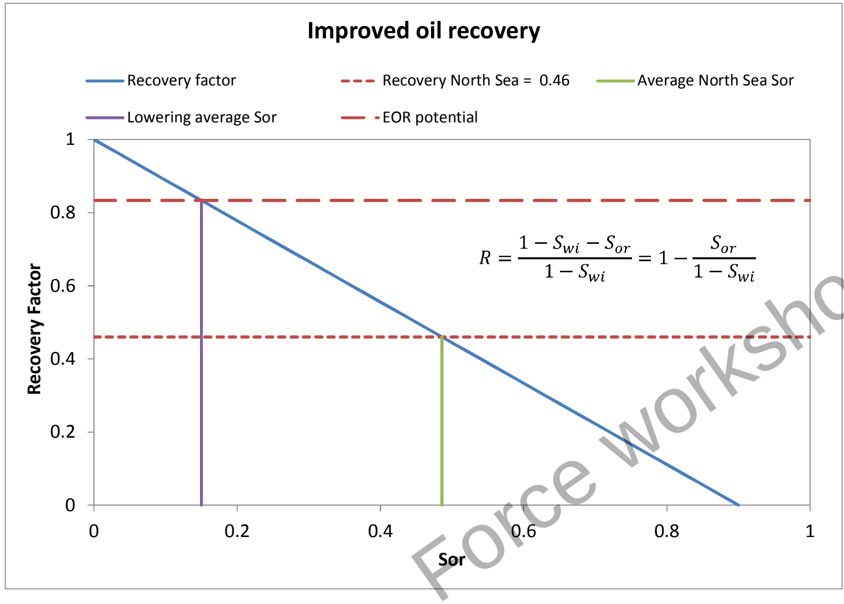
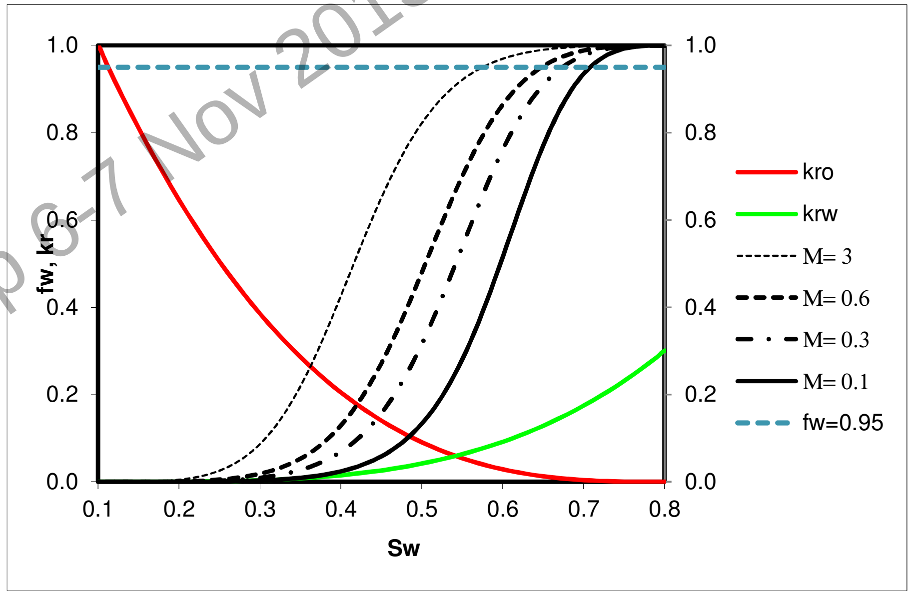
Flow diversion mechanisms, main types of diversion chemicals, laboratory testing Snorre

