Structural style and hypothesis for sealing fault mechanism in the Rotliegend - central K&L blocks

GDF Production Nederland BV

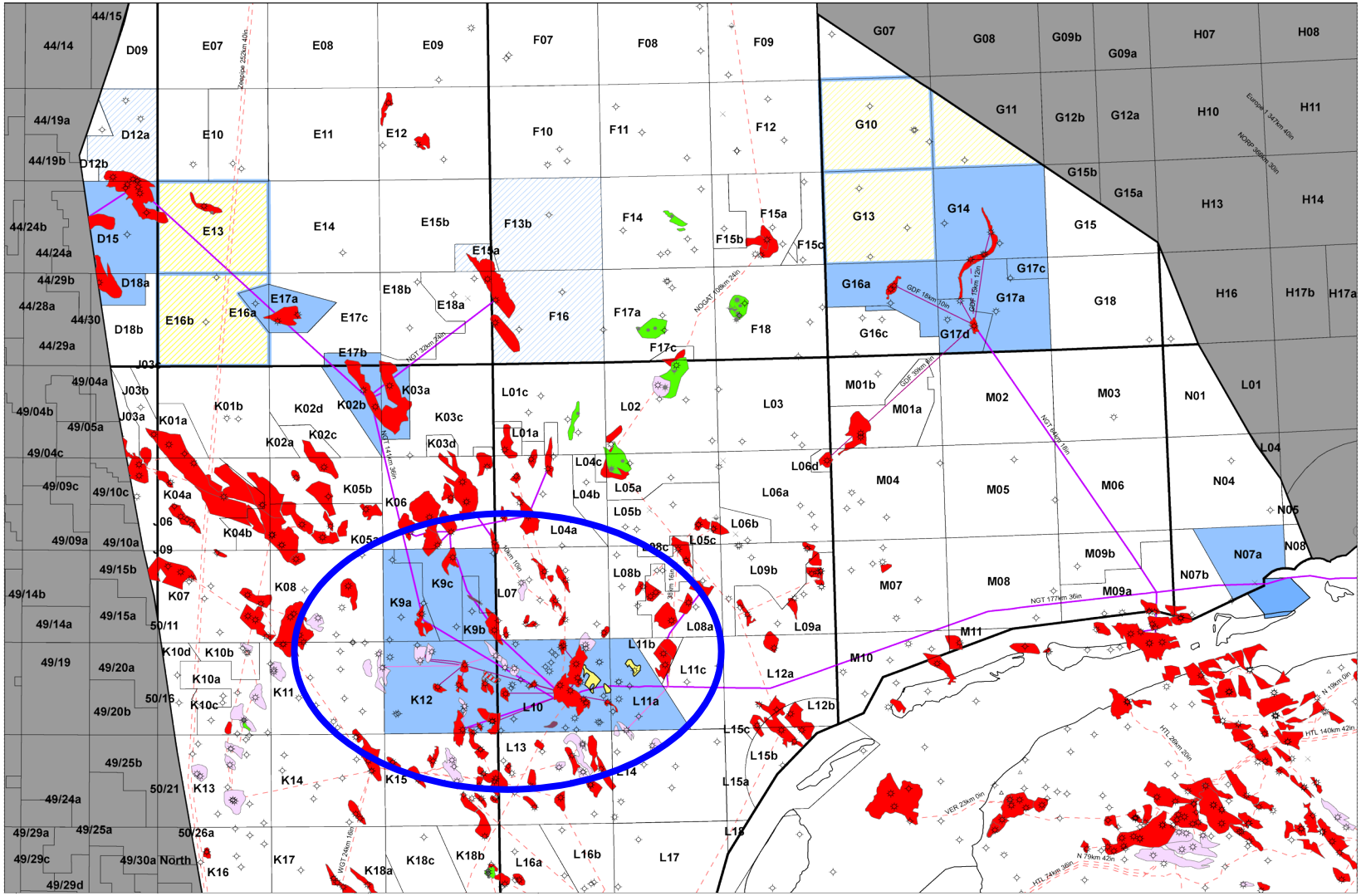
Richard Rijkers

‘Rifting’ workshop 5 June 2008 EBN-TNO

Program

- Introduction
- Structural style
  - Reverse faulting
  - Field cases
- Sealing faults
  - Reactivation circle
  - Cataclasis
  - Fault seal probability map
- Discussion

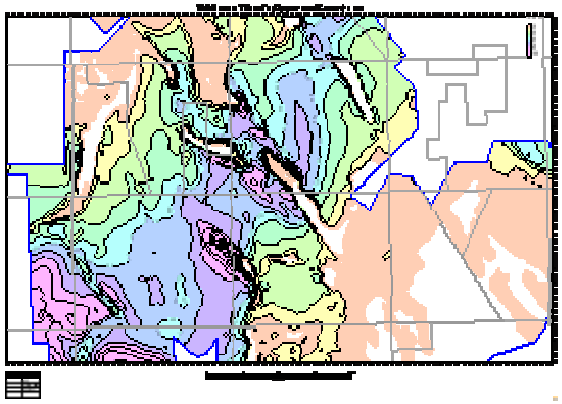
Gaz de France Central K&L Asset



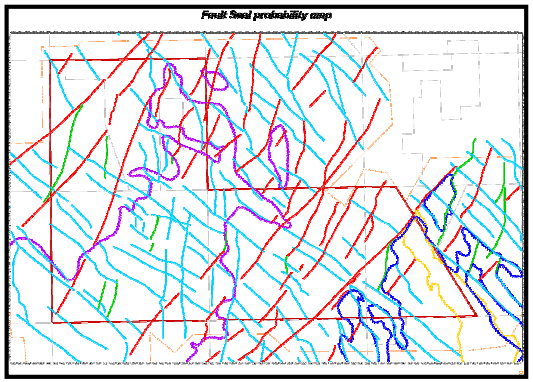
Project *work-in-progress*

- Objectives
  - Regional mapping with focus on fault development and structural style
  - Discuss a model on sealing fault mechanism
- .... to optimize exploration and development drilling in the central K&L asset

Geological maps



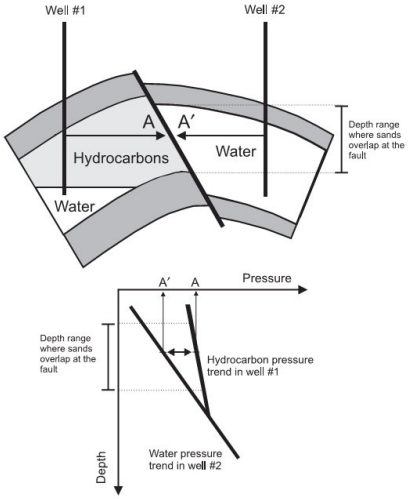
Faults



Reservoir

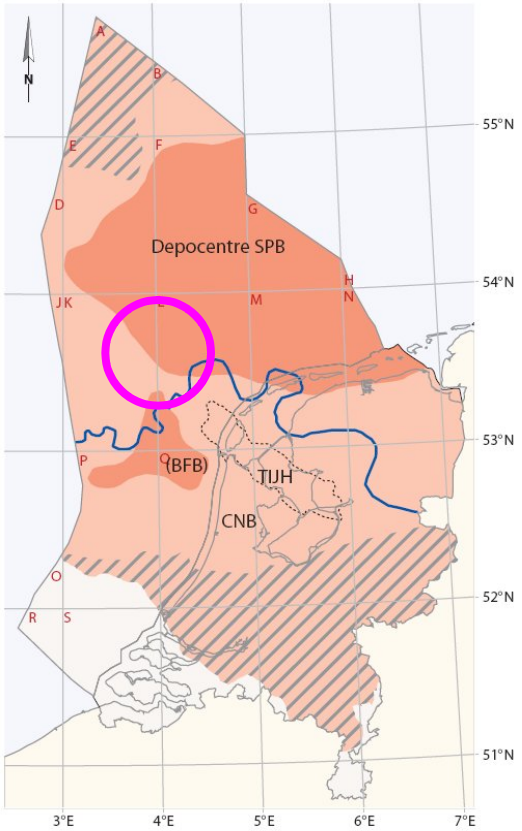
Pressure
GWC
Gas composition

Fault seal or no seal ?



- Introduction
- Structural style
  - Rifting
  - Field examples
  - Reverse faulting
- Sealing faults
  - Cataclasis
  - Reactivation circle
  - Fault seal probability map
- Conclusions

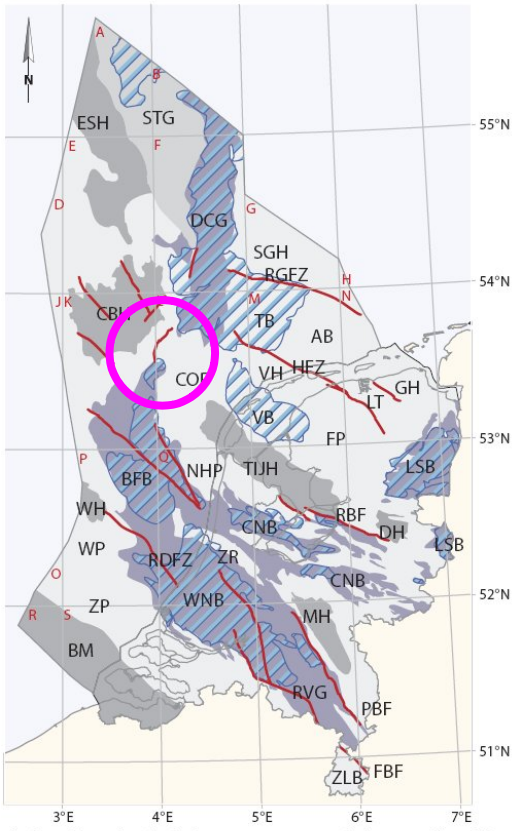
Tectonic setting of the central K&L asset



b. Late Permian structural elements

Middle Permian

Deposition ROSL

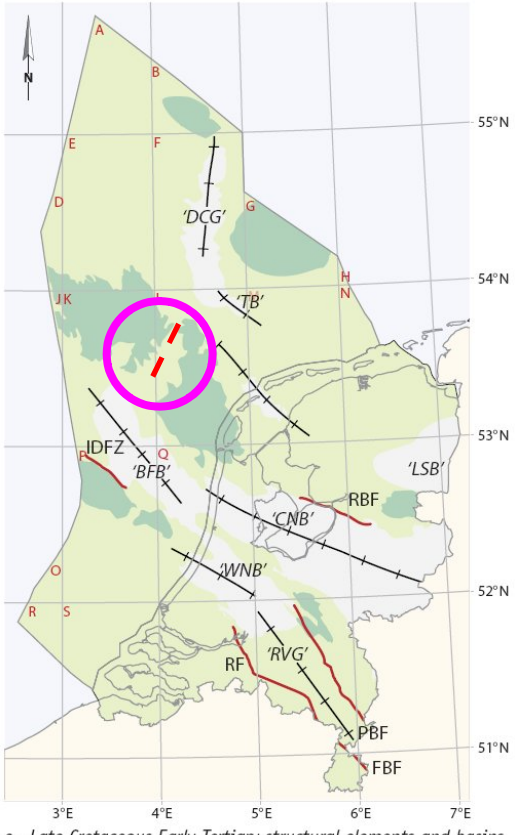


d. Late Jurassic - Early Cretaceous structural elements (Late Kimmerian phases)

