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

GDF Production Nederland BV

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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**

**Fault seal or no seal?**

- Reservoir
  - Pressure
  - GWC
  - Gas composition
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

Middle Permian
Deposition ROSL

Late Jurassic
Rifting and erosion
Central Offshore Platform

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

Probable spill point

GWC

Saddle between K12-A5 and K12-A4

K12-A5 dry compartment

West

East

Depth
K12-A Late Cretaceous oblique reverse faulting N-S
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*  

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

- GWC -3905 mTVD
- GWC -3886 mTVD
Structural element map Central K&L Asset

Tectonic inversion

BFB

L10-S2

K12-A

K12-B

'BBB'

COP

NHP

TJH

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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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- 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 than 45°) is not possible

Reverse oblique reactivation is possible along an effective dip $\alpha'$ where $15^\circ < \alpha' < 30^\circ$
The reactivation circle: application example

reactivation circle

mapped fault

$S_n \max$
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

- Grain crushing in faults: cataclasis
- Diagenetic minerals: kaolinite & siderite
- Permeability decrease: matrix 10 mD vs. gouge 0.1 mD
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
$S_H$ maximum horizontal stress

**Today**

$S_H$-max directions

**Late Cretaceous**

$S_H$-max directions
Sealing fault analysis

Modern fault seal analysis combines:
- Seismic data
- (micro-) Structural information
- Reservoir pressure

Juxtaposition diagrams
- Lithology vs fault throw

Shale Gouge Ratio
- \( \text{SGR} = \sum \text{(shale bed thickness) / throw} \times 100\% \)

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 \(\text{ (fault dip} = 60^\circ)\)

- Reference fault trajectory
- Orientation of \(\sigma_h\)
- Fault strike and reactivation range

- High normal stress on fault, no reactivation
- Low normal stress on fault
- Stress orientation on fault is suitable for reactivation
- Medium sealing potential
- Lowest sealing potential possibly leaking
- High sealing potential