FORCE 06.11.13

IRIS

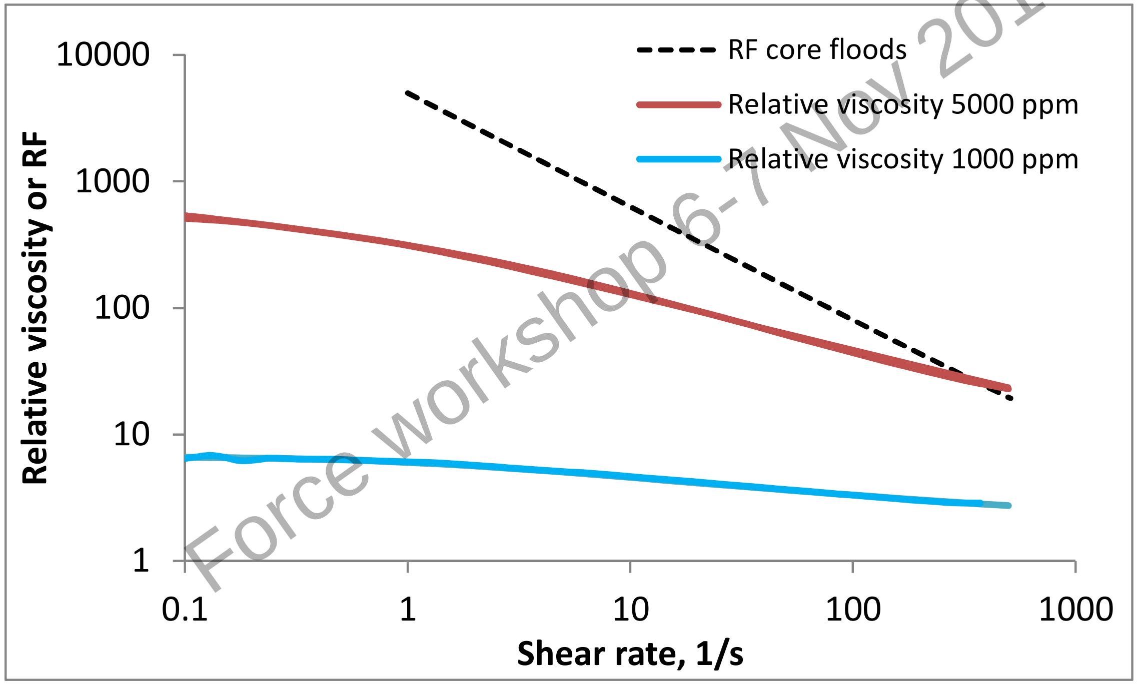
Sweep efficiency





- Large EOR potential by improving the sweep efficiency which can be exploited by mobility control
  - Increasing the water viscosity
  - Decreasing the water permeability
  - Flow diversion by decreasing flow through high permeability streaks

Mobility control



SPE 165225, Reichenbach-Klinke

- For some polymers, mobility reduction can be substansial, even at low polymer concentration

In-depth plugging

IRIS

- No need for in-depth plugging if layers are isolated – low cost near wellbore blocking will work
- In-depth plugging if communications between layers – fomation of barriers will improve the sweep
- Volume, cost and complexicity increases by depth
- Some critical parameters
  - Good injectivity
  - Delayed and controlled plugging – mechanisms for activations
  - Fluid-fluid and fluid-rock interactions
  - Gelation models to match lab scale bulk and flood experiments and up-scaling to field scale

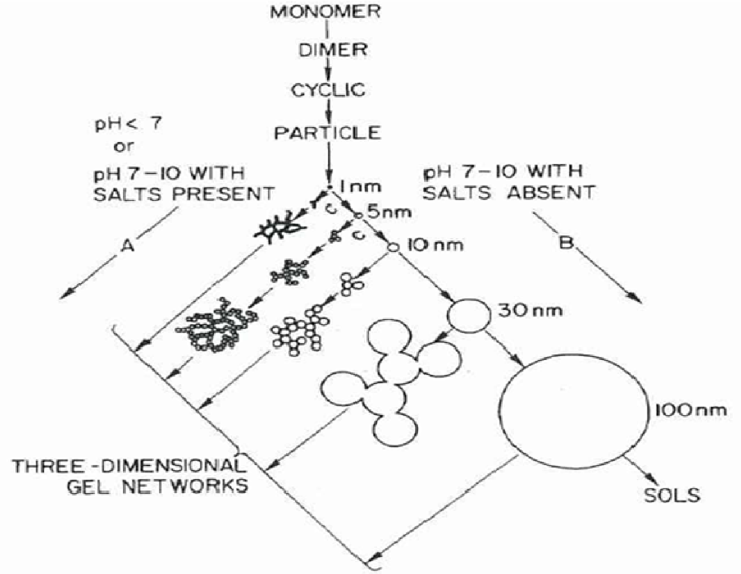
In-depth plugging

IRIS

- Deep diverting gel – Delayed crosslinked gel
  - Al-citrate as crosslinker → LPS
- Temperature triggered plugging → Bright water
- Alkaline sodium silicate
  - Pre Lowsal – Offshore alkaline flooding was no option due to incompatibility due to precipitation in seawater and no available sources for soft water
  - Post Lowsal – Injection of soft water is possible and may even be attractive
  - Alkaline sodium silicate after a soft water preflush is an environmental attractive in-depth alternative