Late Jurassic

Rifting and erosion

Central Offshore Platform



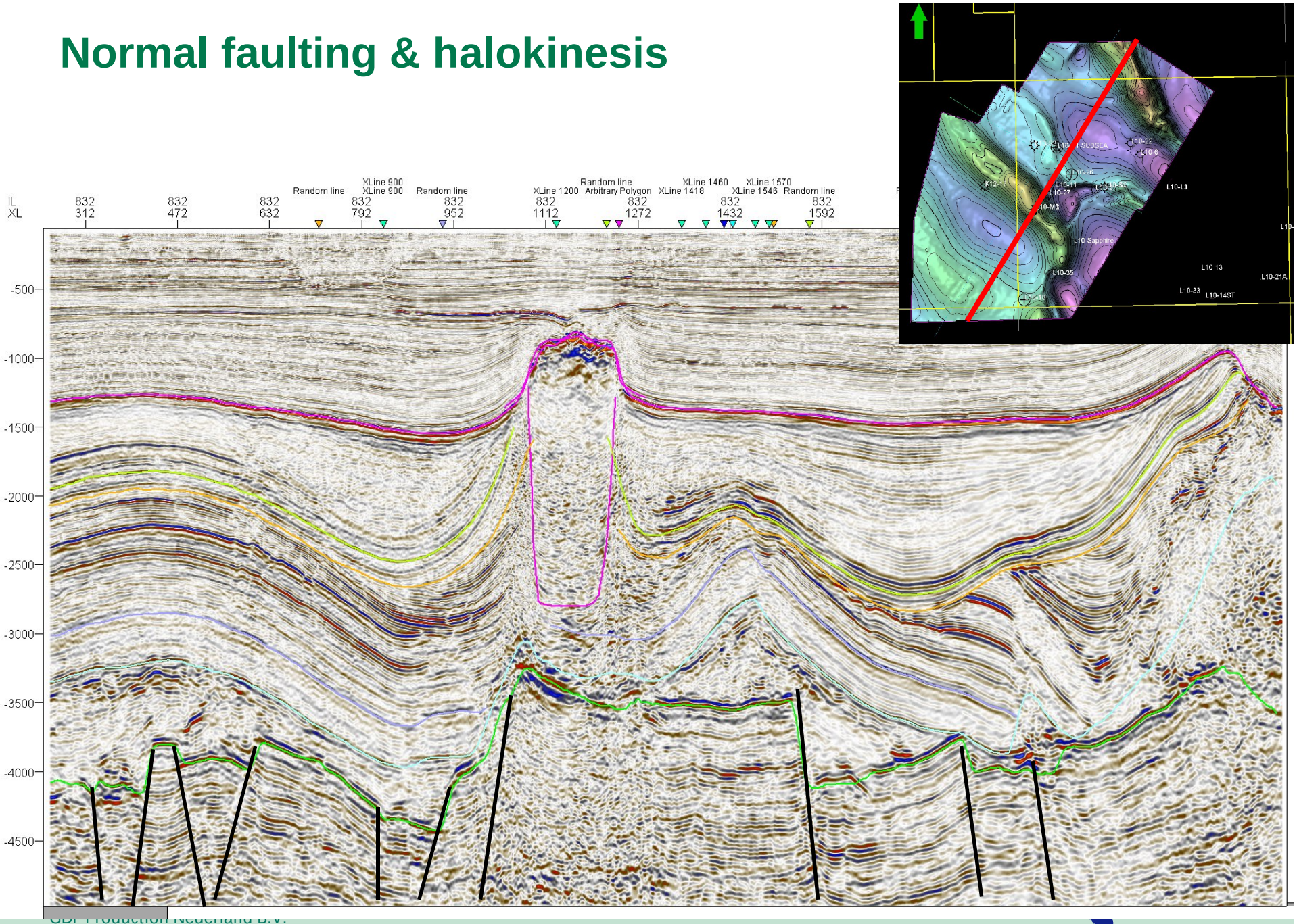
e. Late Cretaceous-Early Tertiary structural elements and basins (Subhercynian and Laramide phases)

Late Cretaceous

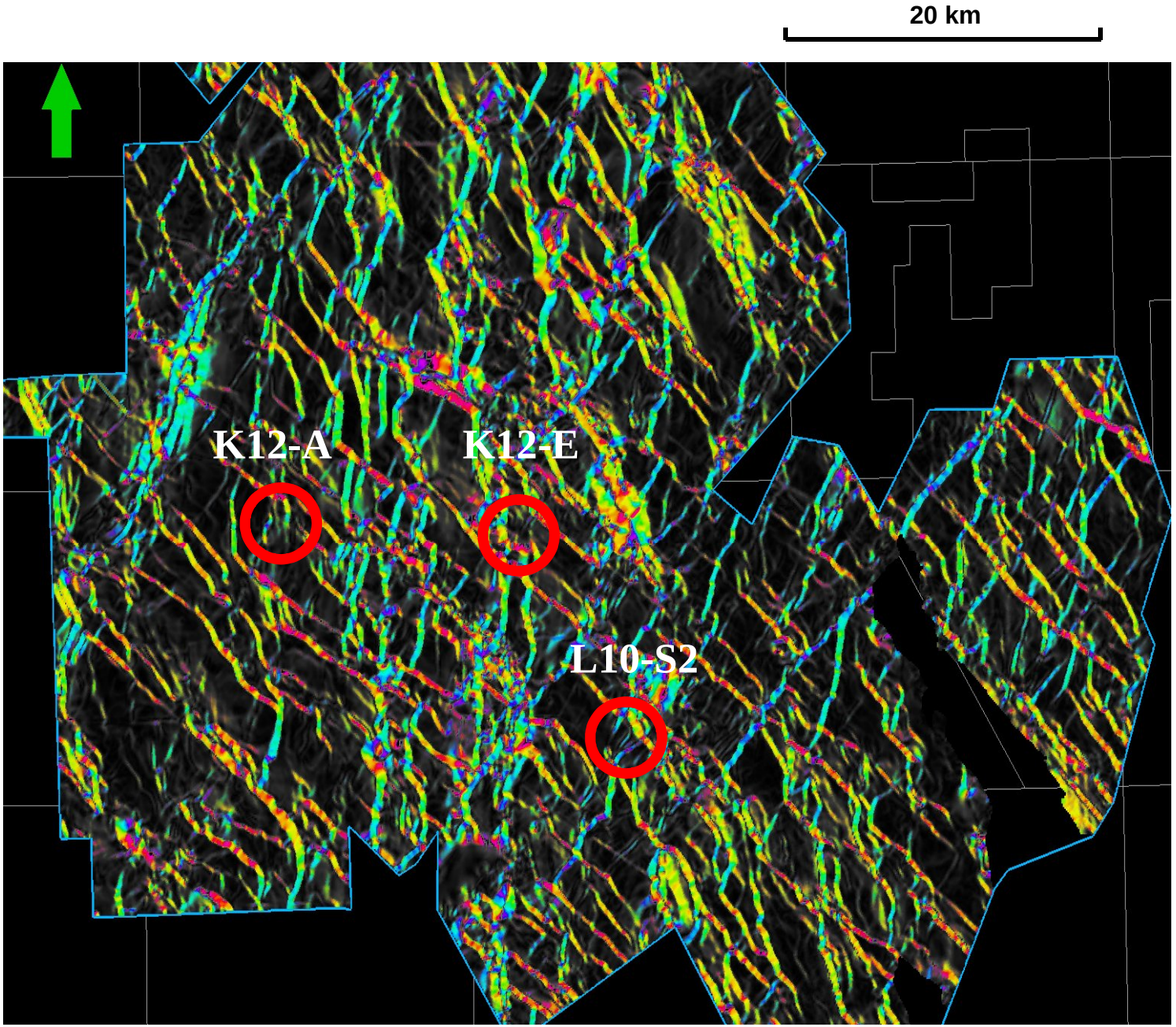
Tectonic inversion and

fault reactivation

Normal faulting & halokinesis



Faults at Top Rotliegend



Fault strike orientations:

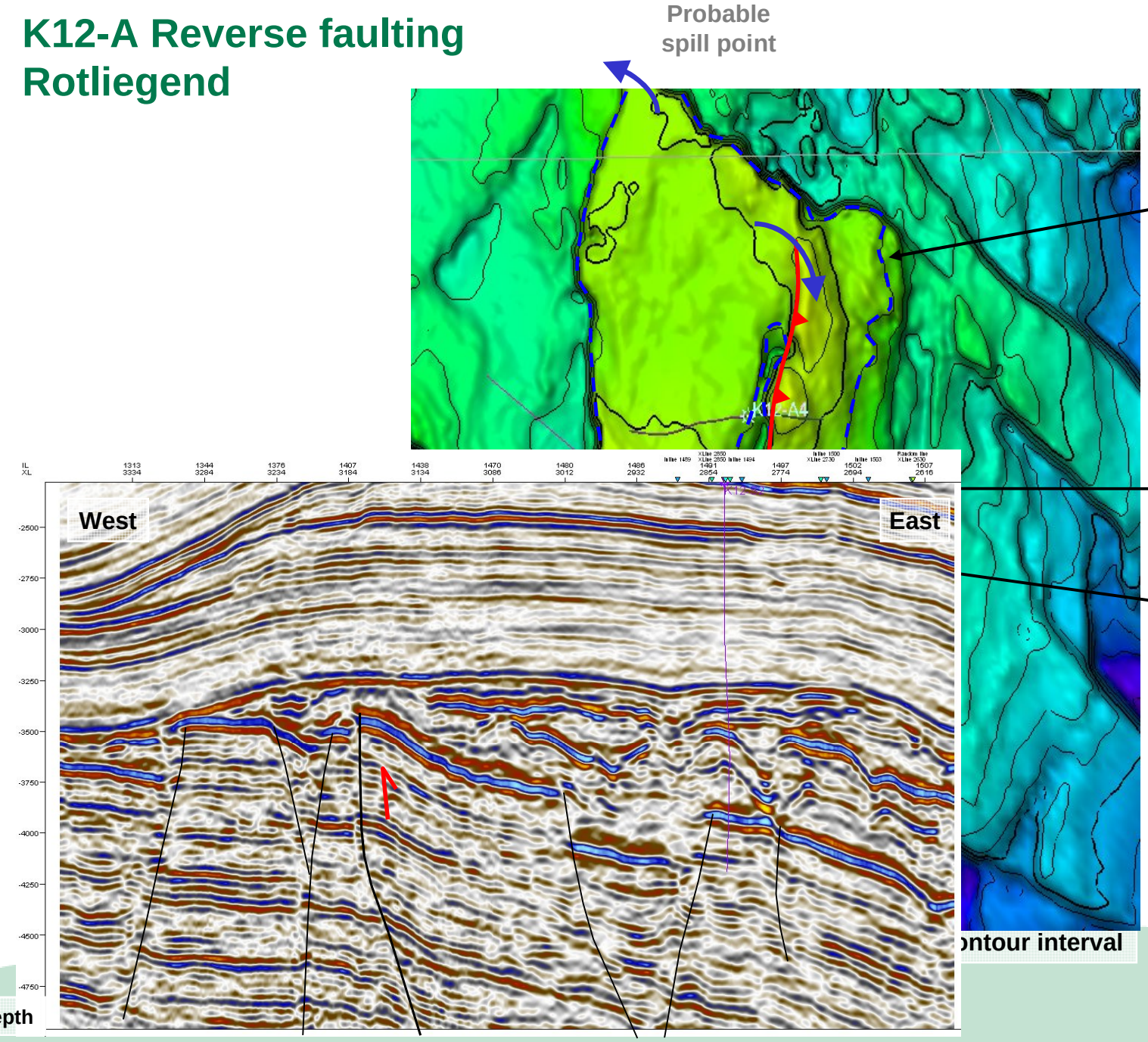
NW-SE

N-S

NNE-SSW

NE-SW

K12-A Reverse faulting Rotliegend



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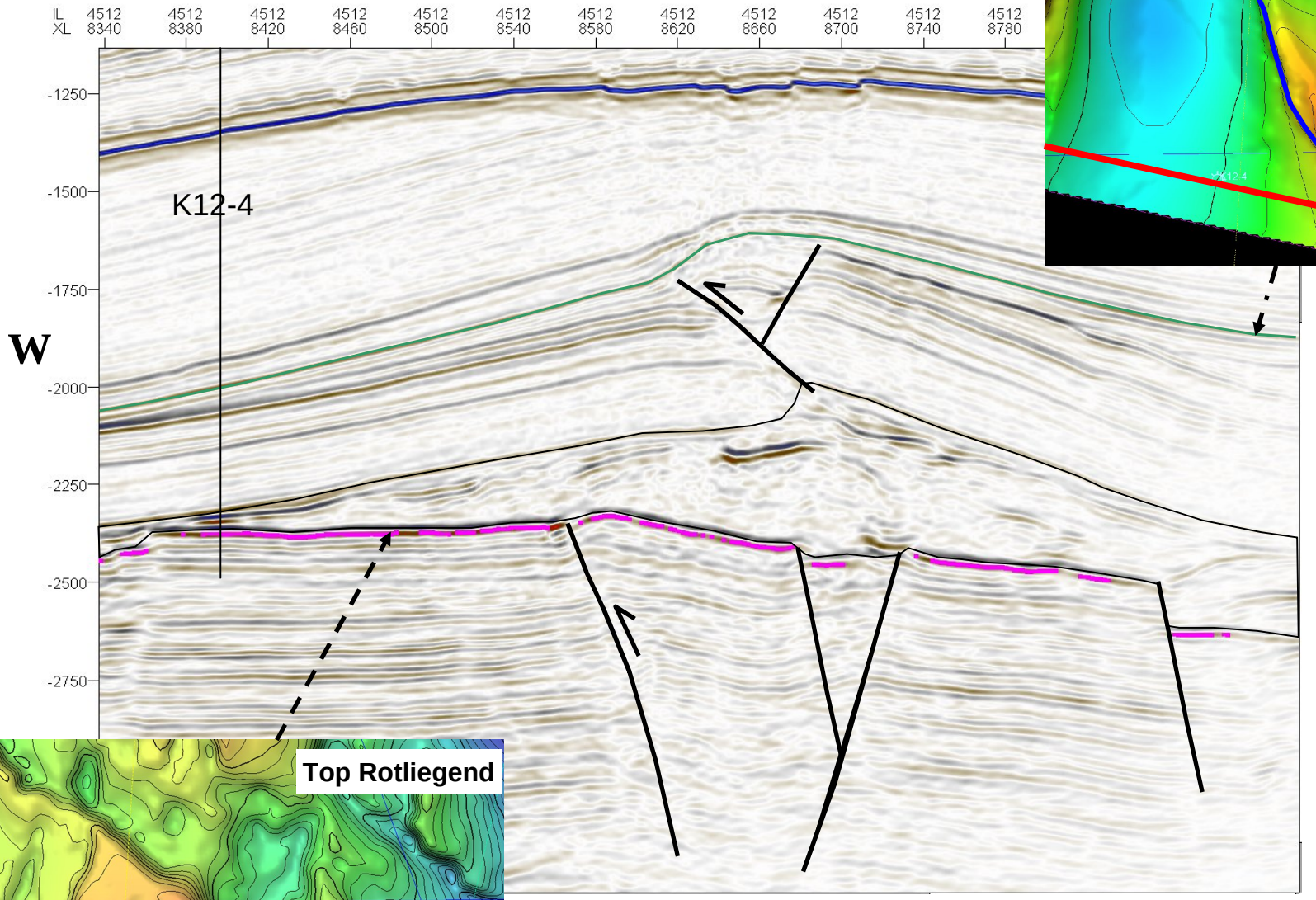
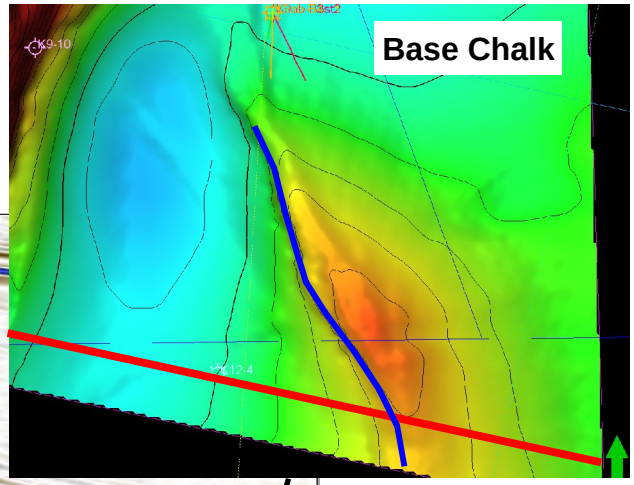
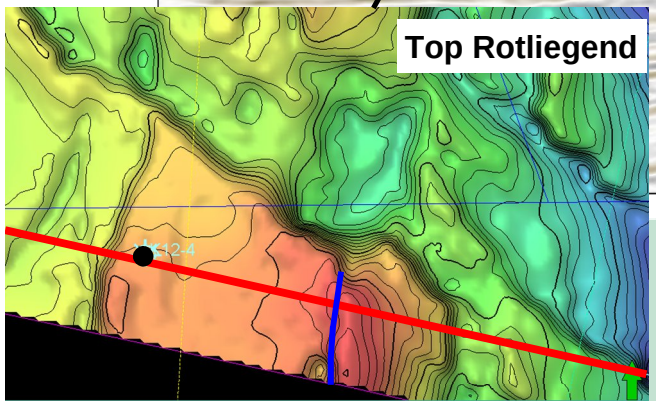
K12-A Late Cretaceous oblique reverse faulting N-S







