Presentation at Exploration Day

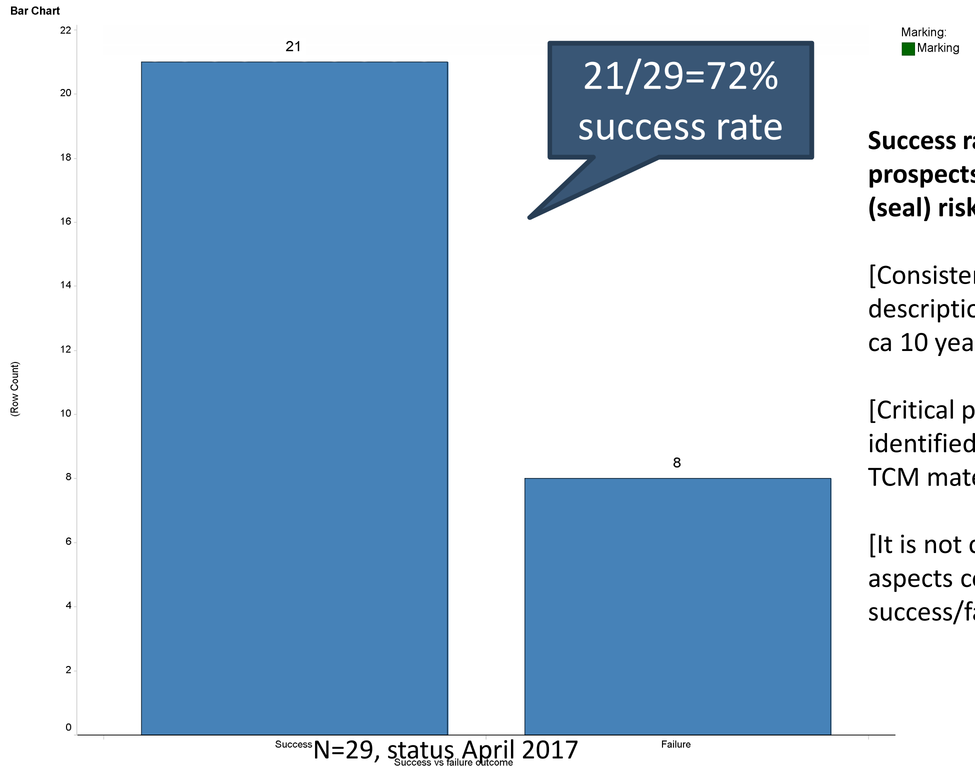
Demystification of fault sealing statements & aspects

www.ebn.nl

Why are fault properties important ?

Business case

- Compartmentalisation frequently observed, and mainly caused by the presence of faults
- A lack of understanding of the level and extend of compartmentalisation may prevent a fully optimal drainage and recovery of hydrocarbons alas **leaving value in the ground**.
- How can EBN support operators to better understand fault properties??



Success rate of drilled prospects with critical fault (seal) risk (N=29)

[Consistent prospect description documented since ca 10 years]

[Critical pre-drill fault seal risk identified after manual check of TCM materials]

[It is not clear how fault sealing aspects contributed to success/failure]

Column heights in fault-bounded traps

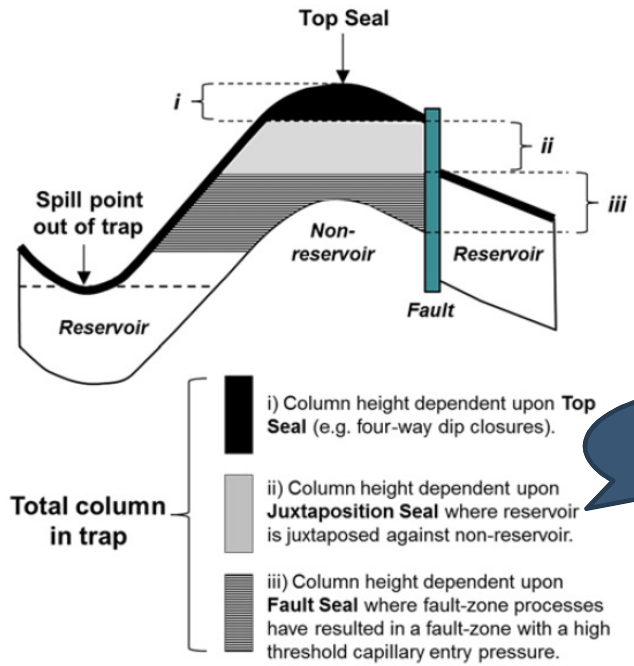


Fig. 3. Schematic cross-section (not to scale) showing the main sealing components in a fault-bounded trap. The relative position of the Juxtaposition Seal and Fault Seal components will vary along the fault surface.

