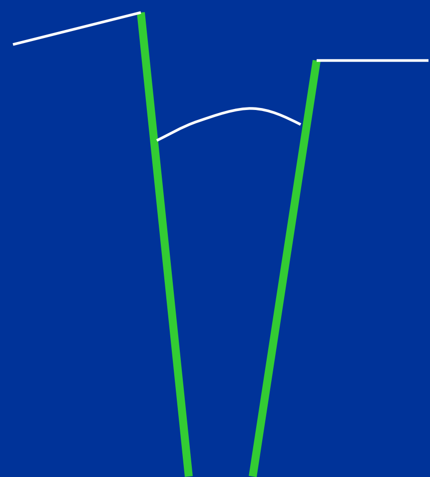
Rotation of main stress axes

Simplified model

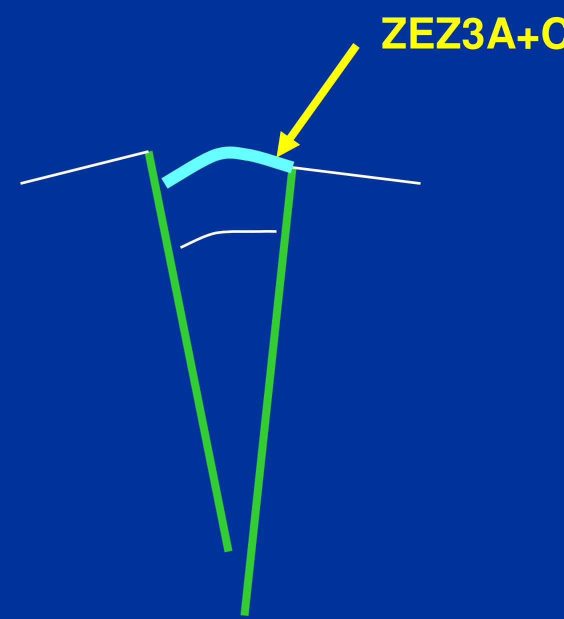
NAM

Observations – detailed (1)

Often folding in fault wedge observed, confirming compressional reactivation.



bulging of Rotliegend
and basal ZEZ2C



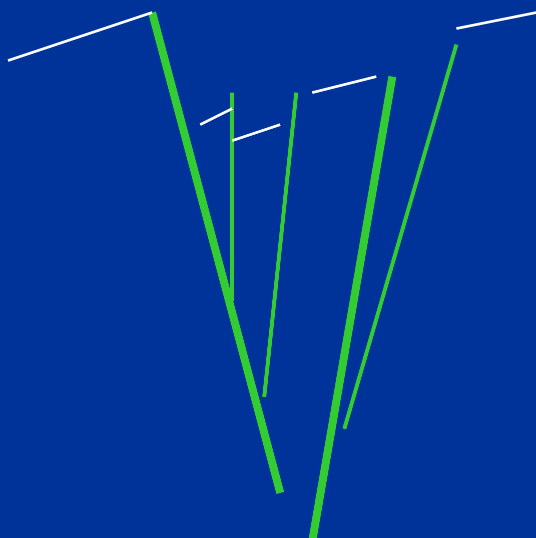
bulging of Rotliegend,
ZEZ2C **and** ZEZ3A+C.

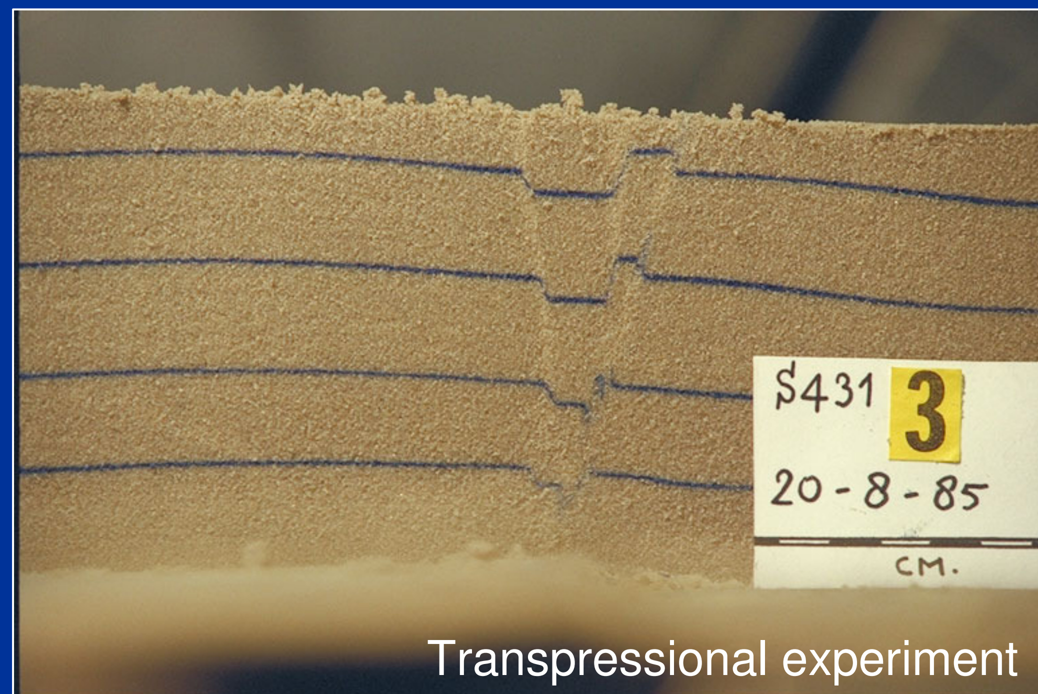
NAM

Red line = Top Rotliegend

Observations – detailed (2)

And often faulting of fault wedge observed into smaller wedge-shaped fault blocks.