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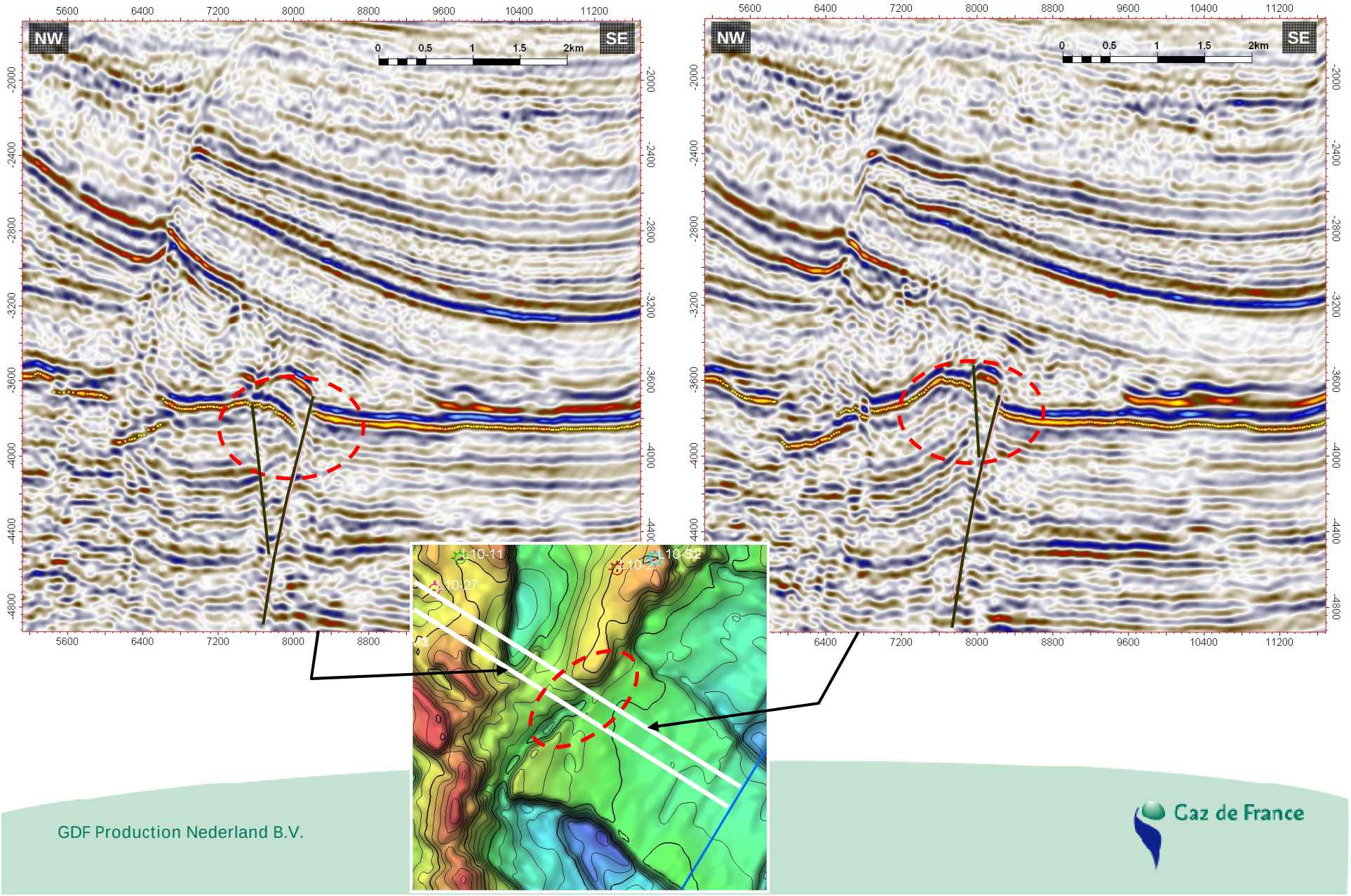
K12-A Summary

- K12-A field is divided in three compartments by NNE-SSW and N-S faults
- N-S faults *compressionally* reactivated during Late Cretaceous
- K12-A *southeast* compartment is isolated
  - K12-A *northeast* compartment communicates with K12-A *west*
- Why is K12-A southeast block dry?
  - uplifted during Late Cretaceous after gas charging ?
    and/or
  - N-S sealing fault …?

L10-S2 Reverse faulting along NE-SW fault

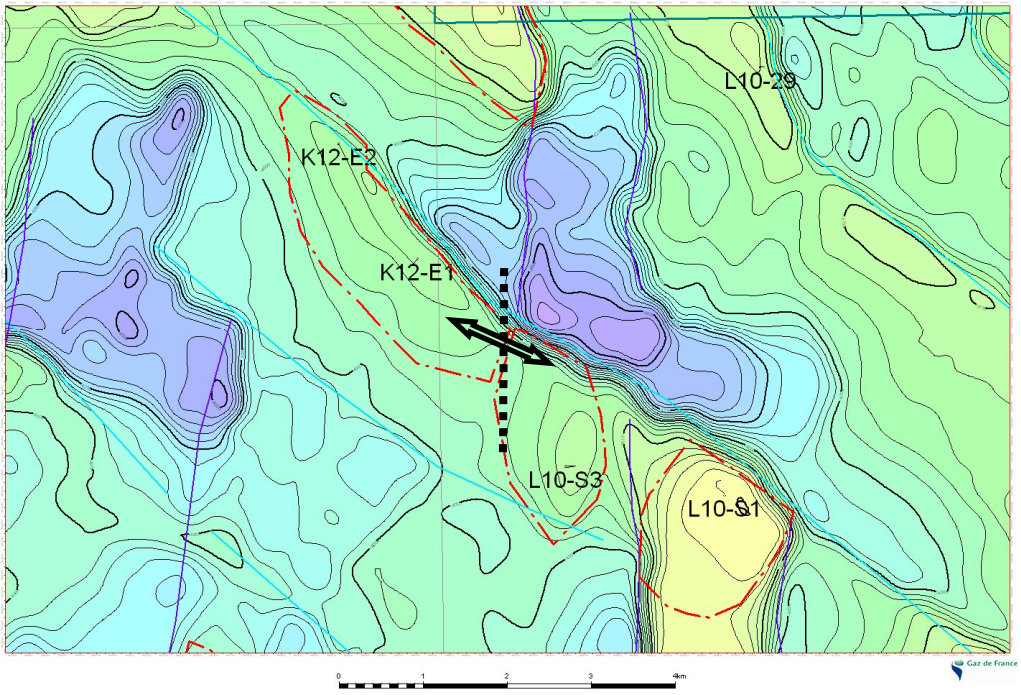


K12-E & L10-S3

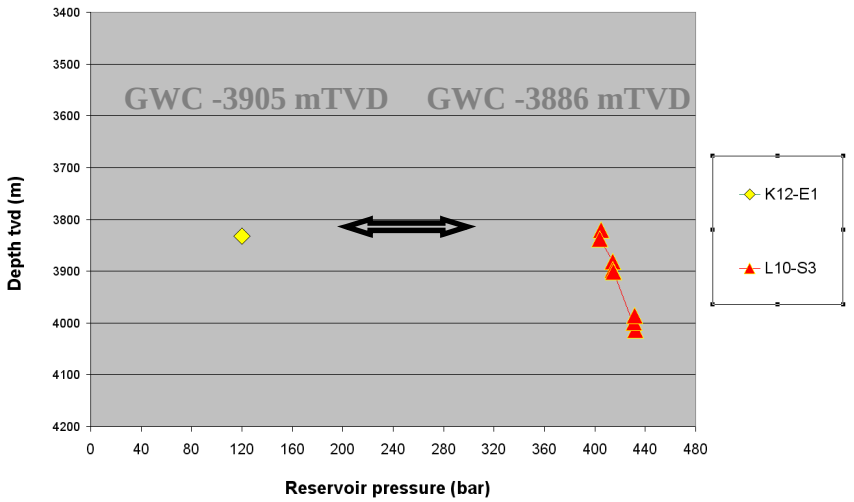
- Sandstone reservoir in juxtaposition
  - Gas spill in northern part of field
- K12-E1/E2 were drilled in 1985/1986
- L10-S3 was drilled in 1997 with ‘virgin’ pressure
- N-S sealing fault ?

Top Rotliegend depth

K12-E & L10-S3



Virgin reservoir pressure in L10-S3 drilled in 1997 after 10 years of production in K12-E



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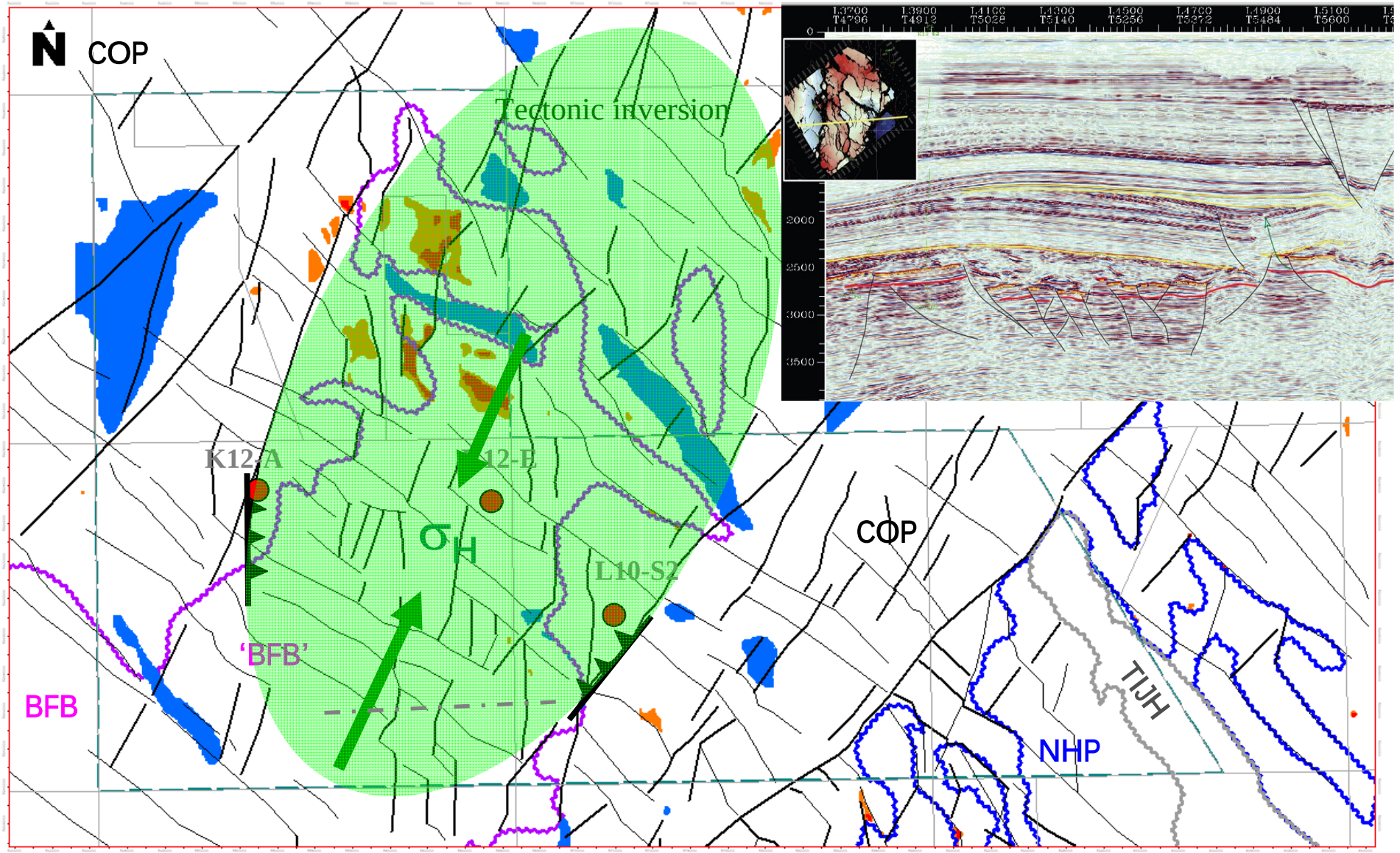
Structural element map Central K&L Asset



