# GEOANZ #1

## ADVANCES IN GEOSYNTHETICS

7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE

# Performance of Geosynthetic Clay Liners in high-risk applications

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# Content:

GCL and calcium rich subgrades

GCL and non-standard liquids

GCL and high thermal gradient

GCL and arsenic rich tailings

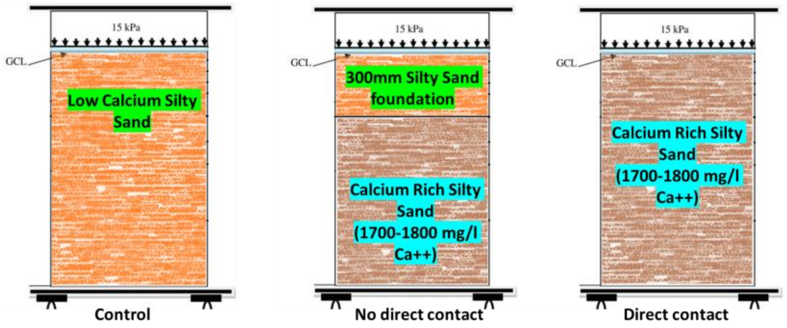
# GCL hydration depends on:

| Foundation | GCL | External |
| --- | --- | --- |
| • Water content<br>• Soil type<br>• Pore water chemistry<br>• Mineralogy<br>• Macro structure<br>• Compaction and subgrade density<br><br>(**Subgrade WR**C) | • GCL manufacture/structure<br>• GCL mass per unit area<br>• Pore structure of the bentonite and GCL geotextile<br>• Nature/type of the bentonite<br>• Initial water content<br><br>(**GCL WRC**) | • Confining stress<br>• GCL placement<br>• Temperature & Thermal cycles<br>• Permeant<br>• Steady-state thermal gradient<br>• Time |

# GCL and calcium rich subgrades:

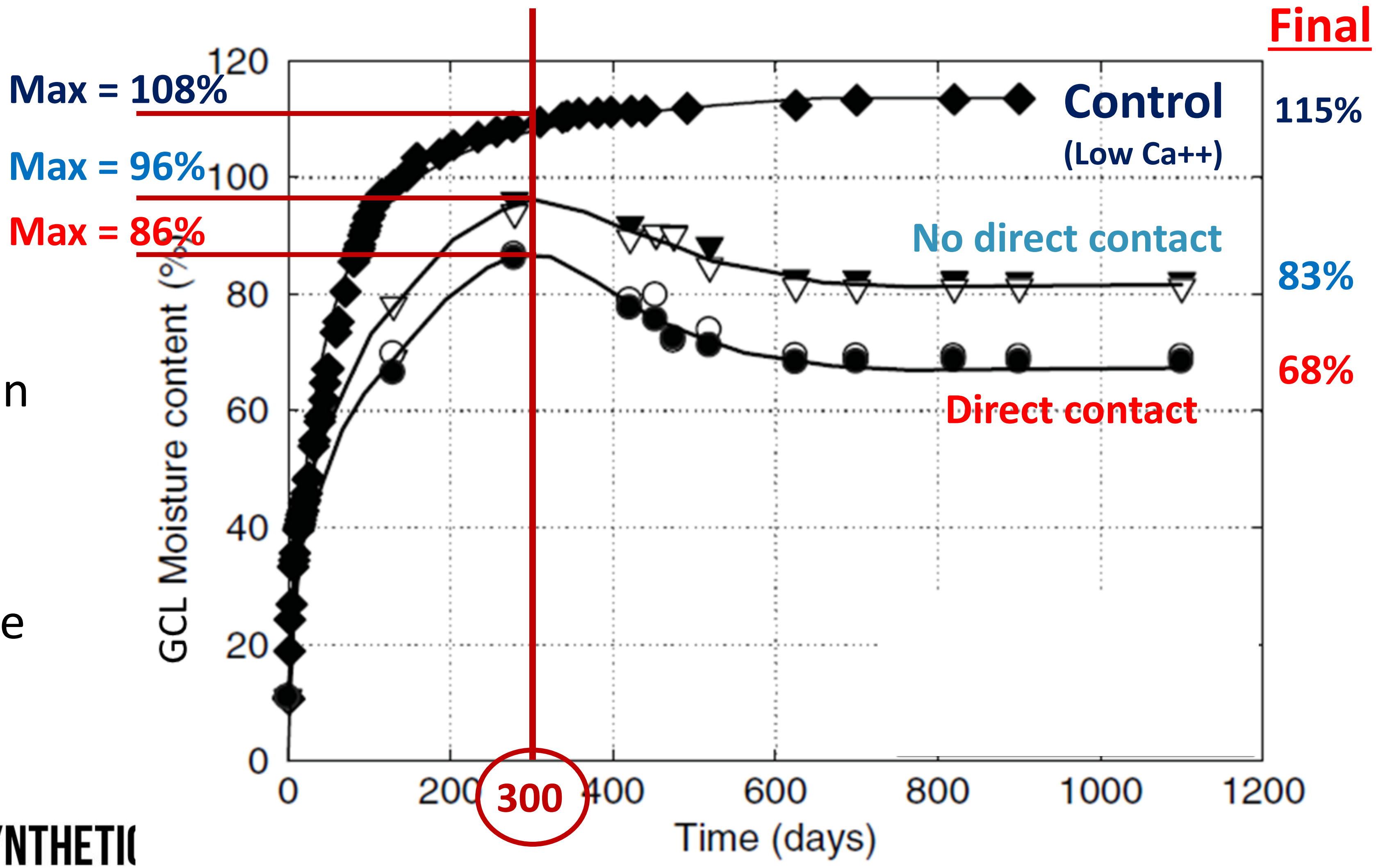
# Subgrade pore water chemistry

Rowe and Abdelatty (2012)




- It is because of exchange of Ca++ from subgrade with Na in the GCL

- Calcium exchange => loss of bond water => loss of moisture => lower final water content