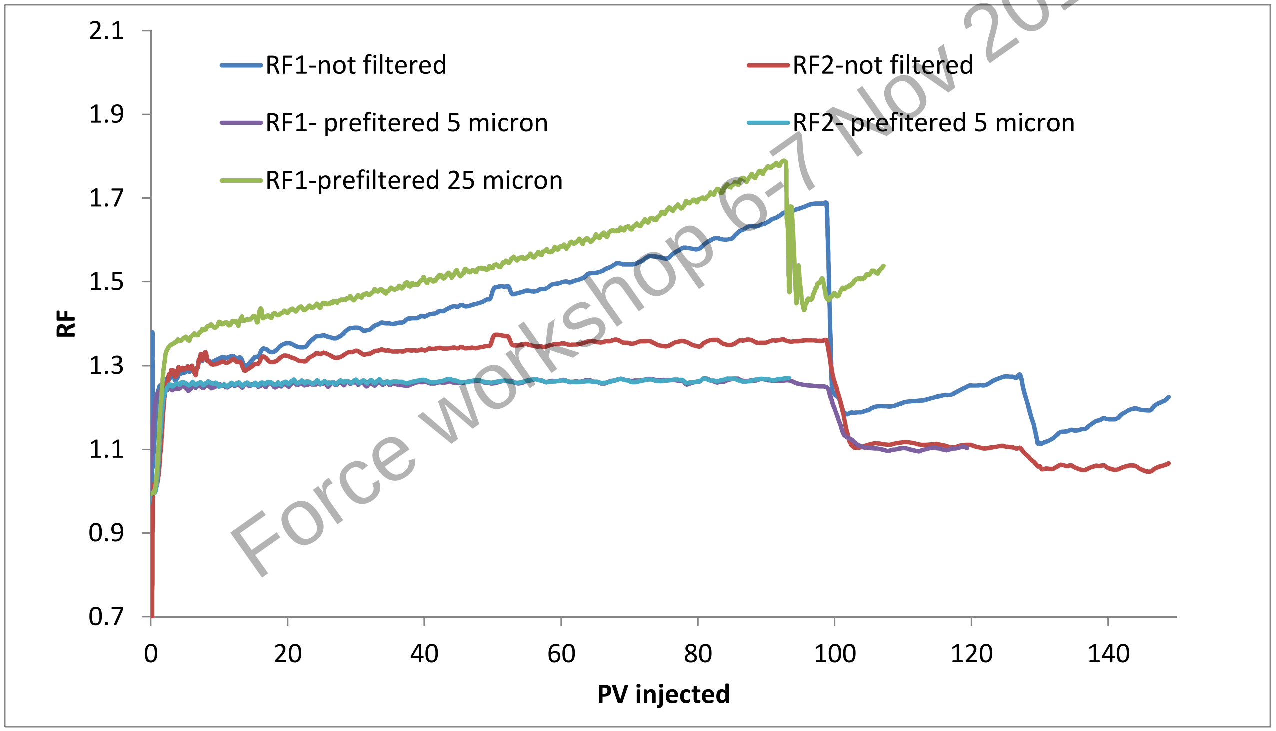
Alkaline sodium silicate

- Conformance control method for more than 90 years
- Water like viscosity
- Gelation activated by suitable activators, such as acid and temperature
- Sodium silicate flexibilibility $(SiO_2)_n:(Na_2O)$
  - Si to Na ratio controls the alkalinity, gelation type etc.
- Gelation can be understood by aggregate formation from nano scale to micro- and macro-scale
- Plugging of porous media either by in-situ gelation or by filtration of micro-size aggregates



Sodium silicate injectivity

IRIS

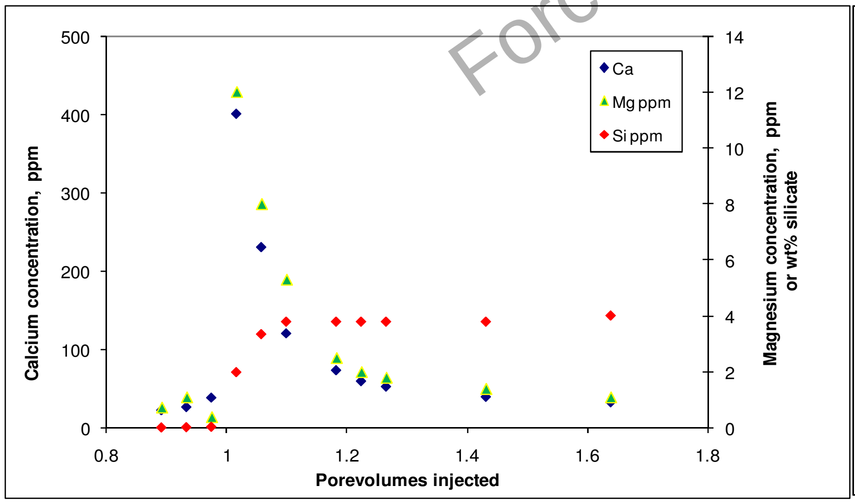


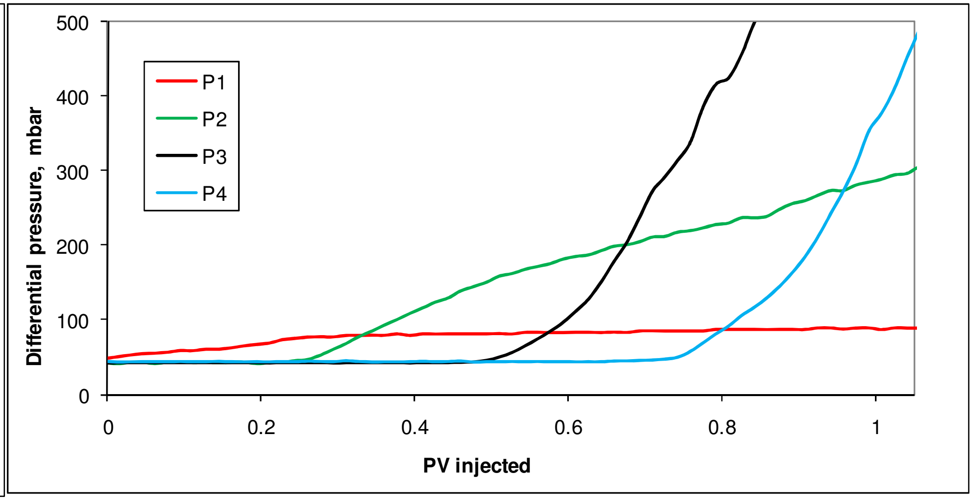
- Diluted sodium silicate injected through Berea cores (R ~5 μm)
  - Pressure increase in front core if filter size > pore size

Effect of preflush

IRIS

- Soften the formation water and cation exchange (CEC)
- Example – Tap water (20 ppm Ca) preflush
  - High concentration Ca bank due to ion exchange
  - Combination of Ca-silicate precipitate and rapid gelation
  - Plugging time in porous media more rapid than bulk gelation time
  - With NaCl/KCl preflush, no Ca bank and plugging time in porous media similar to bulk gelation time





SPE 143836 Stavland et al.