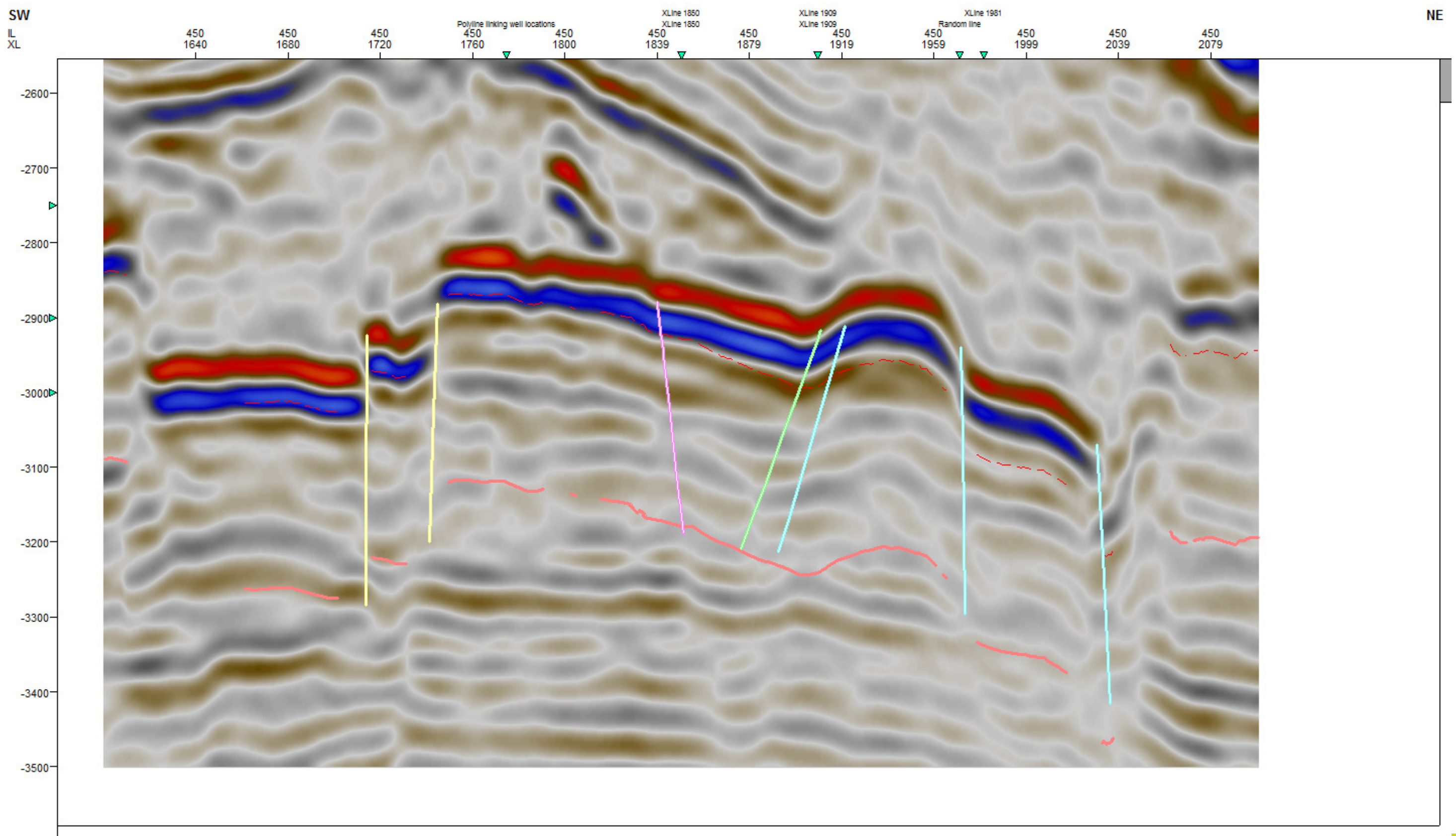
(Bretan, 2016)