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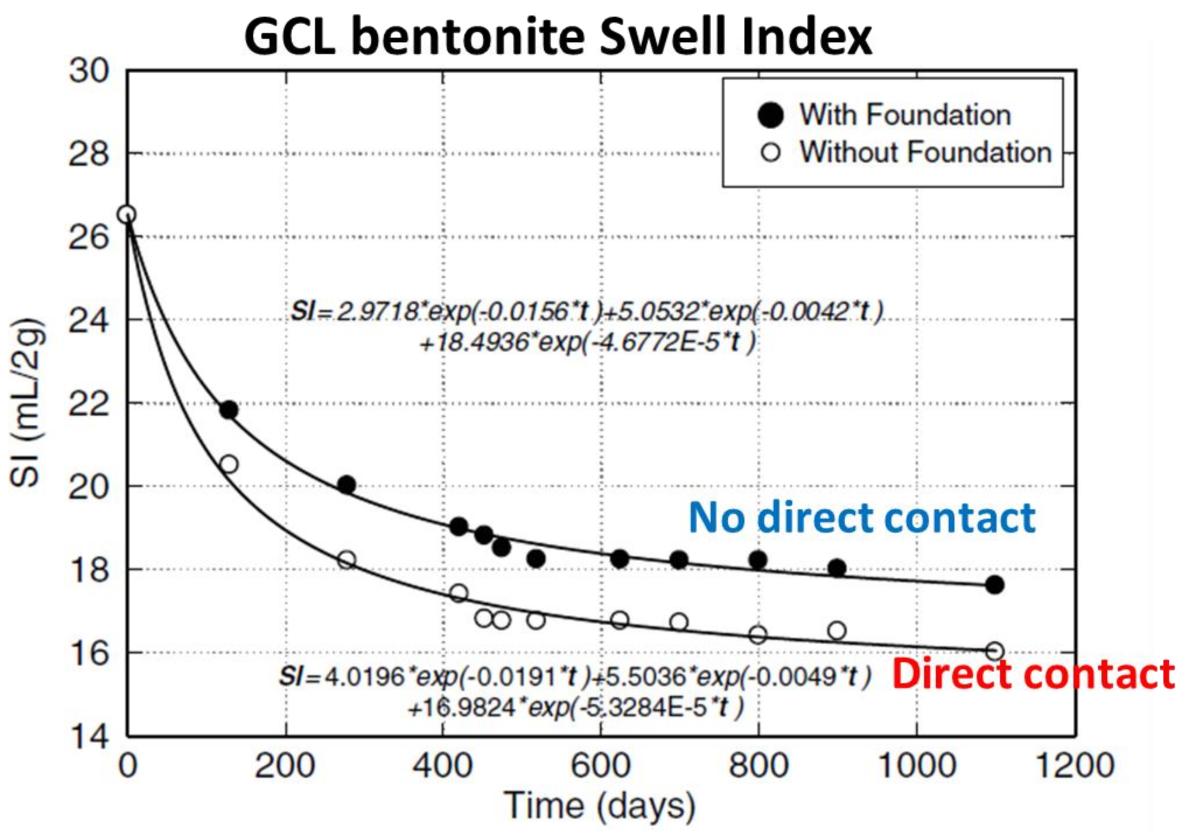
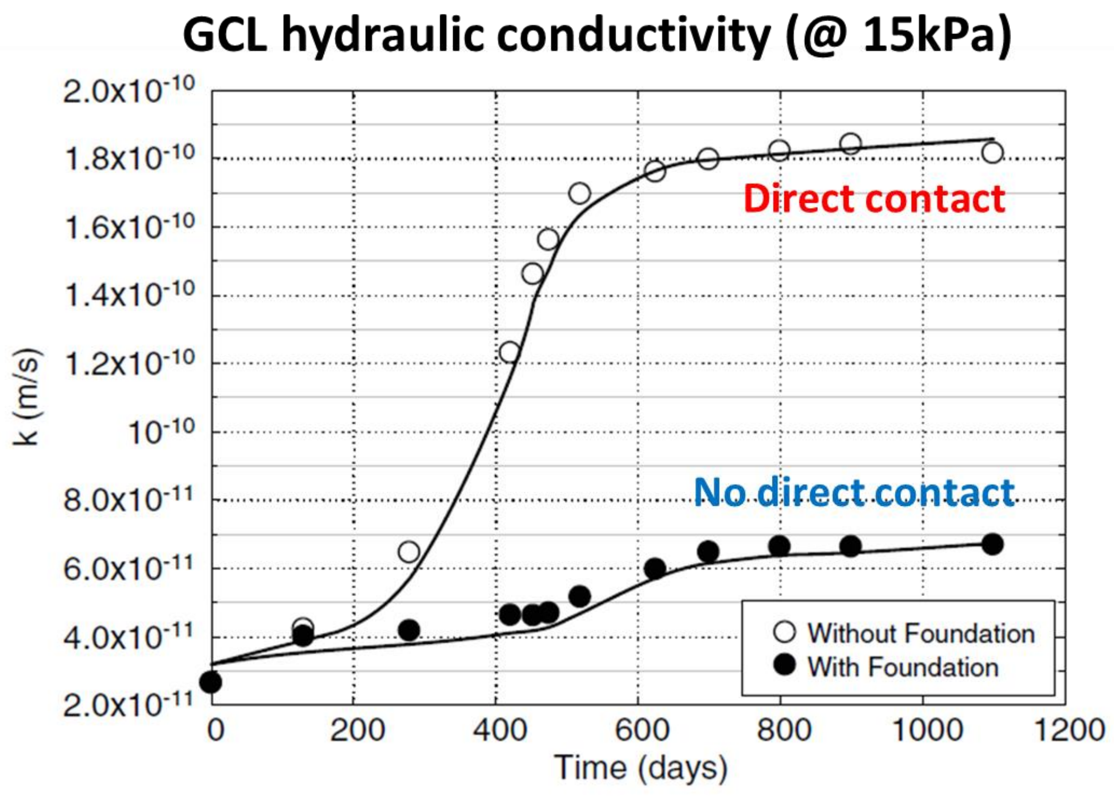
## Rowe and Abdelatty (2012):



