Hydraulic/Gas Performance of GCLs

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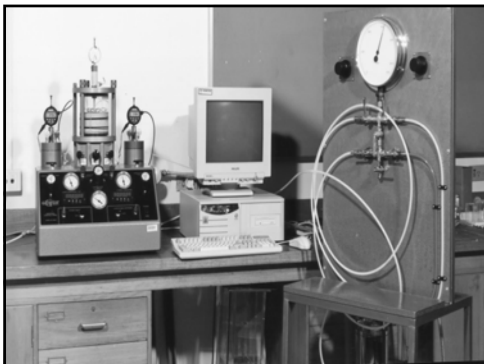
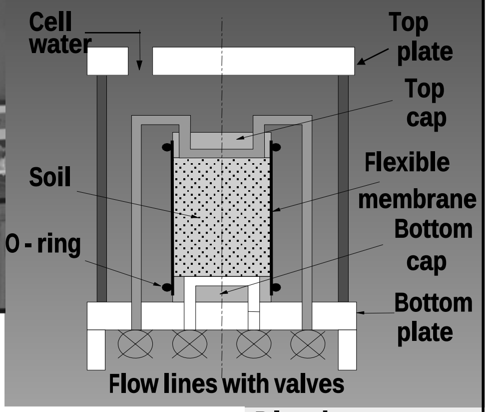


Flexible Wall Permeameter



Hydraulic Conductivity Testing
ASTM D 5887

Advantages

- Minimal or no sidewall leakage
- Better control of stress
- Saturation by backpressure
- Short test times

Disadvantages

- High costs
- More training
- Difficulties at low stress

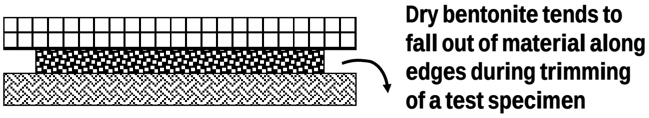
Selecting a sample for testing

- ☺ Random sampling
- ☺ Sampling of questionable material

Trimming a test specimen

- ☺ Problems tend to be different for different classes of GCL
- ☺ No special technique is required-just cut a circular specimen with a sharp knife or a sharp circular die

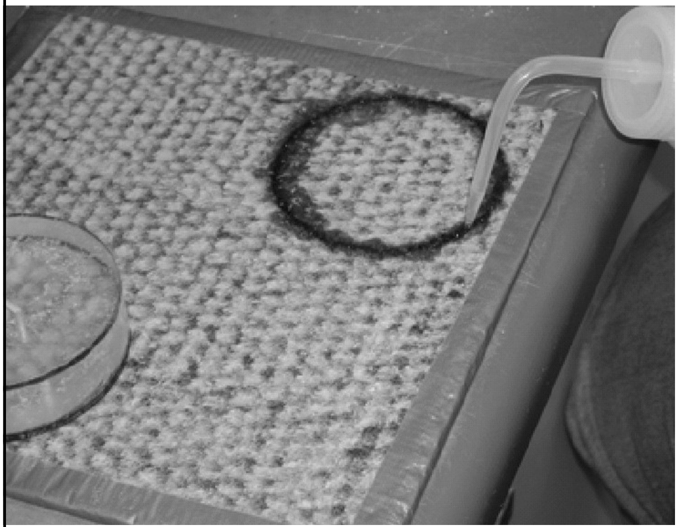
Problems can develop with edge leakage when ND or SB GCLs are tested



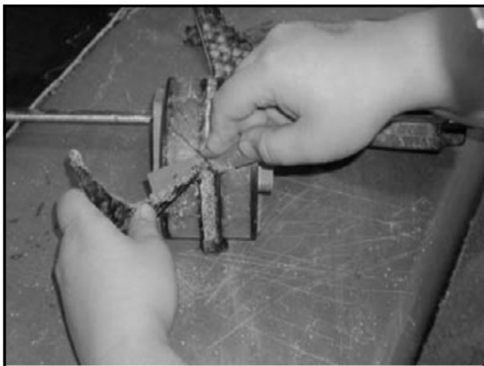
Suggested procedure to minimize this problem:

- ☺ Mark a circle the size of the test specimen on the GCL
- ☺ Wet the GCL along the circle with a squirt bottle
- ☺ Use a sharpened tube (die) to stamp a circular test specimen-add more water with squirt bottle on the inside of the die before removing the die.

GCL sample preparation



Cutting a GCL sample from a 30 cm^2 square specimen



Sample Trimming

GCL Sample ready for Testing

Selecting an Effective Confining Pressure

<u>Conformance Test:</u>

Maximum effective confining stress is 70 kPa

<u>Performance Test:</u>

Stress should be selected to be representative of field conditions. Typical overburden stresses are:

Soil: 20 kPa (represents 1 m of soil cover)

Solid Waste: Depends on depth of landfill, compaction, etc.

<u>NOTE:</u> **The compressive stress needs to be the least compressive stress acting on the GCL when the GCL is expected to work since HC decreases with increasing overburden stresses.**

Selecting a permeant liquid

ASTM D-5084 specifies tap water, unless the requester indicates some other type of water

For performance tests, suggest using tap water if the hydraulic conductivity to water is to be determined

Permeation with leachate & chemicals is considered later (ASTM D-6766)

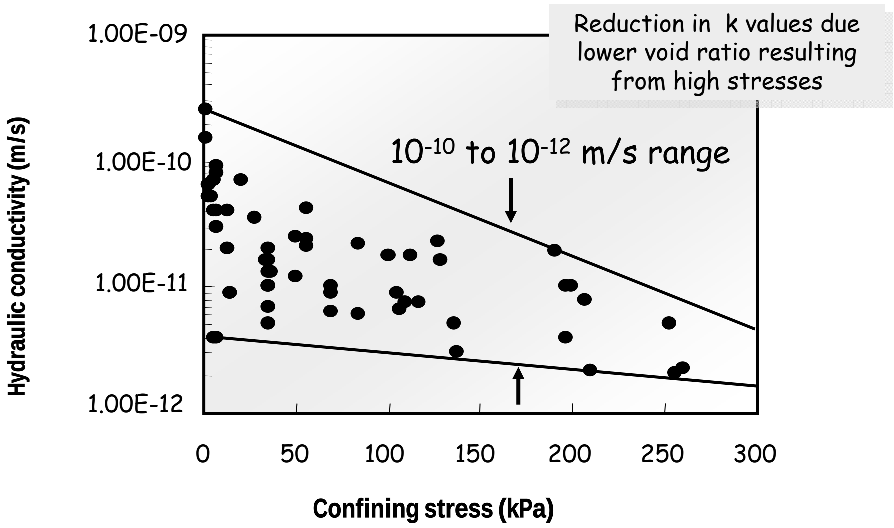
Selecting a hydraulic gradient

Ideally the hydraulic gradient should equal the value expected in the field.

This is often impractical because flow rates would be too low to measure accurately, or the test too long to perform

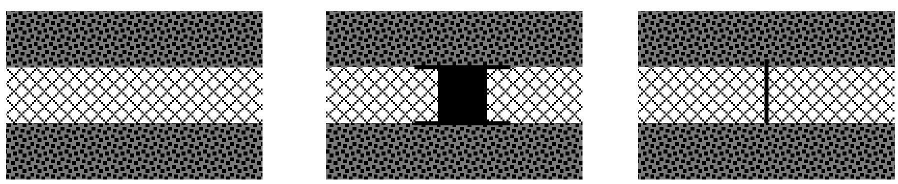
ASTM D-5084 recommends a maximum HG of 30

Hydraulic conductivities of GCLs to Water



Different cases studied (Bouazza et al., 1996)

