Workshop Rifting systems and its significance for hydrocarbon exploration in the Netherlands, Utrecht, June 5th 2008

Impact of rifting on fluid migration in the Netherlands

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TNO | Kennis voor zaken

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- Rifting & permeability framework
- Permeability framework, pressure distribution & fluid migration
- Case study examples
  - Terschelling Basin & Dutch Central Graben
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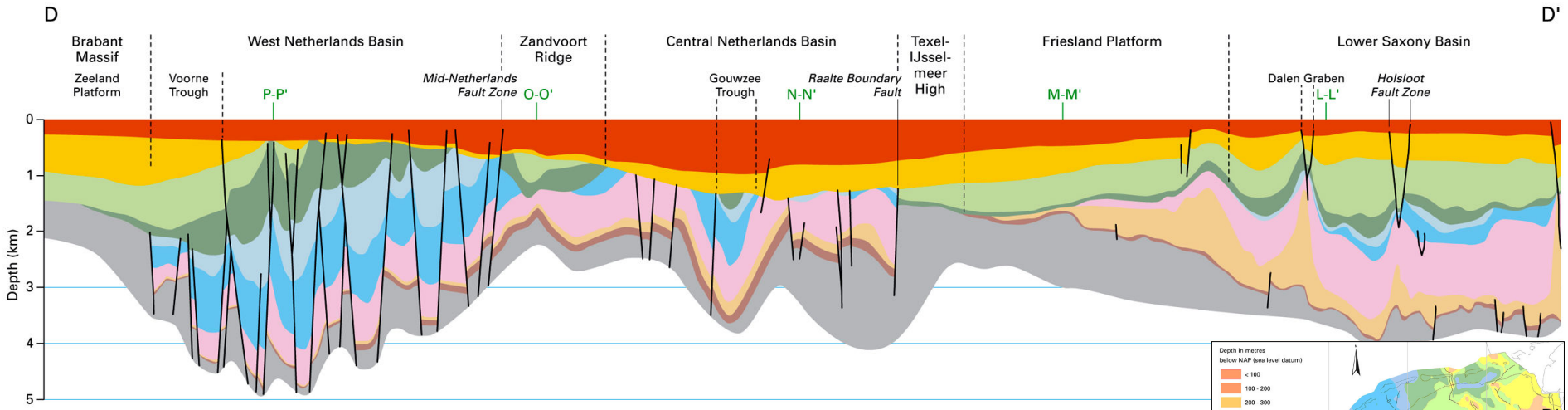
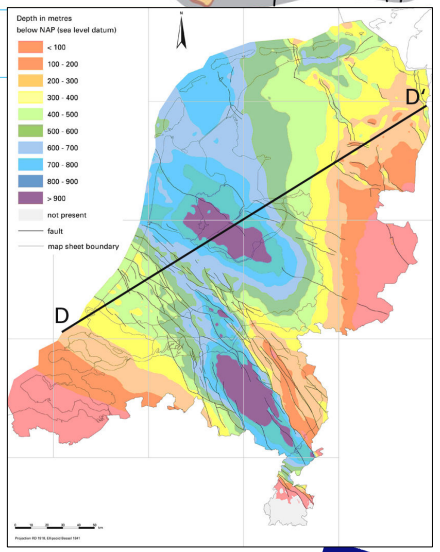
Approach