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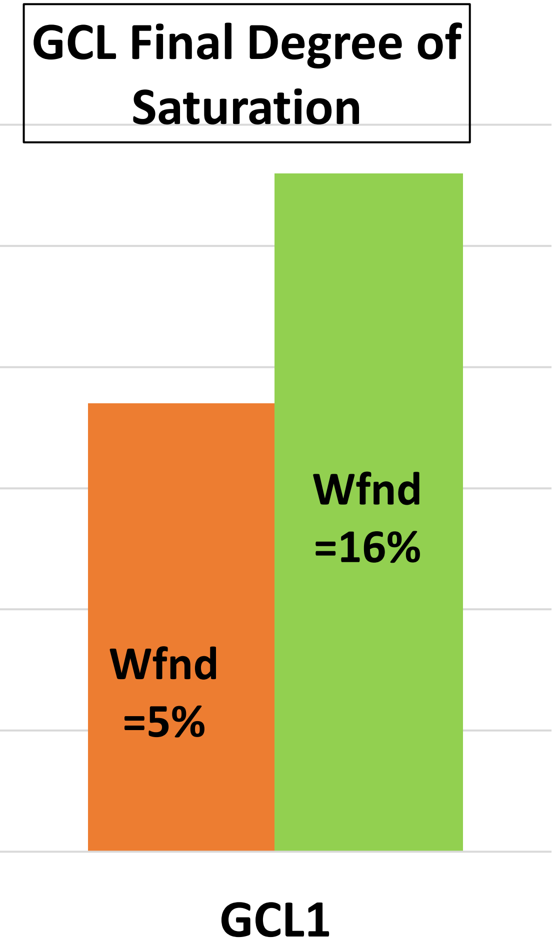
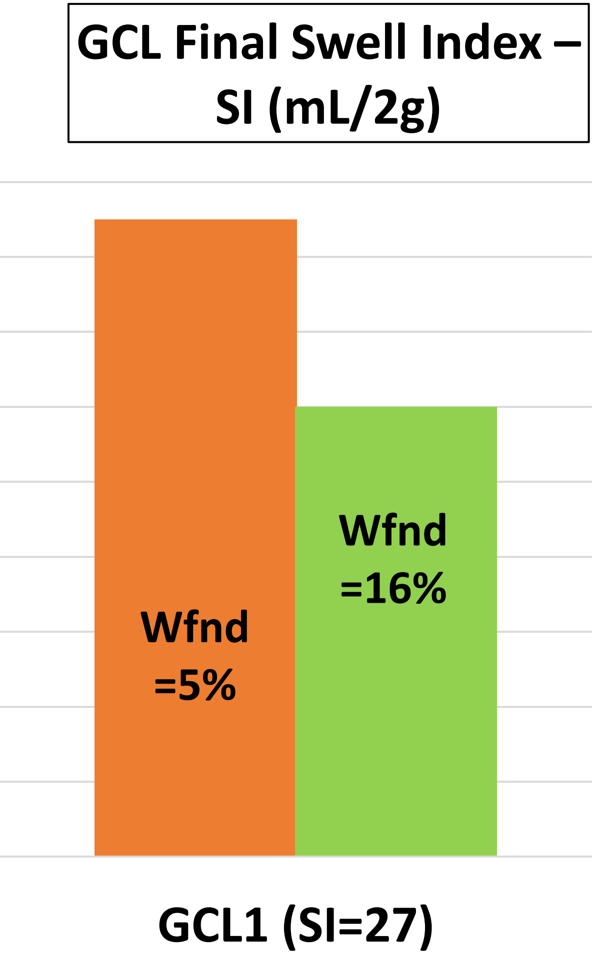
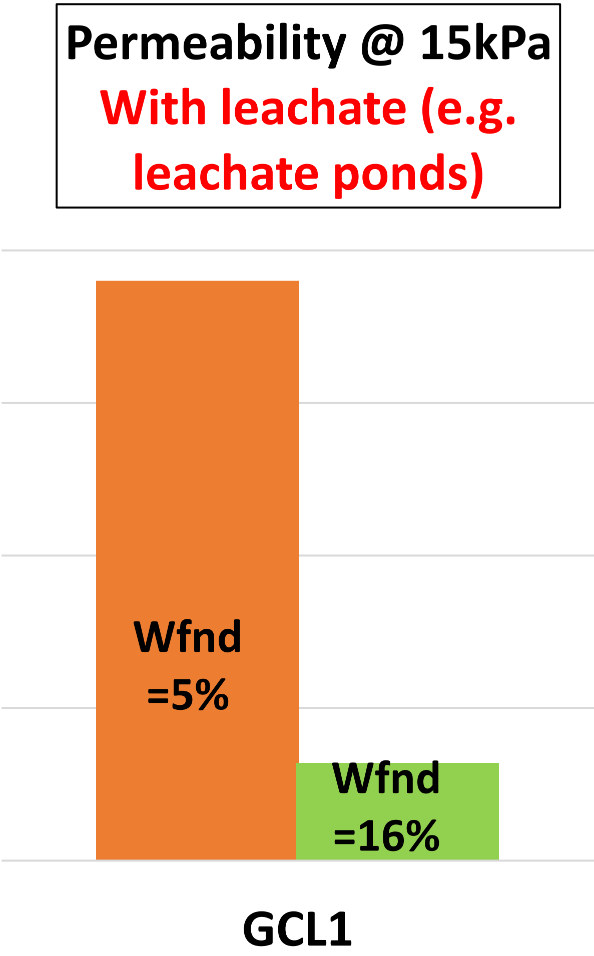
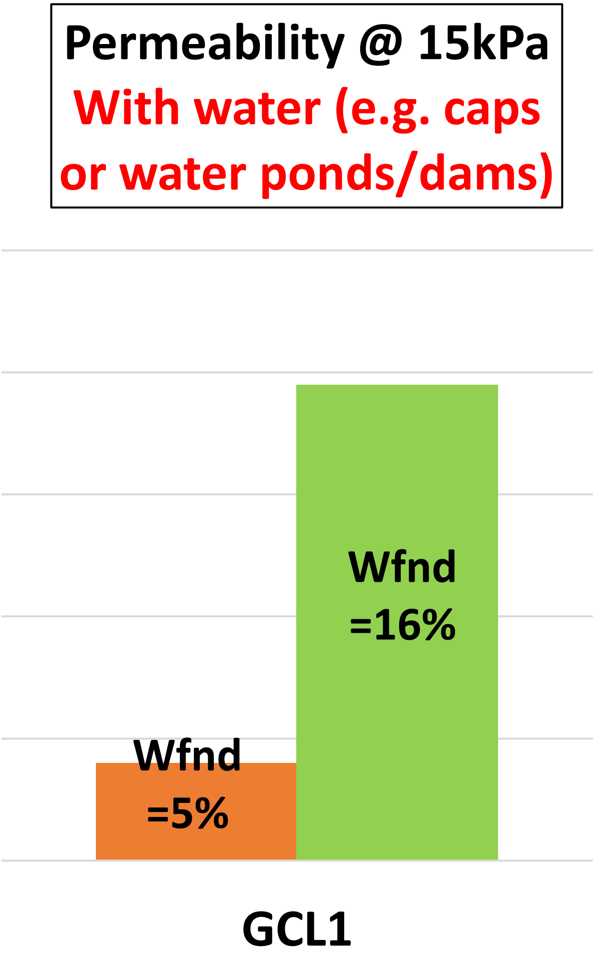
**Rowe and Abdelatty (2012, 2020):**

Higher confinement can change this



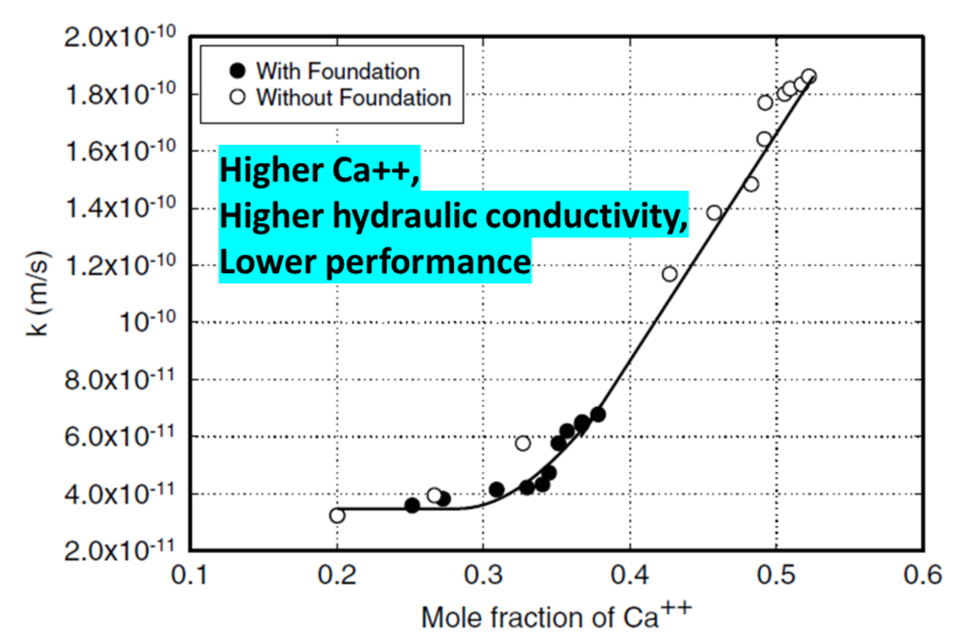



# Lessons learned:

- The **chemistry** of **both** the **<u>pore water in the subgrade</u>** and **<u>final permeant</u>**, along with **subgrade water content** (and of course confinement) will all affect the final hydraulic conductivity of the GCL in many practical situations.