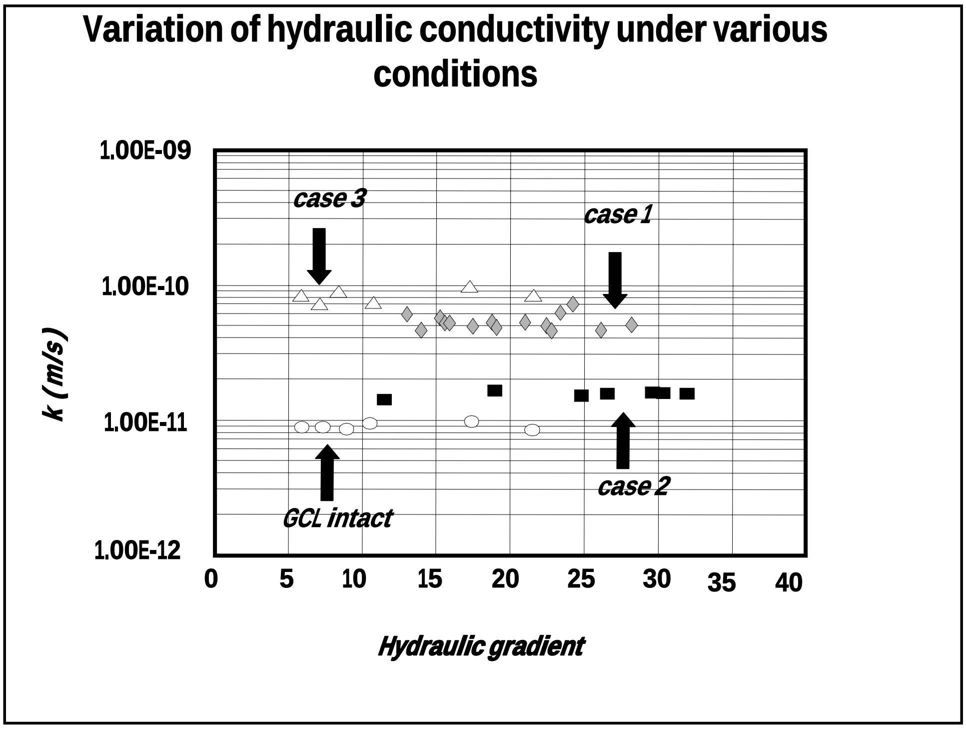
case 1 | *case 2* | *case 3*



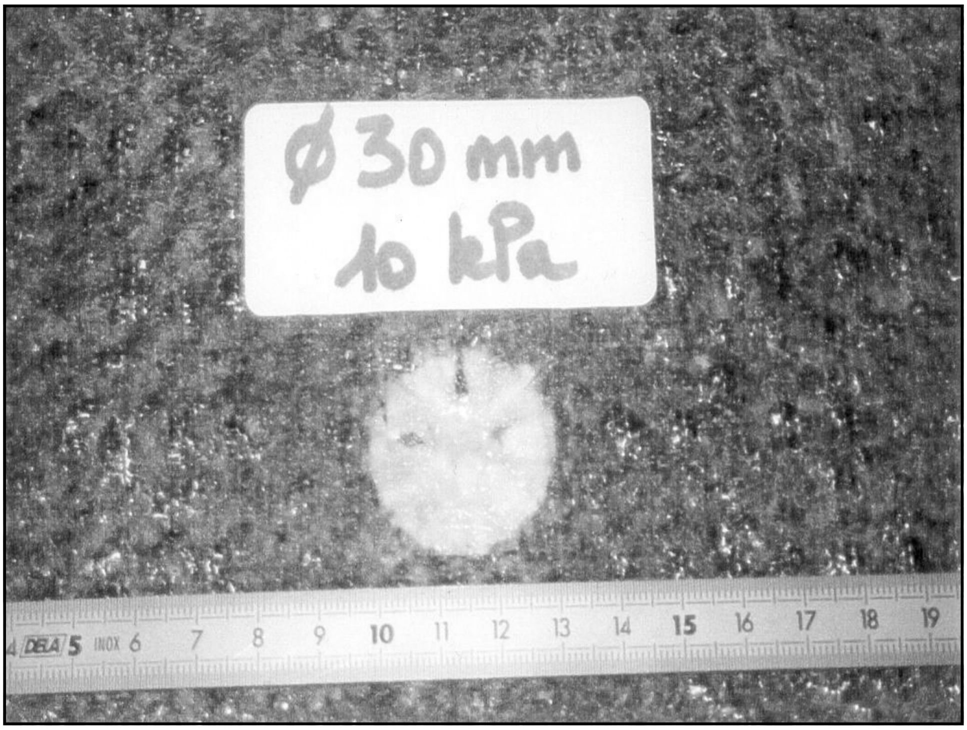
GCL strained to 15%

10 mm hole

GCL punctured with a 10 mm pin

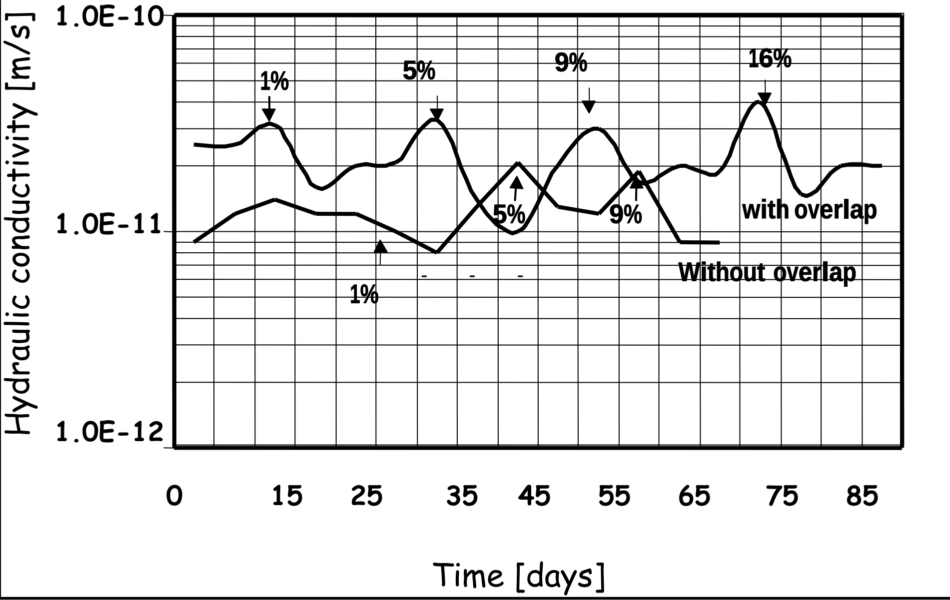


Variation of hydraulic conductivity under various conditions
1.00E-09
1.00E-10
1.00E-11
1.00E-12
k (m/s)
case 3
case 1
case 2
GCL intact
0
5
10
15
20
25
30
35
40
Hydraulic gradient

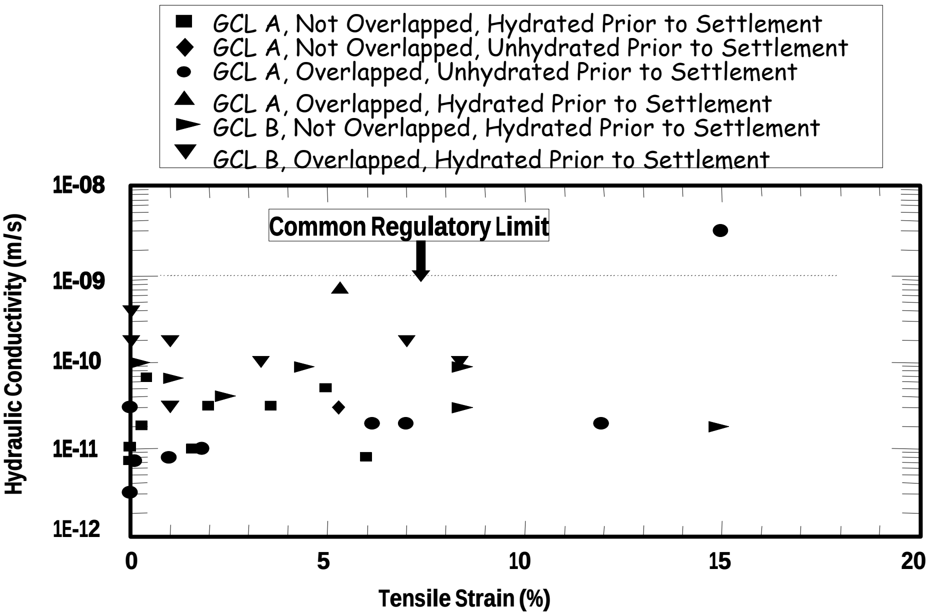


Ø 30 mm
10 kPa

Effect of Differential Settlement on HC of GCLs (La Gatta et al., 1997)



Effect of Differential Settlement on HC of GCLs

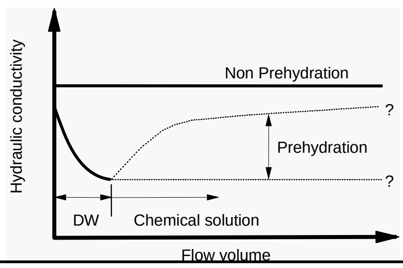


Chemical compatibility and First exposure effect

Chemical compatibility is a great concern, because bentontie does not swell against chemical solutions.