- Juxtaposition seal analysis
  - E.g. Allan diagrams@, juxtaposition triangle plots
- Fault & fault seal analysis*
  - **Empirical** (e.g. methods deploying Shale Gouge Ratio (SGR), Clay Smear Potential (CSP), Capillary Entry Height (CEH))
  - Analytical (e.g. Mohr-Coulomb criterion)
  - (Semi-) Numerical (Finite Element Modelling, Discrete Element Modelling)

Myth

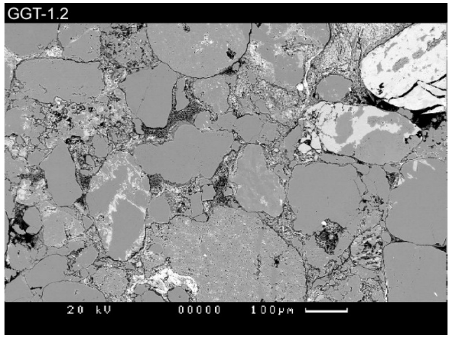
* Leakage of hydrocarbons through a water-wet fault zone occurs when the excess (buoyancy) pressure generated by the hydrocarbon column exceeds the capillary threshold pressure of the fault-zone **material**.

It’s all in the gaps !



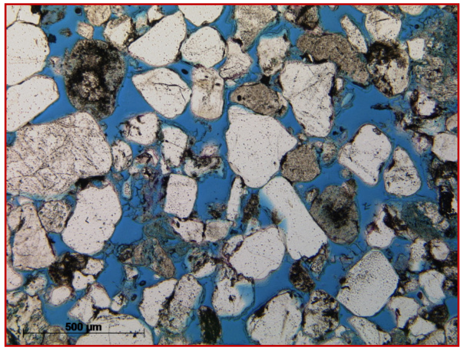
Multi-scale data (each at their resolution & length)

10^{-6} m — 10^{-3} m — 1 m — 10^{3} m — 10^{6} m



SEM

Core



Thin section

Core plug & SWS

Outcrop analogue

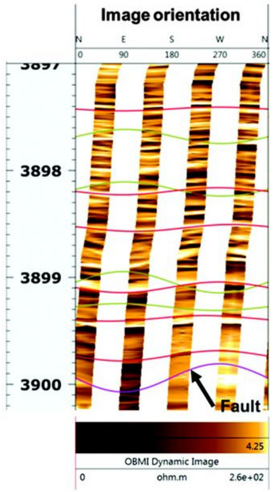
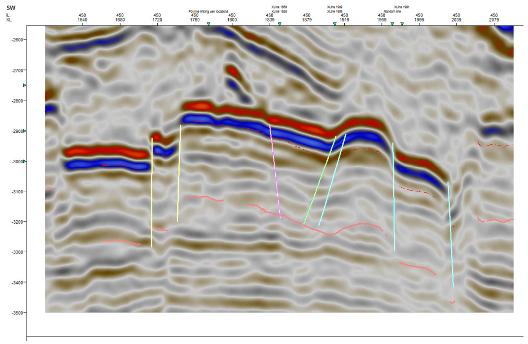
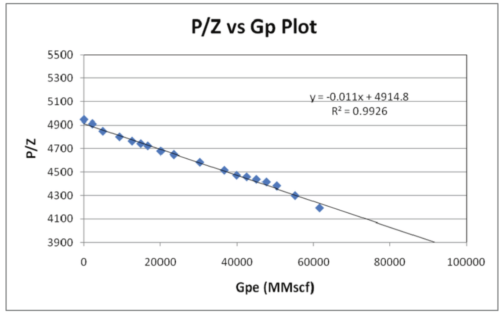