Effect of soft water preslug

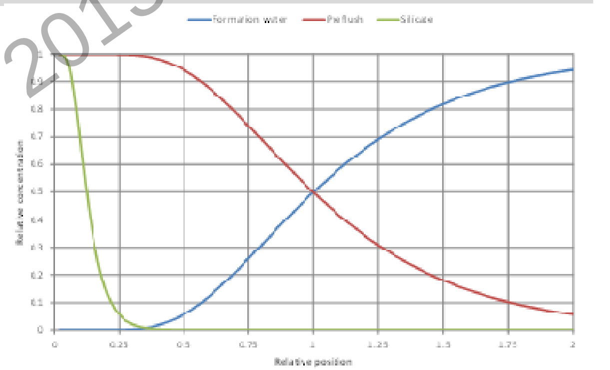
- Close to injector
  - Formation water effectively displaced by soft water
  - No risk of hard water and silicate mixing
  - Silicate injectivity is good and retention is low
- Deeper into the formation
  - Risk of hard water and silicate mixing (10%)
  - Some reduction in injectivity and increased retention
- Deep into the formation
  - Severe risk of hard water and silicate mixing
  - Permeability reduction and retention increases
  - Precipitation of divalent ions, fronts sharpen

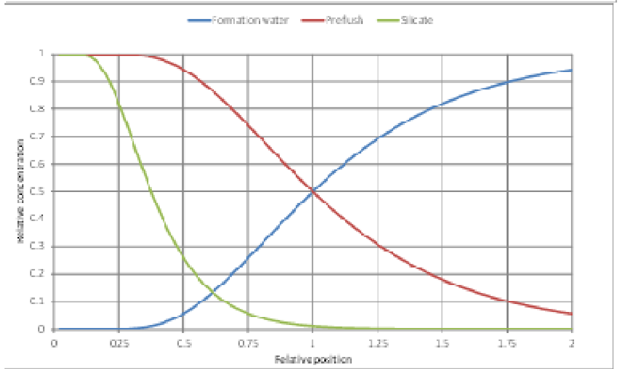
Depth is here controlled by preflush volume and dispersion