When clay liners are permeated with sequential liquids, *k* is dominantly affected by the first wetting liquid.

Prehydration is expected to maintain the low *k* even when permeated with chemical solutions and waste leachate. However, it depends on how GCL gets prehydrated, and little data have been reported so far.



What is chemical compatibility?

- The hydraulic conductivity is a function of both the porous medium and the properties of the liquid, or

$$k = K\left[\frac{\gamma_f}{\mu_f}\right]$$

Where

k = hydraulic conductivity (m/s)

K = intrinsic permeability (m^2)

γ_f = unit weight of fluid

μ_f = viscosity of fluid

Changes in hydraulic conductivity can result from three mechanisms:

- Changes in the intrinsic permeability resulting from applied loads (e.g., consolidation):

$$\Delta k = \Delta K\left[\frac{\gamma_f}{\mu_f}\right]$$

- Permeation of a relatively inert porous medium with a liquid with properties that are different than water (e.g., oil flow through sand):

$$\Delta k = K\ \Delta\left[\frac{\gamma_f}{\mu_f}\right]$$

- Interactions between the porous medium and the liquid resulting in changes in the pore structure of the medium (i.e., compatibility):

$$\Delta k = \Delta K\ \Delta\left[\frac{\gamma_f}{\mu_f}\right]$$

Chemical solutions

Single-species solutions
($NaCl$, $CaCl_2$, $AlCl_3$, etc.) with different concentration.

Multi-species solutions
($NaCl$-$CaCl_2$, $LiCl$-$CaCl_2$) having different *I* (ionic strength) and *RMD* (ratio of monovalent to divalent).

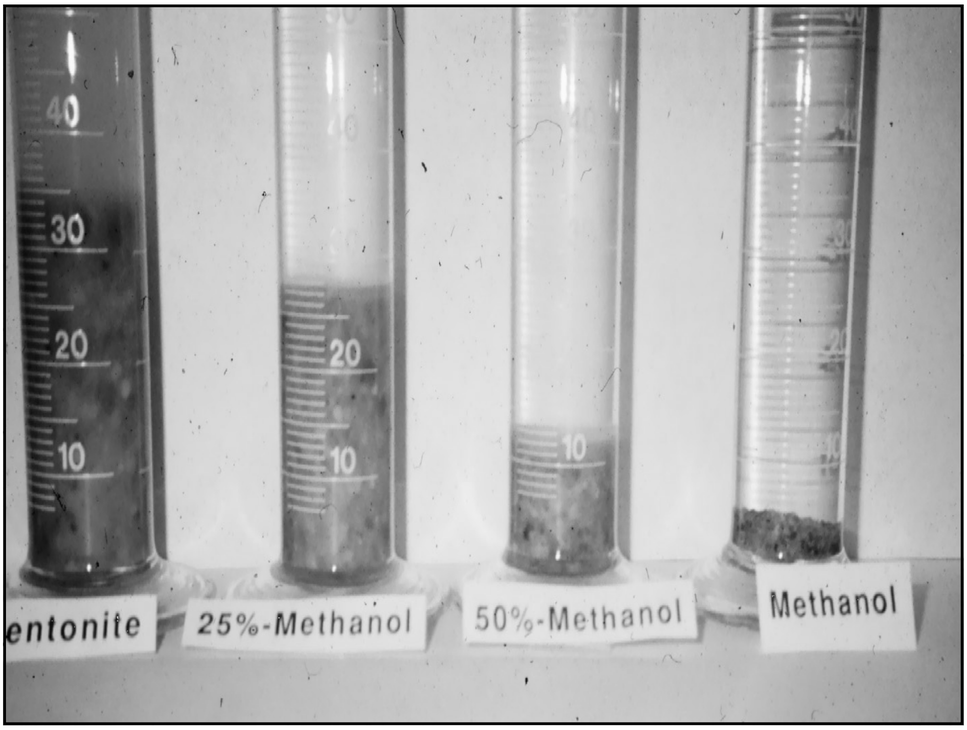
$$I = 0.5 \sum_{i=1}^{n} c_i z_i^2$$

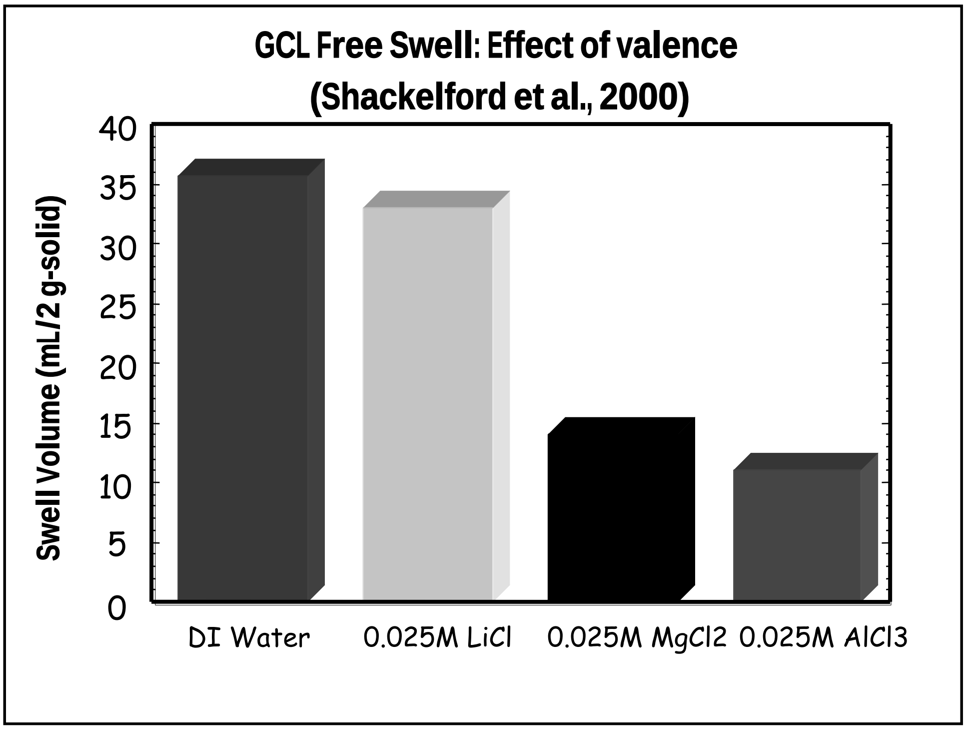
$$RMD = \frac{c_1}{\sqrt{2\, c_2}}$$

c_i: the concentration of *i*th ion,
z_i: the valence of *i*th ion,
c_1: the concentration of monovalent cation,
c_2: the concentration of divalent cation

