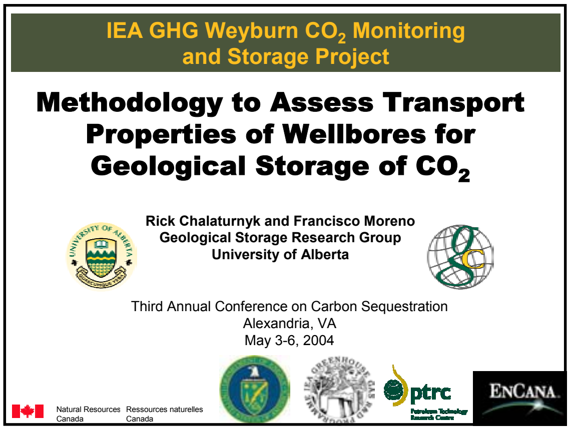
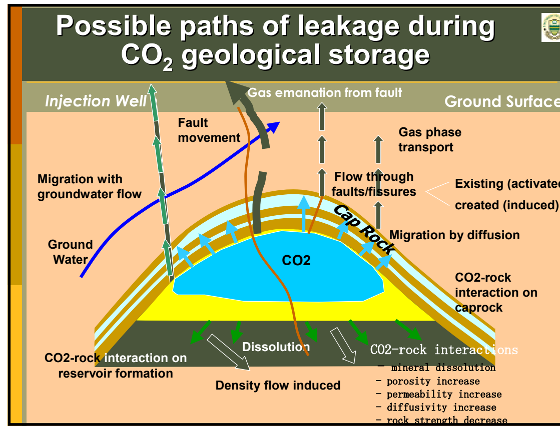
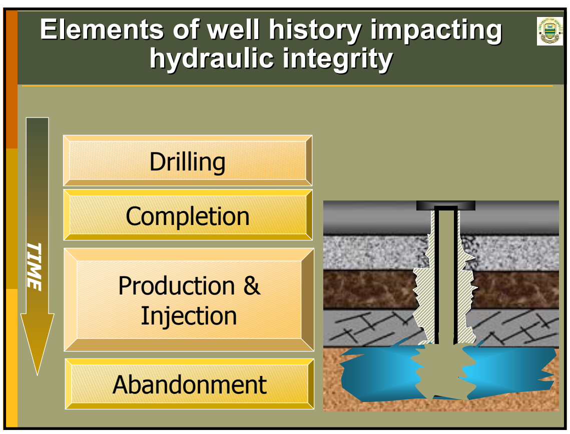
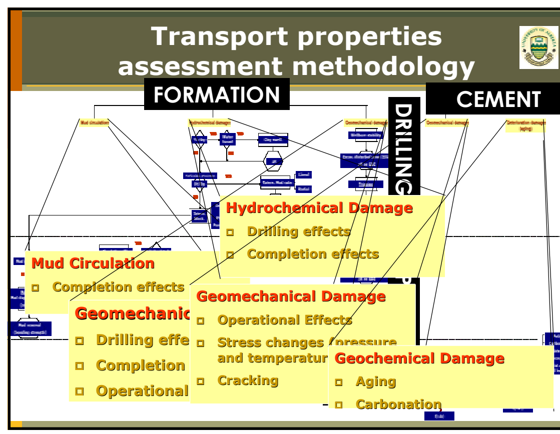
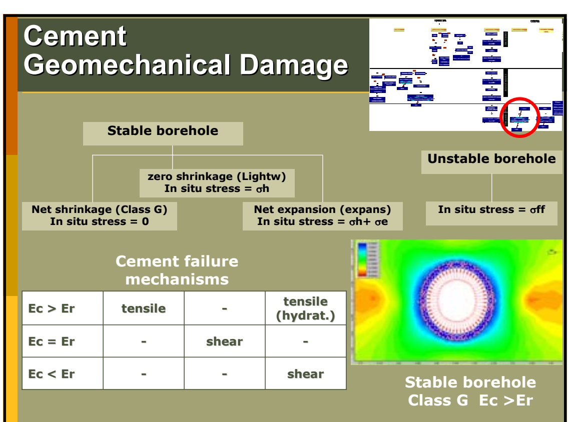
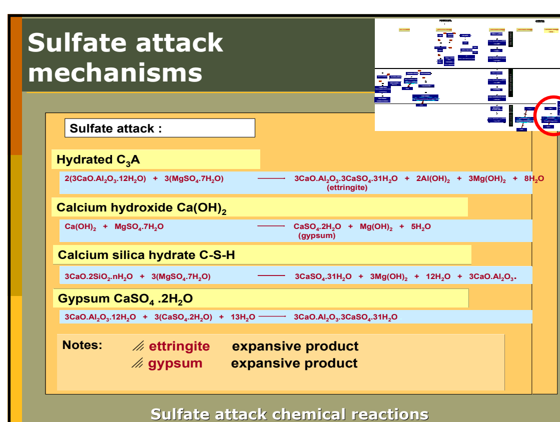