- 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

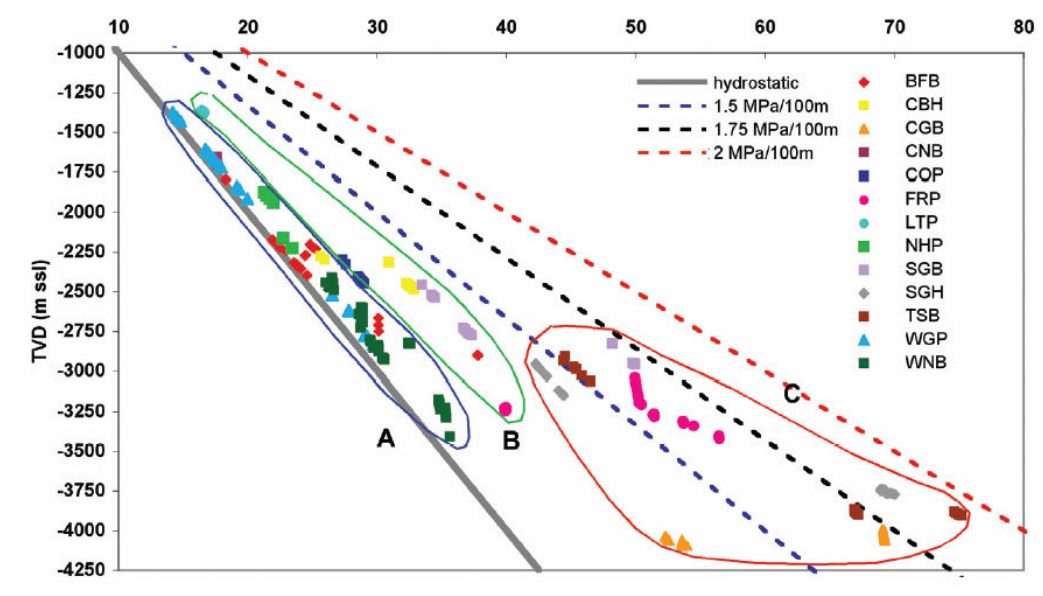
Post-rift units: regionally extensive

Regional characterization pressure and fluid migration systems

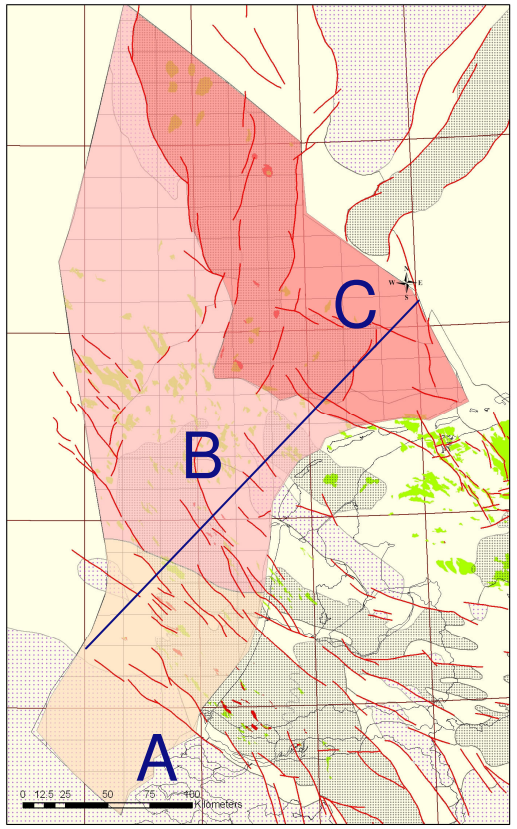
A. Normally pressured

B. Intermediate overpressured

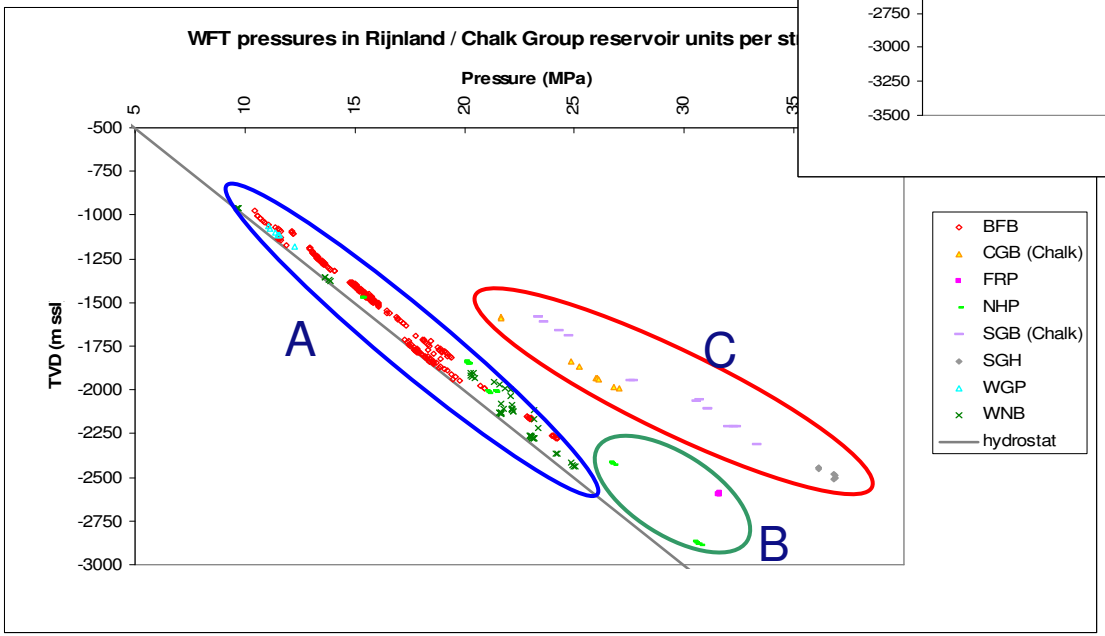
C. Significantly overpressured

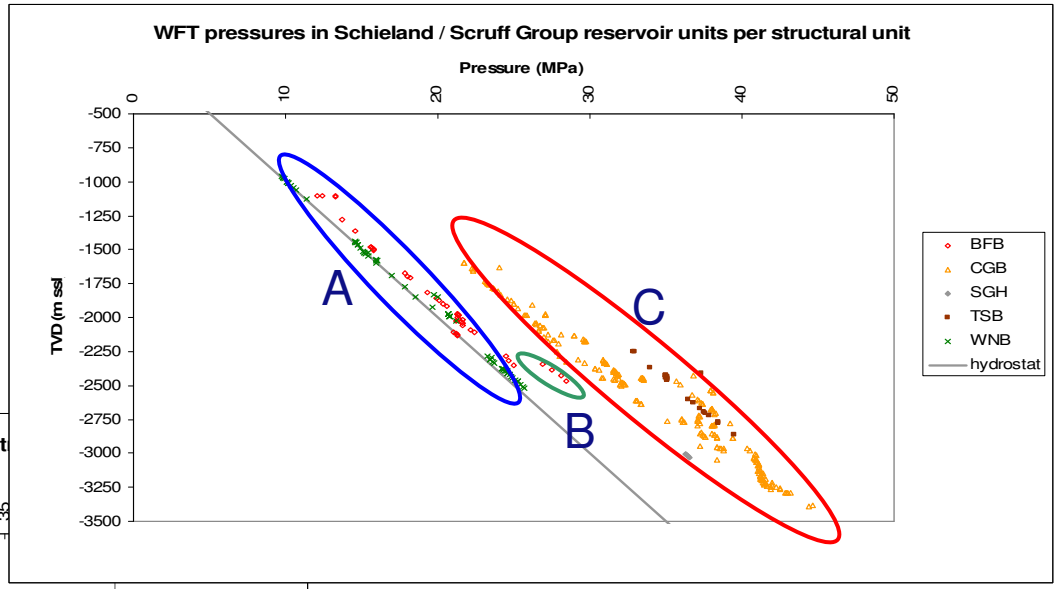


Fluid pressures in Germanic Trias groups



Regional characterization pressure systems
Cretaceous and Upper Jurassic units





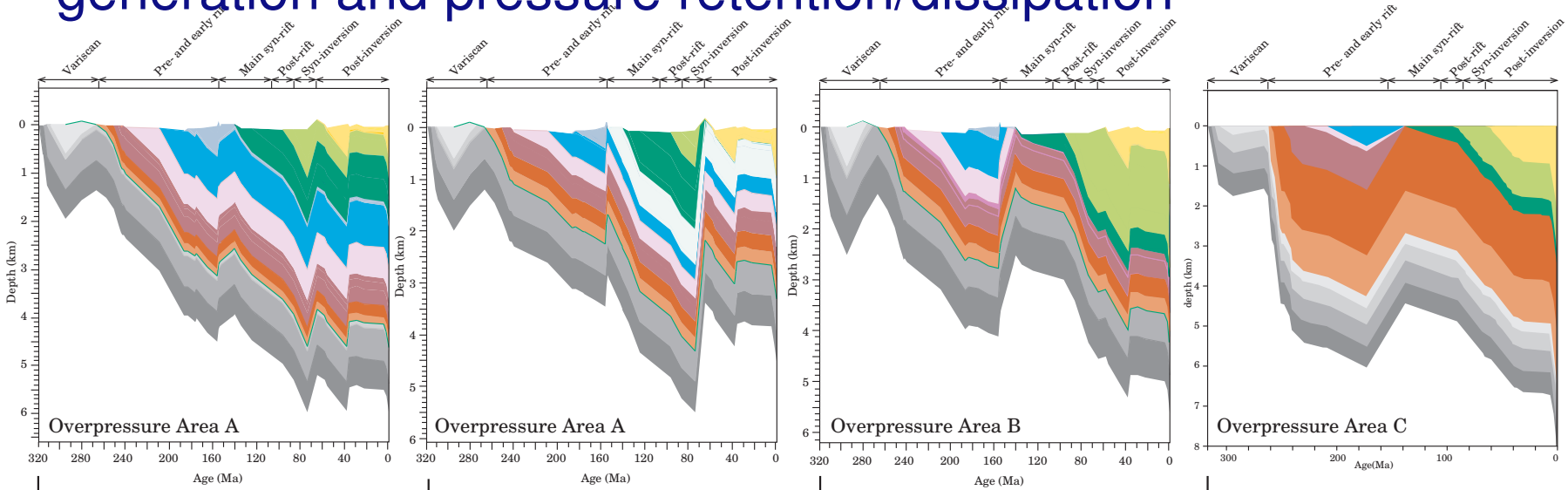
General causes of regional pressure distribution

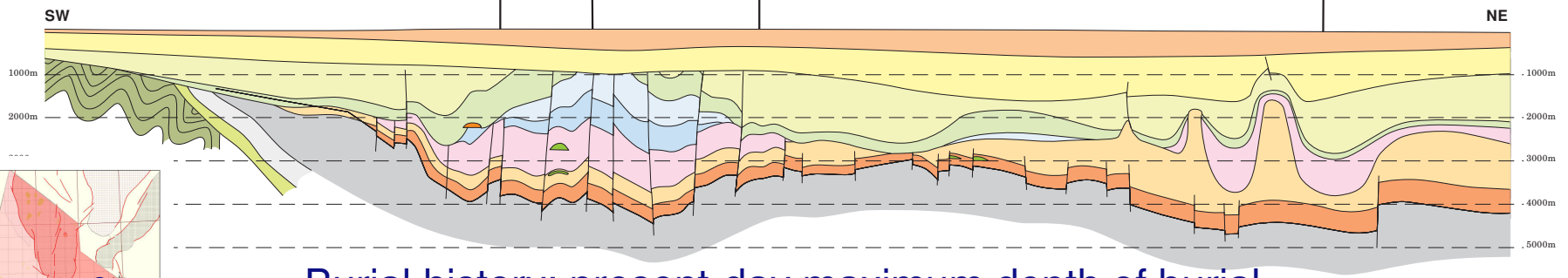
- Processes affecting pressures (and fluid flow)
  (processes generating pressures, e.g. burial and sedimentation; processes dissipating pressures, e.g. lateral and vertical dewatering*)

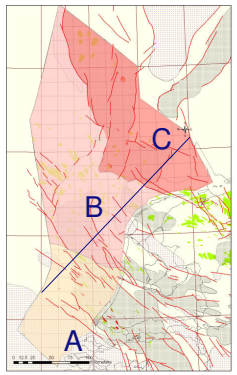
- Hydraulic characteristics
  (permeability, storage coefficient/compressibility - lithology - faults and fractures; for multiphase flow also Pc)

***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







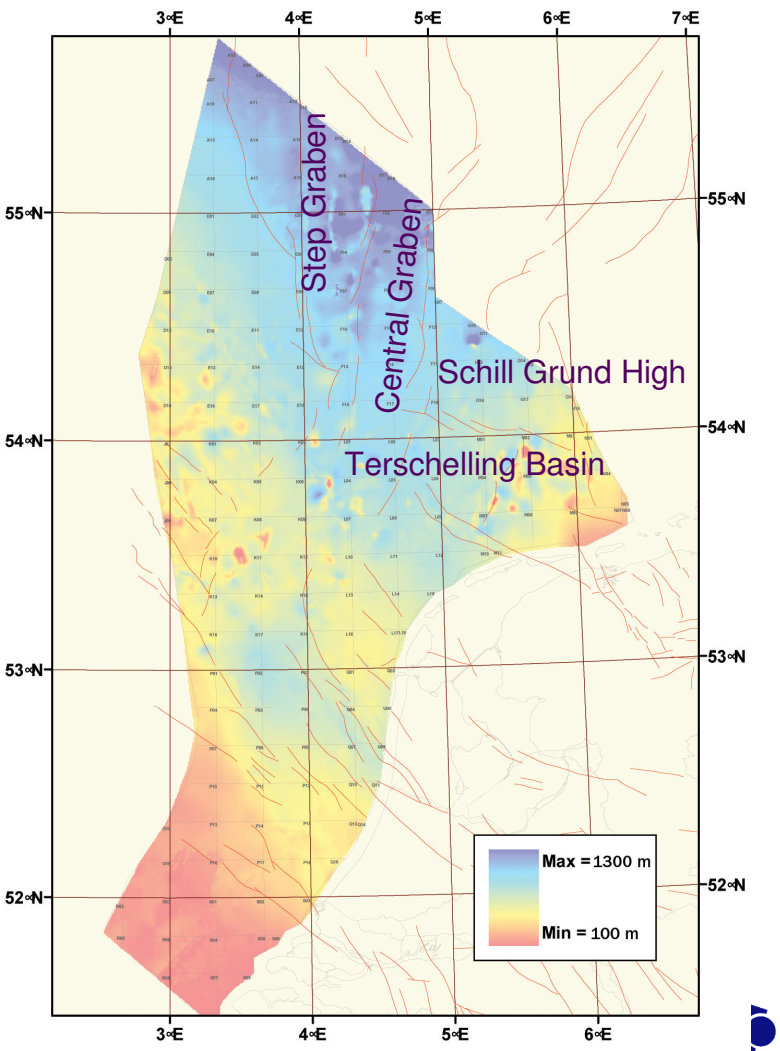
- Burial history; present-day maximum depth of burial
- Depth of burial
- Facies/lithological composition
- Geological structure (deep reaching faults vs salt structures)

Important factor influencing present-day pressure distribution: recent sedimentary loading

Northward increasing thickness Upper North Sea Group

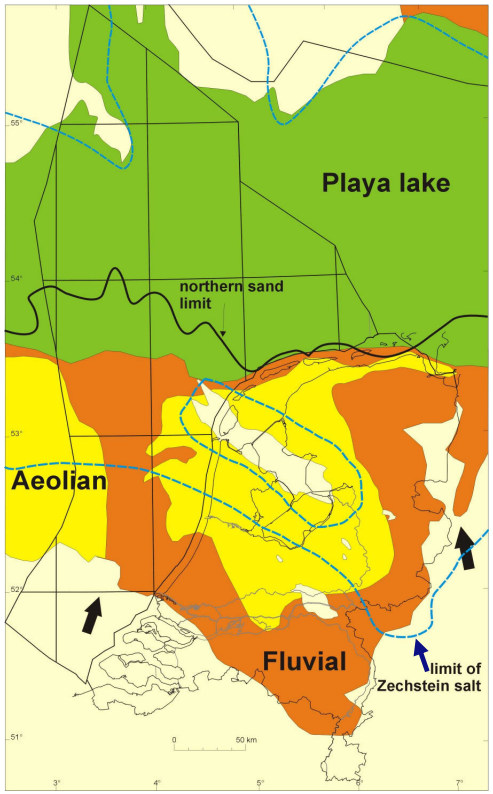
- **Northward increasing Pliocene & Quaternary sedimentary loading**
- **(Northward increasing overpressures due to recent sedimentary loading)**