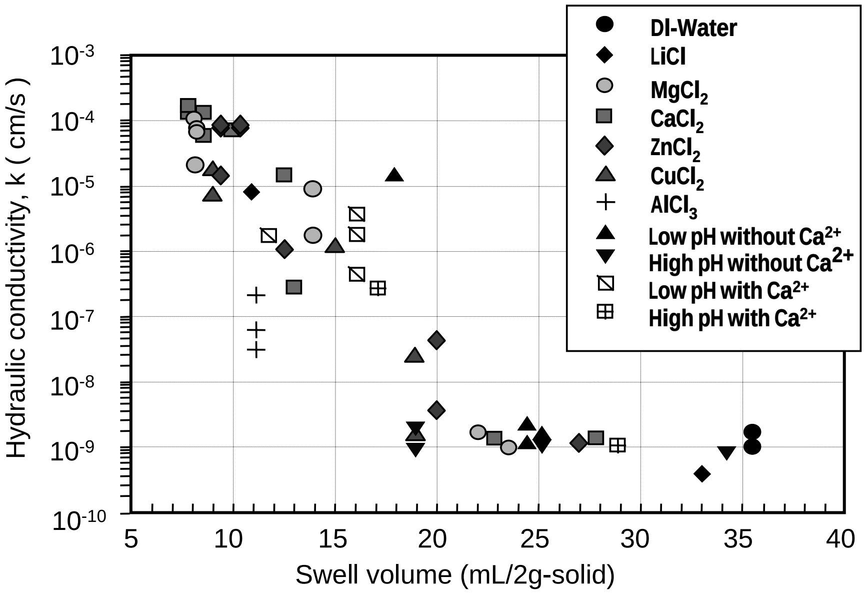
Atterberg Limits

Pore Fluid	Na Bentonite			Ca Bentonite		
	LL	PI	k (m/s)	LL	PI	k (m/s)
D-W	603	567	6E-12	124	98	6E-11
1000 mg/l $CaCl_2$	466	426	-	103	73	-
73,500 mg/l $CaCl_2$	86	45	6E-9	74	46	3E-10
1000 mg/l NaCl	502	462	-	109	80	-
10,000 mg/l NaCl	224	184	-	93	63	-

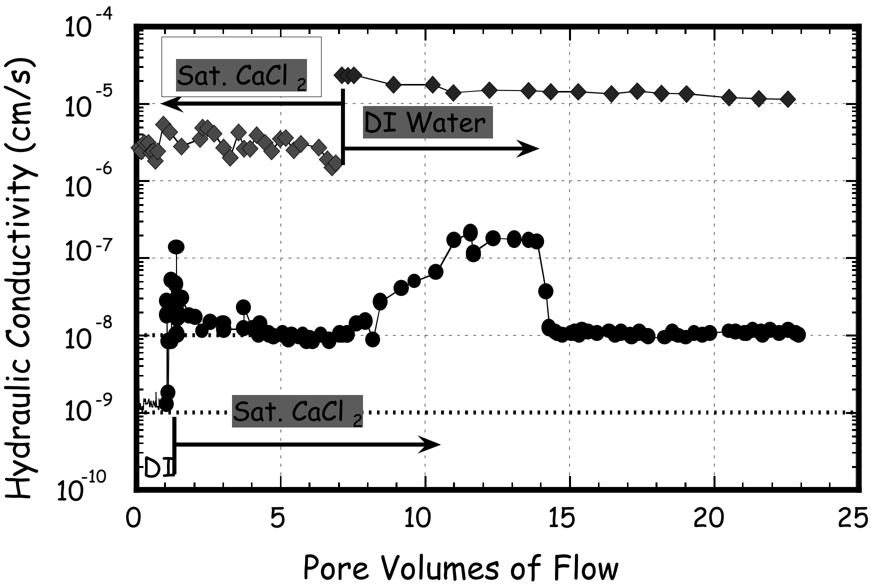

entonite
25%-Methanol
50%-Methanol
Methanol

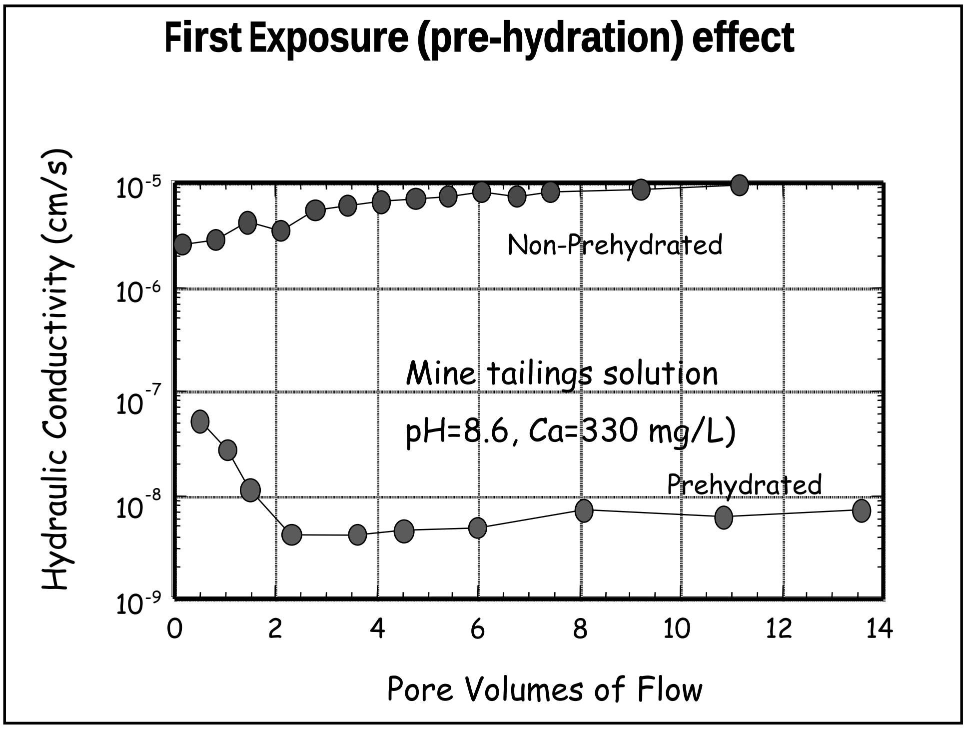

GCL Free Swell: Effect of valence
(Shackelford et al., 2000)
Swell Volume (mL/2 g-solid)
40
35
30
25
20
15
10
5
0
DI Water
0.025M LiCl
0.025M MgCl2
0.025M AlCl3

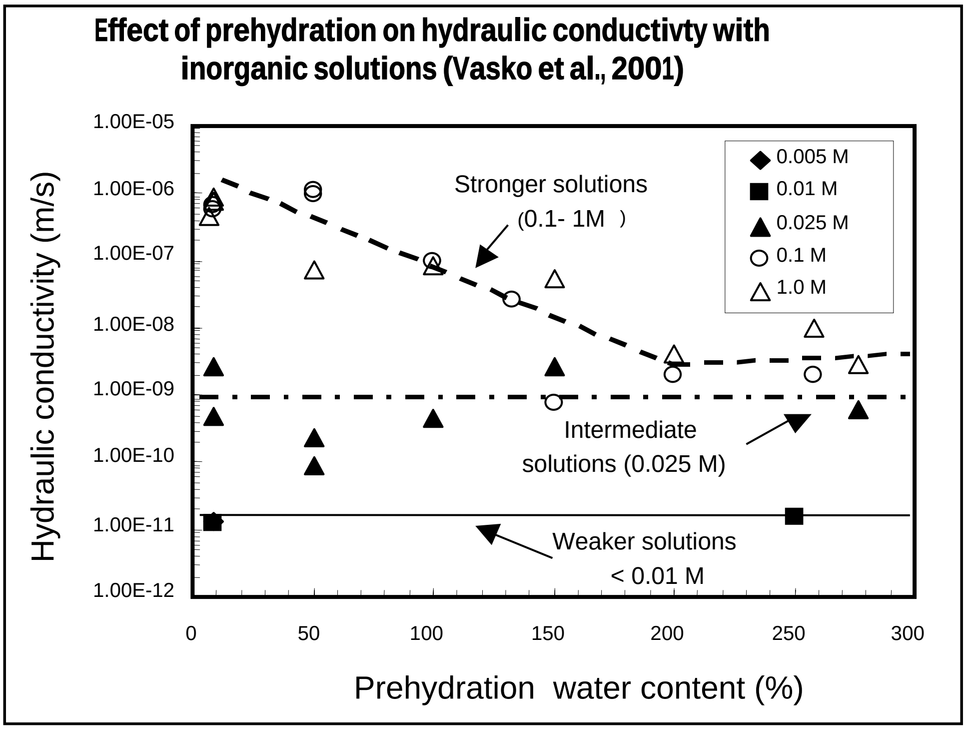
Variation of k versus swell volume (Katsumi et al. 2004)