Transpressional experiment

Structural analogue in sandbox model

Unravelling regional structural evolution

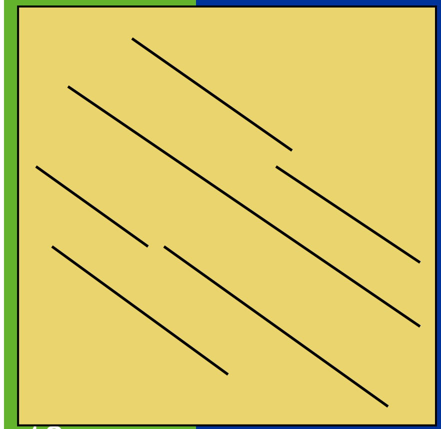
Pre-Carb	Carboniferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary

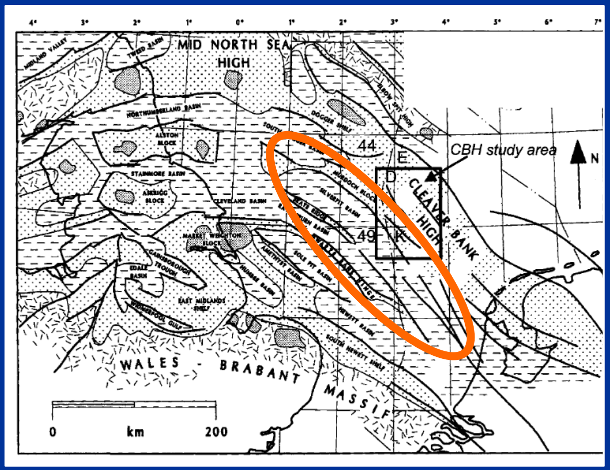
Variscan

The Variscan fold belt and its northern foreland basin became subjected to post-orogenic wrench deformation. (Stephanian/ Early Permian; Ziegler, 1990)

In Southern North Sea NW-trending wrench fault systems developed in response to prevailing regional stress pattern. (Coward, 1993; Corfield et al., 1996)

Erosion pattern of Top Carboniferous in SNS indicates the existence of NW-SE trending horst-graben systems (van Wijhe, 1987).

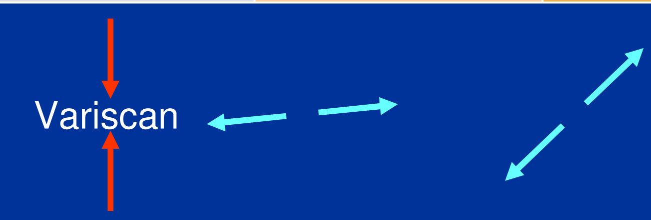




Schematic structural framework during **Early Carboniferous** (Besley, 1998). Notice presence of NW-SE fault trend.

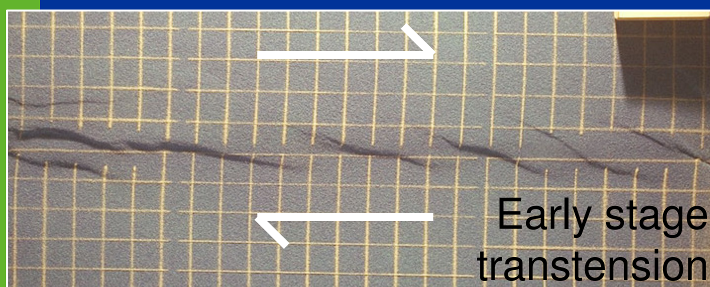
Unravelling regional structural evolution

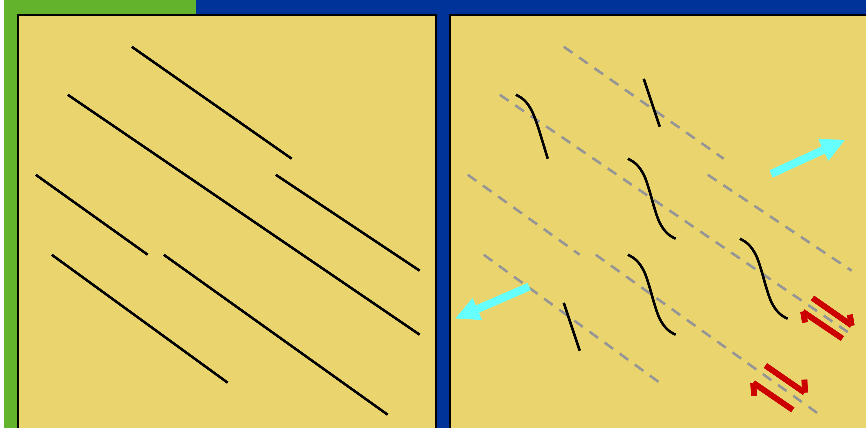
Pre-Carb	Carboniferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary



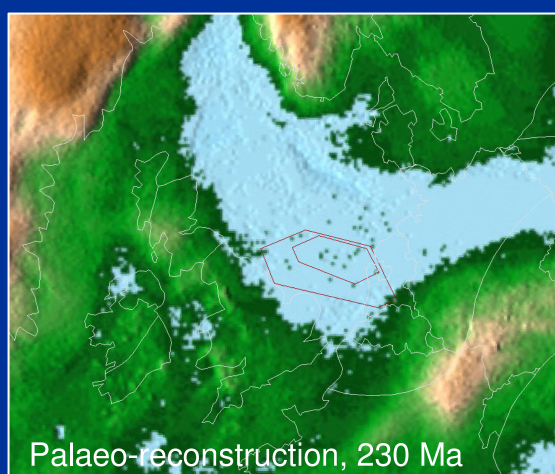
The Early Kimmerian tectonic phase (Carnian, Triassic) caused rapid subsidence of a number of fault-bounded structures, incl. Broad Fourteens Basin (Geluk et al., 1996).

In the Early Triassic, the North Sea became subjected to regional tensional stresses related to the increasing rifting activity in the Norwegian Greenland Sea and in the Tethys domain (Ziegler, 1990).