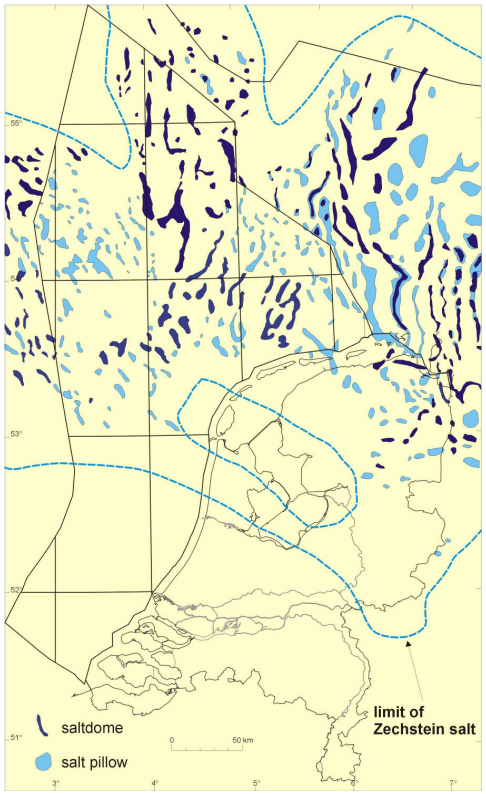
1300 m

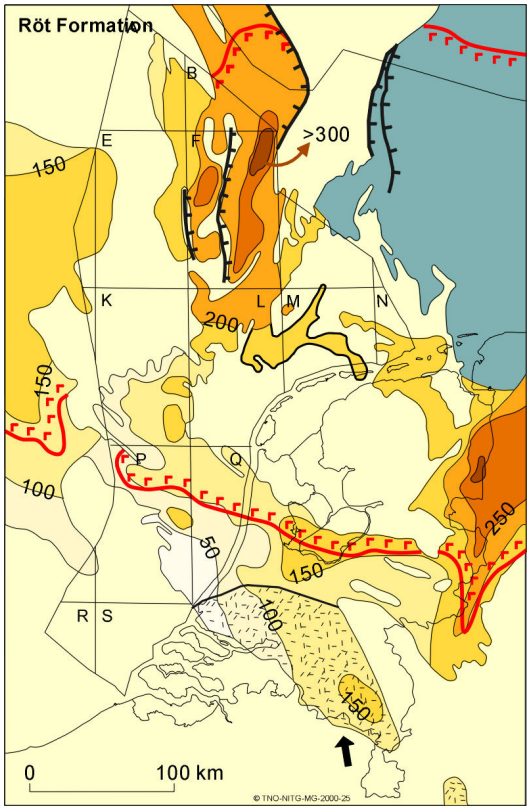


<100 m

Factor influencing pressure retention/dissipation: Facies



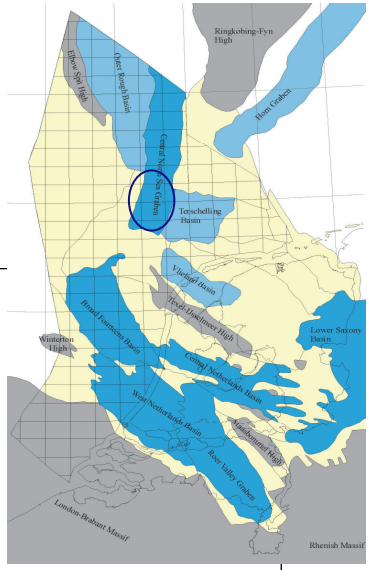


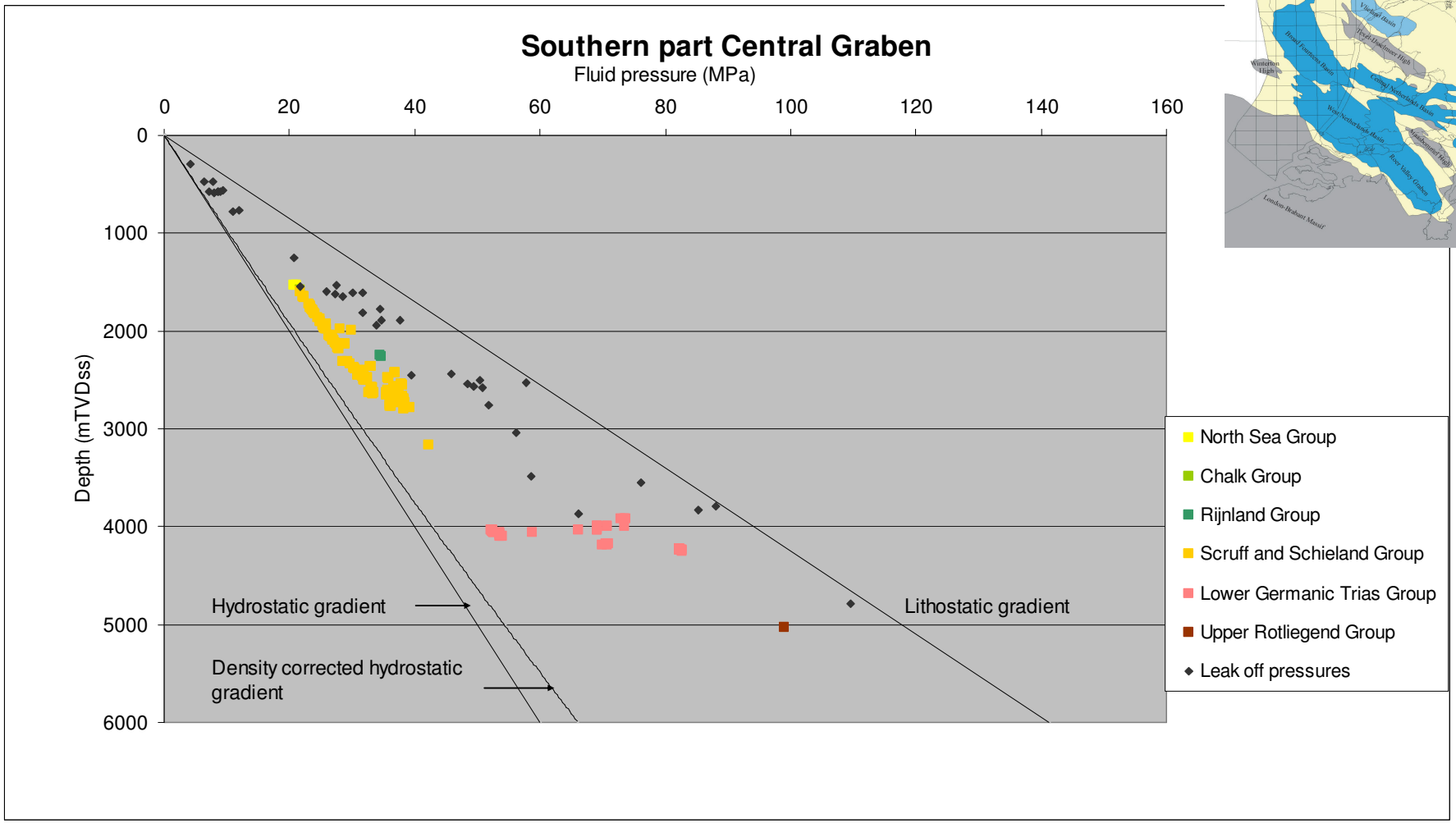


Upper Rotliegend Zechstein salts Upper Triassic salts

- Southward changes of facies to more porous and permeable lithologies

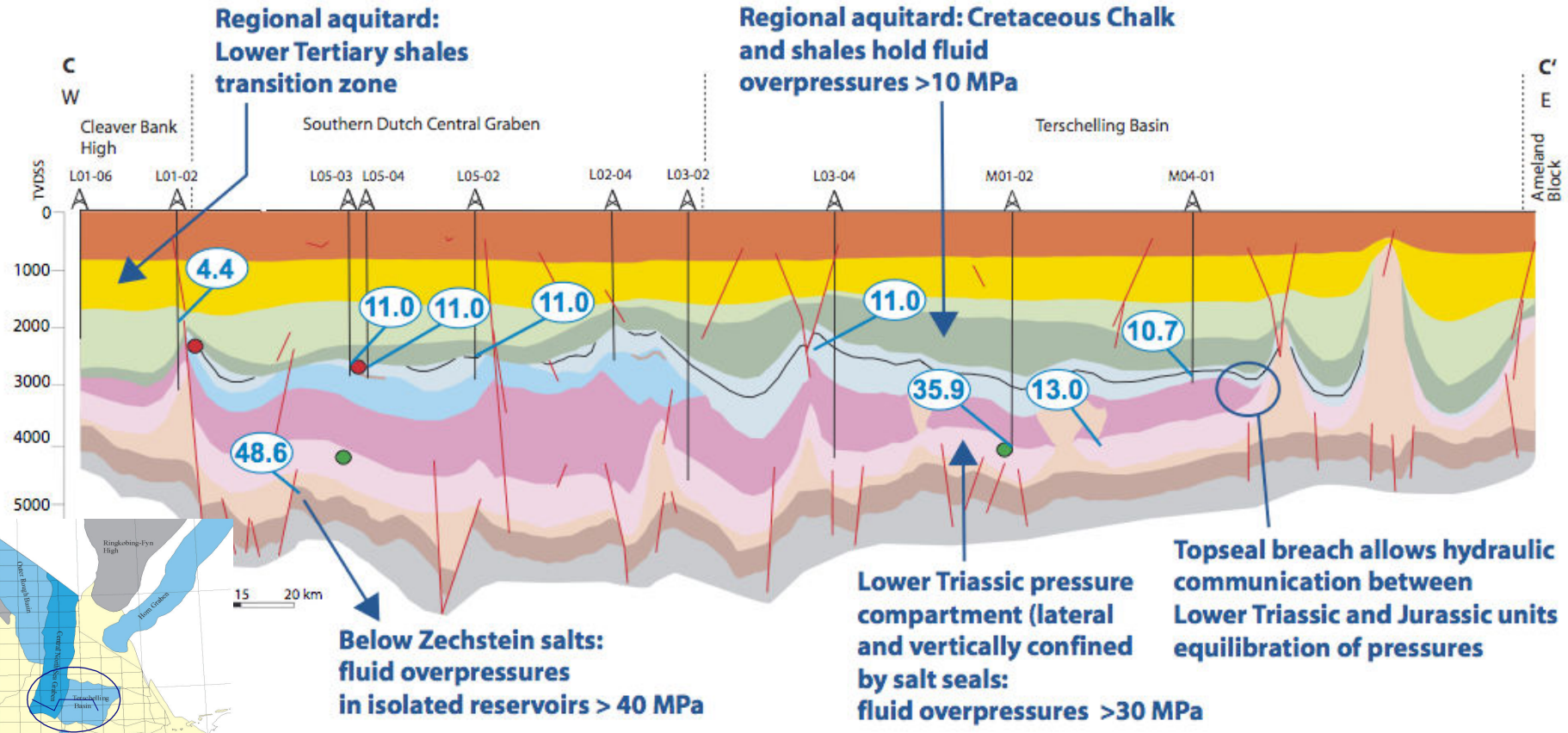
Pressure characteristics northern offshore