IEA GHG Weyburn CO_2 Monitoring and Storage Project
Methodology to Assess Transport Properties of Wellbores for Geological Storage of CO_2
Rick Chalaturnyk and Francisco Moreno
Geological Storage Research Group
University of Alberta
Third Annual Conference on Carbon Sequestration
Alexandria, VA
May 3-6, 2004
Natural Resources Canada
Ressources naturelles Canada
ptrc
EnCana


Possible paths of leakage during CO_2 geological storage
Injection Well
Gas emanation from fault
Ground Surface
Fault movement
Gas phase transport
Migration with groundwater flow
Flow through faults/fissures
Existing (activated)
created (induced)
Cap Rock
Migration by diffusion
Ground Water
CO2
CO2-rock interaction on caprock
Dissolution
CO2-rock interaction on reservoir formation
Density flow induced
CO2-rock interactions
- mineral dissolution
- porosity increase
- permeability increase
- diffusivity increase
- rock strength decrease

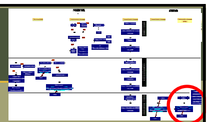

Elements of well history impacting hydraulic integrity
TIME
Drilling
Completion
Production & Injection
Abandonment


Transport properties assessment methodology
FORMATION
DRILLING
CEMENT
Hydrochemical Damage
Drilling effects
Completion effects
Mud Circulation
Completion effects
Geomechanical Damage
Operational Effects
Stress changes (pressure and temperature)
Cracking
Geomechanic
Drilling effe
Completion
Operational
Geochemical Damage
Aging
Carbonation


Cement Geomechanical Damage
Stable borehole
Unstable borehole
zero shrinkage (Lightw)
In situ stress = σh
Net shrinkage (Class G)
In situ stress = 0
Net expansion (expans)
In situ stress = σh+ σe
In situ stress = off
Cement failure mechanisms
Ec > Er | tensile | - | tensile (hydrat.)
Ec = Er | - | shear | -
Ec < Er | - | - | shear
Stable borehole
Class G Ec >Er

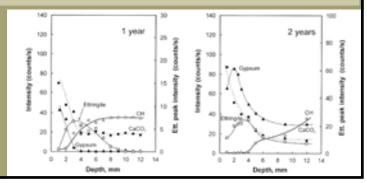

Sulfate attack mechanisms
Sulfate attack :
Hydrated C_3A
$2(3CaO.Al_2O_3.12H_2O) + 3(MgSO_4.7H_2O) \longrightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O + 2Al(OH)_2 + 3Mg(OH)_2 + 8H_2O$
(ettringite)
Calcium hydroxide $Ca(OH)_2$
$Ca(OH)_2 + MgSO_4.7H_2O \longrightarrow CaSO_4.2H_2O + Mg(OH)_2 + 5H_2O$
(gypsum)
Calcium silica hydrate C-S-H
$3CaO.2SiO_2.nH_2O + 3(MgSO_4.7H_2O) \longrightarrow 3CaSO_4.31H_2O + 3Mg(OH)_2 + 12H_2O + 3CaO.Al_2O_3.$
Gypsum $CaSO_4$.$2H_2O$
$3CaO.Al_2O_3.12H_2O + 3(CaSO_4.2H_2O) + 13H_2O \longrightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O$
Notes:
ettringite expansive product
gypsum expansive product
Sulfate attack chemical reactions

Sulfate attack mechanisms

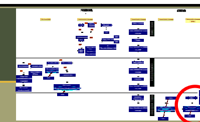


- pH >12-12.5 — only ettringite formation can take place and is responsible for the expansion.
- 8 < pH < 11.5 — gypsum formation and C-S-H composition, resulting loss of strength and expansion.
- pH < 8 — the calcium leaching and decalcification of C-S-H is the main degradation mechanism