- <u>Final</u> water content and degree of saturation of the GCL is more important than maximum water content of the GCL.

- The higher the cations concentration in the subgrade, the lower the performance of the GCL:



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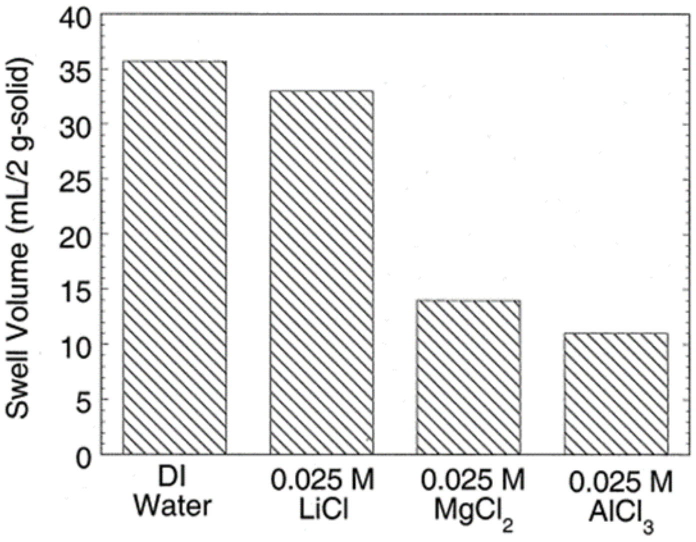
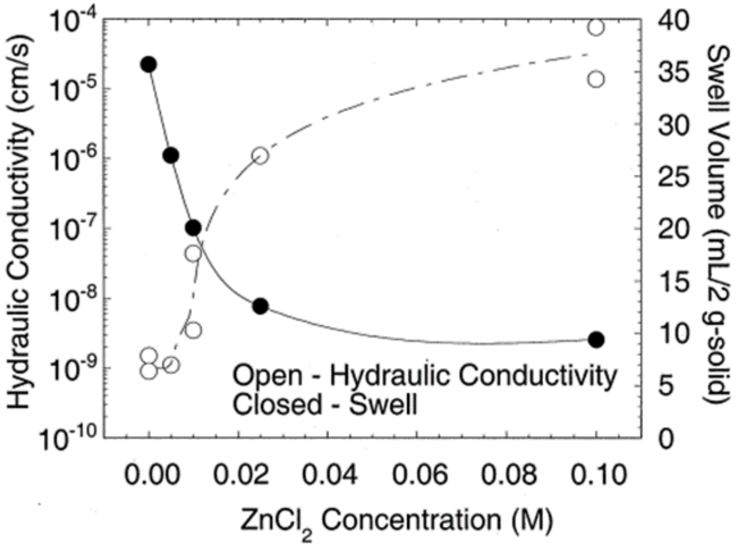
# GCL and non-standard liquids:

- Single-species salt solutions
- Multispecies inorganic salt solutions
- High/low PH permeants

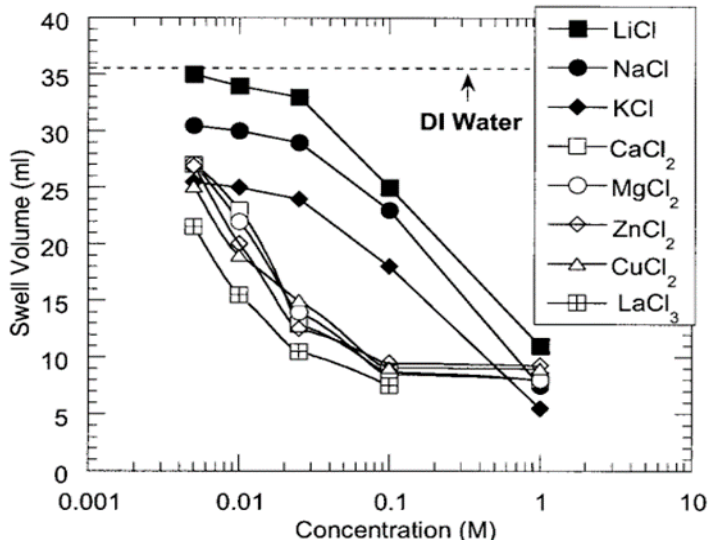
# GCL performance hydrated with Single-species salt solutions:

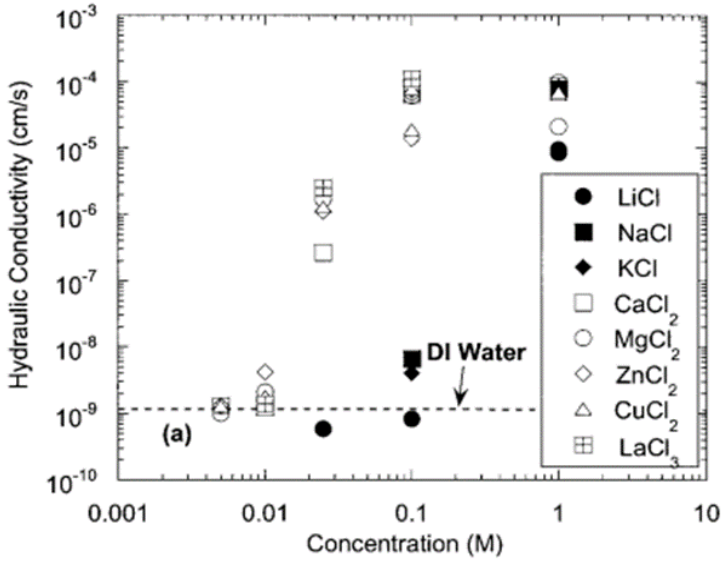
Effect of permeant:
Shackelford et al. (2000)




Effect of concentration:
Jo et al. (2001)