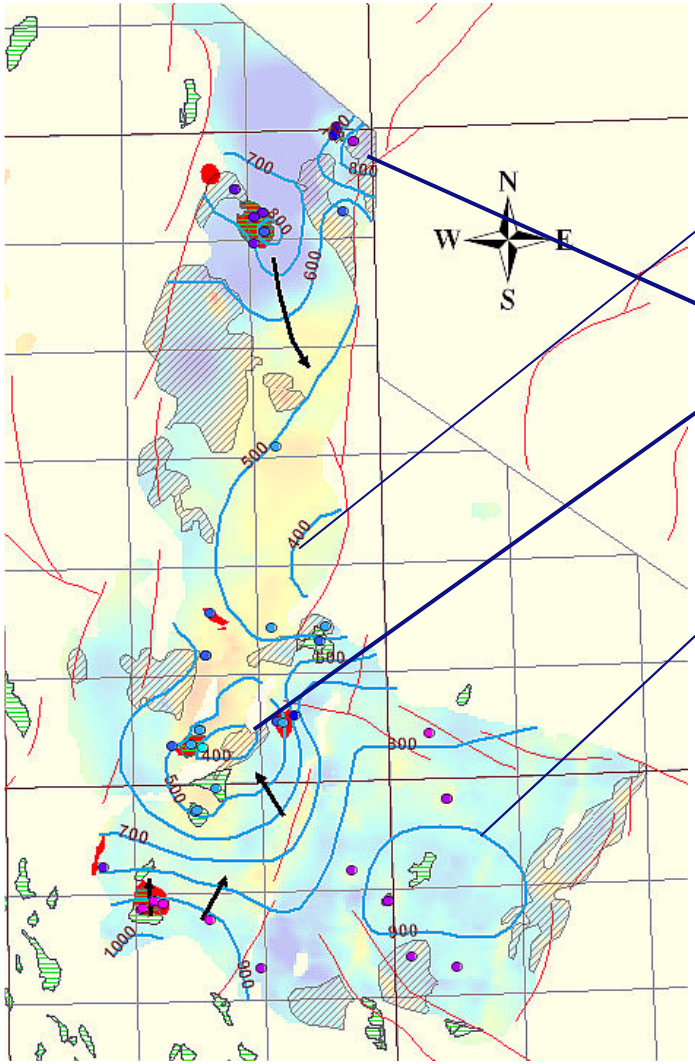
Permeability framework and Overpressures

Jurassic-Triassic pressure compartments



11.0 = P_{excess} (MPa)

Hydraulic head in Upper Jurassic sandstones

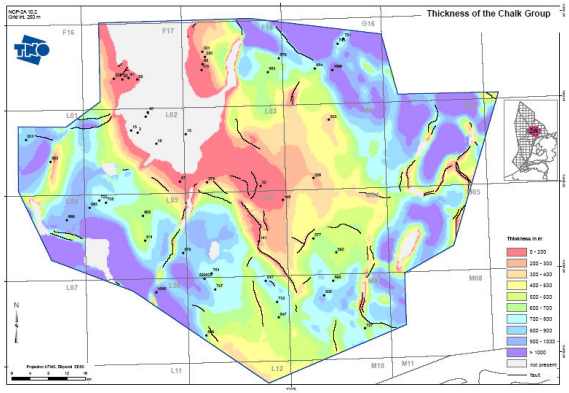


(hydraulic head: $H_w = P_w / \rho_w g - z$)

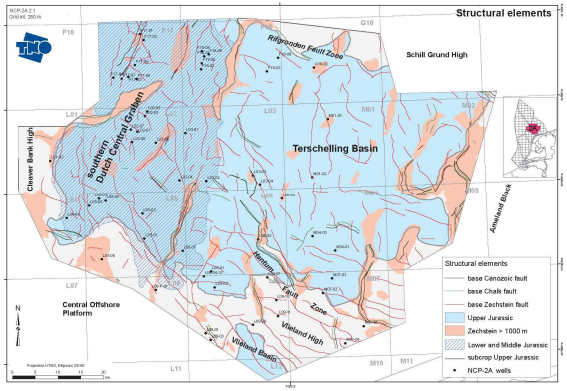
Regional lateral dewatering towards inverted basin centre DCG

