SINTEF Group

- **Private**
- **Independent**
- **Non-profit**

Location:  
- **Trondheim**
- **Oslo**
- **Houston**
- **Hirtshals**
- **Mo i Rana**

**SINTEF Group turnover 2001:**  
NOK 1.7 billion  
($)230 million

**1929 employees**  
(year 2001)
IKU established in Oslo

Moved to Trondheim

IKU Petroleum Research
Privatized.
SINTEF (100%) Shareholder

Changed name to SINTEF Petroleum Research

Offices in Houston, Bergen and Stavanger
Wellbore Stability and Data Acquisition in Fractured Formations

Johan Tronvoll
Research Director
SINTEF Petroleum Research
Outline

- Fractured formations
- Drilling problems in fractured rocks
- Data required to diagnose wellbore stability problems
- Tools required to diagnose wellbore stability problems
- Mudlosses as a means of reservoir characterization
- Summary
Typical fractured & fluid loss formations

- Carbonate reservoirs & large anticlines
- Formations in the vicinity of salt domes
- Specific brittle & laminated formations
- Fault zones
- High permeability channel sands
- …
Drilling problems

- Mudlosses limits mudweight
- Too low mudweight or severe mudlosses may induce kicks
- Kicks may result in loss of hydrostatic head, poor hole cleaning and wellbore instabilities
- Weighing up of mud may result into further losses
- LCM may harm fracture conductivity in productive layers
Data to diagnose wellbore instabilities

- Rock mechanical data
  - Stresses (density log, LOT, ELOT, Minifracs) – may be difficult to obtain
  - Rock strength & stiffness (MWD/LWD, cuttings & cavings, cores)

- Formation porosity, permeability & mineralogy
  (MWD/LWD, cuttings & cavings, cores)

- Mud chemistry & temperature

- Downhole P, T

- Well orientation & architecture
Tools to analyze wellbore instabilities

- Formation strength
  - FORMEL, LMP
  - Shale database -ShaCal, rock strength database
- Wellbore collapse
  - PSI, FEM analysis, empirical models
- Pore pressure
  - Basin modeling – PRESSIM
  - Seismic modeling
  - NMR
- Mudlosses
  - 2D analytical fracture model
- Wellbore dynamics
  - Kick simulator, hole cleaning simulator
Geomechanical Data
- from cores

Continuous SCRATCH measurements
- on a real layered core material

Geomechanical Data
- from cores

Continuous SCRATCH measurements
- on a real layered core material
Geomechanical Data
- from cuttings and debris

SAMSS tool for measuring strength and stiffness -

CWT tool for measuring sound velocity -

- on mm size samples
Geomechanical Data
- from downhole measurements

FORMEL and LMP  ➔  Strength and Stiffness from well logs

Simulates rock mechanical test on fictitious core

Correlations for shales  ➔  Strength and Stiffness from sonic logs
Wellbore Stability
Stability problems in shales during drilling

Modelling of operable Mud-Weight Window

Time-Delayed Instabilities

Mud Chemistry Effects
Stable wall at 3.0 mm

Well Pressure: 16.5 MPa

Formation Properties
UnConfined Strength: 15.00 MPa

Mudweight window at depth 1700 m
- Mudweight window: 1.50 sg (25.0 MPa) - due to tensile failure
- Shear failure limit: 1.08 sg (18.1 MPa) - due to shear failure

Units: SI

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Stability Chart

Time since drilling: 1 day
Depth of investigation: 3.0 mm

Well Pressure: 16.0 MPa

Unstable wall at 3.0 mm

Formation Properties
UnConfined Strength: 15.00 MPa

Mudweight window at depth 1700 m

- Mudweight window
- Fracture gradient
- Shear failure
- Tensile failure

For stable well (at 1700 m):
- Lower limit: 1.08 sg (18.1 MPa) - due to shear failure
- Upper limit: 1.54 sg (25.7 MPa) - due to tensile failure

Fracture gradient: 1.50 sg (25.0 MPa)

Units: Oilfield, SI
**Preventing Shale Instabilities**

**Output Options**
- MW: Mudweight Window
- BX: Borehole X-section
- ST: Stability vs Time

**Auxiliary Parameters**

**Input data**
- Wellbore Data:
  - Inclination: 20 degrees
- Formation Conditions:
  - Pore Pressure: 20 MPa
- Formation Properties:
  - Weak Plane Strength (rel.): 0.500

**Mudweight window at depth 1700 m**

- Mudweight window
- Fracture gradient
- Shear failure
- Tensile failure

**Limits for stable well (at 1700 m):**
- Lower limit: 1.25 sg (20.9 MPa) - due to shear failure
- Upper limit: 1.54 sg (25.7 MPa) - due to tensile failure

**Warning:** Fracture gradient = 1.50 sg (25.0 MPa)

**Units:**
- Oilfield
- SI
Stability Chart

Well Pressure: 18.5 MPa

Unstable wall at 3.0 mm

In situ stresses:
- \( \sigma_v \)
- \( \sigma_h \)

Formation Properties
- Weak Plane Strength (rel.): 0.500

Mudweight window at depth 1700 m:
- Mudweight window
- Fracture gradient
- Shear failure
- Tensile failure

For stable well (at 1700 m):
- Fracture limit: 1.25 sg (20.9 MPa) - due to shear failure
- Fracture limit: 1.54 sg (25.7 MPa) - due to tensile failure

Fracture gradient: Fracture gradient = 1.50 sg (25.0 MPa)
Well Pressure 16.0 MPa

Unstable wall at 3.0 mm

Formal Properties
Weak Plane Strength (rel.) 0.500

For stable well (at 1700 m):
Tensile limit: 1.54 sg (25.7 MPa) - due to tensile failure
Shear failure limit: 1.25 sg (20.9 MPa) - due to shear failure
Fracture gradient: Fracture gradient = 1.50 sg (25.0 MPa)
Modeling of fracture growth in hollow cylinder tests with boundary-element code DIGS
How can mud loss be monitored?

Electromagnetic flowmeter
Resolution 10 l/min

www.geolog.it
Mud loss measurements

Mud loss dynamics in fractured rock
(Beda & Carugo 2001)
Why mud loss should be modeled?

- More efficient handling of mud loss problems during drilling
- Formation characterization based on mud loss measurements
Key industrial benefits:

1. Information on reservoir properties is gathered 'accidentally' during normal drilling operation.

2. Rock is characterized in situ.

3. Properties can be evaluated that are difficult to obtain from cores (e.g. fracture properties).
Analytical mud loss model
Mud Loss into a Single Fracture

SINTEF Mud Loss Demo
Summary

- Fractured formations require understanding of the complexity of the well & formation dynamics
- Unconventional data acquisition is needed
- Models have to be flexible in terms of input data – most classical models are too ‘rigid’
- Mudlosses or influx during drilling may be modeled to diagnose wellbore instabilities or as a reservoir characterization method
- A lot of R&D is ongoing – more field data required