Image log & wireline



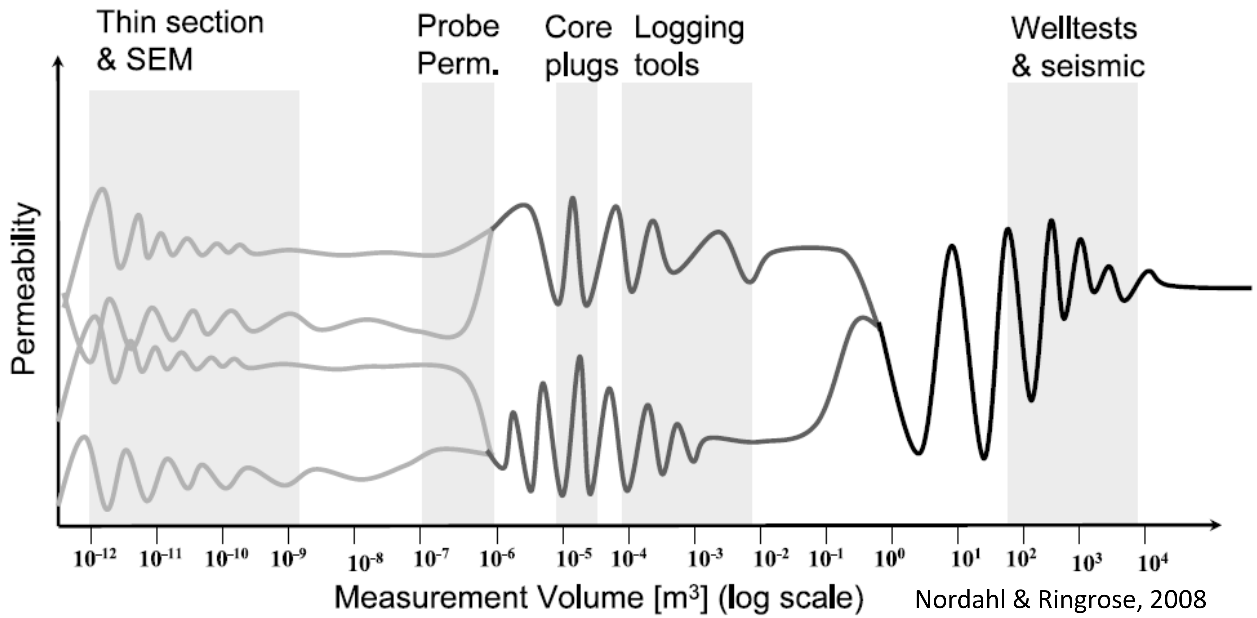
Seismic data



Material balance

Acquire – calibrate - validate

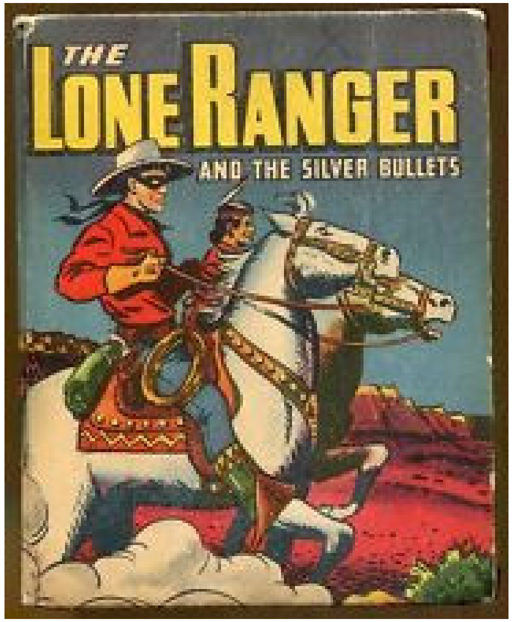
- Any (hypothetical) method used for fault seal prediction (numerical, analytical, empirical) will require
  - The ***acquisition*** of (scale-dependent) data
  - ***Calibration*** of the method against that data
  - ***Validation*** of the predictions against field data



Nordahl & Ringrose, 2008

Some pitfalls & (mis)conceptions

- No silver bullet (no simple solution)
- Abuse/misuse of terminology (e.g. juxtaposition sealing vs fault sealing)
- Oversimplification of fault geometries and relationships
- Lack of multi-disciplinary (holistic) support across all scales
- Biassed a/o dogmatic approach and application of concepts and techniques
- Lack of sensitivity/uncertainty testing → single case solutions / concepts
- Post-stamp focus
    - (focus on small field area only, not incorporating existing knowledge/data available in a larger area around the field due to lack of funding/resources/data/etc)
- Rotliegend faults dominated by cataclasis
- Public transformations in tools calibrated to clay smear dominated faults in Brent type fields and rocks, algorithms proven to be out of sync