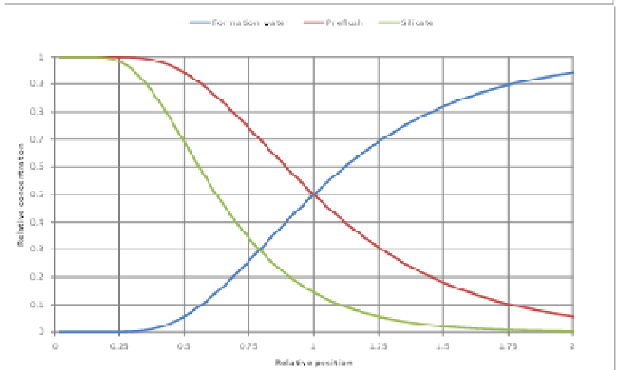
Cation exchange

K – Ca, Mg, … at Preflush/FW mixing front

Na – K at Silicate/Preflush mixing front

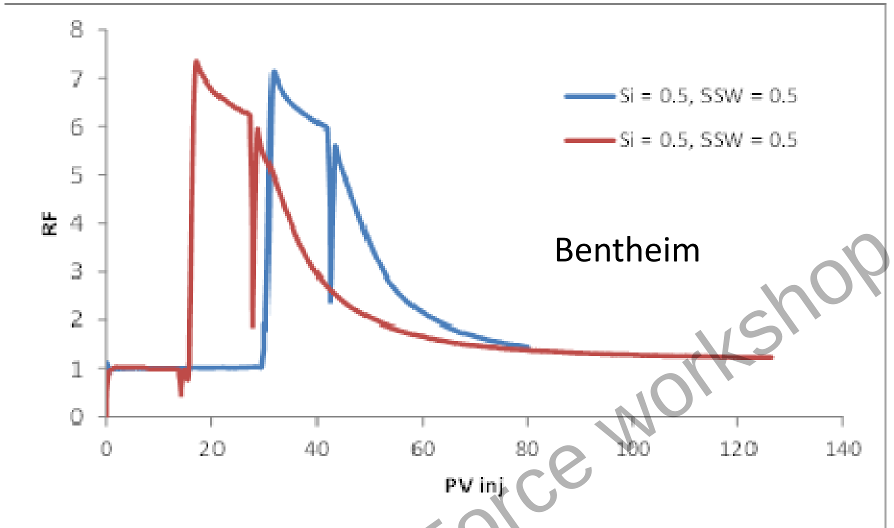


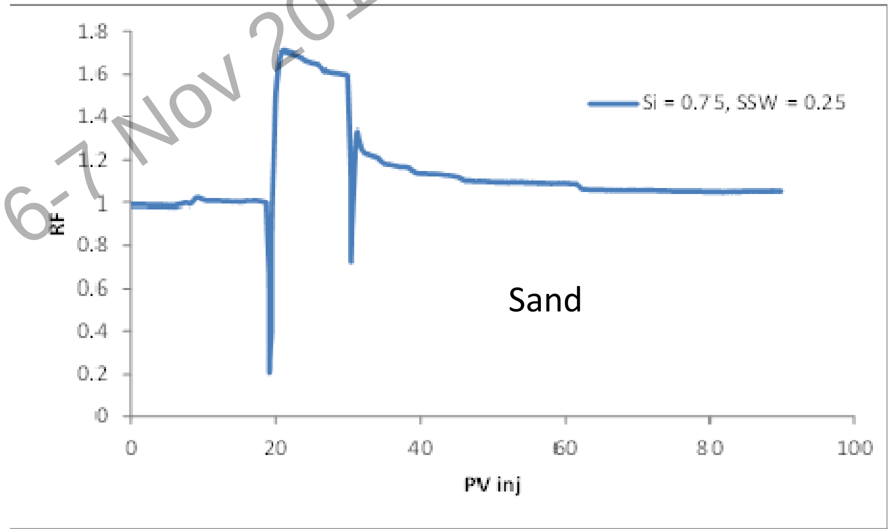


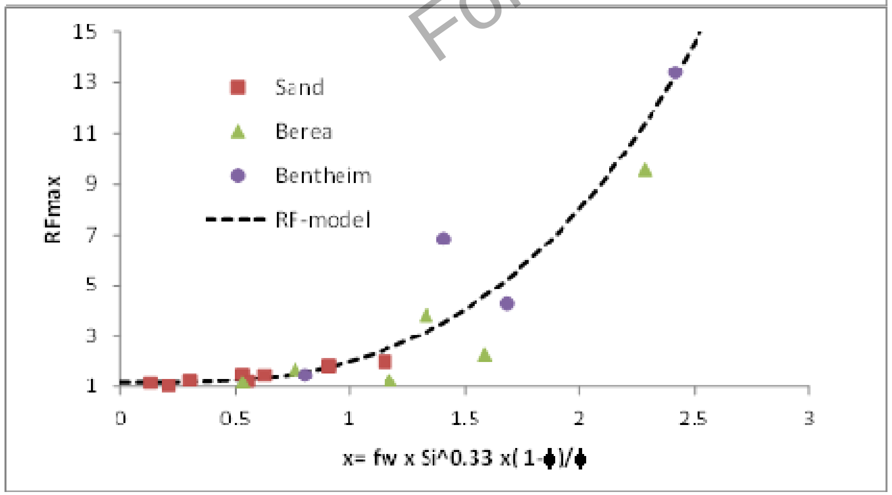


Mobility reduction

IRIS



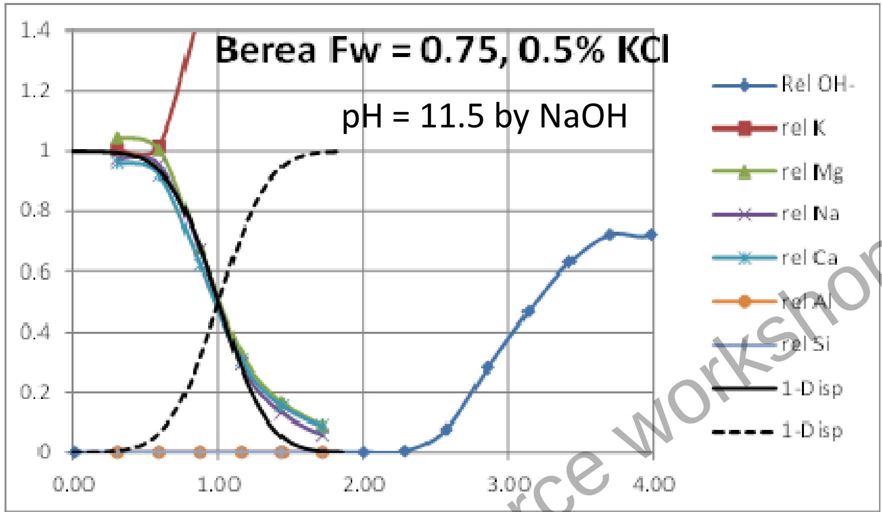


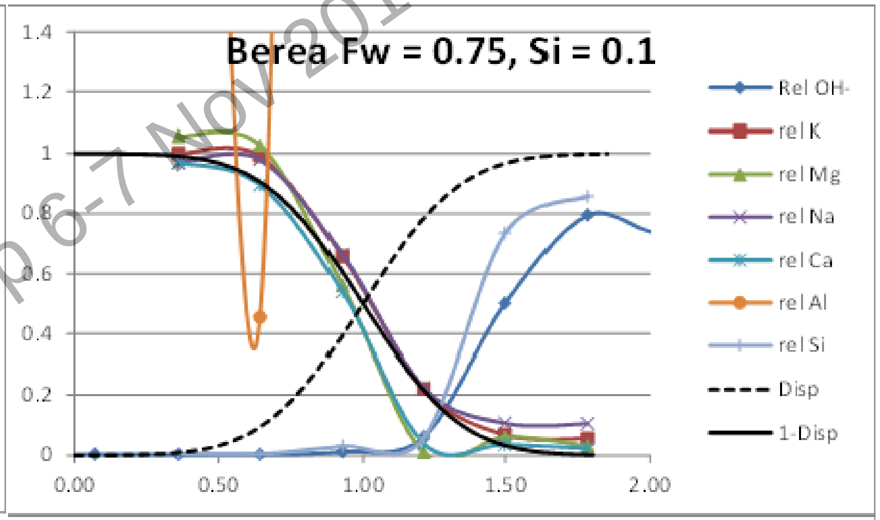


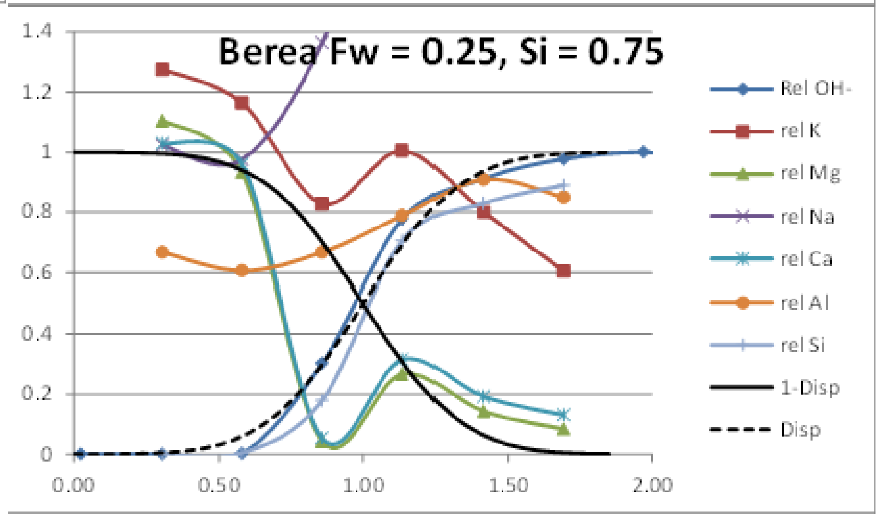
$$RF = 1.15 + X^3, \text{ where } X = FW^1 Si^{1/3} \frac{1-\varphi}{\varphi}$$

Effluent ion production – silicate retention