Including local dewatering along salt structures

Pressure retention in Terschelling Basin



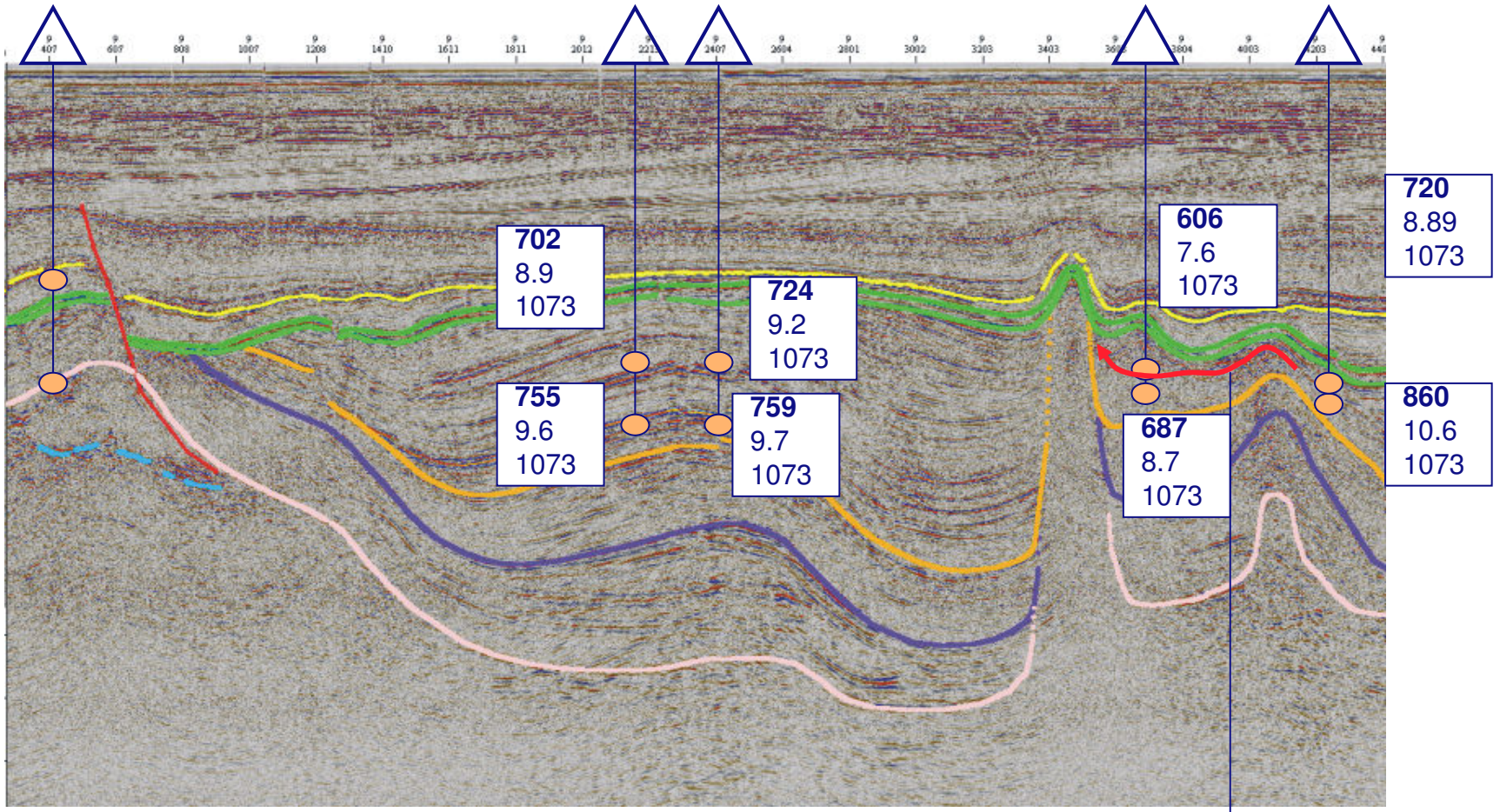
Thickness Chalk



Salt structures

Overpressure distribution and fluid flow in Schieland/Scruff groups F3 block

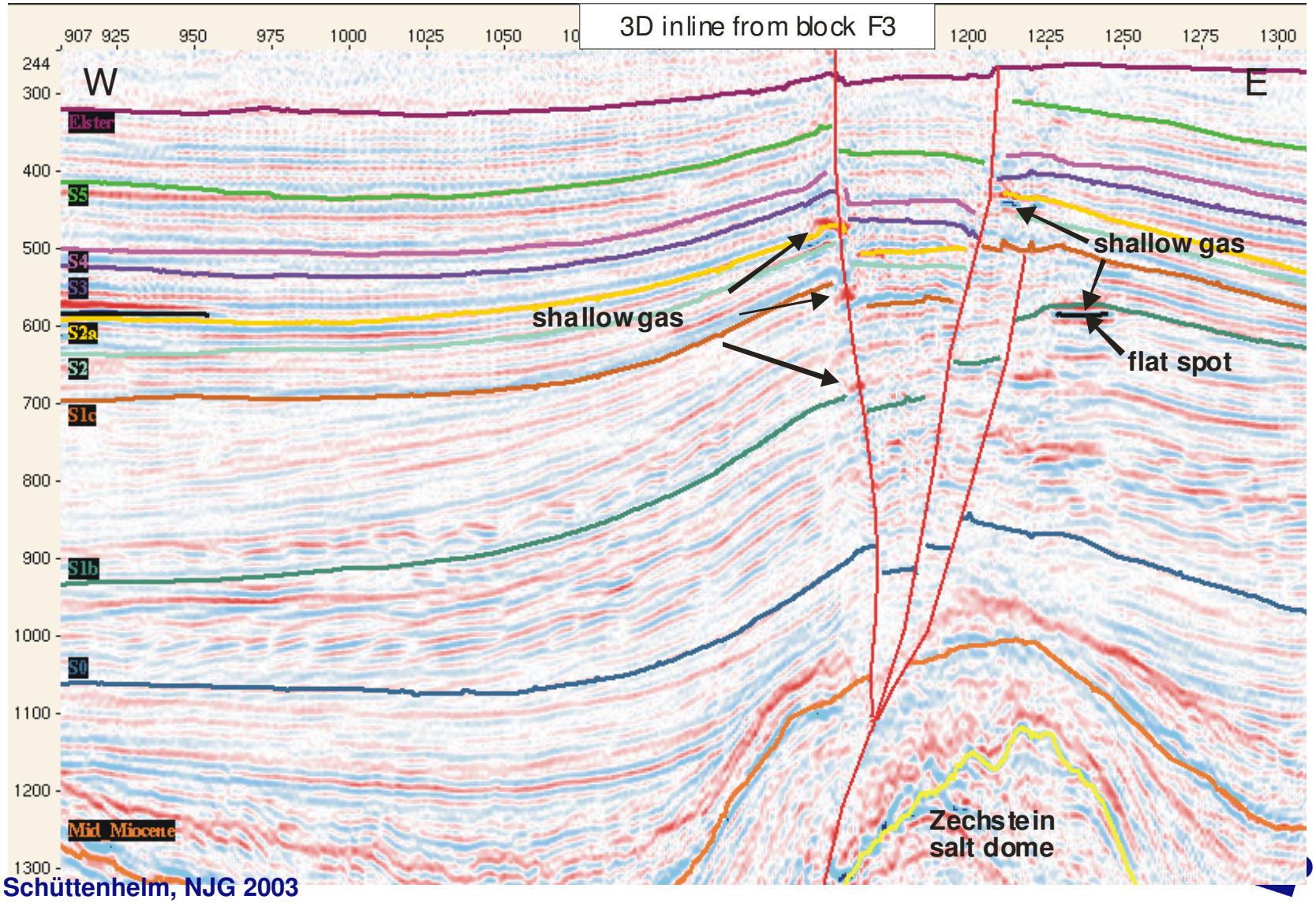
Northeastern part block F3



860 **Density head (m)**
10.6 Overpressure (MPa)
1073 Reference density (kg/m3)

Dewatering towards salt structure

Leakage along salt-related faults in northern part block F3

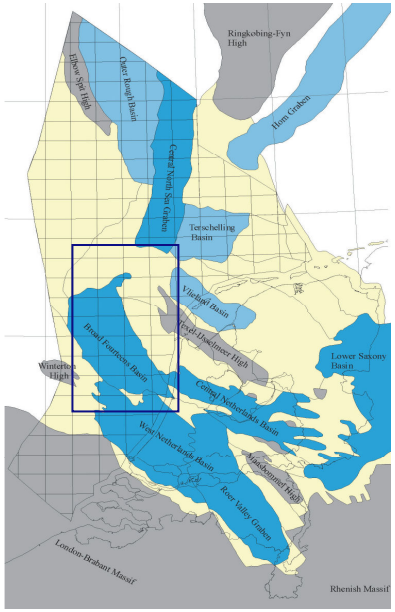


Schroot and Schüttenhelm, NJG 2003

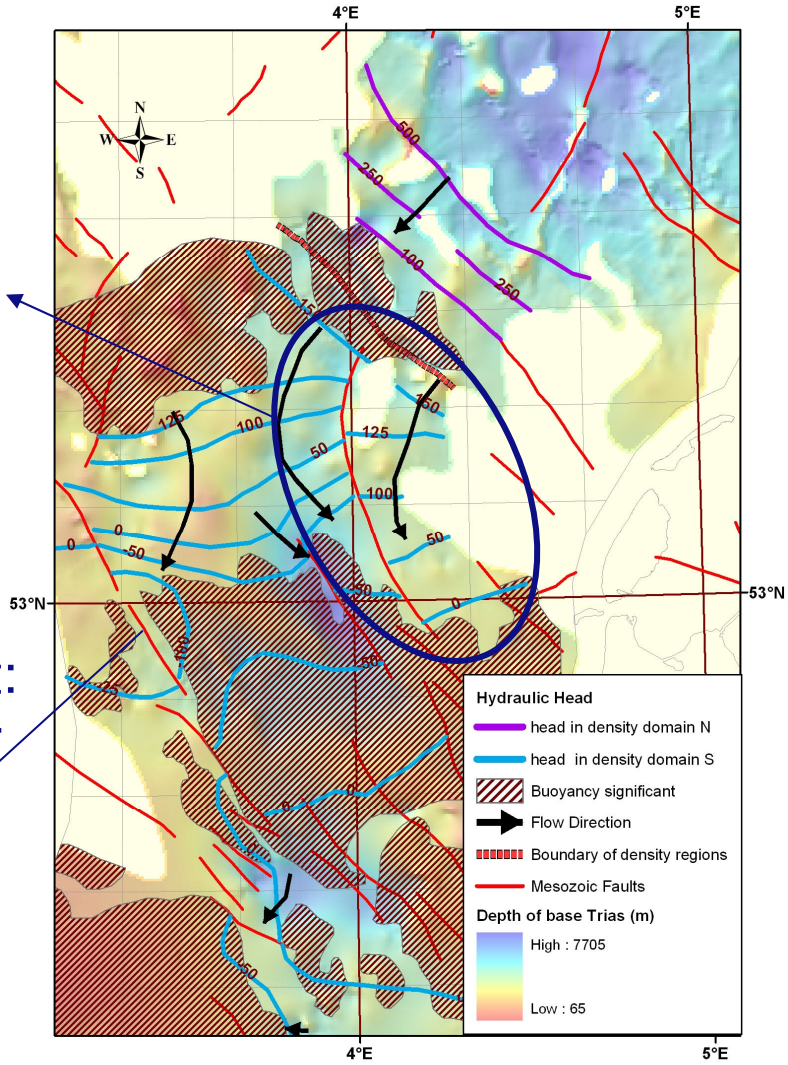
Hydraulic head Lower Triassic sandstones (southern offshore)

- Regional southward decreasing heads

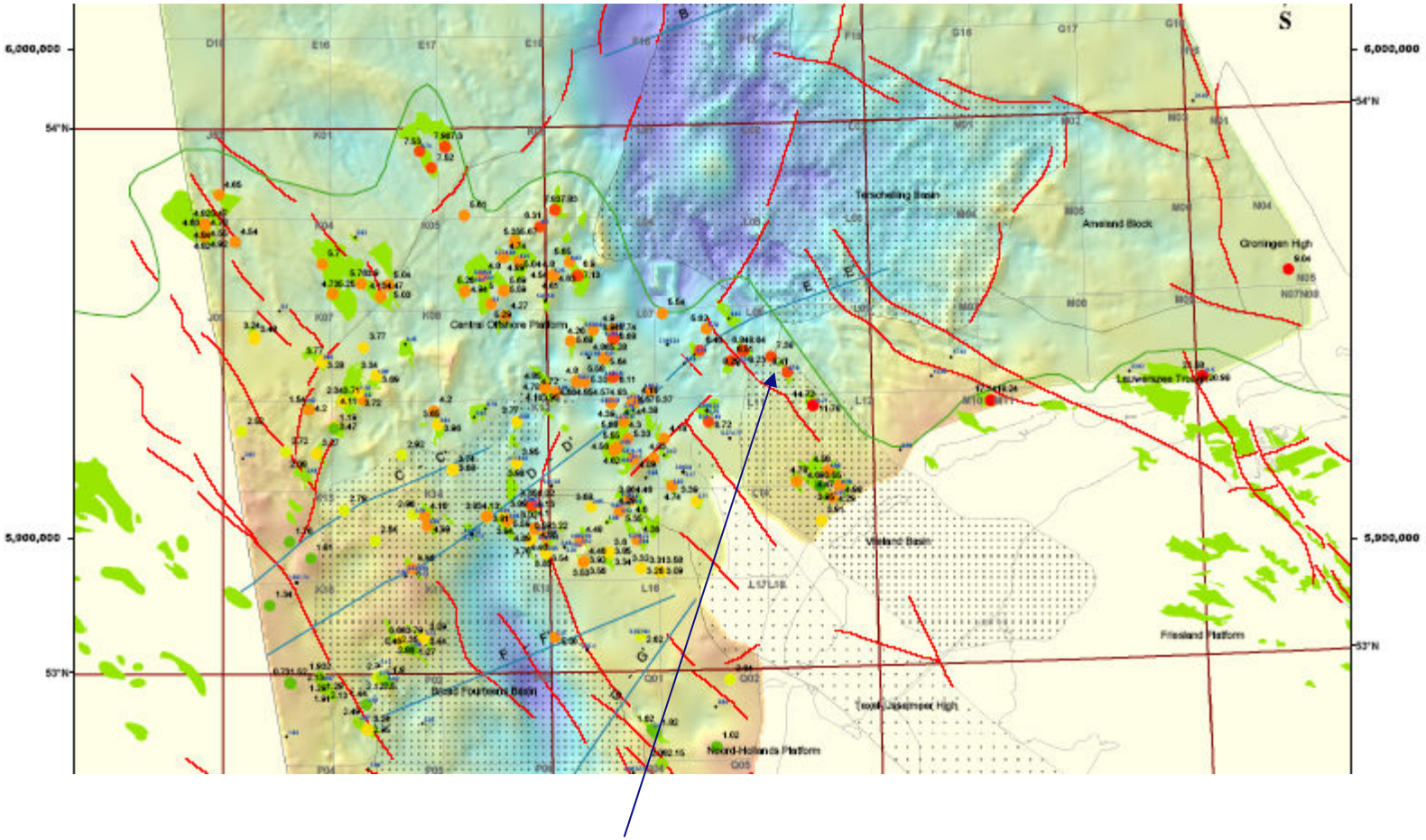
NE basin boundary fault: barrier for groundwater flow