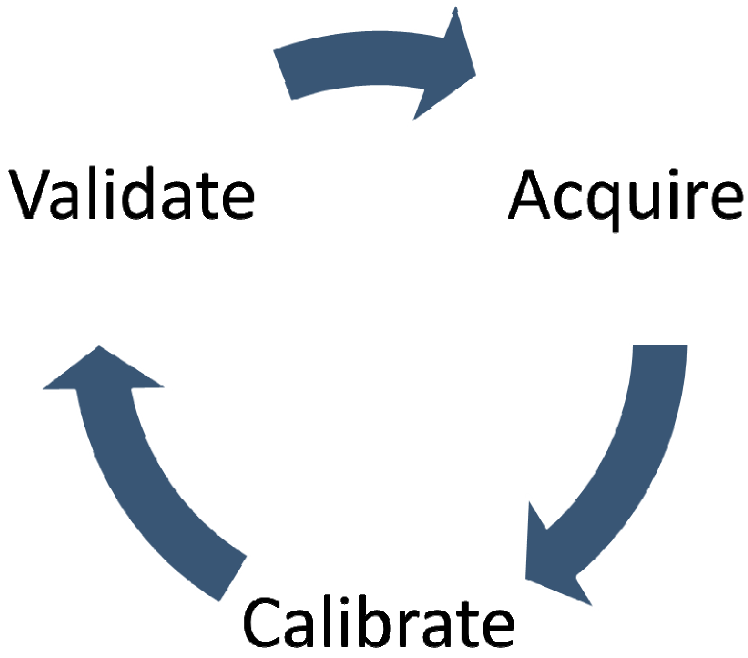


Sub-projects

Several sub-projects are now being carried out with the aim to acquire data for the calibration and validation of (empiric) transformation methods:

- **"Predict fault rock fabric based on outcrop analogues"**: this project is carried out in conjunction with the University of Strathclyde (Glasgow) and aims to characterize/predict fault fabric based on comparison to ***outcrop data***

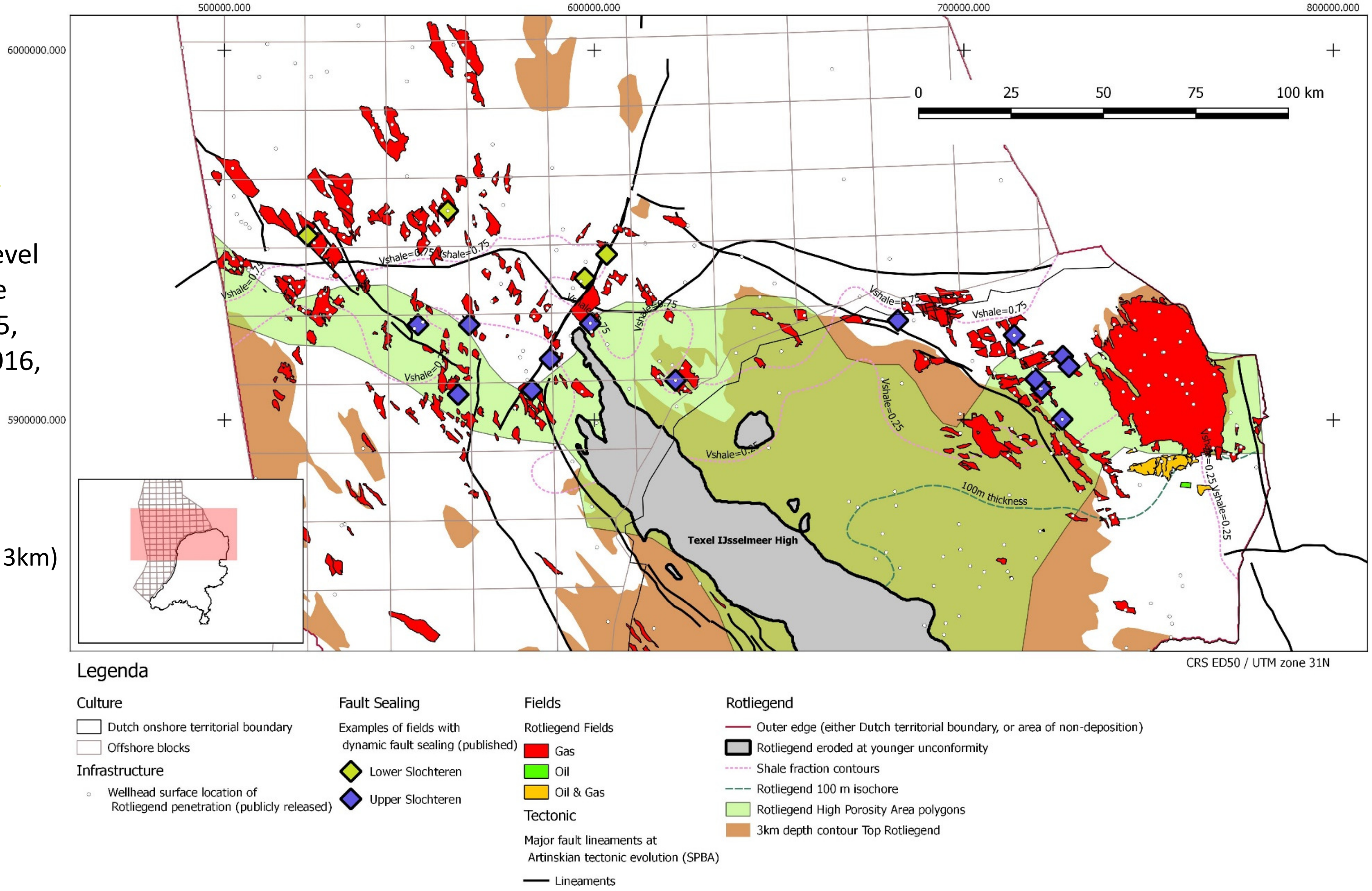
- **"Predict fault rock fabric and properties based on laboratory measurements of fault rock"**: dataset provided by University of Leeds (RDR)