Summary structural style

- Four fault trends in top Rotliegend in Central K&L Asset
  - Geological age of normal and reversed fault activity is mostly obscured by salt (decoupling)
- K12-east and L10-west is located in Mid-Late Jurassic rift zone
  - Normal fault: NW-SE & N-S
- Outside the rift system
  - Normal fault: NW-SE & NE-SW
- N-S and NE-SW oblique reversed faults are active during the Late Cretaceous
- Indications for sealing faults in trend N-S

- Introduction
- Structural style
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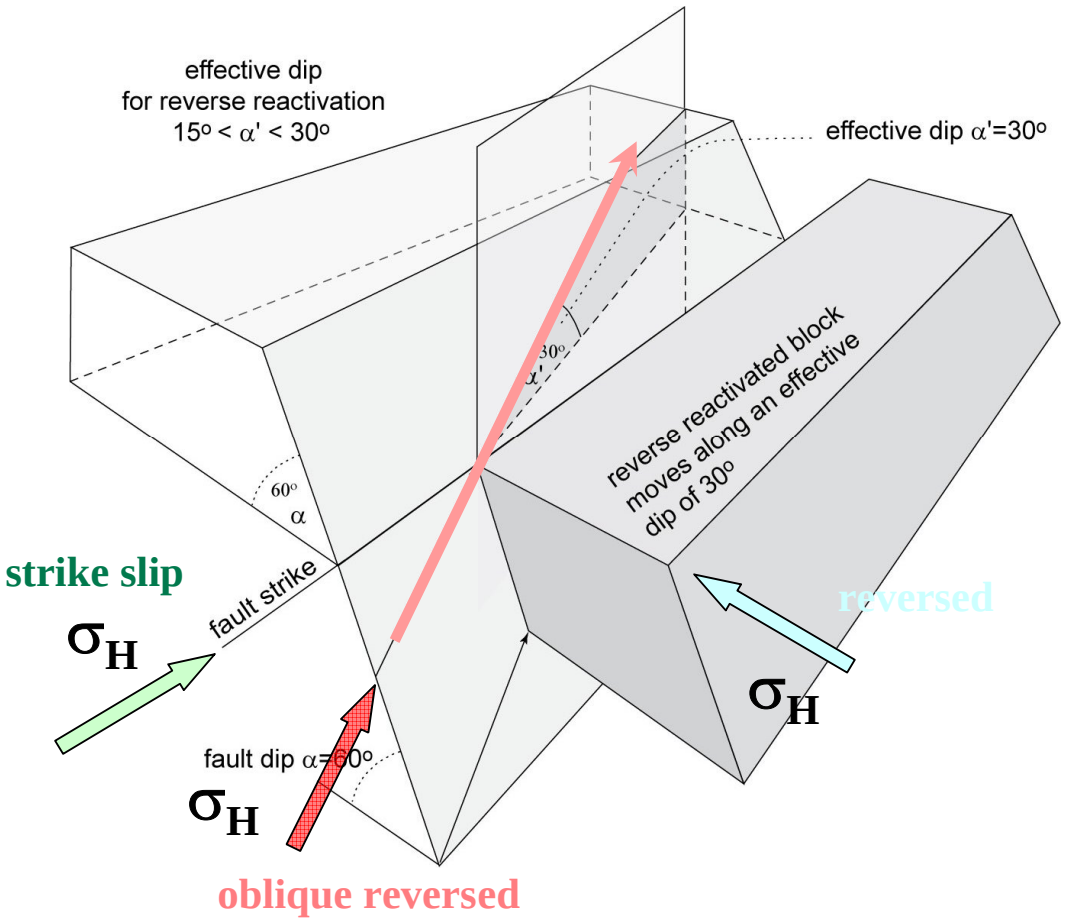
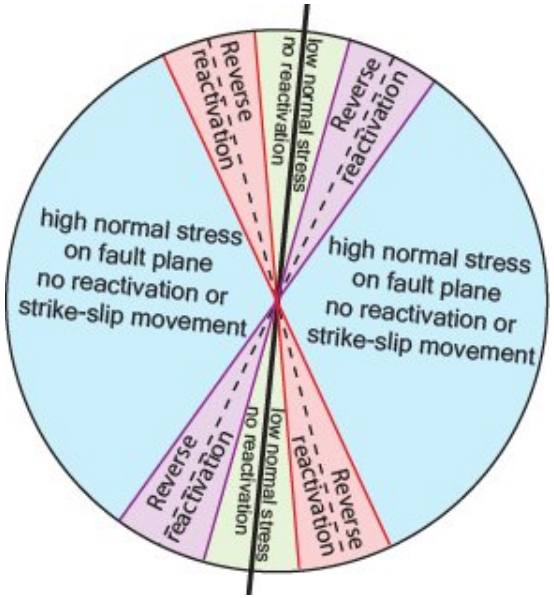
  - Field examples
  - Reverse faulting
- Sealing faults
  - Concept of active dip
  - Fault seal and cataclasis
  - Fault seal probability map
- Discussion

Concept of effective dip

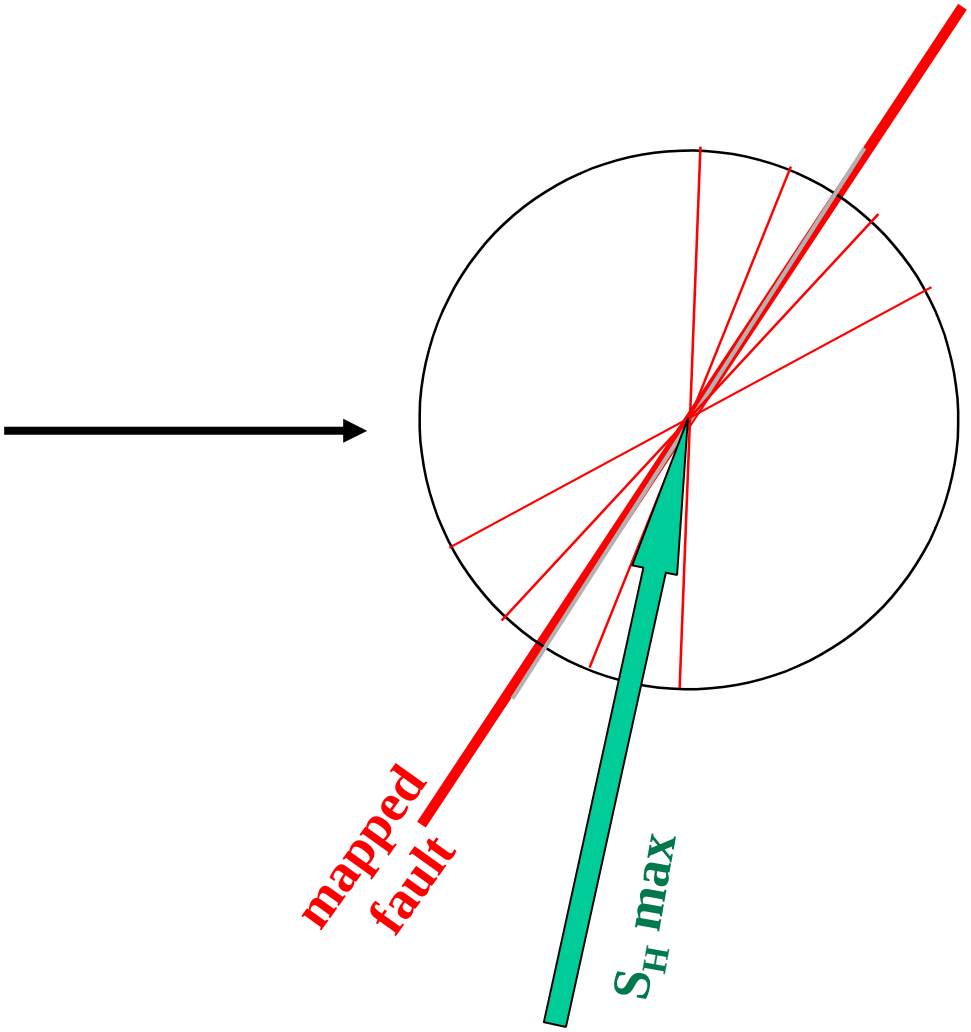


- Reverse reactivation of a plane with a steep dip (more then 45°) is not possible
- Reverse oblique reactivation is possible along an effective dip α' where 15°<α'<30°