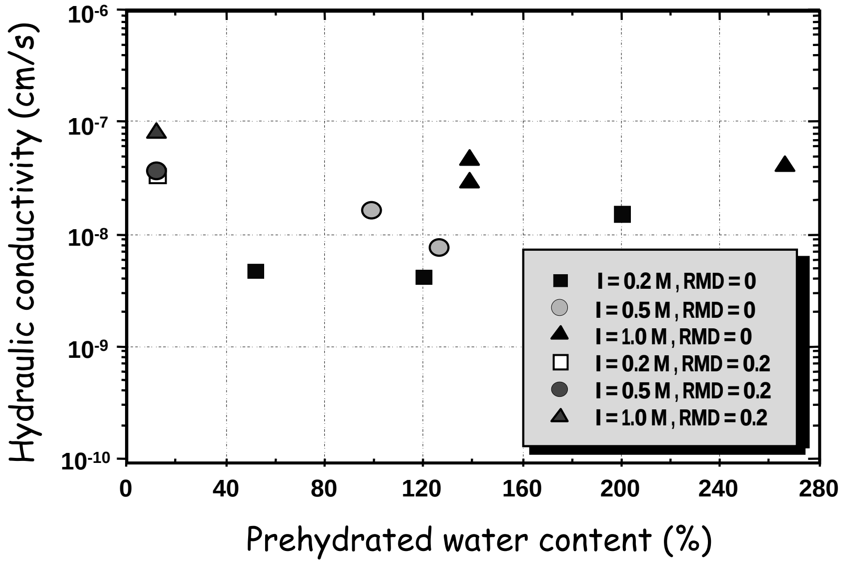
First Exposure (pre-hydration) effect (Shackelford et al., 2000)



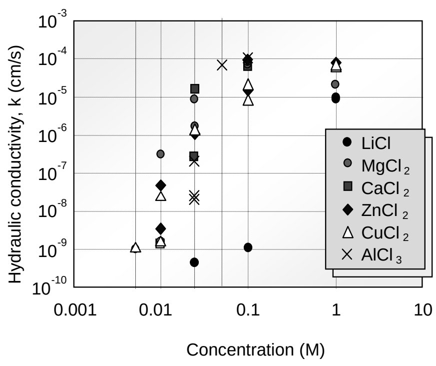

First Exposure (pre-hydration) effect
Hydraulic Conductivity (cm/s)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Non-Prehydrated
Mine tailings solution
pH=8.6, Ca=330 mg/L)
Prehydrated
0 2 4 6 8 10 12 14
Pore Volumes of Flow

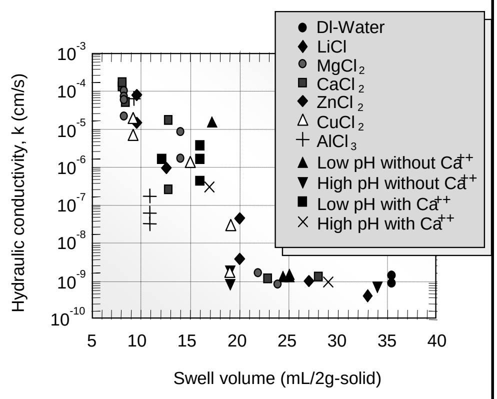

Effect of prehydration on hydraulic conductivty with inorganic solutions (Vasko et al., 2001)
Hydraulic conductivity (m/s)
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
0.005 M
0.01 M
0.025 M
0.1 M
1.0 M
Stronger solutions
(0.1- 1M)
Intermediate
solutions (0.025 M)
Weaker solutions
< 0.01 M
0 50 100 150 200 250 300
Prehydration water content (%)

Effect of prehydration on hydraulic conductivty with inorganic solutions (Katsumi et al., 2004)



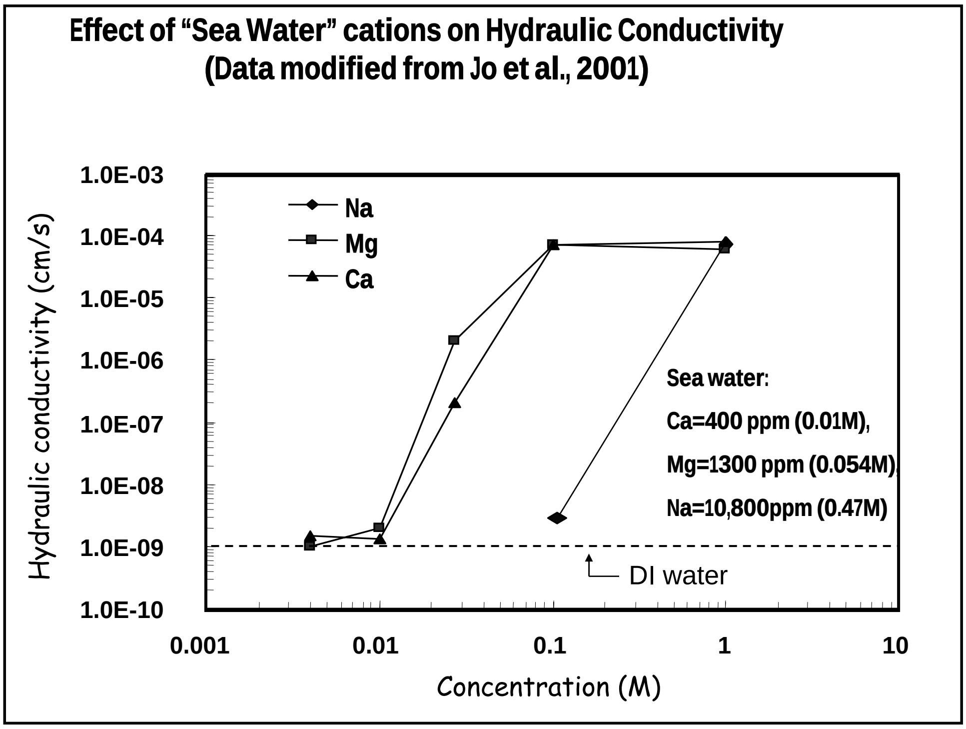
Hydraulic conductivity of non-prehydrated GCL permeated with inorganic chemical solutions