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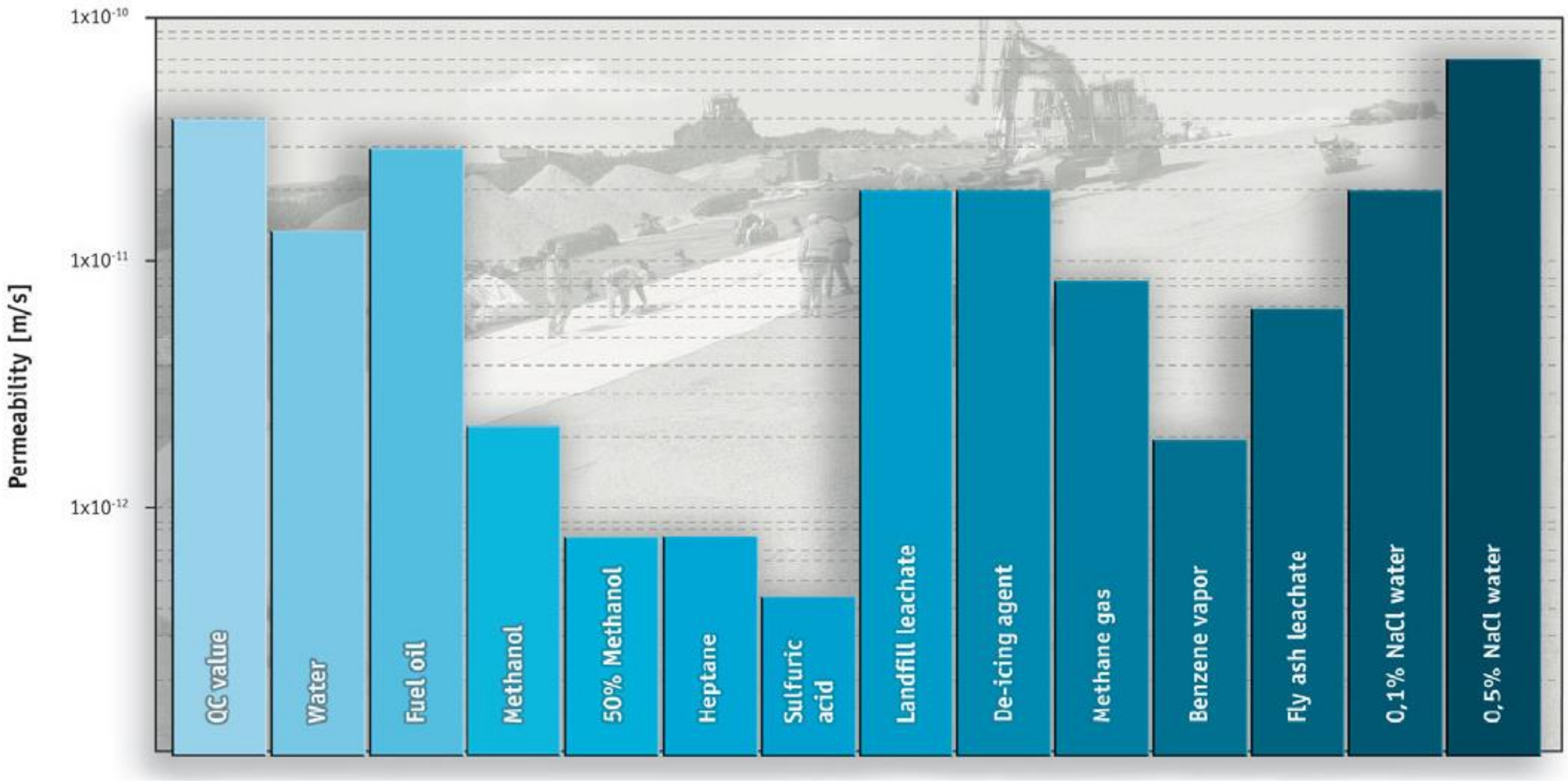
# GCL performance hydrated with Single-species salt solutions:




Permeability of pre-hydrated Bentofix® GCLs with approx. 4,000 - 5,000 g/m² bentonite) tested against various liquids and gases at approx. 30 kN/m² confining stress.



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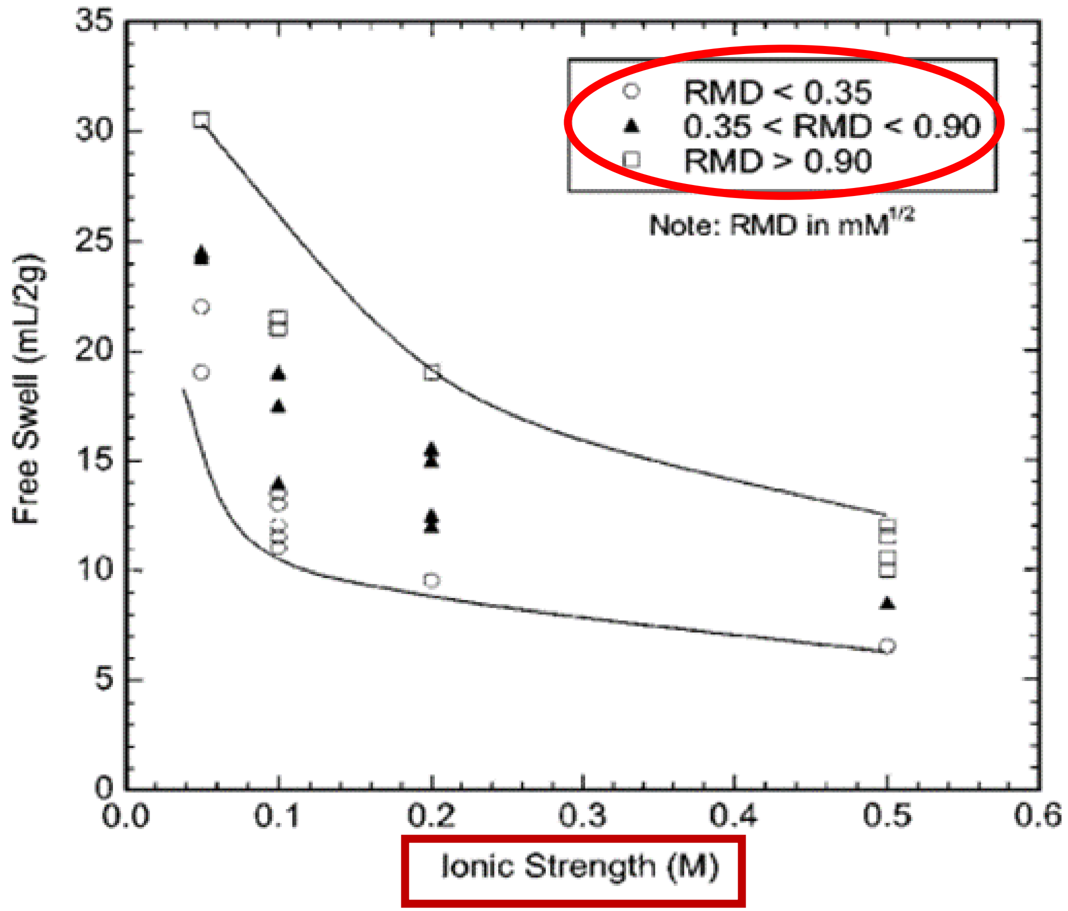
# Lessons learned (Jo et al, 2001):

- For single-species salt solutions, at similar concentration, **swell** was largest with monovalent cations $Na^+$, $K^+$, and $Li^+$ ($NaCl$, $KCl$, and $LiCl$ solutions), smallest with trivalent cation $La^{3+}$ ($LaCl_3$ solutions) and intermediate with divalent solutions ($CaCl_2$, $MgCl_2$, $ZnCl_2$, and $CuCl_2$).
- GCL specimens permeated with solutions containing divalent or trivalent cations had higher **hydraulic conductivity** than GCLs permeated with monovalent solutions or deionized water, unless the divalent or trivalent solutions were very dilute (≤0.01 M).
- Hydraulic conductivity increased as the **concentration** increased, and at high concentration (1 M) only small differences existed between hydraulic conductivities measured with all solutions.