The reactivation circle: application example



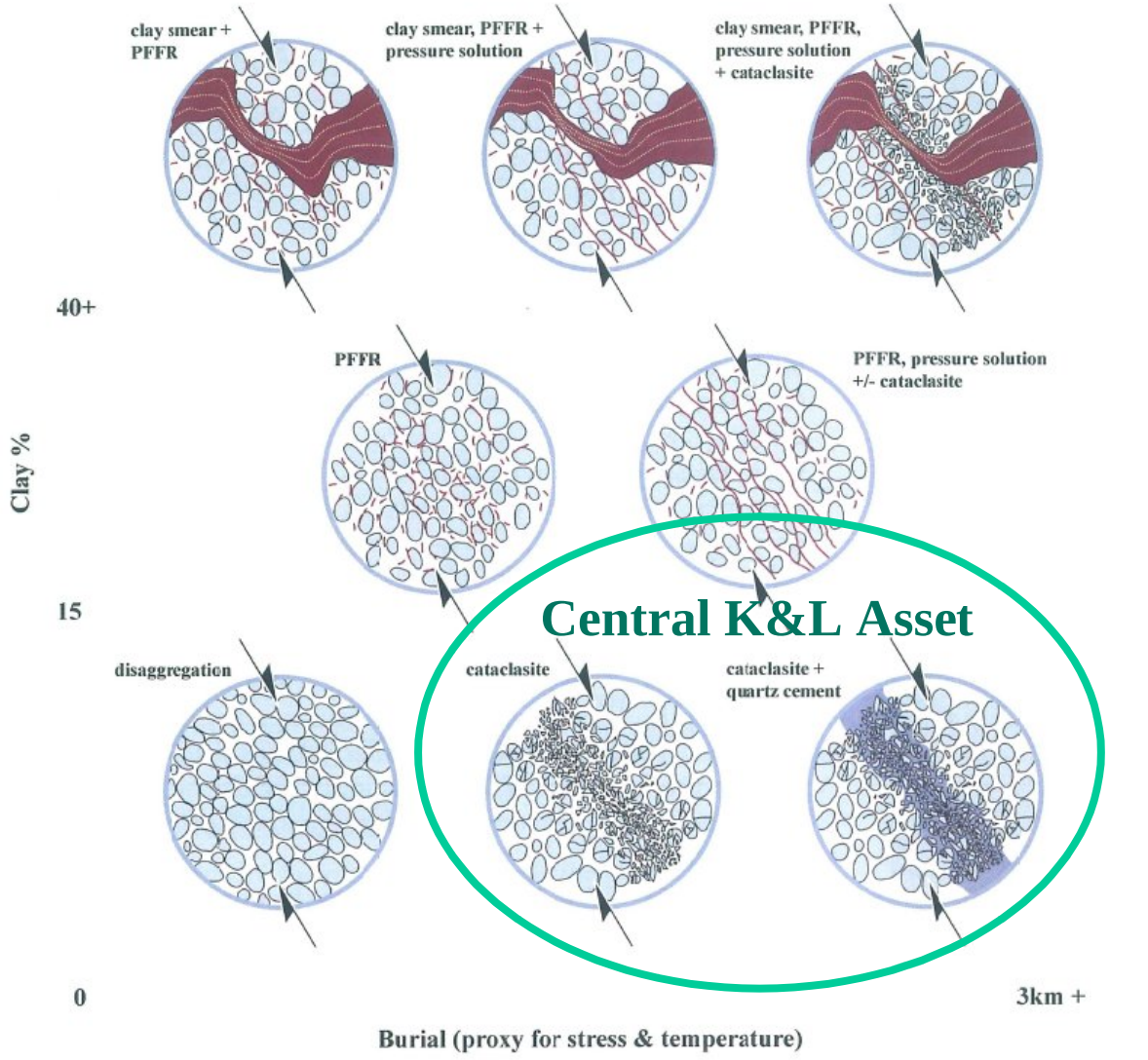
reactivation circle



Fault seal types

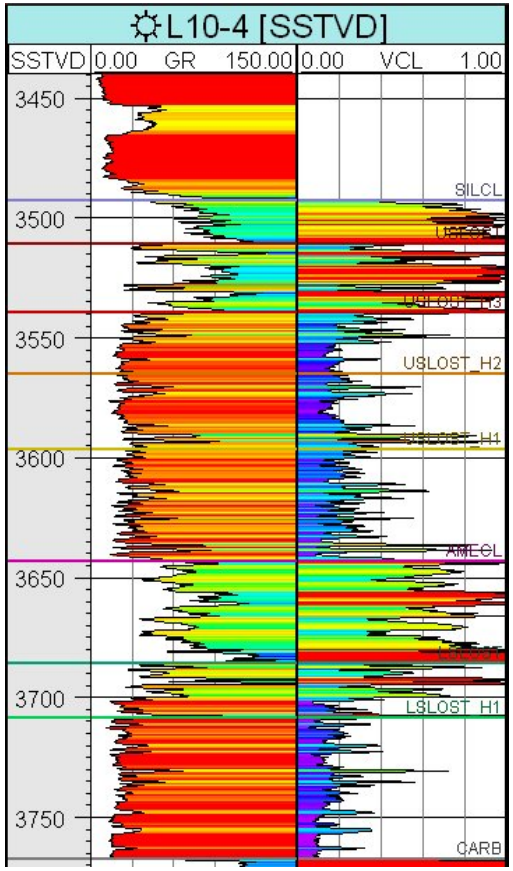
- Clay smear
  - > 40 % clay
  - passive
- Phyllosil. Framework Fault Rock
  - 15-40% clay
- Cataclasis
  - < 15 % clay
  - active

(Jolley et al. 2008)

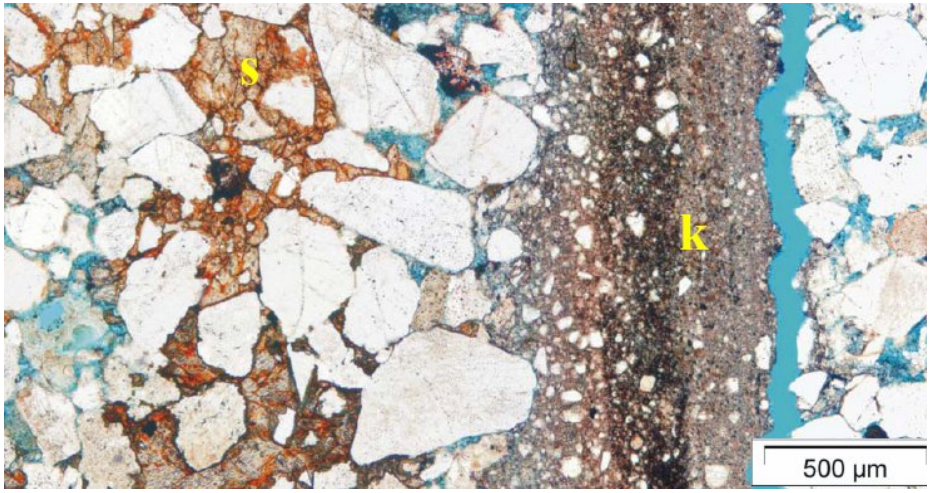


Cataclasis conditions

- Upper and Lower Slochteren:
  - Vcl < 20 %



- Fault cataclasis observed in L10-4

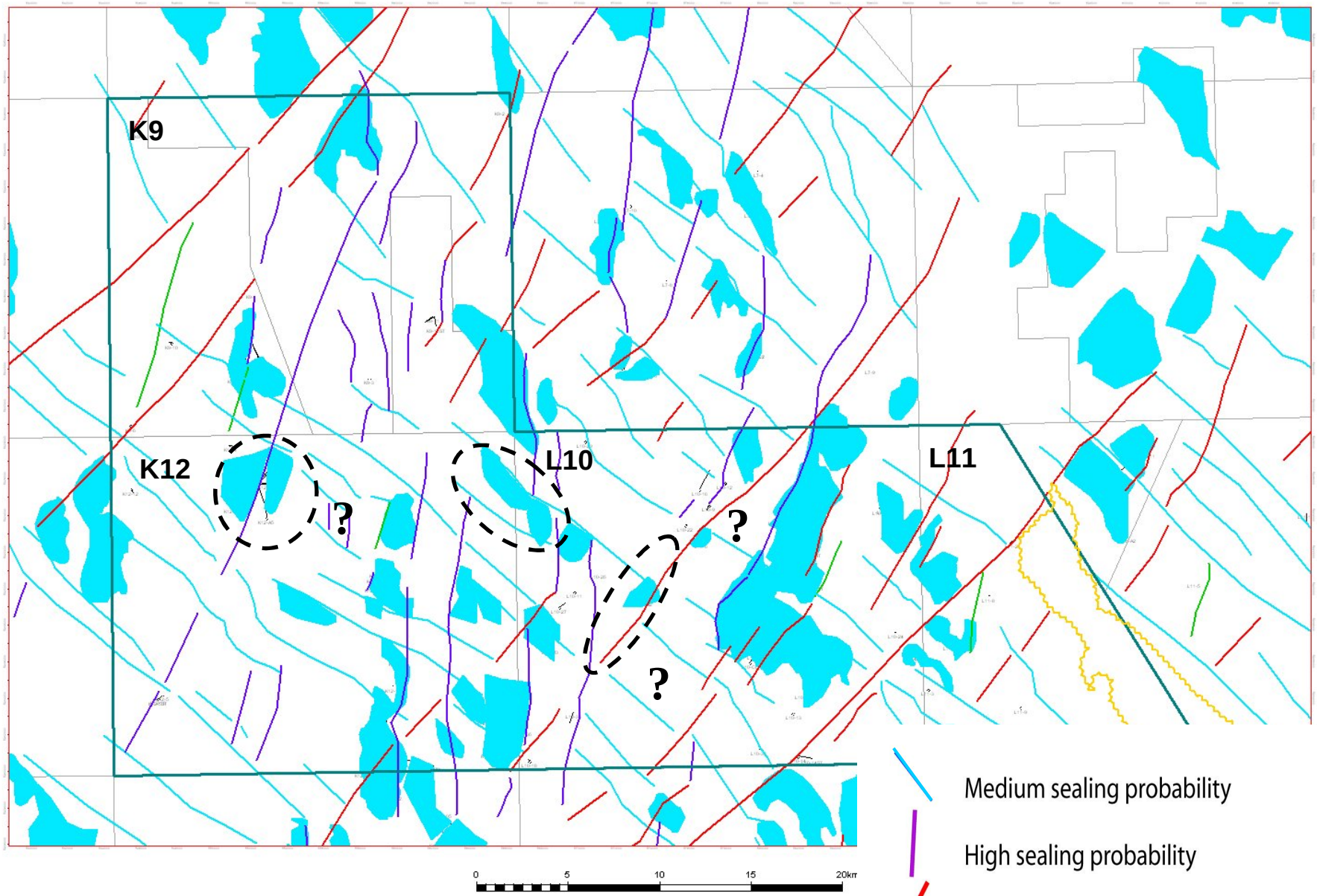


1 Grain crushing in faults: cataclasis

2 Diagenetic minerals: kaolinite & siderite

3 Permeability decrease: matrix 10 mD vs gouge 0.1 mD

Fault Seal probability map

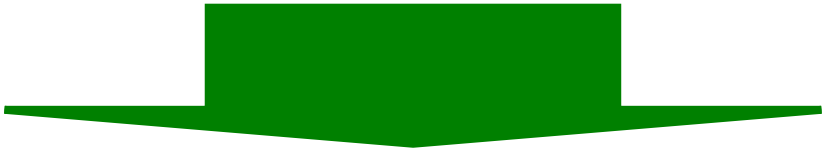


Discussion

- Four main fault orientations have been identified in the Rotliegend in the Central K&L Asset
- These have been categorized into three groups: *high*, *intermediate* or *low* potential for sealing fault behavior
- The reactivation circle can be used as a prognosis tool for *fault sealing potential* by cataclasis
- Cataclasis is formed in N-S and NE-SW reverse faults (Late Cretaceous)
- N-S and NE-SW trending faults have high potential for sealing faults due to cataclasis development