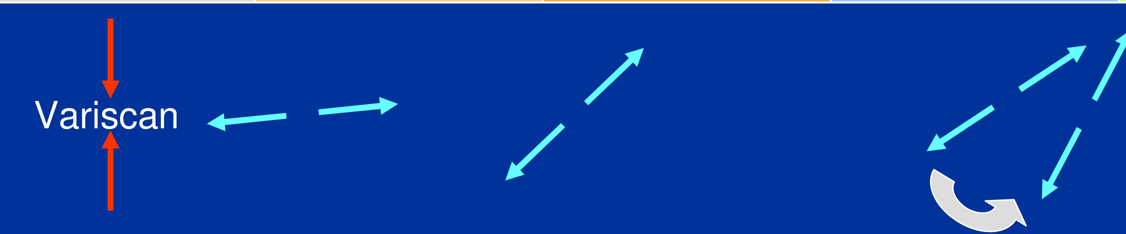
transtension



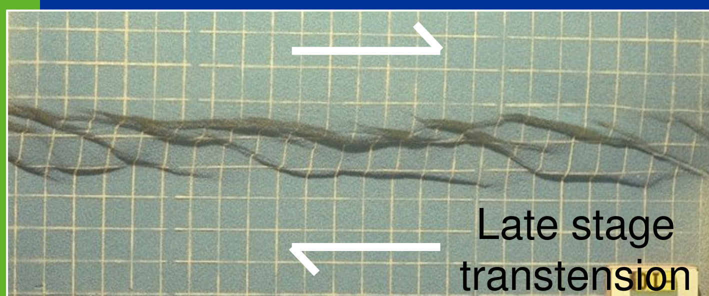
Palaeo-reconstruction, 230 Ma

Unravelling regional structural evolution

Pre-Carb	Carboniferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary

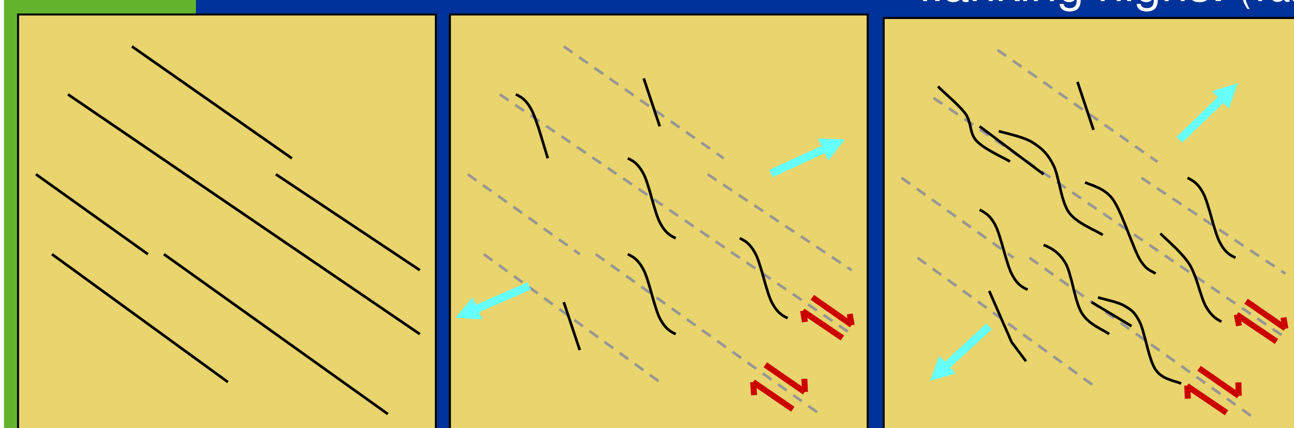


Extensional stress in SNS changes from ENE-WSW and E-W during Middle Jurassic to NE-SW and NNE-SSW during Late Jurassic (Nalpas et al, 1995).



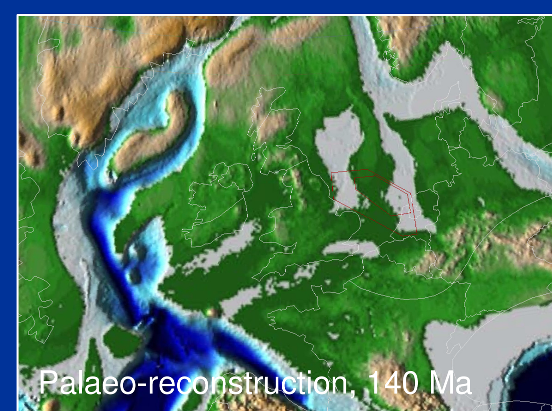
Late-Jurassic to Early Cretaceous: extensional activity in increased (break-up of Laurasia/ opening of Atlantic Ocean (Ziegler 1990, 1992; Glennie & Underhill 1998).

NW-SE trending faults reactivated, inducing rapid subsidence of BFB and uplift of its flanking highs. (van Wijhe et al, 1987)



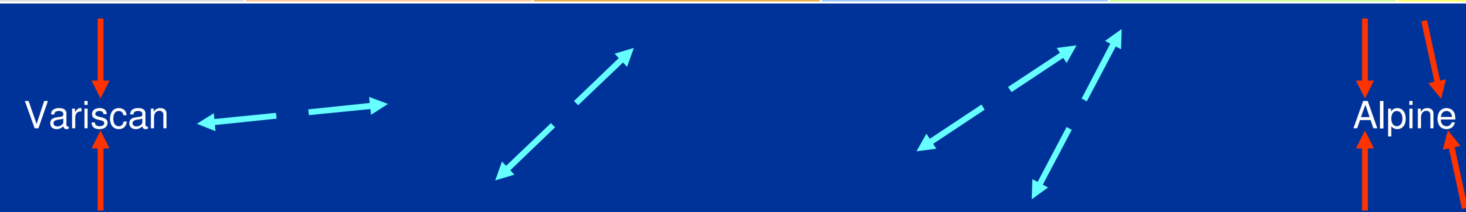
transtension

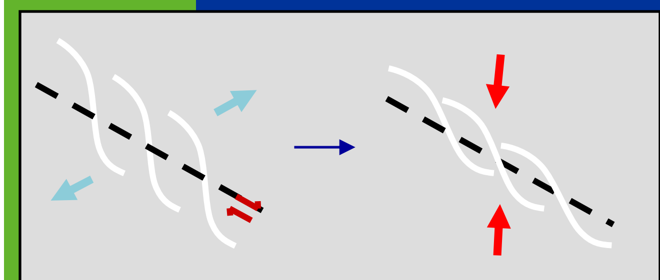
Cont. transtension



Unravelling regional structural evolution

Pre-Carb	Carboniferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary

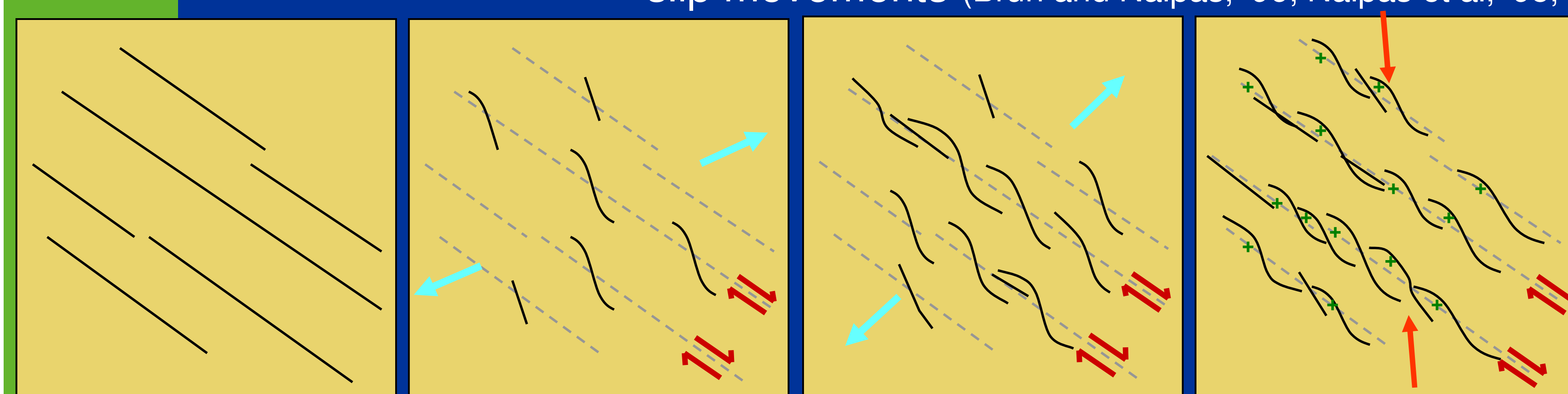




L. Cretaceous – Paleocene: northward compression (convergence Africa & Europe) inducing inversion of BFB (Ziegler ‘90; Huyghe & Mugnier ‘94, ‘95; Nalpas et al, ‘96).