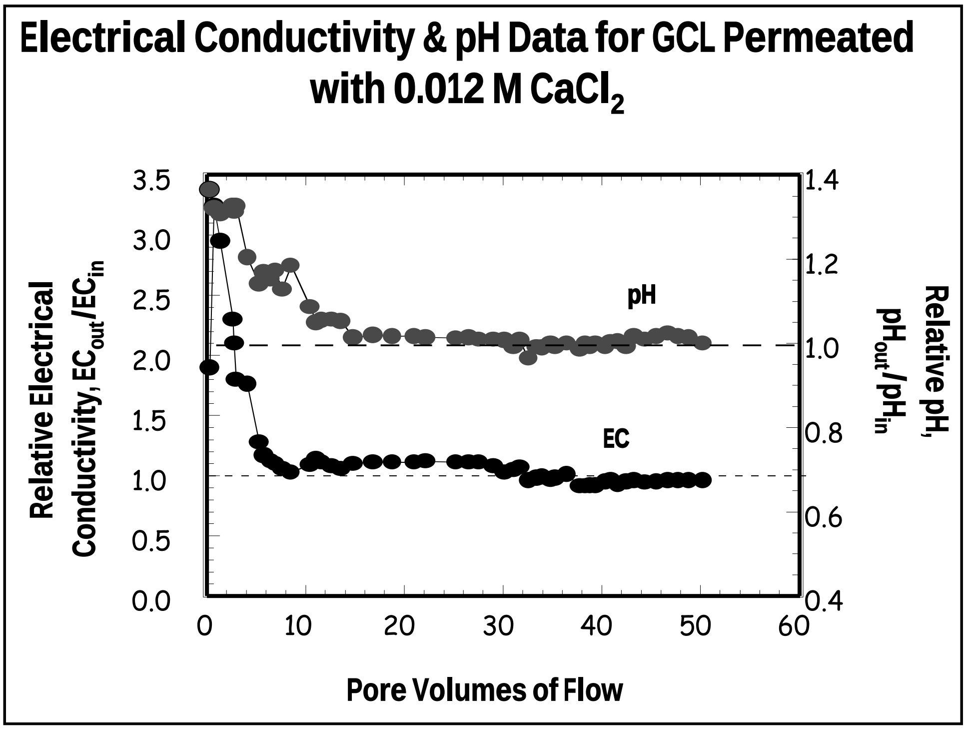




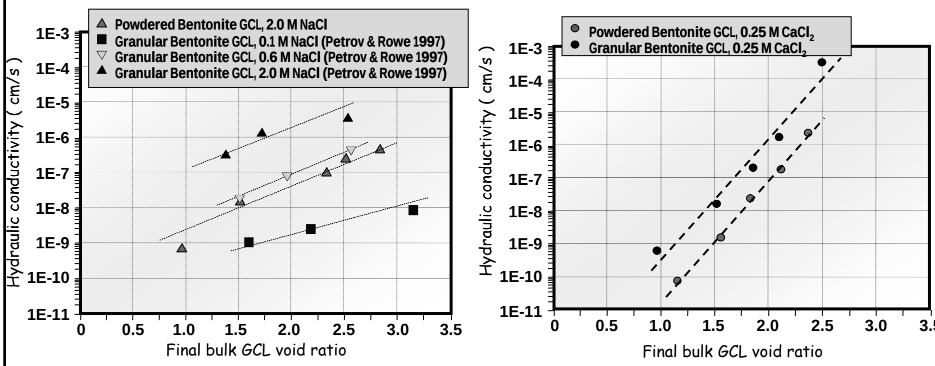
High concentration and poly-valent cations increase in hydraulic conductivity (left).

Less swell results in high hydraulic conductivity (right).


Effect of "Sea Water" cations on Hydraulic Conductivity
(Data modified from Jo et al., 2001)
Hydraulic conductivity (cm/s)
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
Na
Mg
Ca
Sea water:
Ca=400 ppm (0.01M),
Mg=1300 ppm (0.054M),
Na=10,800ppm (0.47M)
DI water
0.001
0.01
0.1
1
10
Concentration (M)


Electrical Conductivity & pH Data for GCL Permeated with 0.012 M CaCl2
Relative Electrical Conductivity, ECout/ECin
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
pH
EC
Relative pH, pHout/pHin
1.4
1.2
1.0
0.8
0.6
0.4
0
10
20
30
40
50
60
Pore Volumes of Flow

Hydraulic conductivity versus void ratio (Katsumi et al. 2004)



Hydraulic conductivity of bentonite can be adversely affected by high salt concentrations, permeation with polyvalent cations such as Ca^{2+} & Concentrated organic chemicals

The effect of chemical or leachate tends to be much more severe when the first wetting liquid is the leachate or chemical

Bentonite is much more chemically resistant if hydrated in fresh water before exposure to the chemical or leachate

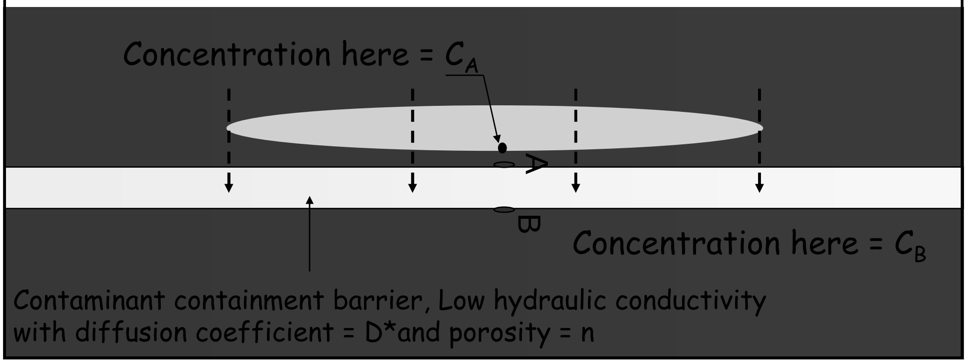
Contaminant Transport Processes

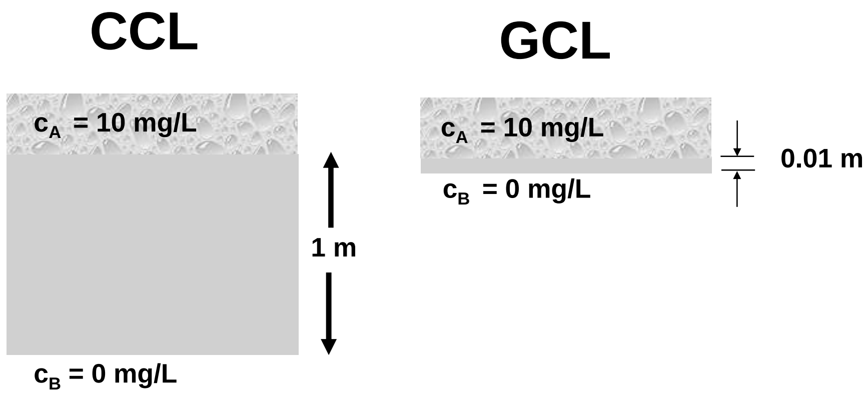
- **Advection (or Convection):**
  - **Migration of solute (contaminant) due to bulk solution flow**
  - **Darcy's Law**
- **Diffusion:**
  - **Migration of solute (contaminant) due to a concentration difference in the absence of bulk solution flow.**
  - **Fick's Law** $$J_D = -nD \frac{\partial c}{\partial x}$$

•How long does it take for contaminants to 'breakthrough' a barrier?