Work-in-progress

- New seismic data K&L asset
- Field scale:
  - structural-geological mapping
  - fault seal analysis at field scale



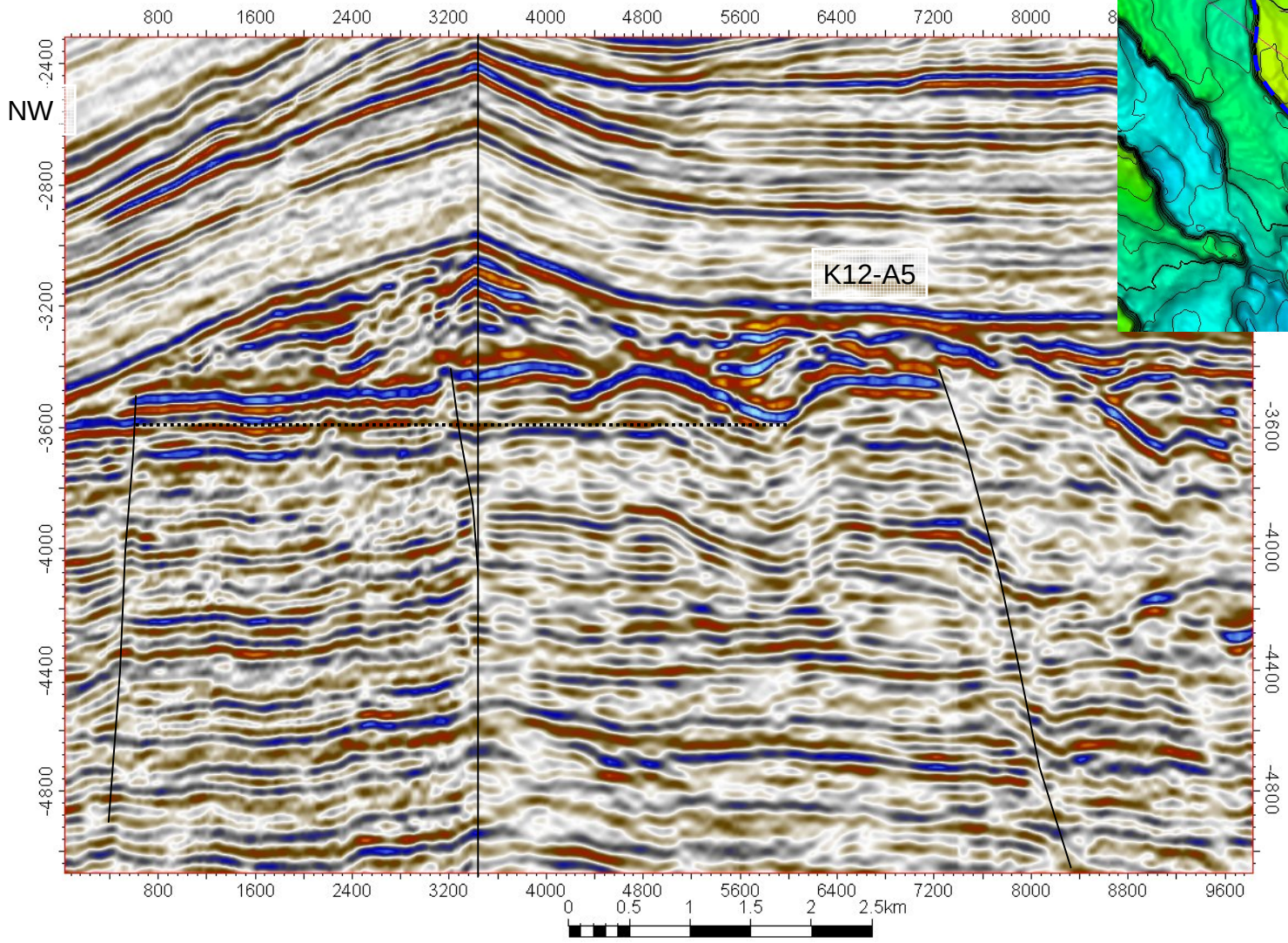
undrained fault blocks near platforms

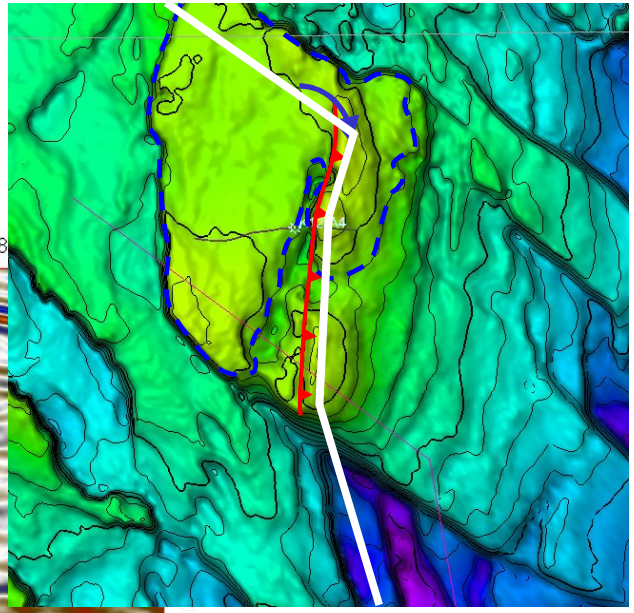
new exploration prospects

?

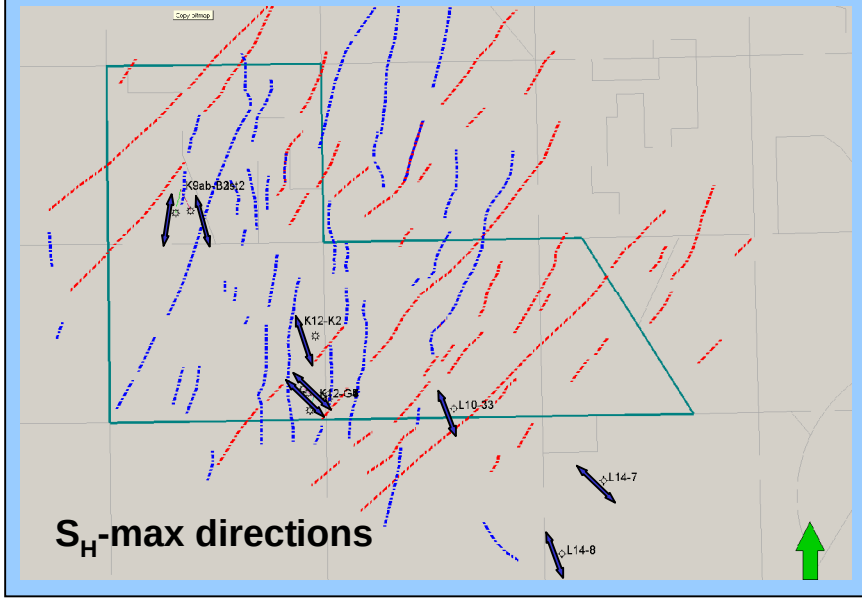
discussion & questions

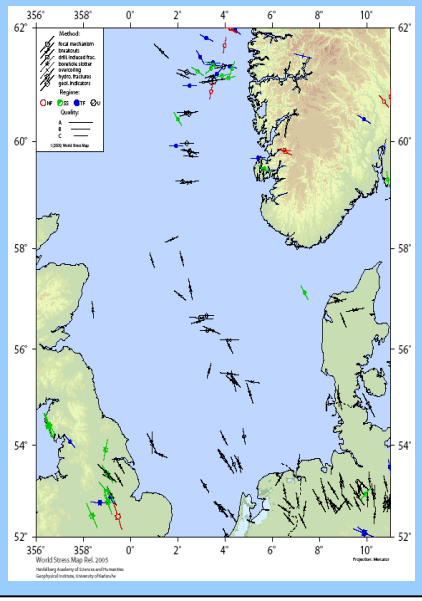
K12-A saddle


NW
K12-A5
800
1600
2400
3200
4000
4800
5600
6400
7200
8000
8800
9600
-2400
-2800
-3200
-3600
-4000
-4400
-4800
0
0.5
1
1.5
2
2.5km