Distribution of attack products quantified by XRD in PC mortar, Na_2SO_4 solution (0.352M, pH 7), Irassar et al., 2003



Acid attack mechanisms



w/c content | Temperature | pH | protocol

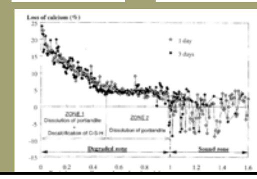
Calcium leaching dependency

Sound cement → $Ca(OH)_2$ → C-S-H → Microporosity

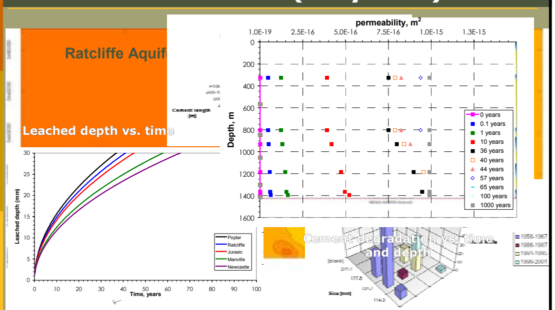
$Ca(OH)_2$ → Macroporosity

Loss of Calcium profile in the solid phase for pure cement paste

(Cade et al., 1999)



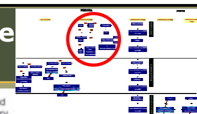
Acid Attack Mechanisms (Weyburn)

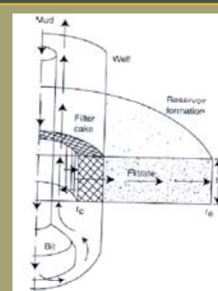


Wellbore diameter histogram

Casing diameter histogram

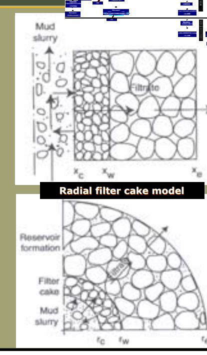
Hydro-Chemical Damage



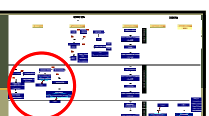


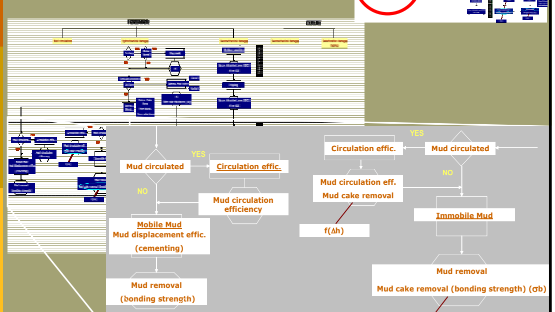
Mud-cake buildup

(Civan, 2000)

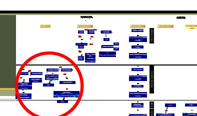


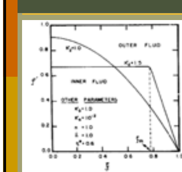
Formation Mud Circulation



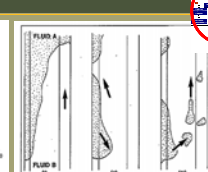


Mud Removal

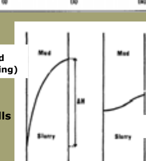




Effect of density on shape of interface (Flumerfet, 1975)



ρcem < ρmud (unstable-fingering)



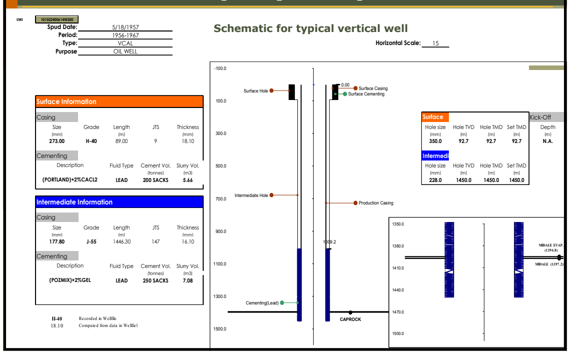
ρcem > ρmud

Interface possibilities in actual wells (Martin et al., 1978)