SE basin boundary fault: dual hydraulic character



All fluid overpressures Upper Rotliegend Group

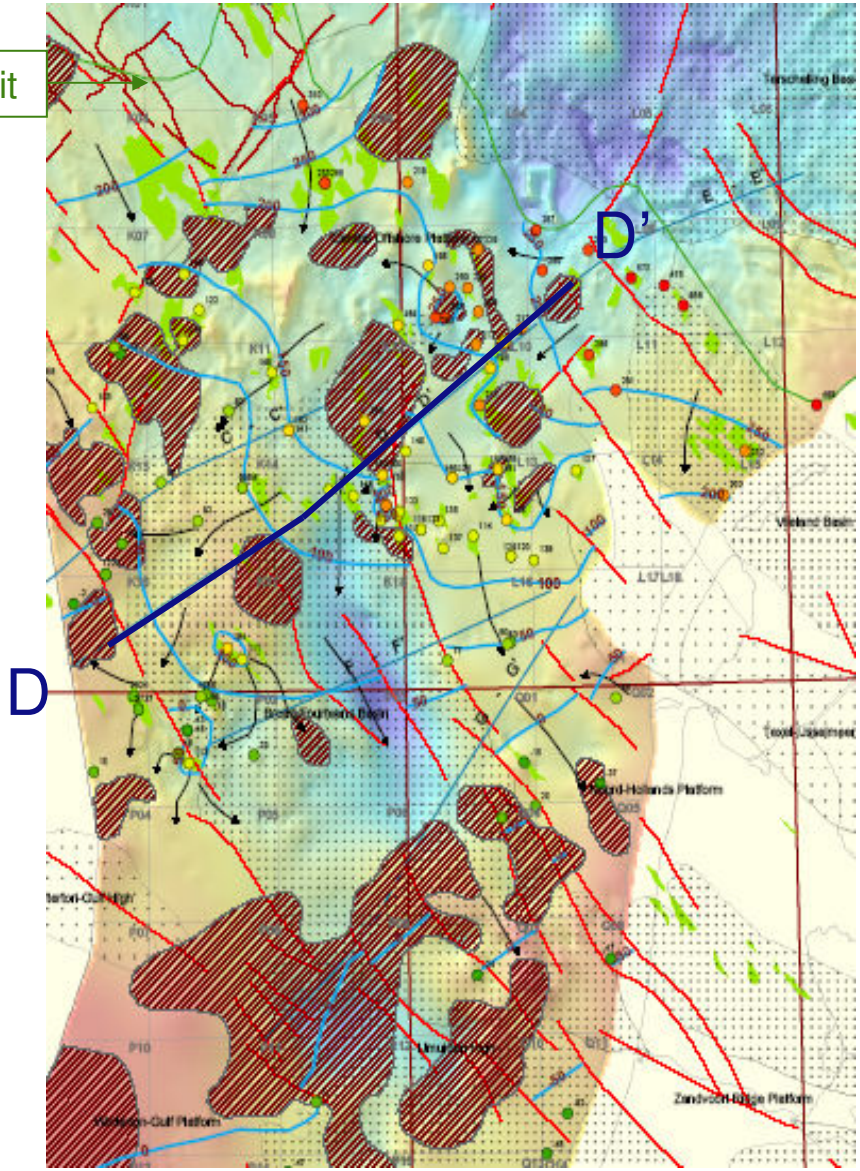


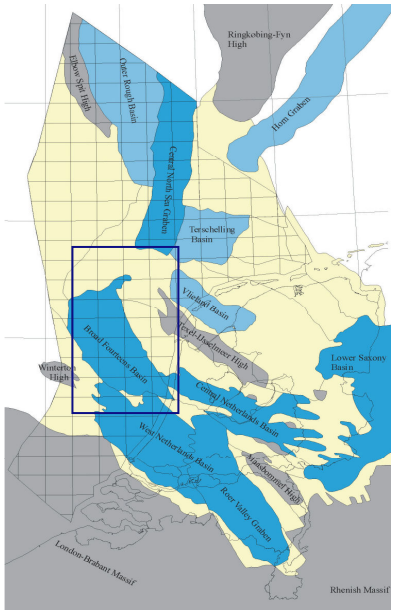
Highest overpressures along northern sand limit

Hydraulic head Upper Rotliegend sandstones

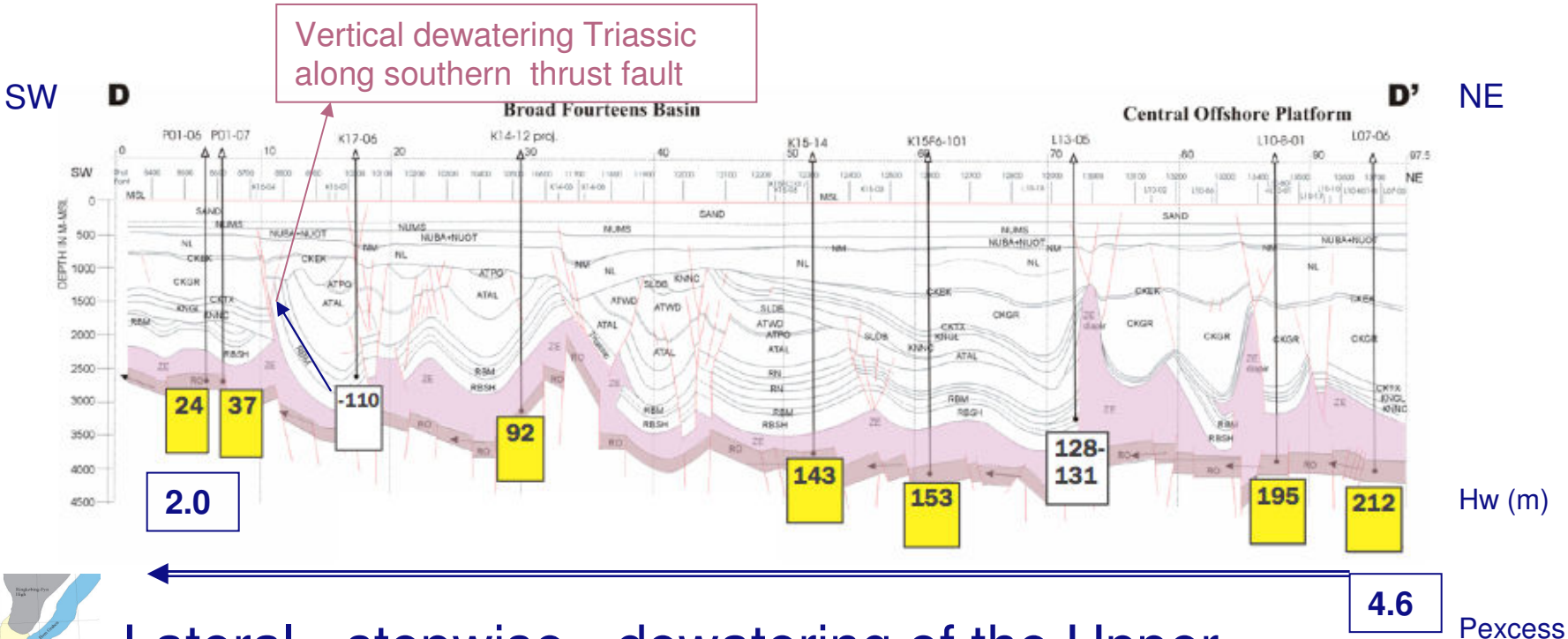
Northern sand limit

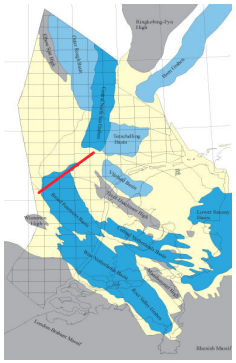
Regional southward decreasing heads in the Upper Rotliegend sandstones





Hydraulic head Upper Rotliegend sandstones





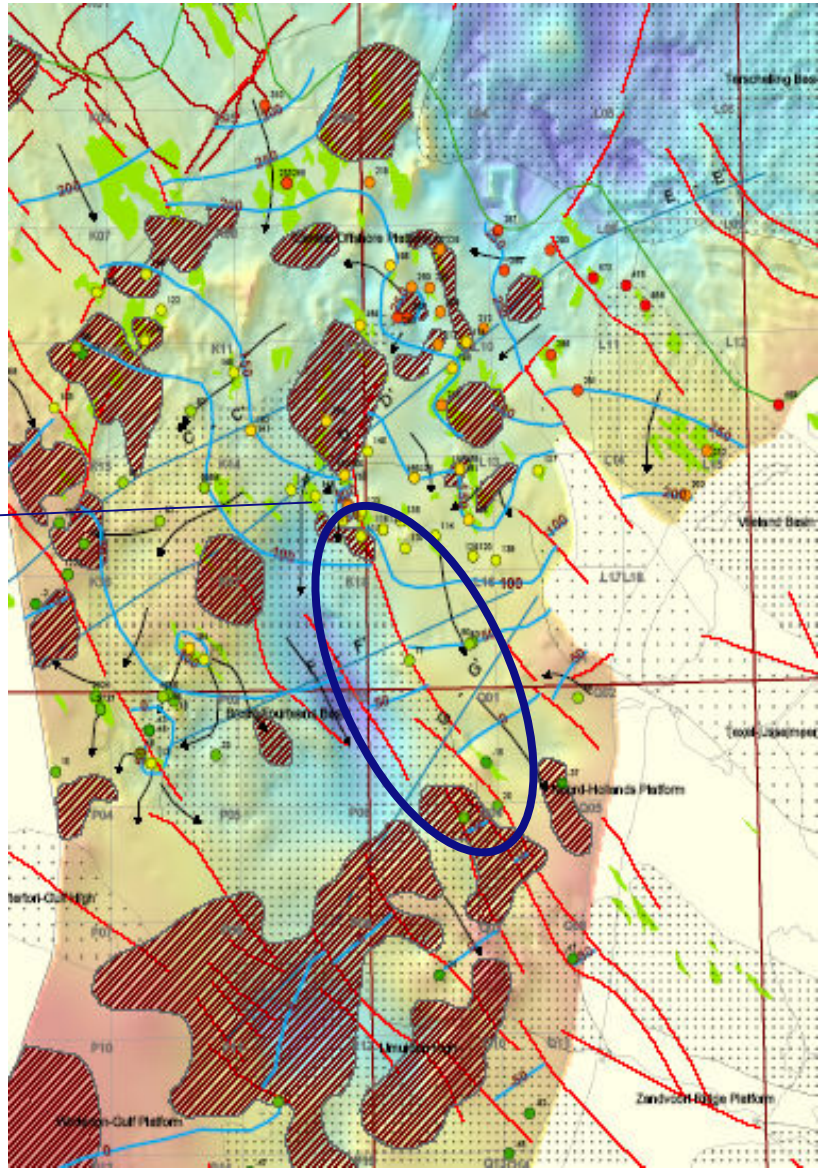
Lateral - stepwise - dewatering of the Upper Rotliegend sandstones below ZE evaporites

