Impact of rifting on fluid migration in the Netherlands

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  • Terschelling Basin & Dutch Central Graben
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Approach

• Petroleumhydrogeological approach

• Focus on present-day characteristics - and indicators - of fluid migration on regional scale

• Based on selected results of different projects, such as:
  • JIP TNO-CSIRO Pressure and hydrodynamic study Southern North Sea Basin (2002-2004)
  • TNO detailed mapping programme Netherlands offshore
  • TNO Thematic mapping programme NL offshore & onshore
Rifting and resulting present-day permeability framework

Pre-rift units: faulted & regionally extensive
Syn-rift units: regionally restricted
  S: by deep reaching faults
  N: by salt structures
Post-rift units: regionally extensive
Regional characterization pressure and fluid migration systems

A. Normally pressured
B. Intermediate overpressured
C. Significantly overpressured

Fluid pressures in Germanic Trias groups
Regional characterization pressure systems
Cretaceous and Upper Jurassic units

WFT pressures in Rijnland / Chalk Group reservoir units per structural unit

WFT pressures in Schieland / Scruff Group reservoir units per structural unit
General causes of regional pressure distribution

- **Processes** affecting pressures (and fluid flow)
  (processes generating pressures, e.g. burial and sedimentation; processes dissipating pressures, e.g. lateral and vertical dewatering*)

- **Hydraulic characteristics**
  (permeability, storage coefficient/compressibility - lithology - faults and fractures; for multiphase flow also Pc)

*Note: flowing water distributes pressures (increasing or decreasing pressures depending on location in flow system)
Main regional differences in factors influencing pressure generation and pressure retention/dissipation

- Burial history; present-day maximum depth of burial
- Depth of burial
- Facies/lithological composition
- Geological structure (deep reaching faults vs salt structures)
Important factor influencing present-day pressure distribution: recent sedimentary loading

- Northward increasing thickness
  Upper North Sea Group

- Northward increasing Pliocene & Quaternary sedimentary loading

- (Northward increasing overpressures due to recent sedimentary loading)
Factor influencing pressure retention/dissipation: Facies

Upper Rotliegend  Zechstein salts  Upper Triassic salts

- Southward changes of facies to more porous and permeable lithologies
Pressure characteristics northern offshore

Southern part Central Graben

Fluid pressure (MPa)

Depth (mTVDSs)

Hydrostatic gradient

Lithostatic gradient

Density corrected hydrostatic gradient

North Sea Group
Chalk Group
Rijnland Group
Scruff and Schieland Group
Lower Germanic Trias Group
Upper Rotliegend Group
Leak off pressures
Permeability framework and Overpressures
Jurassic-Triassic pressure compartments

Regional aquitard: Lower Tertiary shales transition zone

Regional aquitard: Cretaceous Chalk and shales hold fluid overpressures >10 MPa

Below Zechstein salts: fluid overpressures in isolated reservoirs > 40 MPa

Lower Triassic pressure compartment (lateral and vertically confined by salt seals: fluid overpressures >30 MPa)

11.0 = P_{excess} (MPa)
Hydraulic head in Upper Jurassic sandstones

(hydraulic head: $H_w = \frac{P_w \rho_w g}{\rho_w} - z$)

Regional lateral dewatering towards inverted basin centre DCG

Including local dewatering along salt structures

Pressure retention in Terschelling Basin
Overpressure distribution and fluid flow in Schieland/Scruff groups
F3 block

Northeastern part block F3

Dewatering towards salt structure

860    Density head (m)
10.6   Overpressure (MPa)
1073   Reference density (kg/m³)
Leakage along salt-related faults in northern part block F3

Schroot and Schüttenhelm, NJG 2003
Hydraulic head Lower Triassic sandstones (southern offshore)

- Regional southward decreasing heads

NE basin boundary fault: barrier for groundwater flow

SE basin boundary fault: dual hydraulic character
All fluid overpressures Upper Rotliegend Group

Highest overpressures along northern sand limit
Hydraulic head Upper Rotliegend sandstones

Regional southward decreasing heads in the Upper Rotliegend sandstones

Northern sand limit
Hydraulic head Upper Rotliegend sandstones

Lateral - stepwise - dewatering of the Upper Rotliegend sandstones below ZE evaporites

(RO in large part hydraulically continuous on geological time scales)

(Interpreted 2D seismic section from MscThesis Bouw 1999)
Hydraulic head Upper Rotliegend sandstones

NE basin boundary fault; possible barrier for groundwater flow
CO₂ content in natural gas accumulations in Upper Rotliegend sandstones

- NE basin boundary fault: barrier for gas migration
Southern area A: normally pressured
Rijnland Group: decreasing hydraulic heads towards onshore West Netherlands Basin

In Q13 relatively high hydraulic heads & overpressures in Rijnland and Schieland groups

GRADIENT 0.25 bar/km
Possible gas chimney in block Q13

Kijkduin High

1990 3D survey block Q13
(Schroon and Schüttenhelm, NJG 2003)
Additional present-day indicators for fault-related flow: anomalous gas compositions and temperatures

For example: CO$_2$

- 70 Mol% CO2 in Werkendam Fm (AT) at WED-01
- WED-01 cuts through 2 faults & a dyke
- 72 Mol% CO2 in Triassic reservoir at WED-03
- $d^{13}$C-CO$_2$ = -4.4 °/oo

Possible deep origin CO2: thermal destruction carbonates (Dinantian Carbonates?)
Positive temperature anomaly in Ruhr Valley Graben

• Positive temperature anomalies in AND-6 and BRAK-1

• Igneous intrusions in M-Jurassic AND-2,4

• N-S and EW trending faults cutting through Jurassic units

➢ Possible explanation: Upward fluid flow along faults

Conclusions

- Rifting is one of the key factors in shaping the present-day permeability framework

- Present-day rift-related fault zones and salt structures:
  - are low permeable to impermeable barriers for lateral fluid migration, respectively;
  - separate pressure and fluid migration systems
  - provide - directly or indirectly - vertical migration paths for fluids (water, oil, gas)

- Integrated analyses of present-day indicators of fluid migration (e.g. P, T, gas compositions, ..) reveal migration paths for water, oil and gas

- Use all your data in combination with petroleumhydrogeological approaches to identify and understand fluid migration and charging of oil and gas accumulations in the Netherlands