Analogues

- Fault sealing occurences at Rotliegend level (many available through public literature [Corona 2005, Crouch 1996, Darnet 2015, Frikken 1996, Geiss, 2008, 2009, Gras 2016, Rijkers 2008, Strijker 2009, Weijermans 2016] etc)

- Diagnostic criteria ?
  - Present day /past burial depth (90° C ~ 3km)
  - Average porosity
  - Average Vshale content
  - Average gross thickness
  - Average sand & shale bed thickness



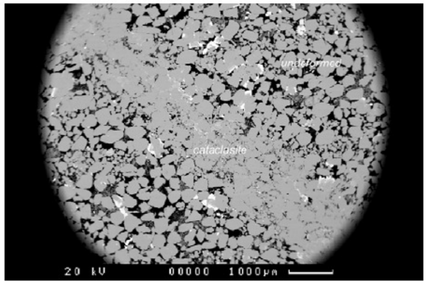
Construction of catalogue

Cataclastic fault rocks

UNIVERSITY OF LEEDS

Figure 3-1 Examples of cataclastic faults in hand specimen. Fault displacements in the mm range are evident.

Cataclastic (and cemented) fault rocks dominate deformation in the Rotliegend (Fisher et al, unpubl; Ligtenberg et al, 2011, Mauthe et al, 2003).



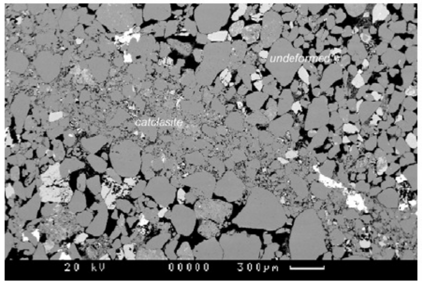


Figure 3-2 Very low magnification BSE micrograph of a cataclastic fault rock and its host sandstone. Note the reduced porosity of the fault rock relative to the undeformed sandstone.

Figure 3-3 BSE micrograph of a cataclastic fault rock and its host sandstone Note the reduced porosity of the fault rock

Cataclasite: rock type formed by progressive grain fracturing and frictional sliding of fragments

Common statement by experts: SGR algorithms are not valid for cataclastic rock

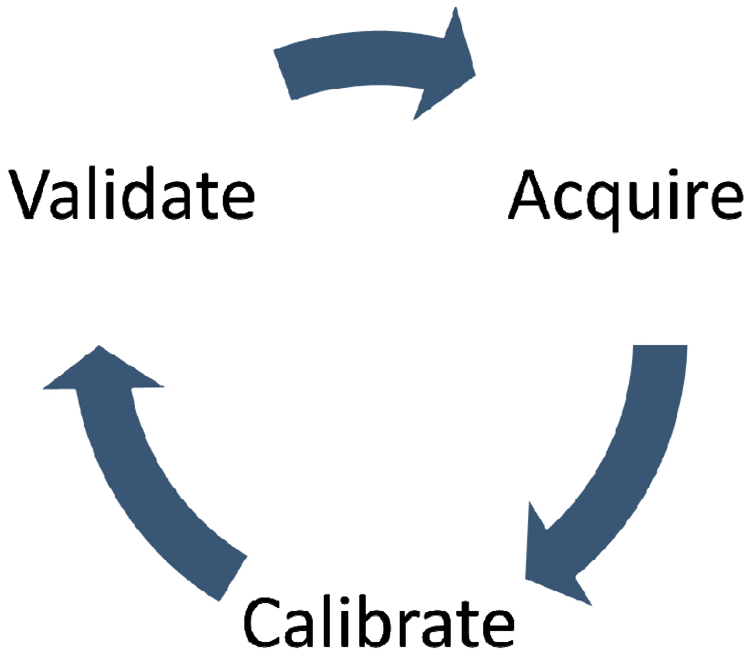
“Laboratory measurements of fault rock”