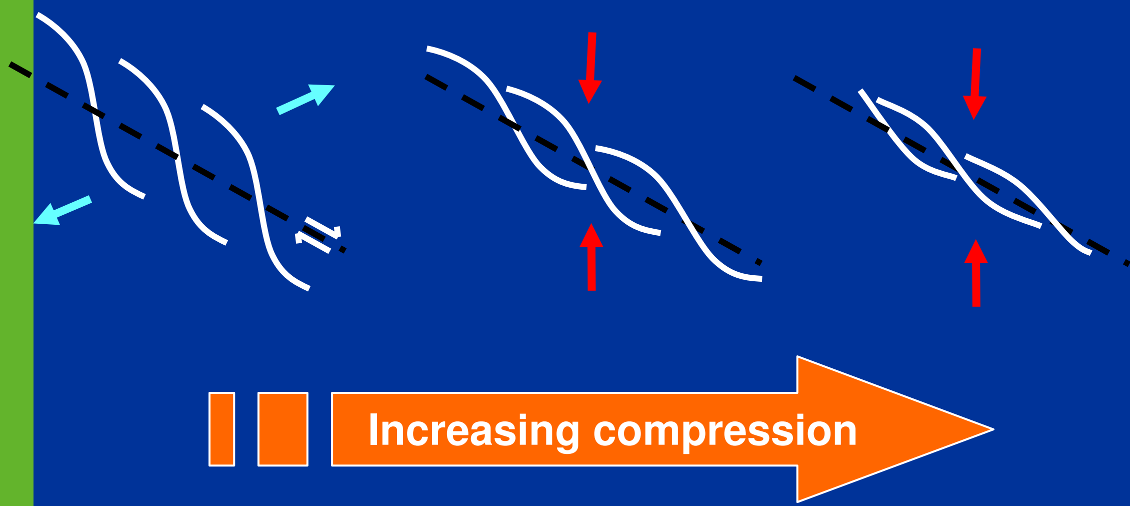
Major thrusts in northern BFB. Strongest uplift end Cretaceous. Regional stress direction: N170º (Nalpas ‘95).

Reactivation pre-existing faults: reversed oblique strike-slip movements (Brun and Nalpas, ‘96; Nalpas et al, ‘95, ‘96).



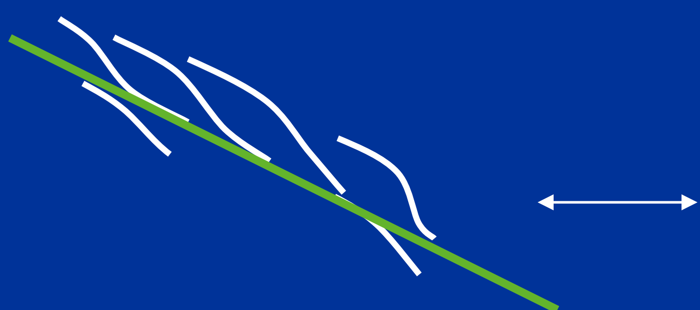
transtension Cont. transtension Oblique inversion

Oblique inversion / transpression



Compressional system flattens sinuous fault block structures and causes oblique partial uplift and rotation, creating pop-up structures.

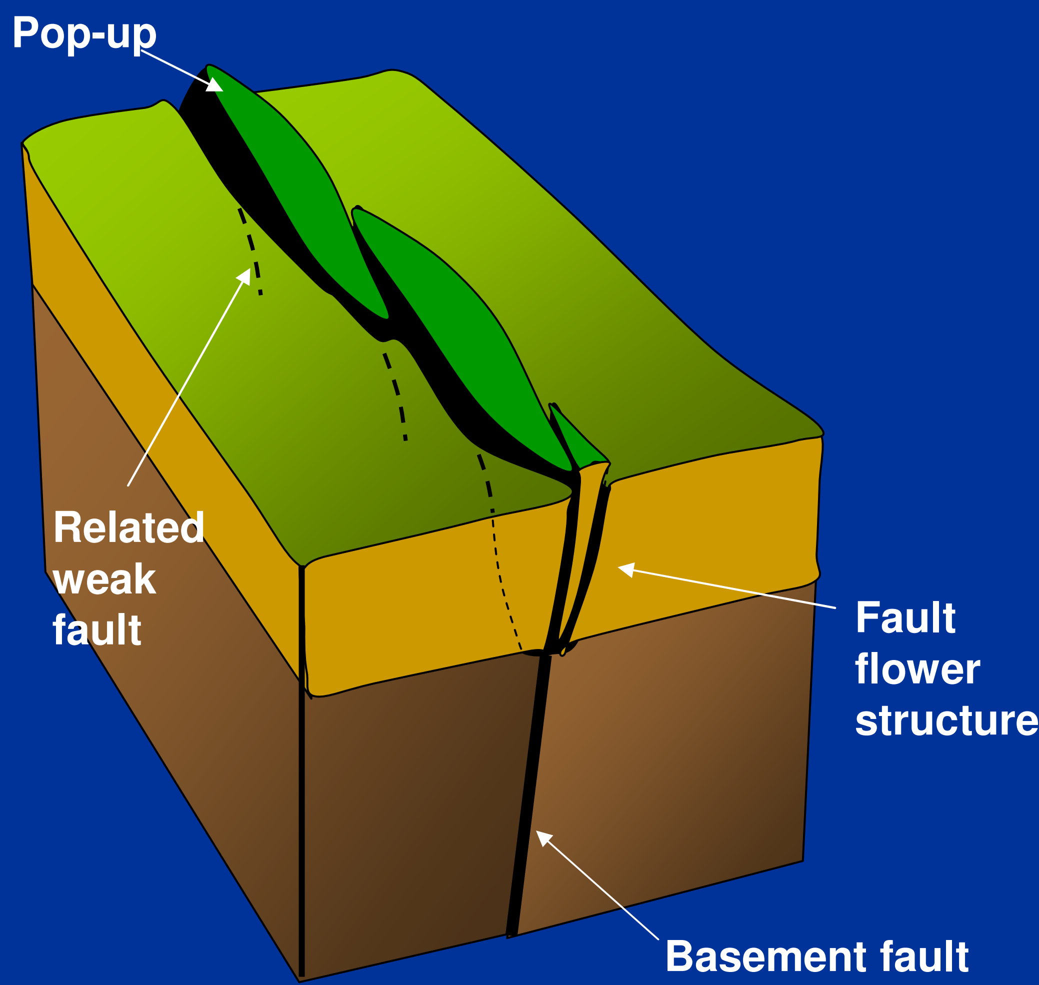
Prolongation of transtensional and transpressional systems could lead to development of continuous (straight) fault planes:

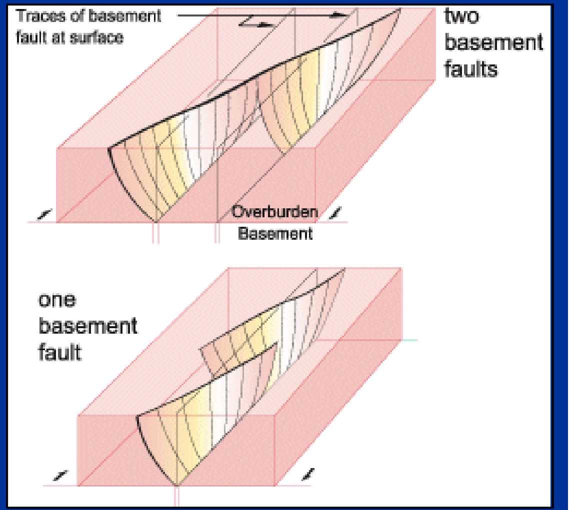


Sandbox analogue

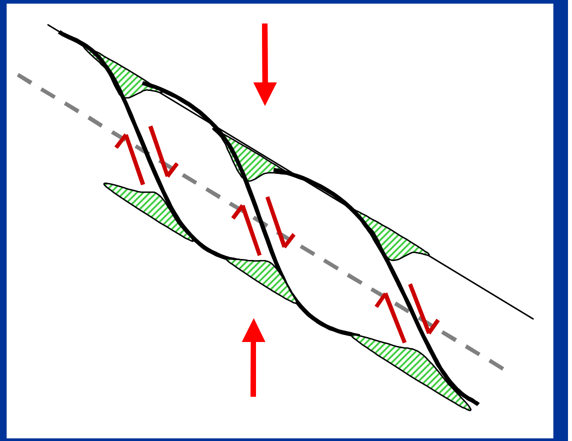
NAM

Fault zone – Model 3D



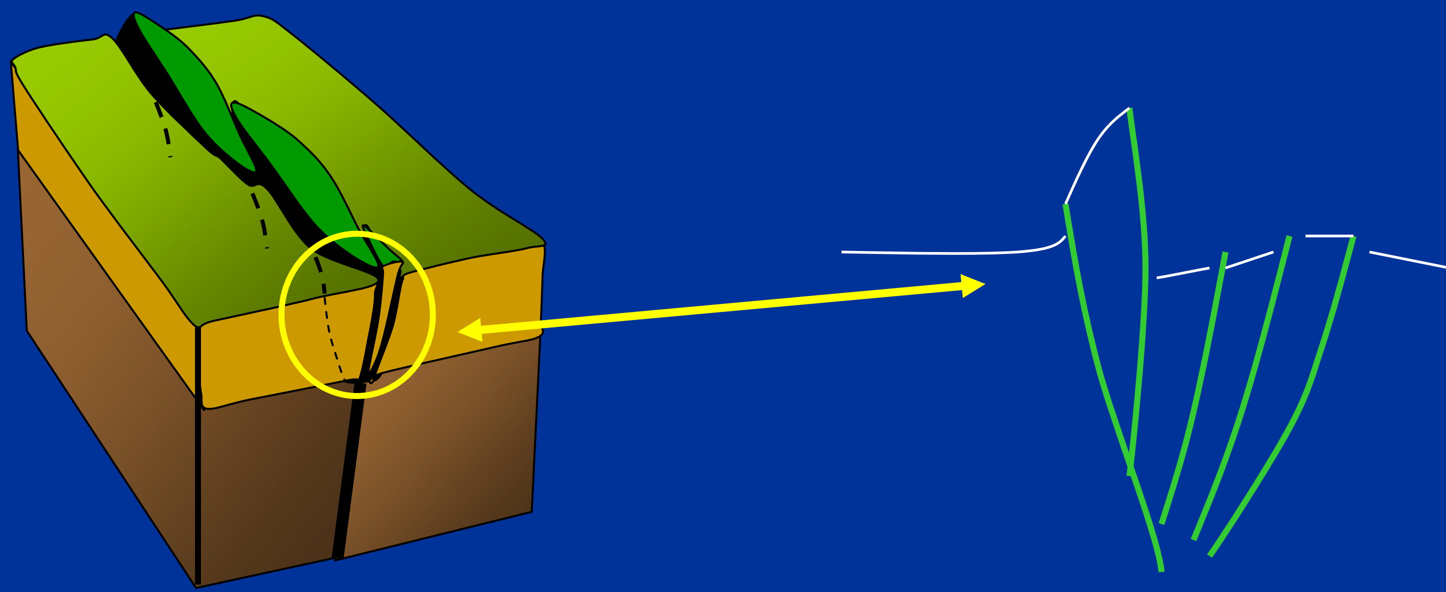


En echelon faults linking with basement fault



Internal fault character and movement

Pop-up development



Example of pop-up structure in Southern North Sea

Pop-up characteristics:

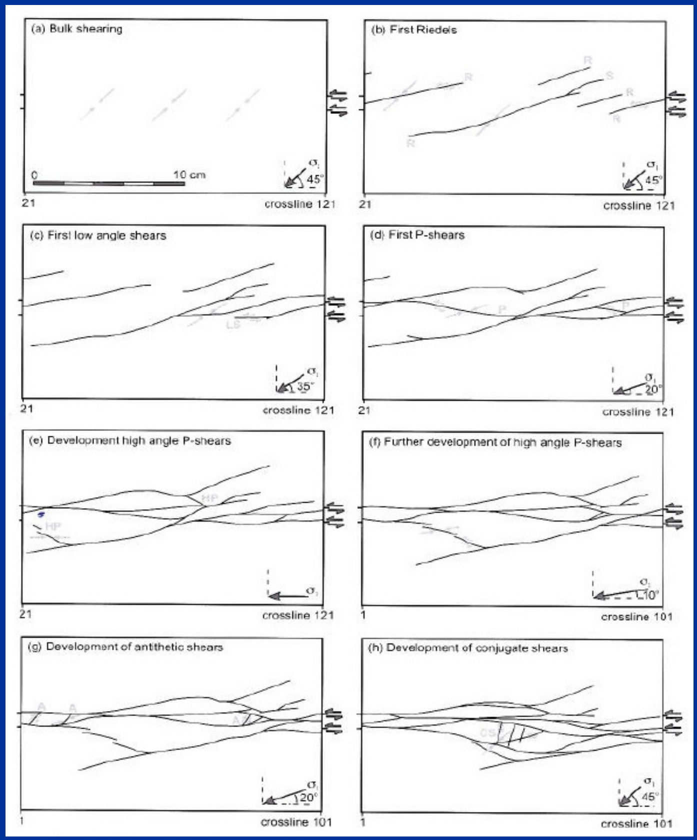
Narrow structures (250-500 m)

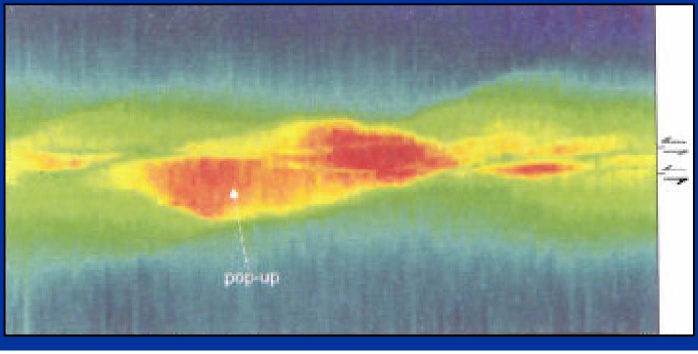
High relief

NW-SE orientated (exceptions exist)

NAM

Fault zone architecture - Reality





Previous presented model was simplified and showing faults likely visible on seismic.

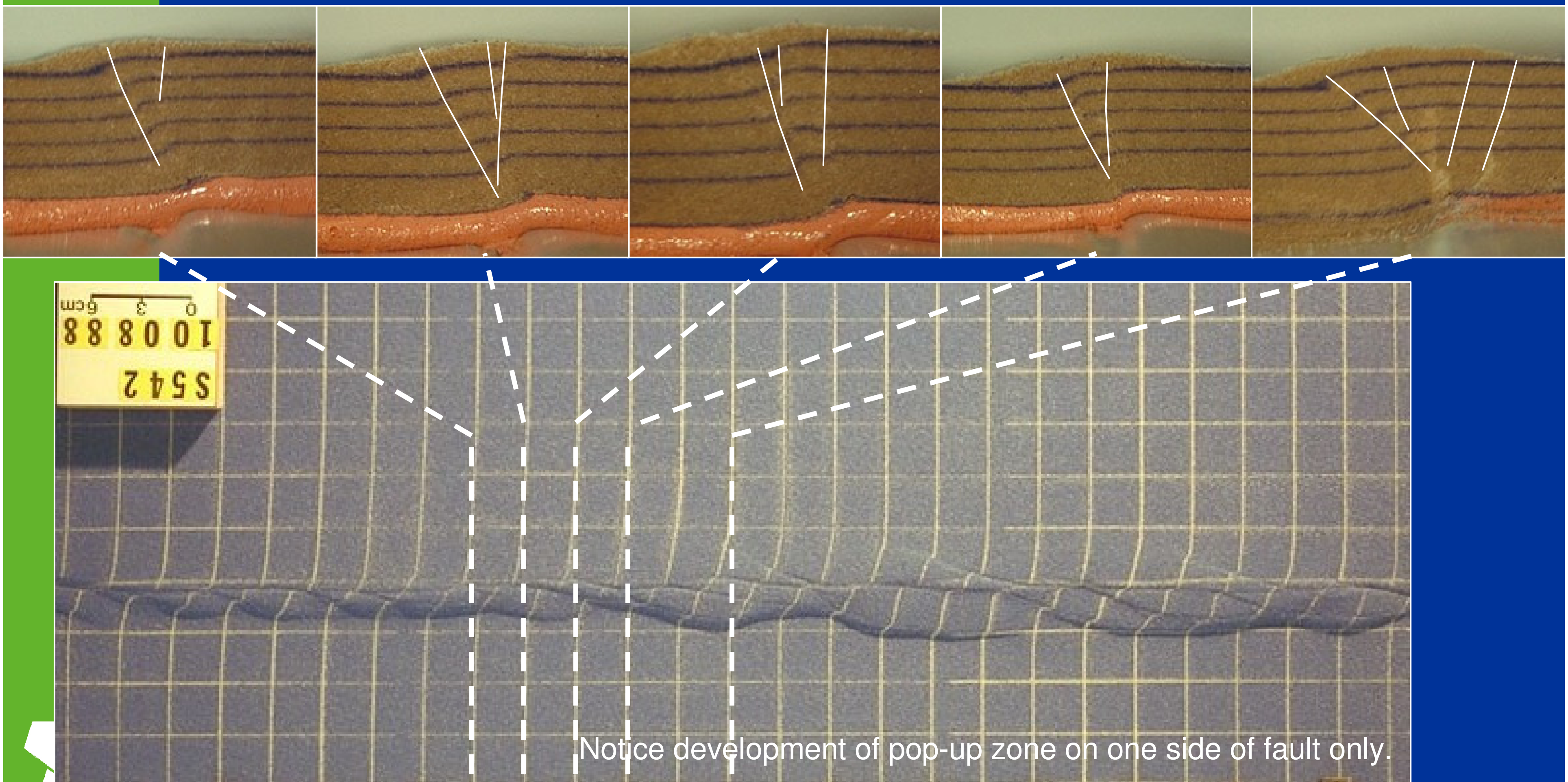
In reality, zones are often far more complex.