# GCL and multispecies inorganic salt solutions:

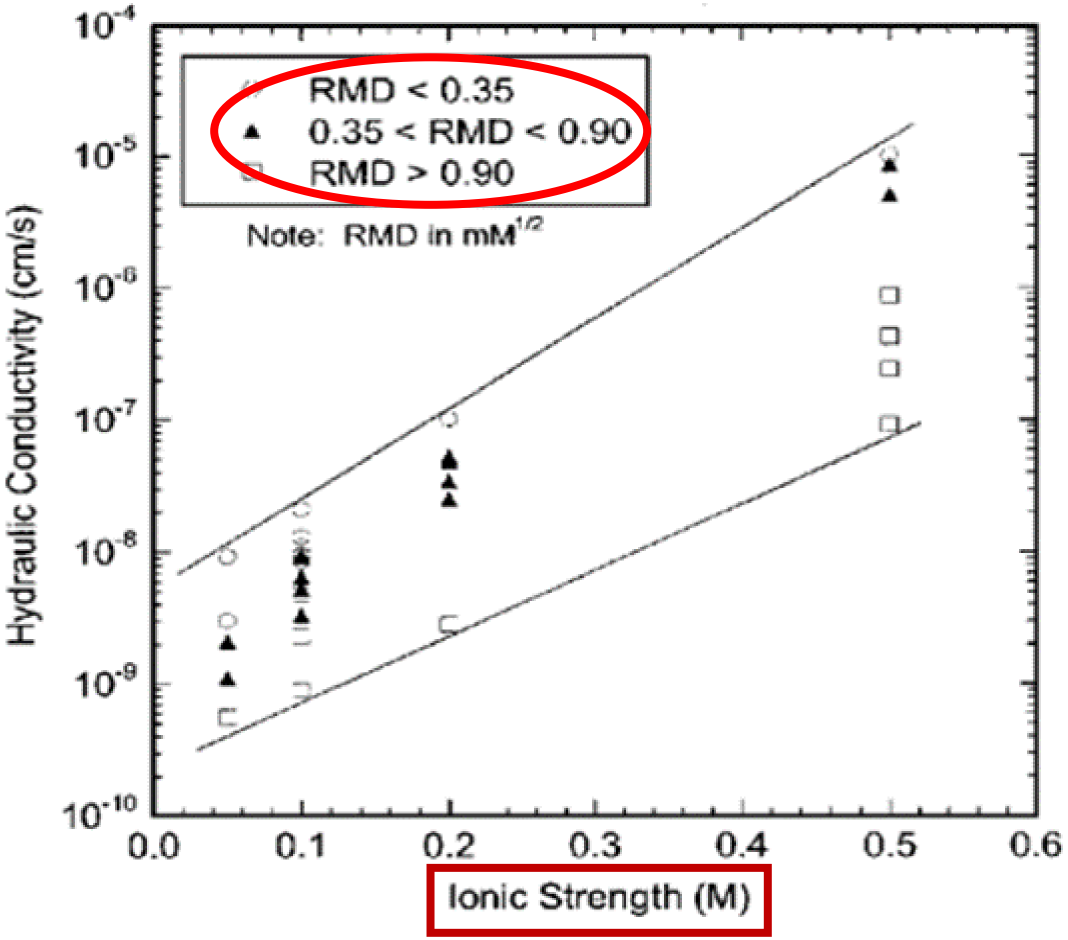
## Free swell:

Benson et al. (2004)




## Hydraulic conductivity:

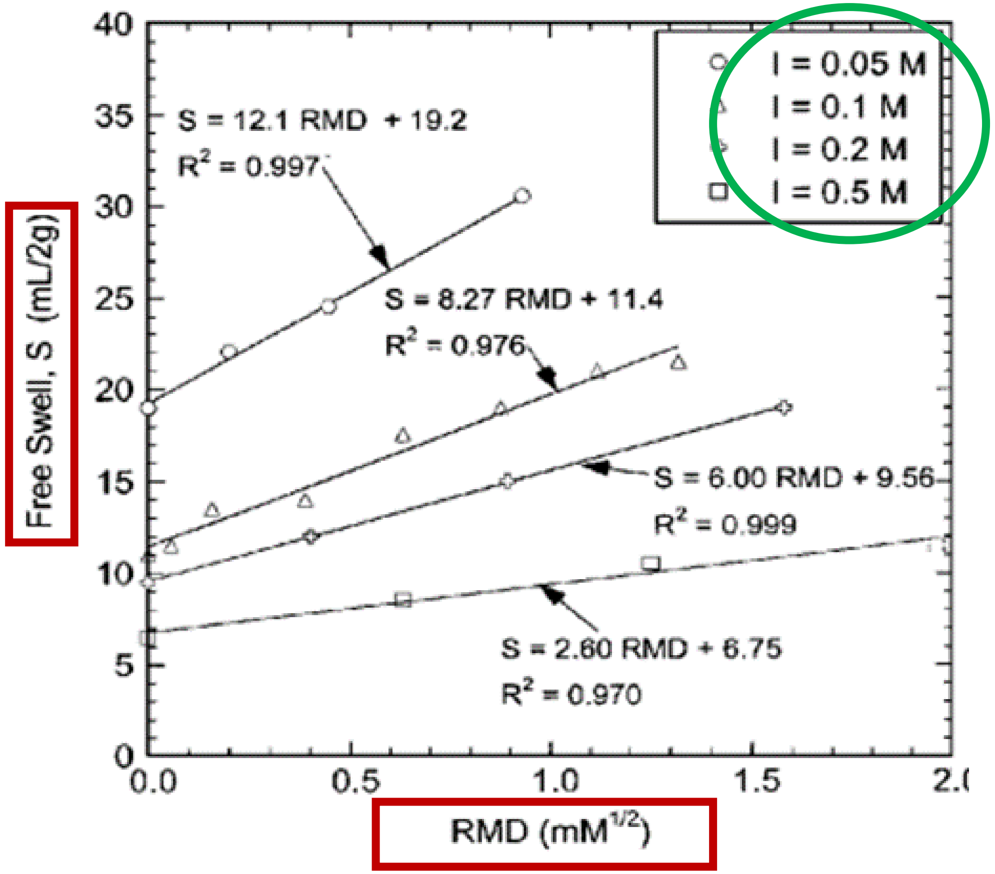
Benson et al. (2004)