UNIVERSITY OF LEEDS

High quality (SCAL) measurements of fault rock properties (both core and outcrop) have been collected at the University of Leeds, including

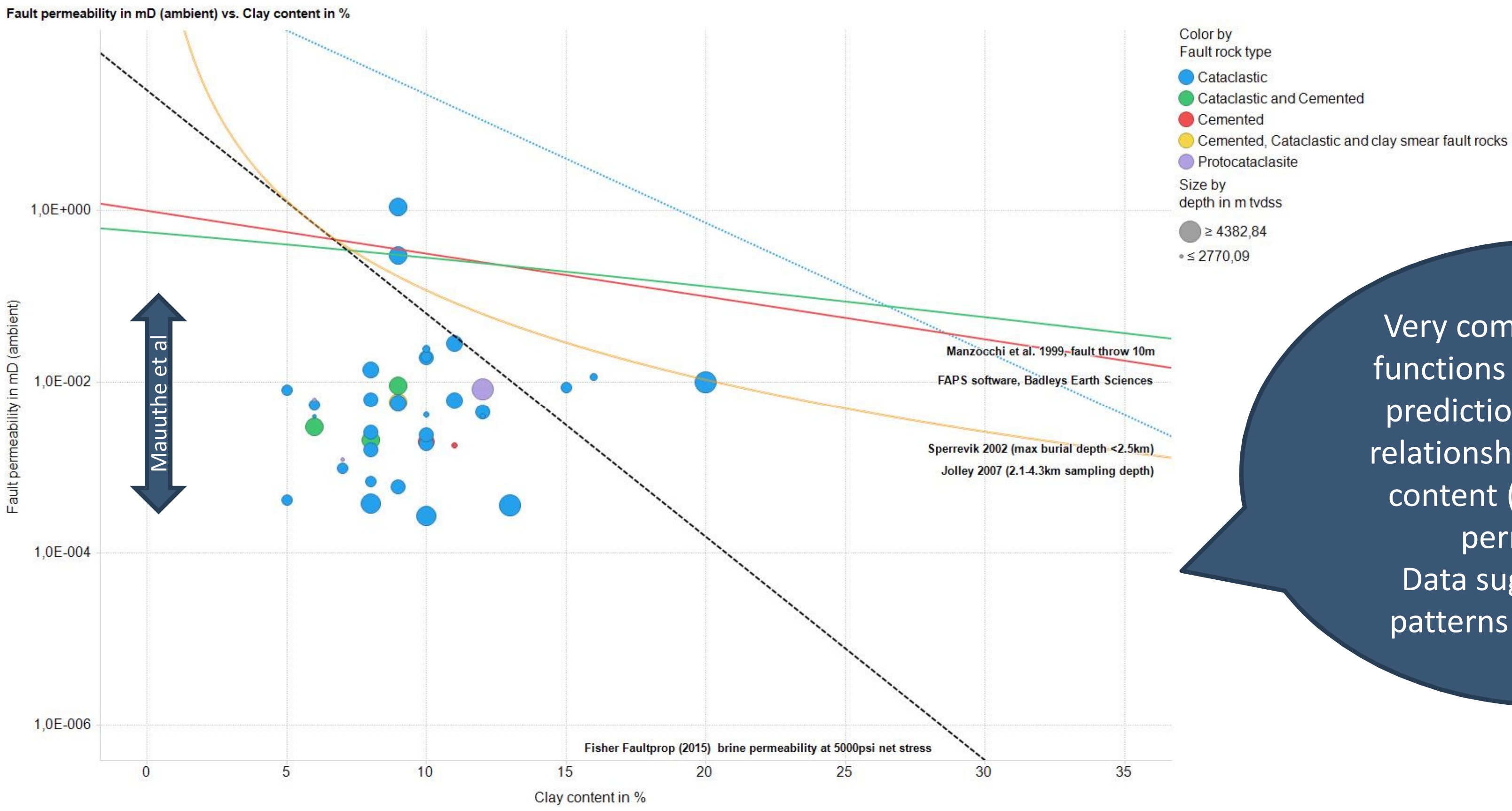
- Rock imaging (SEM)
- XRD
- He porosity en Hg injection porosimetry
- Gas and brine permeability vs confining pressure
- Relative permeability under oil/water and gas/water multi-phase flow
- Capillary entry pressure
- Etc

(Part of) this data will be publicly released (courtesy Total) and is now being investigated for raising alternative fault property transformations and functions.