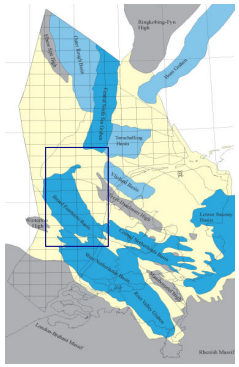
(RO in large part hydraulically continuous on geological time scales)

(Interpreted 2D seismic section from MscThesis Bouw 1999)

Hydraulic head Upper Rotliegend sandstones

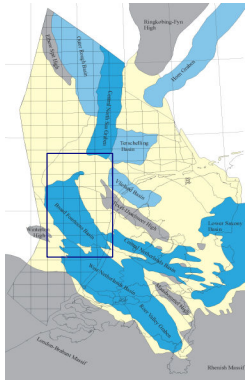
NE basin boundary fault; possible barrier for groundwater flow

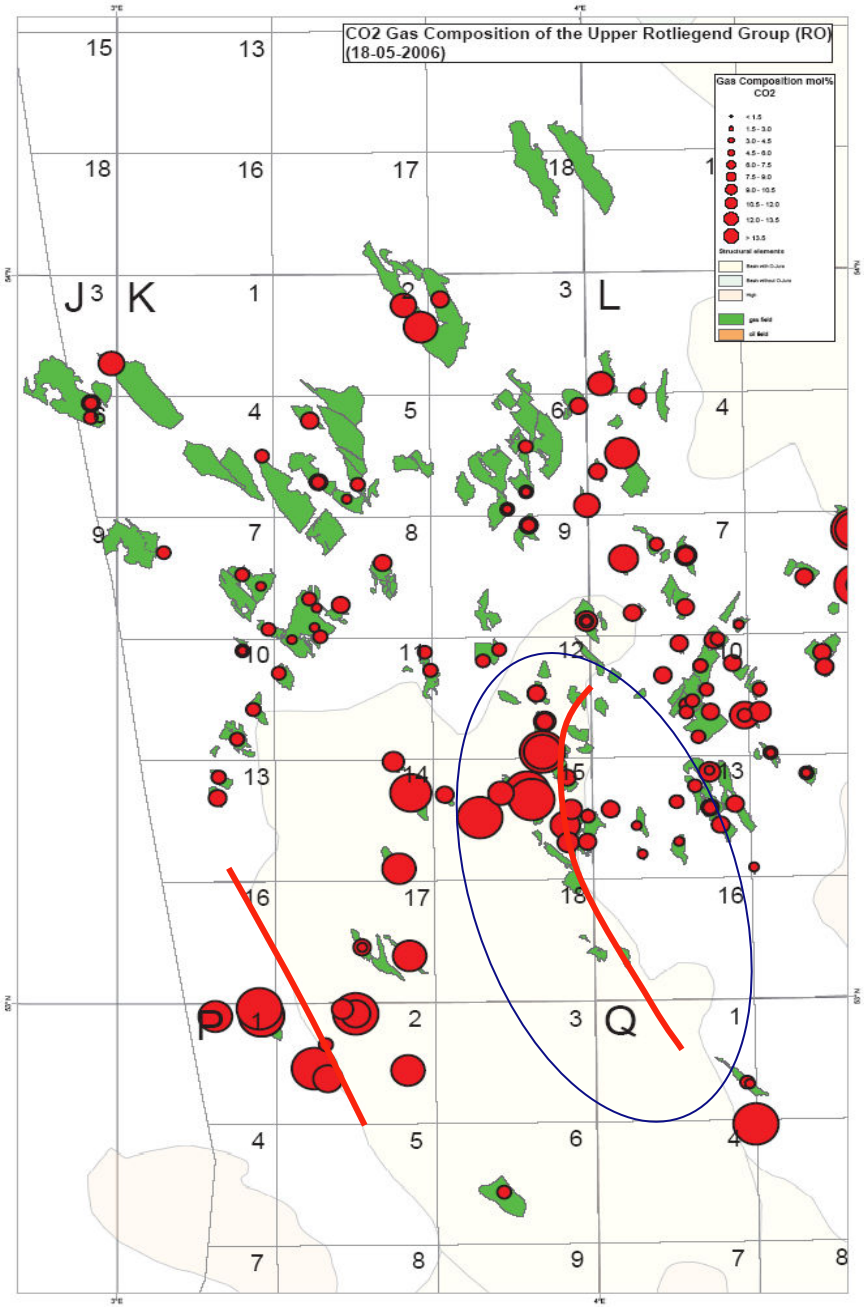




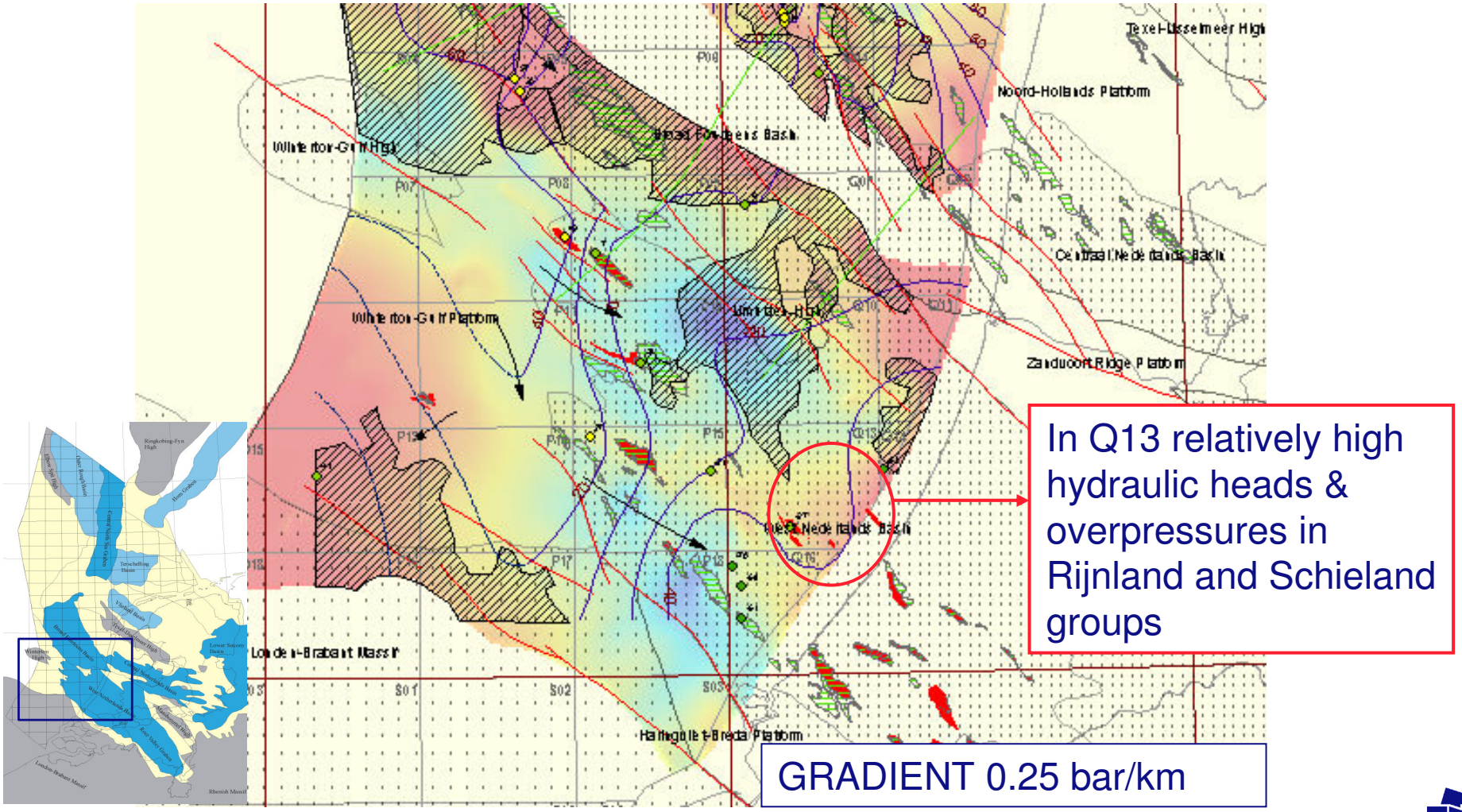
CO_2 content in natural gas accumulations in Upper Rotliegend sandstones