(Schellart & Nieuwland, 2003; *3D evolution of a pop-up structure above a double-basement strike-slip fault: some insights from analogue modelling*)

NAM

Fault zone architecture - Variation

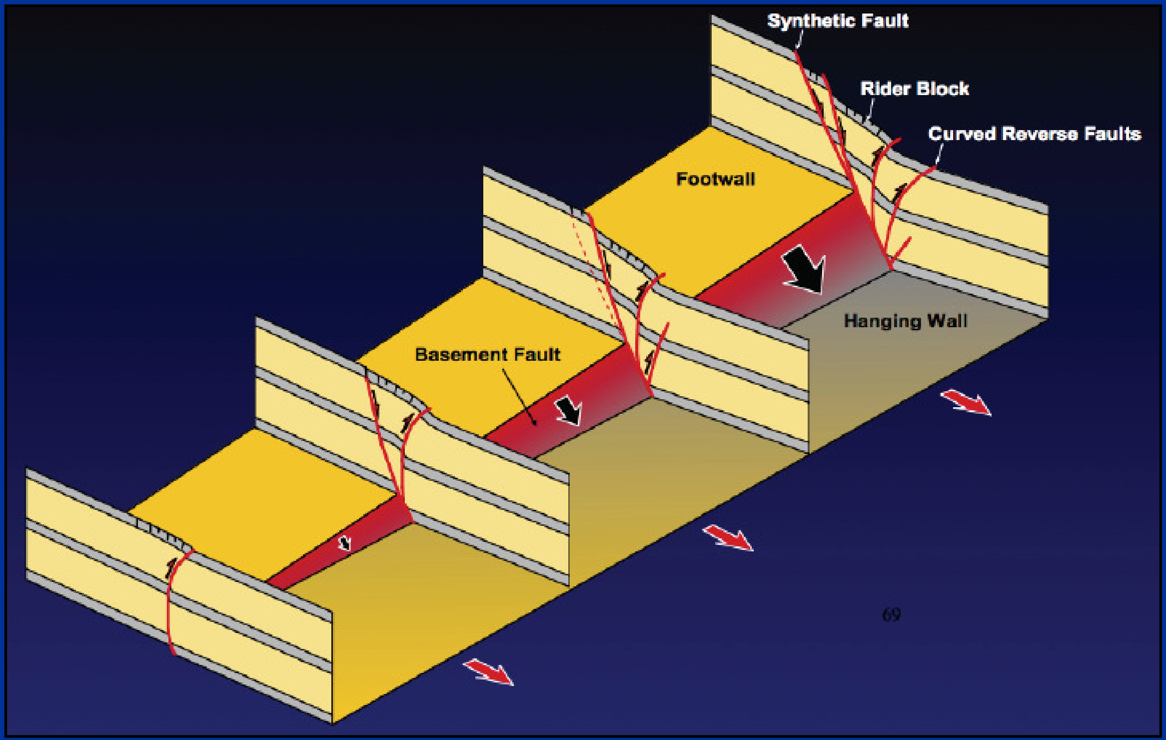
High variation in fault patterns along fault strike:



Variation along strike due to lense-shaped structure development.

NAM

Fault zone architecture - Variation

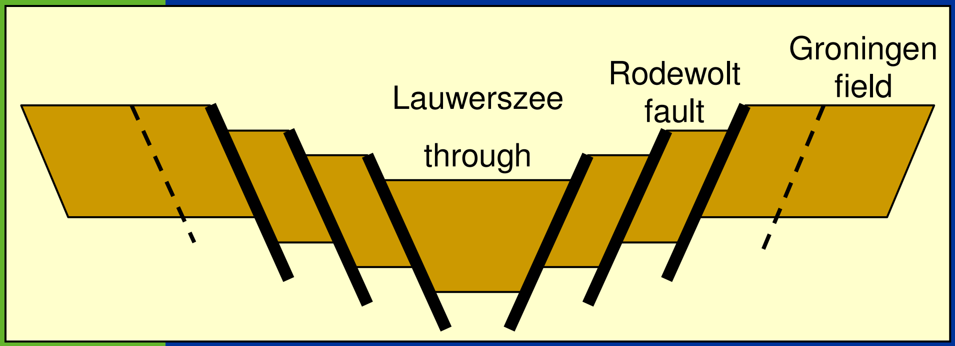


Variation along strike due to original variation in fault throw along strike.

NAM

Fault Dynamics

Observations in NE Netherlands



Same fault system present in northeast Netherlands.

Characteristics:

Major faults, e.g. Rodewolt fault zone.

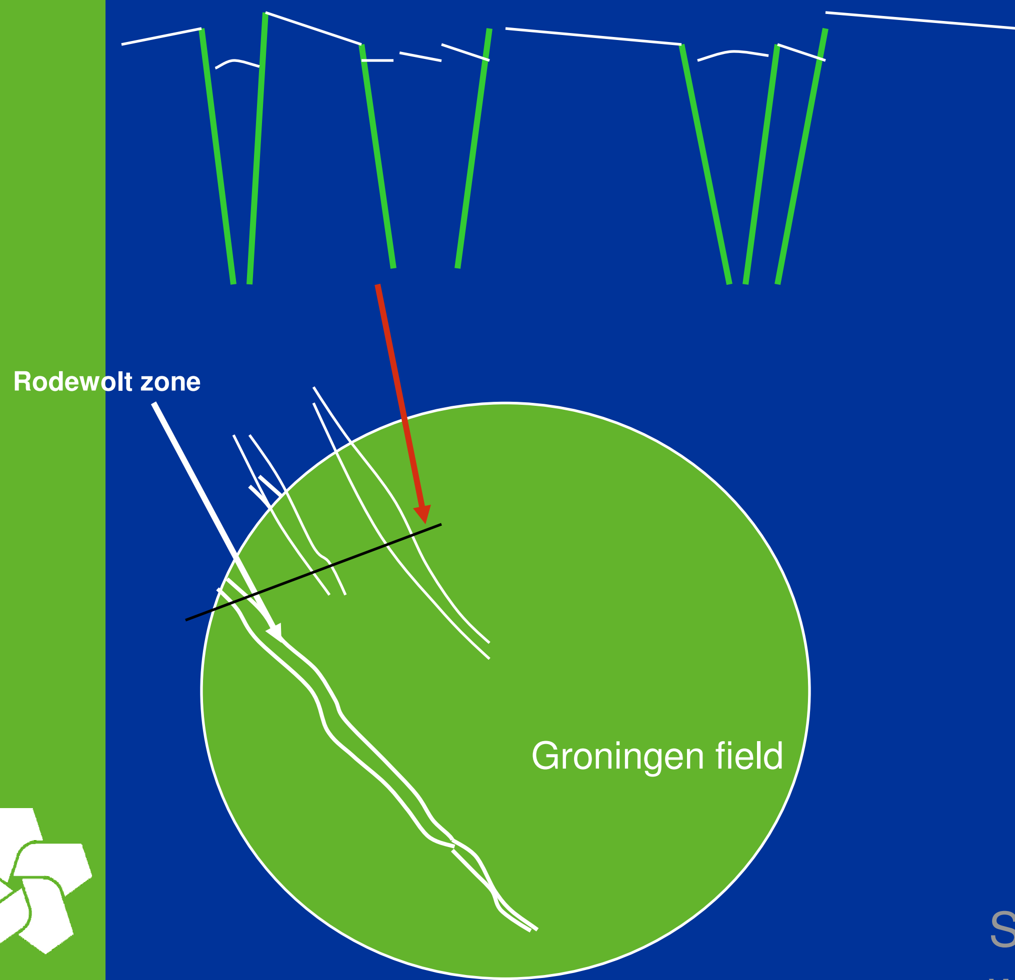
Faults run parallel to Lauwerszee graben axis.