IRIS





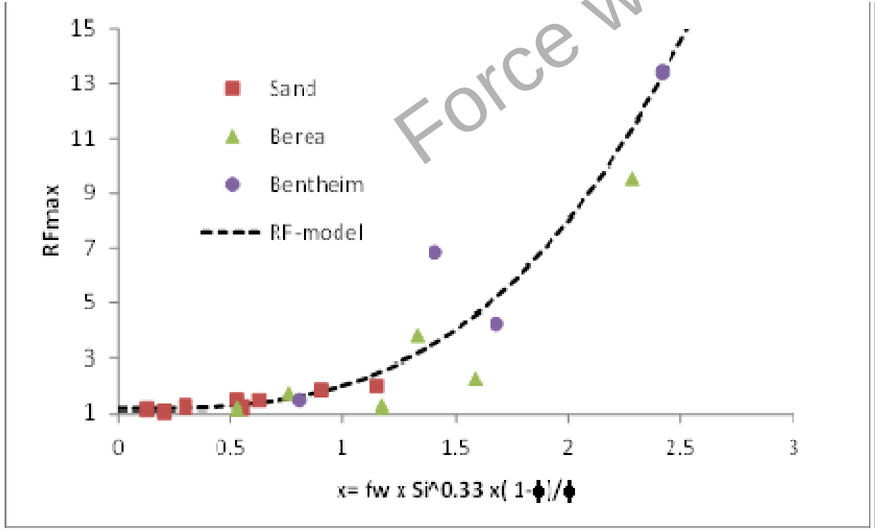


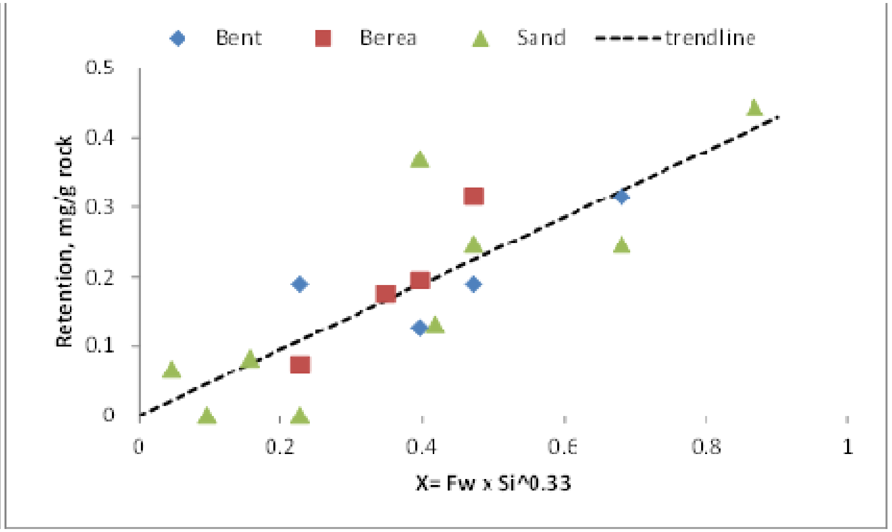
- Derived dispersion profiles
- Delayed silicate breakthrough time – silicate retention
- Lower Mg and Ca concentration at breakthrough, in agreement with precipitated Mg,Ca-silicate in effluent
- Delayed Ca and Mg bank, probably because of dissolving precipitates
- Relative Al and Si profiles are similar in sand (Al-impurities in silicate solution), but not in Berea. However, maximum Al concentration < 30 ppm