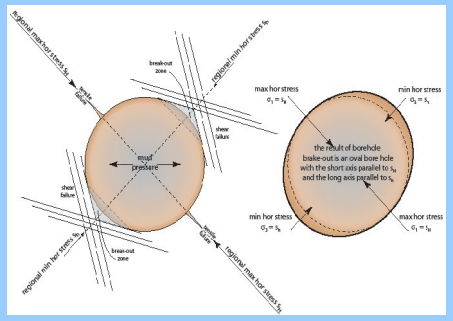


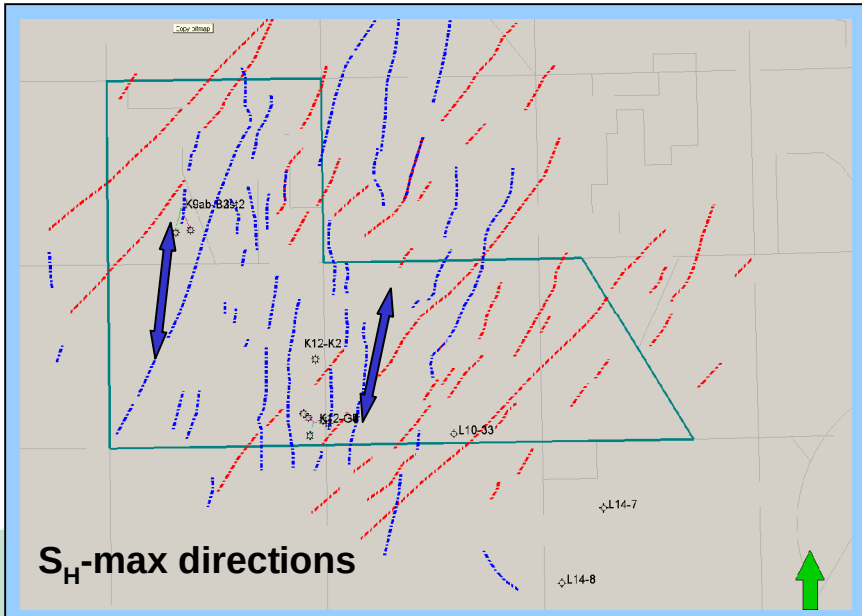
S_H maximum horizontal stress



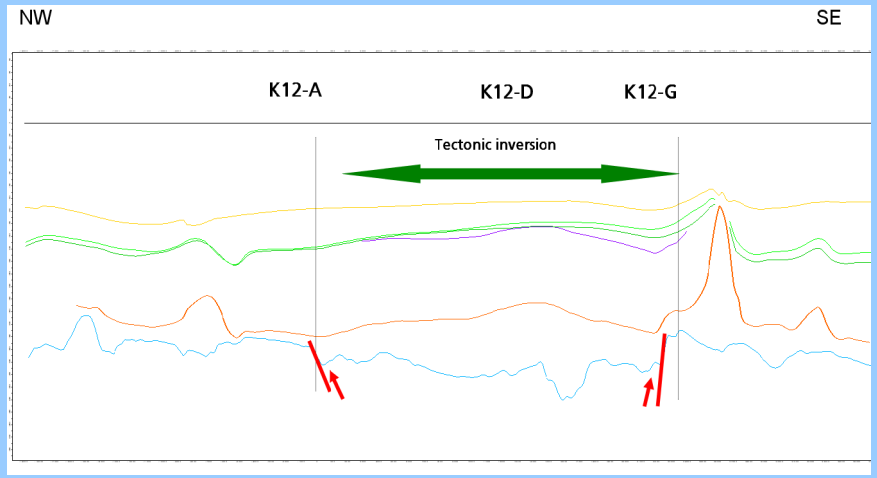


today



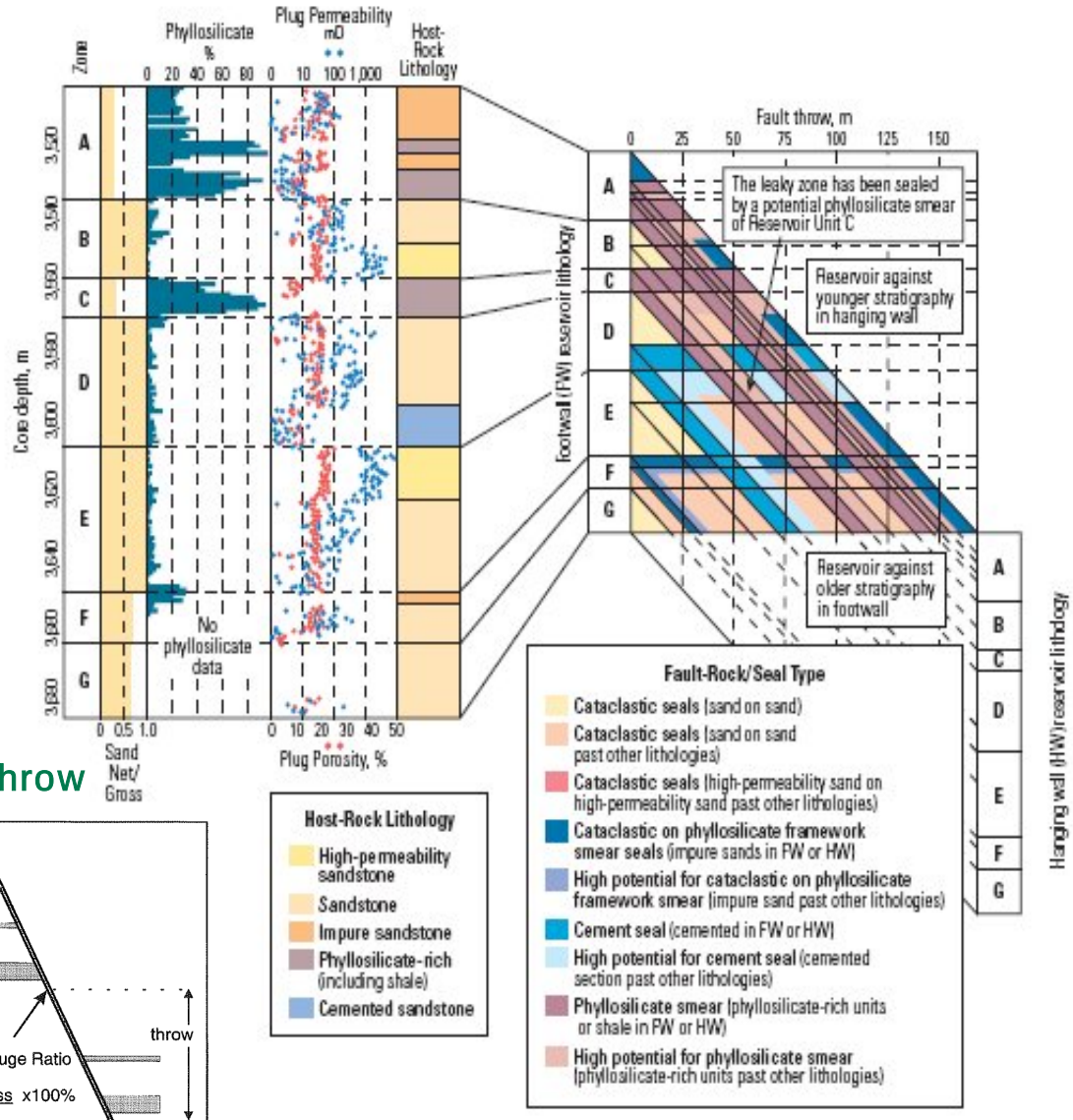


Late Cretaceous



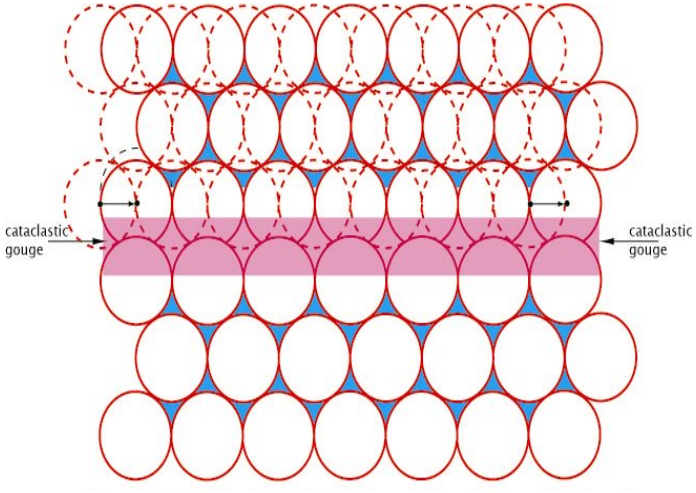
Sealing fault analysis

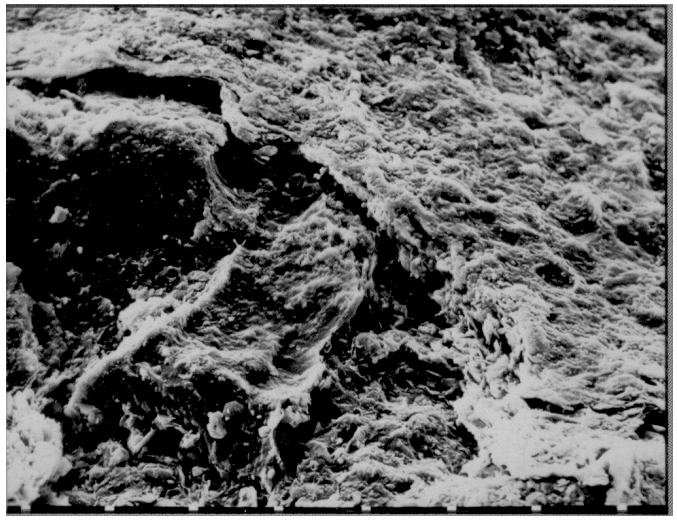
- Modern fault seal analysis combines:
  - Seismic data
  - (micro-) Structural information
  - Reservoir pressure
- Juxtaposition diagrams
  - Lithology vs fault throw
- Shale Gouge Ratio
  - SGR = Σ (shale bed thickness) / throw x 100%
- Fault seal types
  - Clay smear
  - Phyllo. Framew. FR
  - Cataclasis



What is a cataclastic rock ?

- Cataclasis is the process of breaking of grains and grinding them into a very fine-grained sealing fault gouge
- The process of cataclasis requires high normal stress on a shear zone (shear in combination with high normal stress)
- The required conditions are found in *reverse faults*





Reactivation tool (fault dip = 60º)