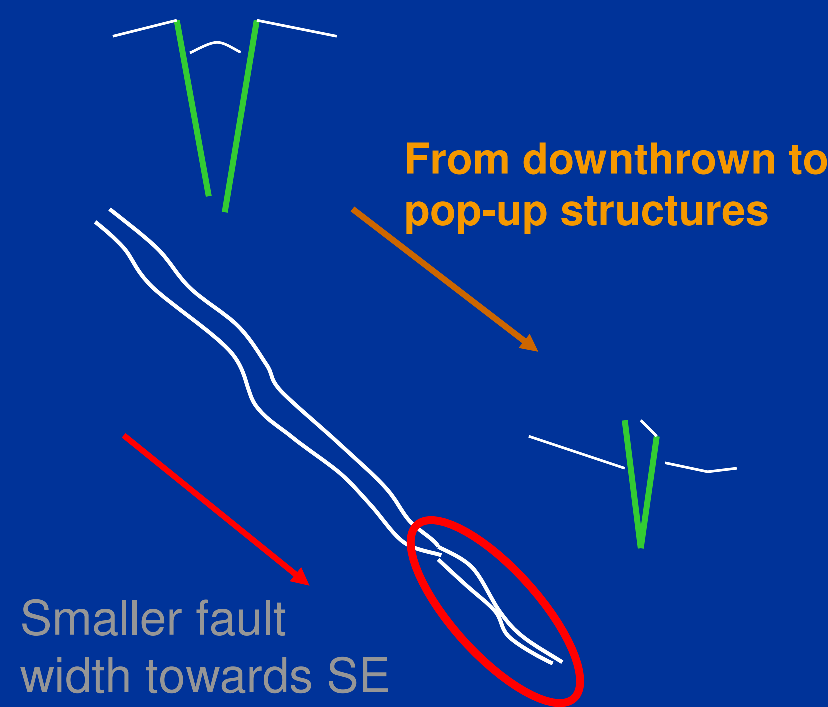
Lauwerszee Trough has pre-Carboniferous basement faults.

Internal fault blocks change from downthrown to up-thrown along fault strike.

Observation – in cross-section

Wedge-shaped fault blocks present that are folded and faulted, similar to BFB and UK area.





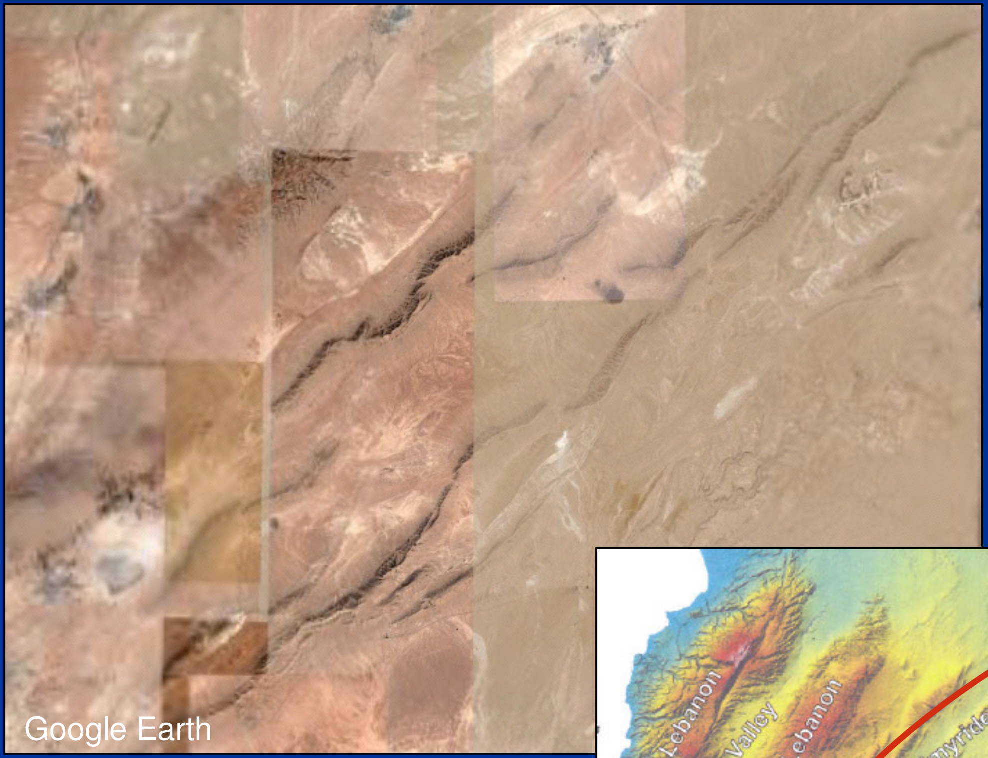
NAM

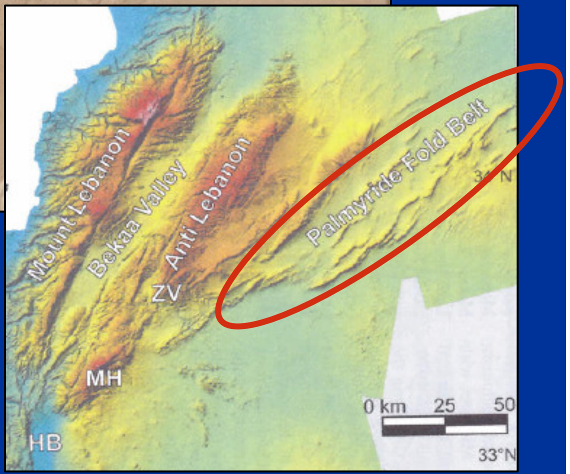
Conclusions

- Regional approach is crucial to understand structural complexity.
- Presence of large-scale NW-SE fault systems played a dominant role in the rifting and inversion phases in the Southern North Sea.
- Knowledge of the development mechanism of deep-seated NW-SE basement faults and their influence on structure development is important to understand the internal character of pop-up structures.
  - Orientation of faults
  - Internal character (faulting/compartmentalisation)

NAM

Structural Analogue





Palmyride Fold belt

(Syria)

Permian – Triassic (or older) failed rift of the Levantine margin and subsequent oblique inversion (45º angle) by Late Mesozoic and Cenozoic compression. (McBride et al., 1990)