Silicate retention

IRIS

- Retention of silicate (measured as mg/g rock) is proportional to $FWxSi^{1/3}$
- Both RF and silicate retention decrease as brine hardness decrease
  - Silicate displacing soft brine will not reduce mobility and silicate loss is insignificant
  - Low silicate concentration displacing hard brine will prior to gelation cause significant silicate loss and delayed breakthrough time
  - Silicate aggregates larger than pore size (which will be produced even at low silicate concentration) will not be displaced

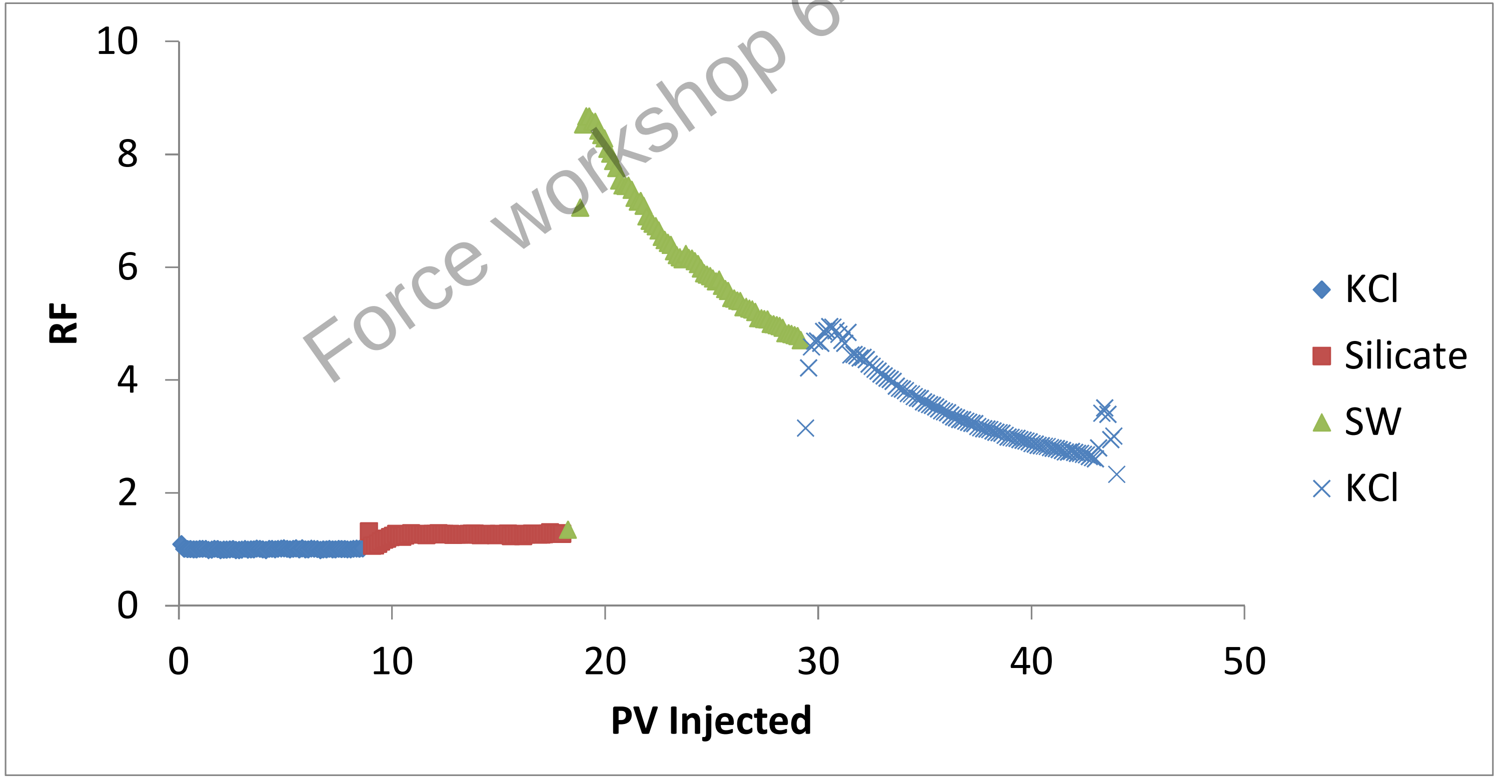




Post flush

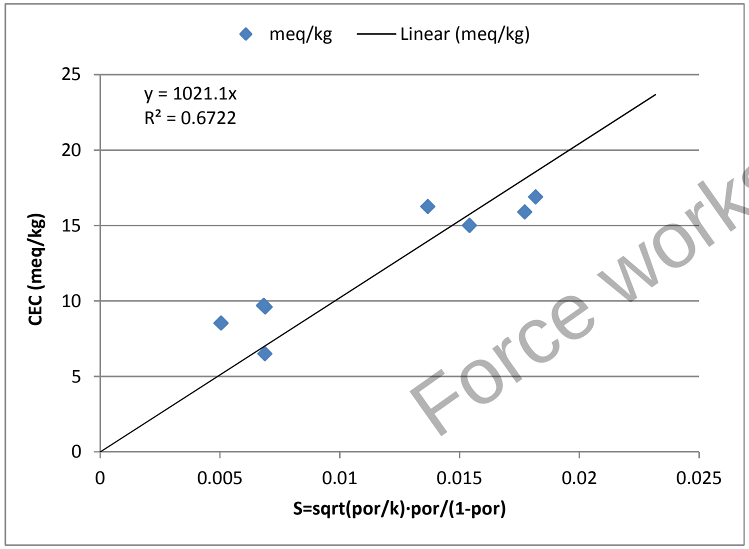
IRIS

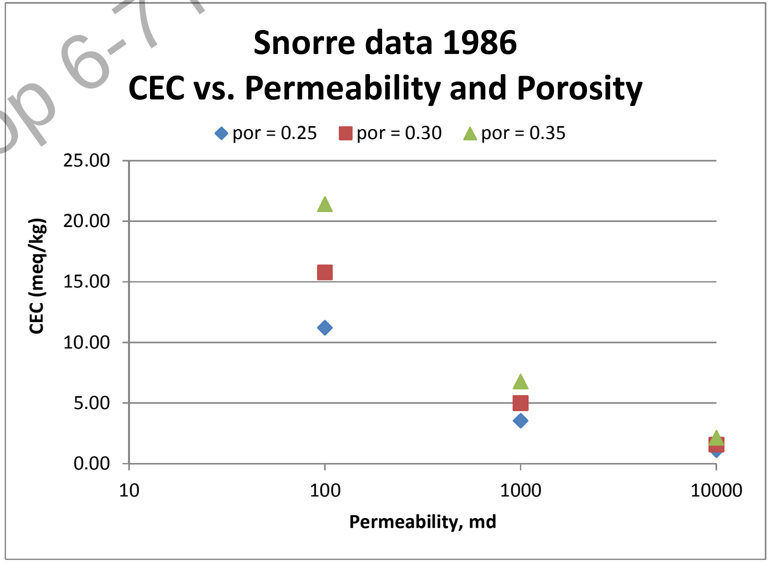
- Soft water preflush followed by seawater
  - Mixing of silicate and seawater with the potential of silicate precipitation
  - Precipitation and RF depends on concentrations and CEC



CEC in high permeability porous media

- Snorre cores (1986) matched to high permeability CEC in the range of 1.7 to 3.3 meq/kg – CEC decreases by increasing permeability

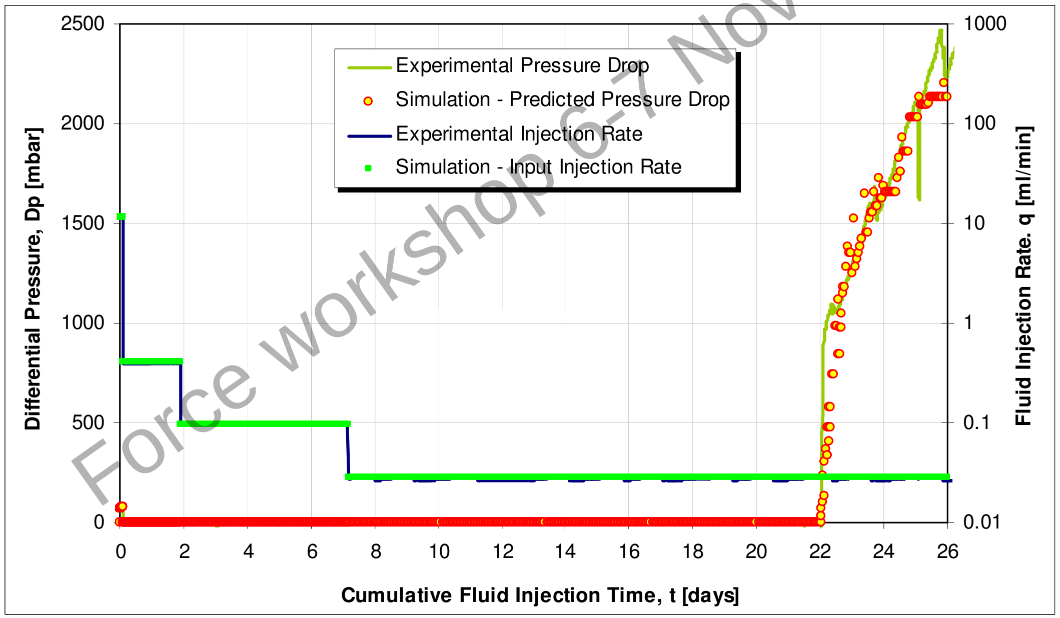




From Phreeqc simulation

- Without allowing for precipiation/dissolution, low concentration preflush – in-depth mixing of silicate and divalent cations is likely
- Allowing for precipitation/dissolution (due to high pH) the simulations predict precipitation of Ca-Mg-silicates and the amount of precipitation increases by increasing the temperature. Precipitation near well is not likely

Simulation of chemical reactions



- Sodium silicate flood experiment at elevated temperature to demonstrate in-depth plugging
- Experiment well matched with simulations (Hatzignatiou et al.)

On designing sodium silicate for in-depth water diversion

- Design parameters
  - Silicate volume and concentration
  - Silicate quality
  - Preflush volume
  - Preflush salinity (ion composition)
  - Make-up water quality
  - Activators external/internal
  - Gelation kinetic
  - Injection rate
  - .....

- Some constraints
  - Demonstration of EOR potential
  - Temperature profile
  - Volume restrictions
  - Reservoir Cation Exchange Capasity
  - Injection pressure limit
  - RO brine regularity-capasity
  - Weather window
  - Silicate disposal
  - ……