- NE basin boundary fault: barrier for gas migration

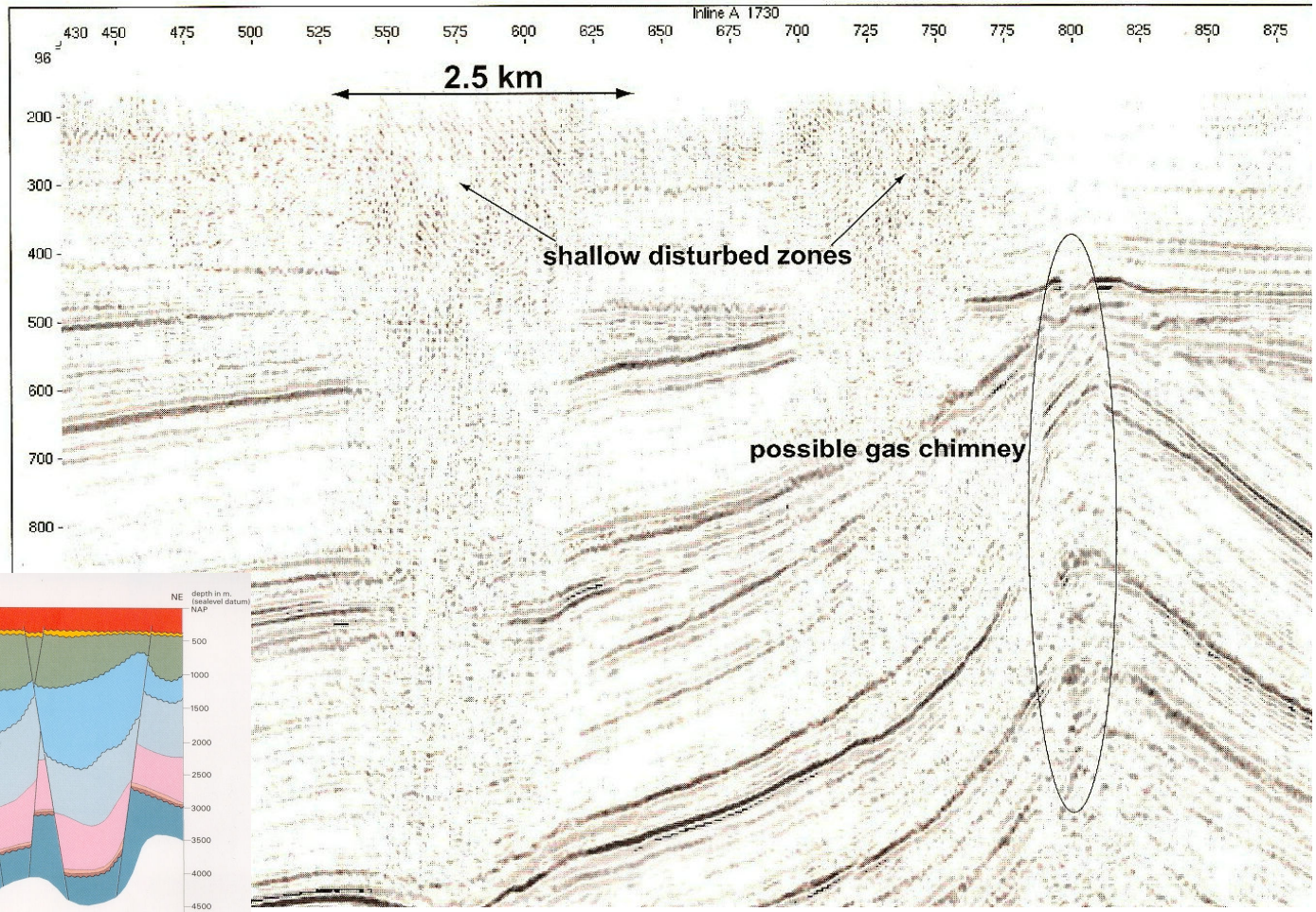




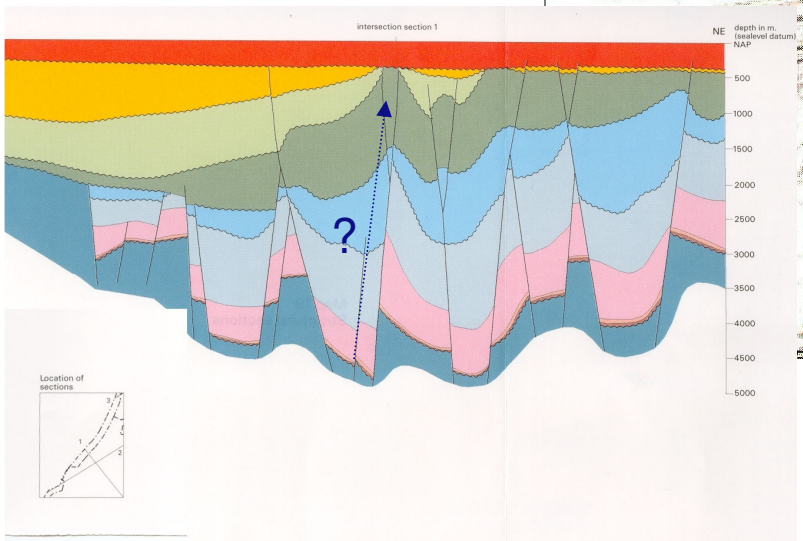
Southern area A: normally pressured
Rijnland Group: decreasing hydraulic heads towards onshore West Netherlands Basin



Possible gas chimney in block Q13



Kijkduin High



1990 3D survey block Q13

(Schroot and Schüttenhelm, NJG 2003)

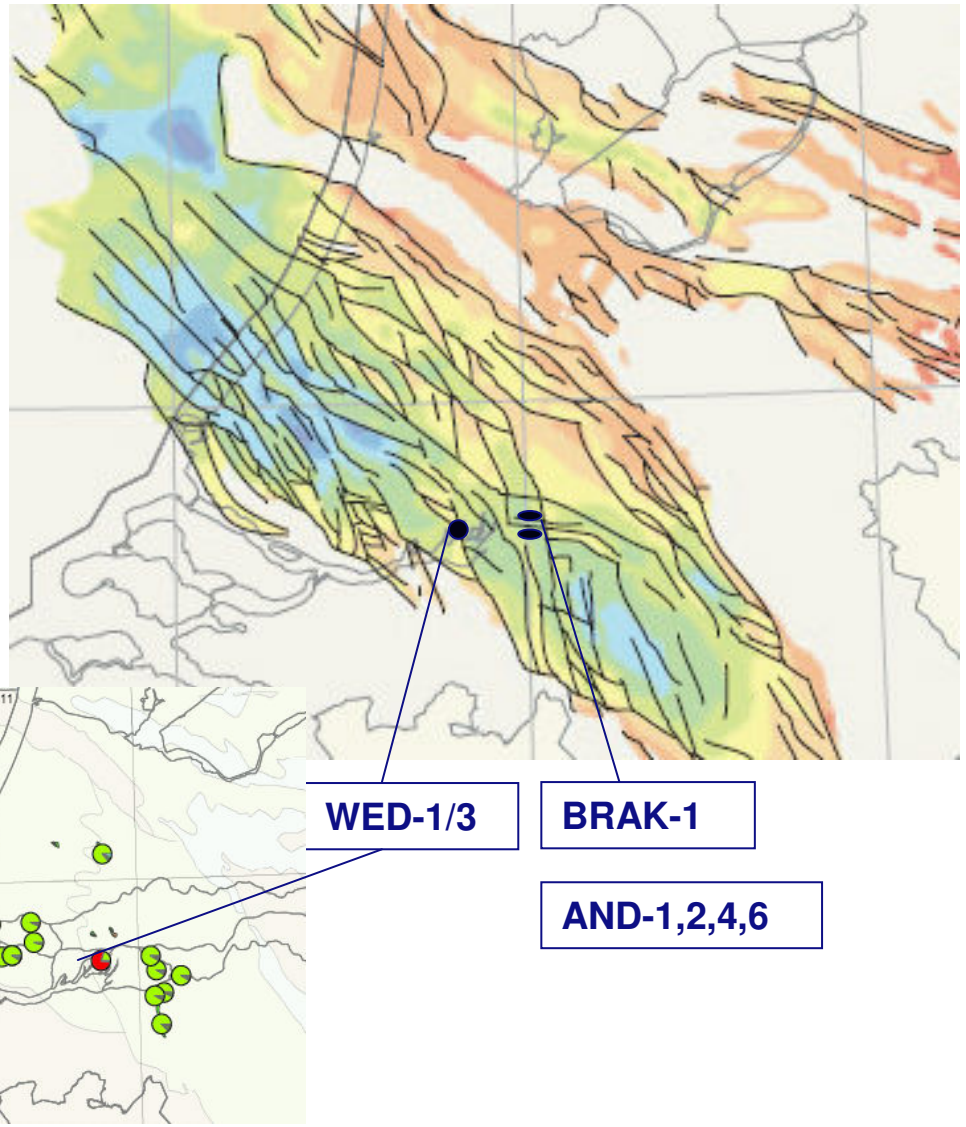
Additional present-day indicators for fault-related flow: anomalous gas compositions and temperatures

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
- $d^{13}C\text{-}CO_2$ = - 4.4 $^{o}/_{oo}$

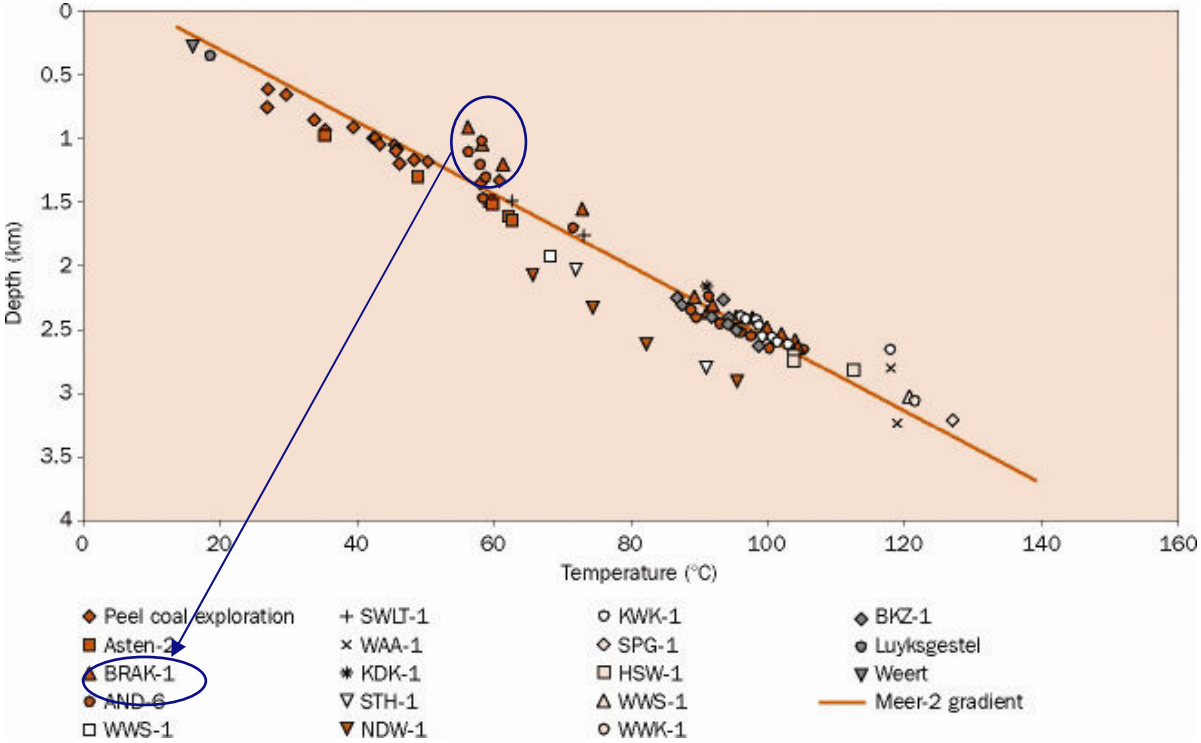
➢ **Possible deep origin CO2: thermal destruction carbonates (Dinantian Carbonates?)**

Depth map Altena FM



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



Van Balen et al 2002 ,Verweij 2003, Verweij et al. 2005; see also Luyendijk et al 2008 (submitted)

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