Examples

- Waste Containment liners

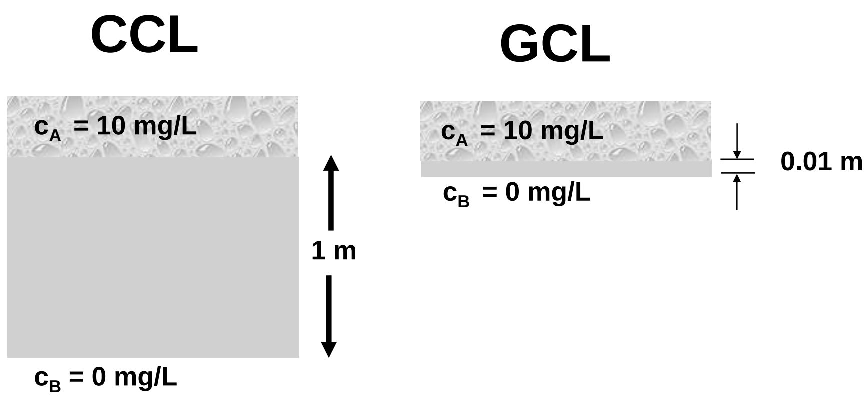




$\Delta c/L$ = (10 – 0) / 1 = 10

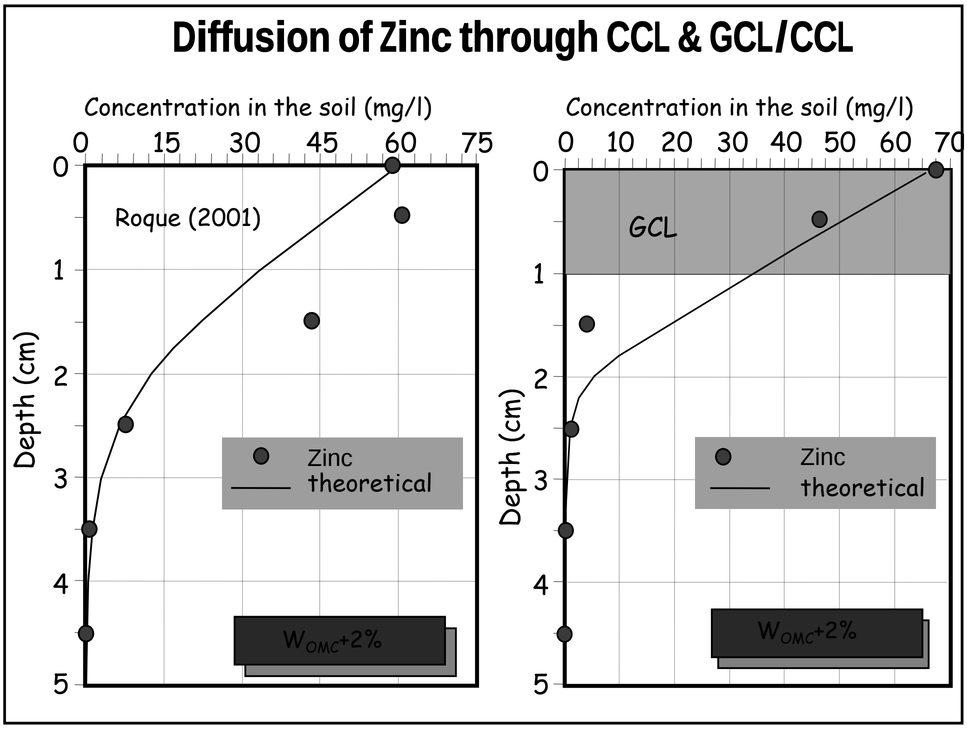
$\Delta c/L$ = (10 – 1) / 0.01 = 1,000

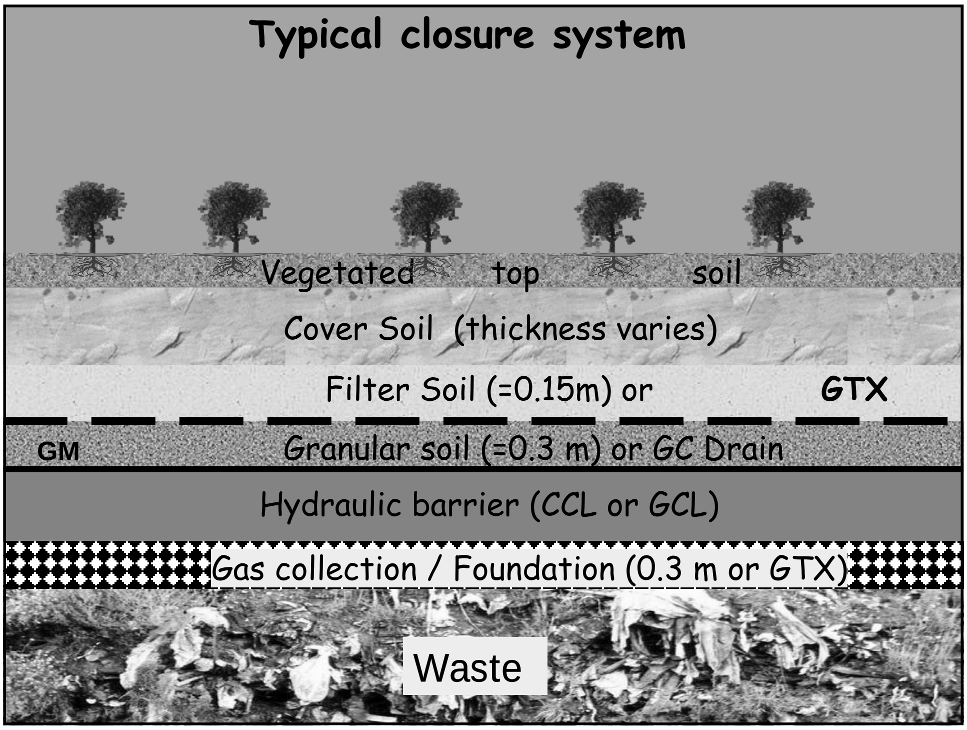
Assuming comparable values for D*,
a GCL will allow more diffusive flux than a CCL.



$\Delta c/L$ = (10 – 0) / 1 = 10
$J_D = D^* \, n \, (\Delta C/L)$
$J_D = (1 \times 10^{-10})(0.30)(10)$
$J_D = 3 \times 10^{-7}$ mg/m^2/s

$\Delta c/L$ = (10 – 0) / 0.01 = 1,000
$J_D = D^* \, n \, (\Delta C/L)$
$J_D = (1 \times 10^{-10})(0.75)(1,000)$
$J_D = 7.5 \times 10^{-5}$ mg/m^2/s


Diffusion of Zinc through CCL & GCL/CCL
Concentration in the soil (mg/l)
0 15 30 45 60 75
Depth (cm)
Roque (2001)
Zinc
theoretical
W_{OMC}+2%
Concentration in the soil (mg/l)
0 10 20 30 40 50 60 70
GCL
Zinc
theoretical
W_{OMC}+2%


Typical closure system
Vegetated top soil
Cover Soil (thickness varies)
Filter Soil (=0.15m) or GTX
GM
Granular soil (=0.3 m) or GC Drain
Hydraulic barrier (CCL or GCL)
Gas collection / Foundation (0.3 m or GTX)
Waste

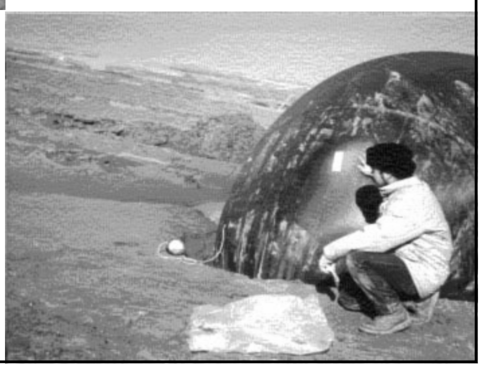
Some Design Issues

Hydraulic Barrier

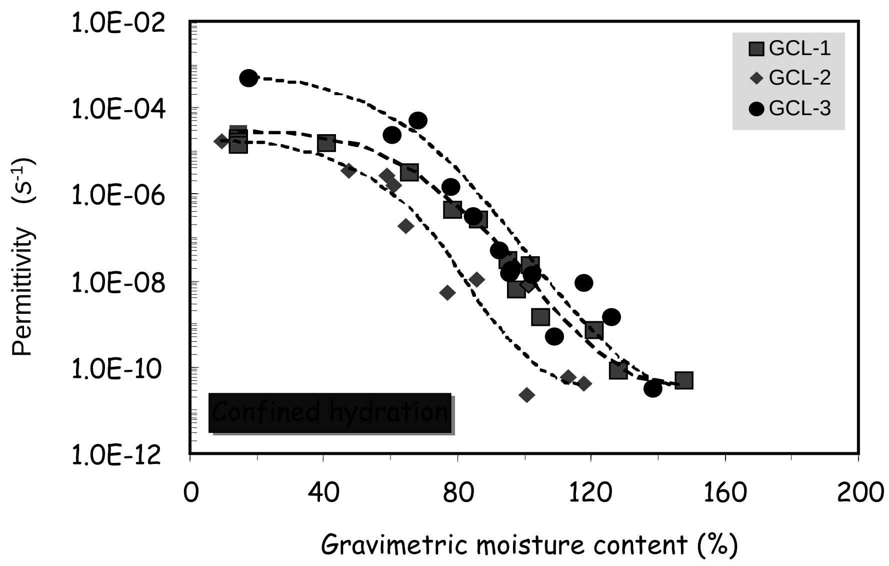
- *Cracking due to dessication*
- *Deformation due to waste sett.*
- *Insufficient resistance to gas flow*
- *Root penetration,Slope Instability*

Gas Collection Layer

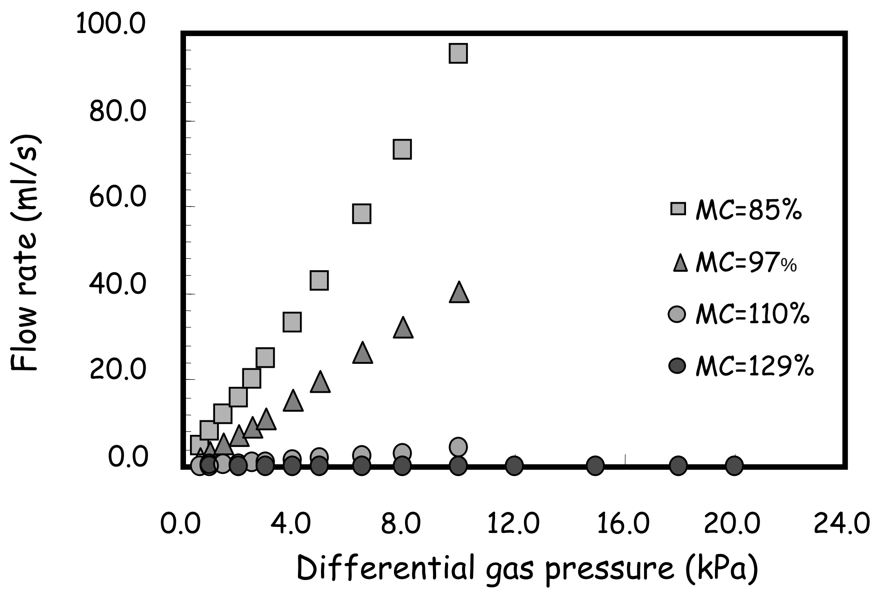
- *Insufficient coverage over waste*
- *Insufficient flow capacity*