# GCL and multispecies inorganic salt solutions:

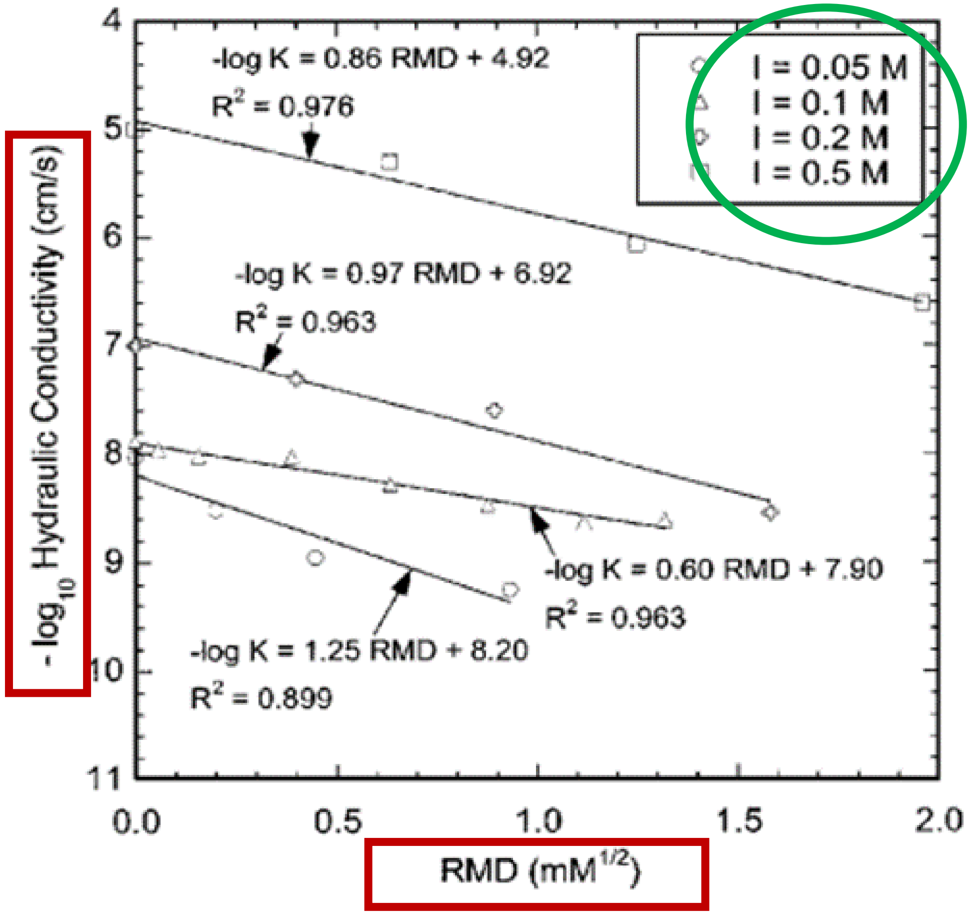
<u>Free swell and RMD:</u>

Benson et al. (2004)




<u>Hydraulic conductivity and RMD:</u>

Benson et al. (2004)



# Lessons learned (Benson et al., 2004)

- For multispecies inorganic salt solutions, **Ionic Strength** and the **relative abundance of monovalent and divalent cations (RMD)** in the permeant solution were found to influence the swell of the bentonite, and the hydraulic conductivity of GCLs.
- Higher RMD results in more swell and less hydraulic conductivity (Positive effect).
- Higher Ionic Strength results in less swell and higher hydraulic conductivity (negative effect).
- RMD has a greater influence for solutions with low ionic strength (e.g., 0.05 M), whereas concentration effects dominate at high ionic strength (e.g., 0.5 M).

# GCL and high thermal gradient:

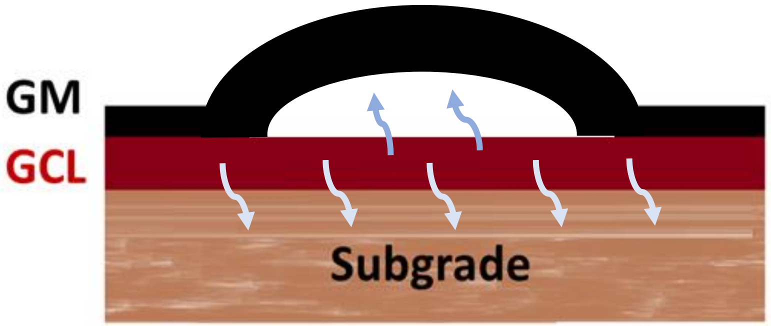
<u>Applicable to:</u>

- Brine ponds
- Solar ponds
- Heap-leach pads
- Landfills

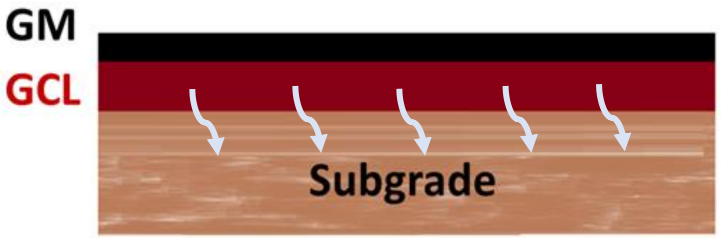
# Effect of thermal gradient:

- One side (top) of the liner has always higher temperature than the other side (bottom)

- This constant temperature gradient can cause:
  - GM WITHOUT wrinkle: GCL water vapour migrates out towards subgrade and GCL moisture content decreases (GCL suction from subgrade cannot catch up to balance the GCL moisture loss)
  - GM WITH Wrinkle: Same as the above, plus GCL moisture evaporation under the wrinkle void space