“Laboratory measurements of fault rock”

UNIVERSITY OF LEEDS



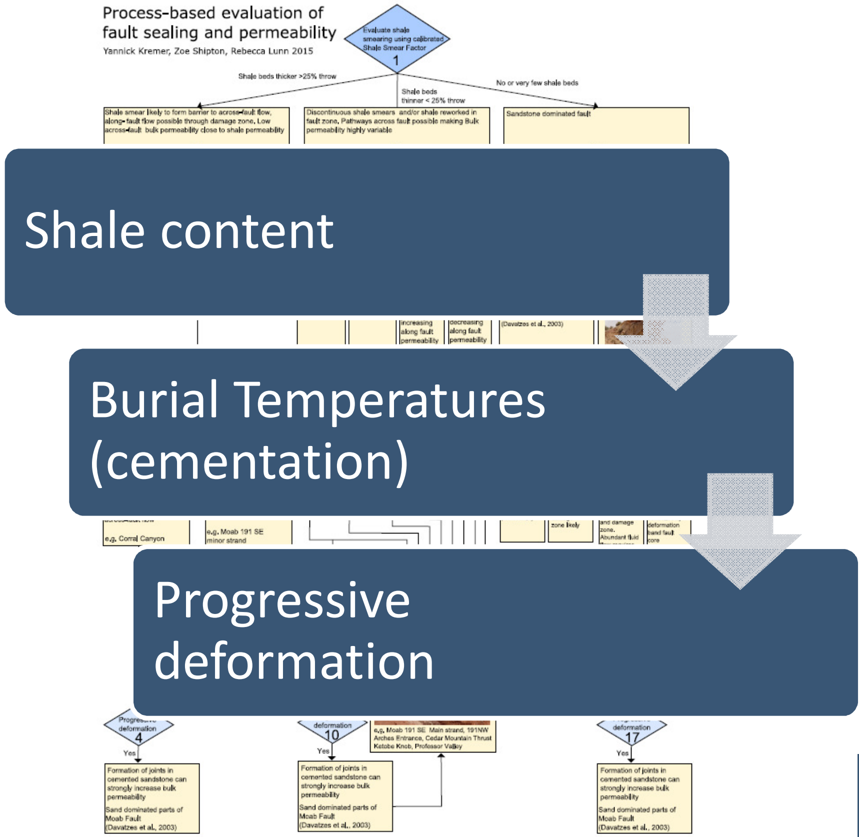
Very common workflow functions for fault sealing prediction are based on relationship between Clay content (SGR) and fault permeability.
Data suggest shotgun patterns for Rotliegend

ebn

“Predict fault rock fabric based on outcrop analogues”

- Cooperation with University of Strathclyde
- Process based workflow
  - to identify key architectures
  - to refine the prediction of fault properties.
- Based on fault outcrop data.
- Tested on actual field data using fairly simple estimates of e.g. fault throw and direction, time of deformation, average shale volume, average bed thickness, burial depth at time of deformation, possible reactivation, etc

Oct 2017 – April 2018



Goals of the project aim to support operators:

- To improve the general knowledge and understanding of fault sealing parameters in a regional context,
- To better understand fault geometries, architecture and fabric to help identifying further requirements and conditions to permeability/entry pressure modeling,
- To benchmark current (empirical) transformation and functions, and identify required improvements,
- To investigate the feasibility of improving existing / raising new empirical relationships,

Deliverables:

- Poster presentations (Fault Sealing Conference, GeolSoc, London, Exploration Day at EBN, PESGB Prospect Fair, etc)
- Catalogue of examples of proven/likely/probable examples of static/dynamic fault sealing
- Database with fault geometry properties
- Improved (calibrated) process-based classification of fault sealing (flowchart)
- Publication

Framing session

Q & A

www.ebn.nl