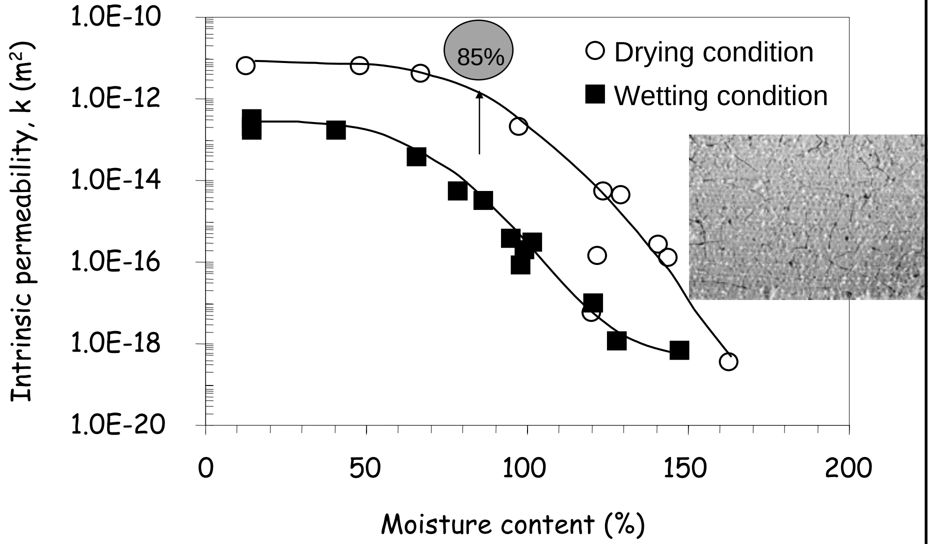
Permittivity versus volumetric water content



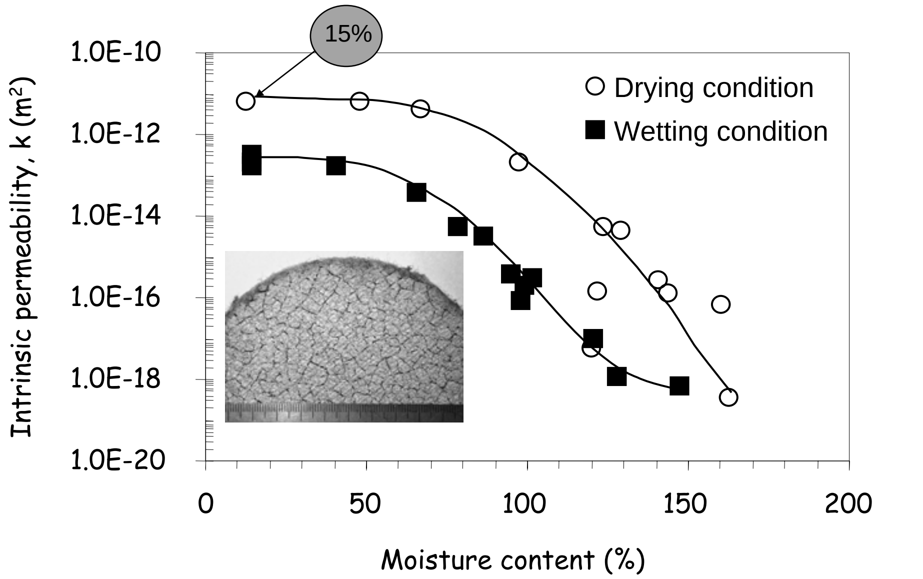
Leakage rate through a composite cap (GCL + GM) with a 5 mm circular defect in the GM



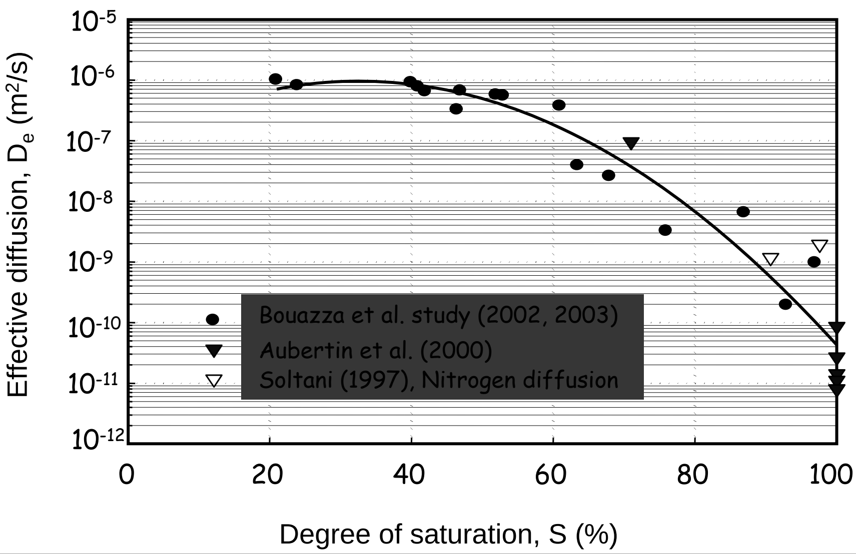
Variation of intrinsic gas permeability of GCLs under wetting and drying conditions



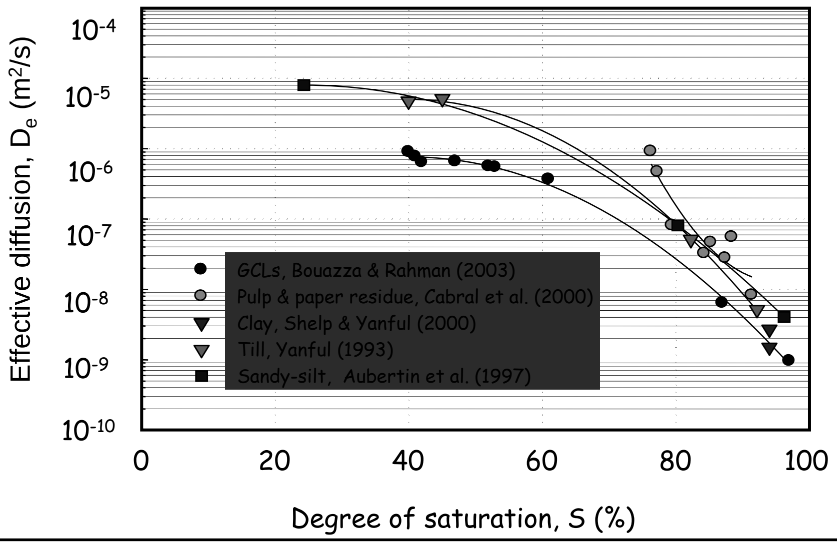
Variation of intrinsic gas permeability of GCLs under wetting and drying conditions



Variation of effective diffusion against degree of saturation



Variation of effective diffusion against degree of saturation: comparison with soils



$$F = D_e\left(\frac{C_0 - C_1}{h}\right)$$

C_o = 0.3 kg/m^3 (atmospheric concentration),

C_1 = 0 (oxygen consumed)

For acid mine drainage, recommended max oxygen flux is 20 to 50 g/m^2/ year

F = 50 g/m^2/year

D_e = 4.5 x 10^{-11} m^2/s

CONCLUSIONS

Geosynthetic clay liners have gained over the past decade widespread popularity but they should not be seen as a panacea to all containment problems.

Data available suggests that they have very low hydraulic conductivity to water and they can maintain their hydraulic integrity over the long term.

The critical aspects about the service life of the GCL as far as hydraulic integrity is concerned can be related to long term chemical compatibility problems

With respect to gas migration, on-going studies suggest that it is dependent on moisture content and types of GCLs.