Density hierarchy

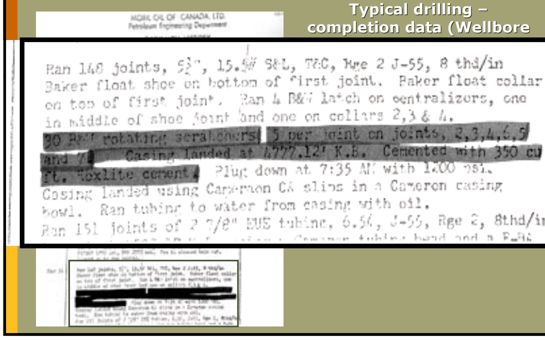
Density of the displacing fluid should be at least 10% higher than that of the displaced fluid

Mud removal (Weyburn)



Mud removal (Weyburn)

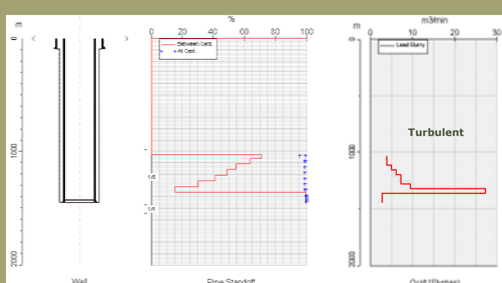
Typical drilling – completion data (Wellbore



MOBIL OIL OF CANADA, LTD.
Petroleum Engineering Department

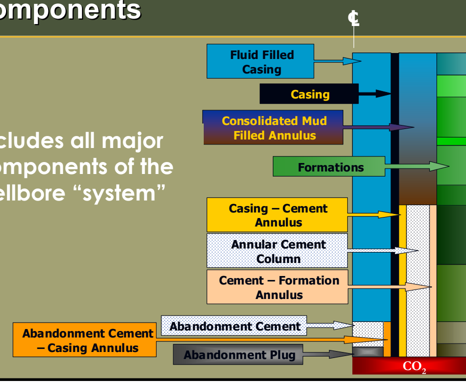
Ran 148 joints, 5½", 15.5# S&L, T&C, Rge 2 J-55, 8 thd/in Baker float shoe on bottom of first joint. Baker float collar on top of first joint. Ran 4 B&W latch on centralizers, one in middle of shoe joint and one on collars 2,3 & 4. 30 B&W rotating scratchers 5 per joint on joints, 2,3,4,6,5 and 7. Casing landed at 4777.12' K.B. Cemented with 350 cu ft. Poxlite cement. Plug down at 7:35 AM with 1200 psi. Casing landed using Cameron CA slips in a Cameron casing bowl. Ran tubing to water from casing with oil. Ran 151 joints of 2 7/8" EUE tubing, 6.5#, J-55, Rge 2, 8thd/in,

Mud removal (Weyburn)

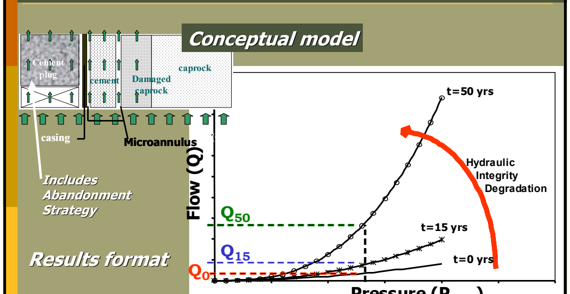


Well Integrity Assessment Components

Includes all major components of the wellbore "system"



Flux (Q) assessment of integrity – based on transport properties



Summary

- Methodology captures all the main components that affect final transport properties of wellbores.
- Recognition of interaction between components.
- New mechanisms can be added (i.e. long term evolution of transport properties).
- Components can be updated as new modeling techniques become available.
- Missing data can be assumed.

IEA GHG Weyburn CO_2 Monitoring and Storage Project

Methodology to Assess Transport Properties of Wellbores for Geological Storage of CO_2

Rick Chalaturnyk and Francisco Moreno
Geological Storage Research Group
University of Alberta

Third Annual Conference on Carbon Sequestration
Alexandria, VA
May 3-6, 2004

Natural Resources Canada Ressources naturelles Canada