**What can be the result?**
**GCL desiccation, even under confinement**



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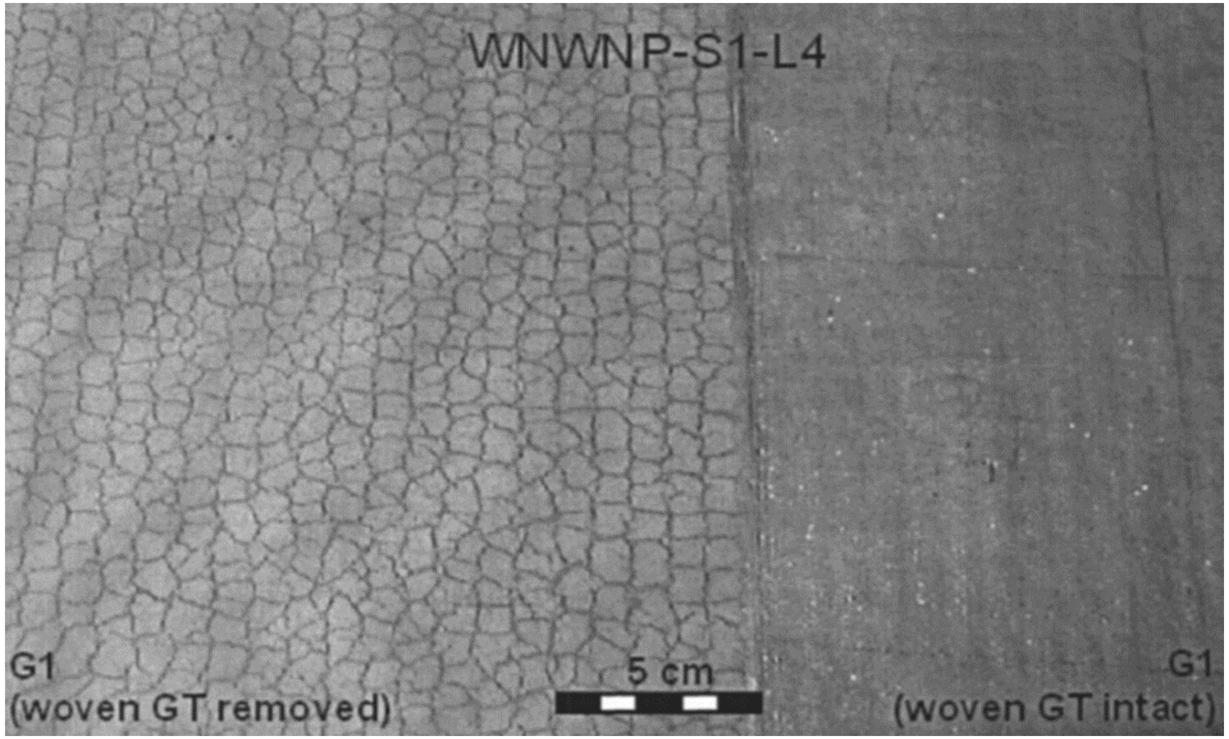
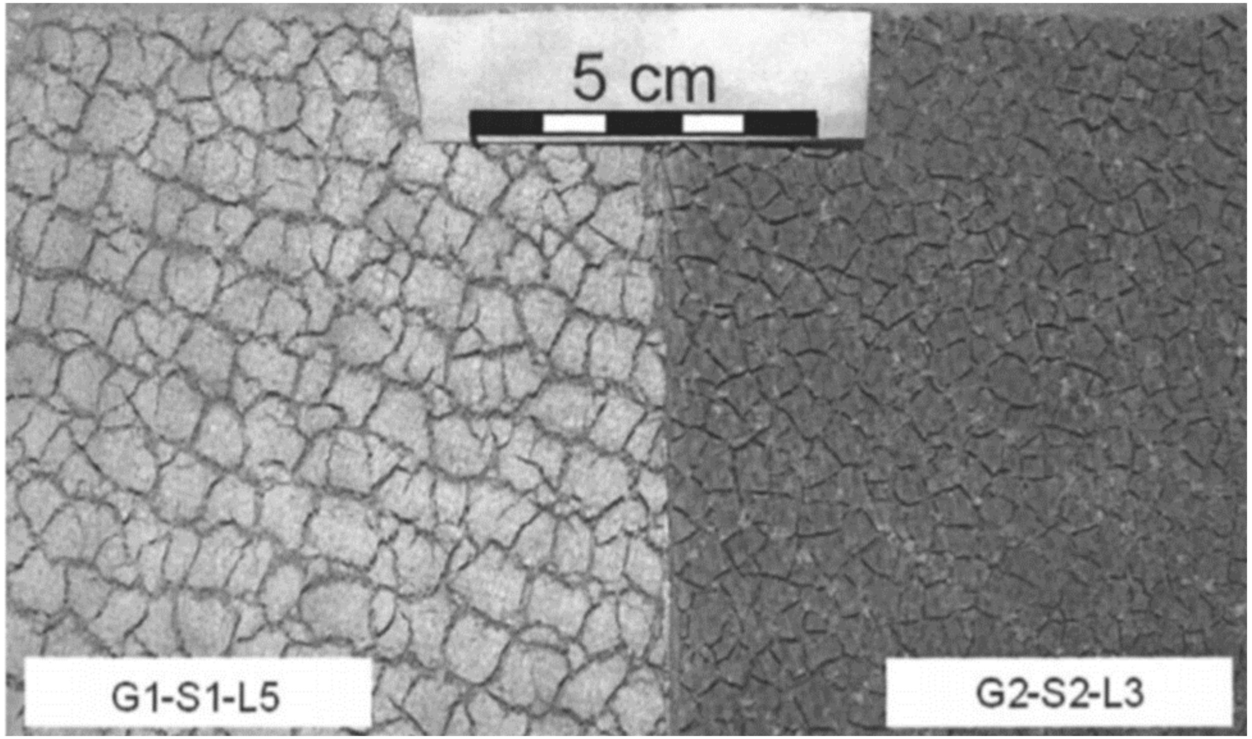
# Effect of thermal gradient:

Southern and Rowe (2005)




15kPa Pressure




50kPa and 70kPa Pressure

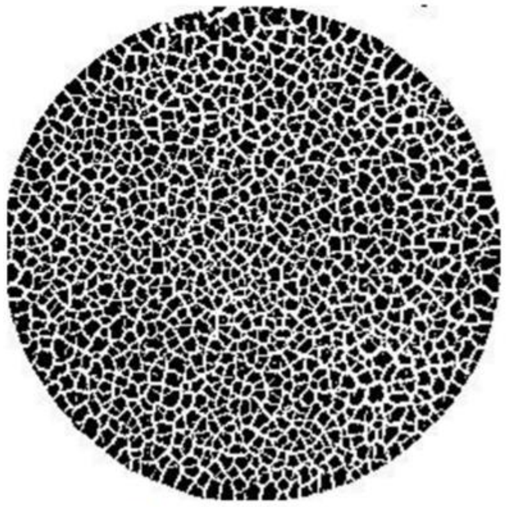
- **Even if the high temperature is maintained for relatively short time, dissociation can still occur (Zhou and Rowe, 2003)**

# Effect of thermal gradient:

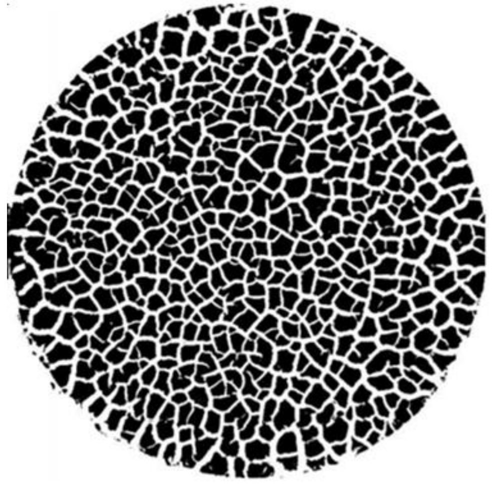
- **Yu et al. (2018) – Brine pond:**

| Experiment Control Parameters | | GCL_A | GCL_B |
|---|---|---|---|
| Duration of Each Stage of Experiment | Subsoil moisture equilibrium | 14 days | 21 days |
| | GCL hydration | 44 days | 56 days |
| | Heating | 39 days | 28 days |
| Temperature applied during equilibrium and hydration stages | Top | 20±1°C | |
| | Bottom | 20±1°C | |
| Temperature applied during heating stage | Top | 78±1°C | |
| | Bottom | 20±1°C | |

| | GCL initial water content | GCL Final water content after hydration from subgrade (room temperature, @ 20kPa) | GCL Final water content at the end of heating period |
|---|---|---|---|
| **GCLA** | 9% | 126% | 7.5%<br>(After 28 days heating @ 78°C) |
| **GCLB** | 11% | 141% | 10%<br>(After 56 days heating @ 78°C) |



(b)GCL_A Column II



(d) GCL_B Column II

Desiccation cracks



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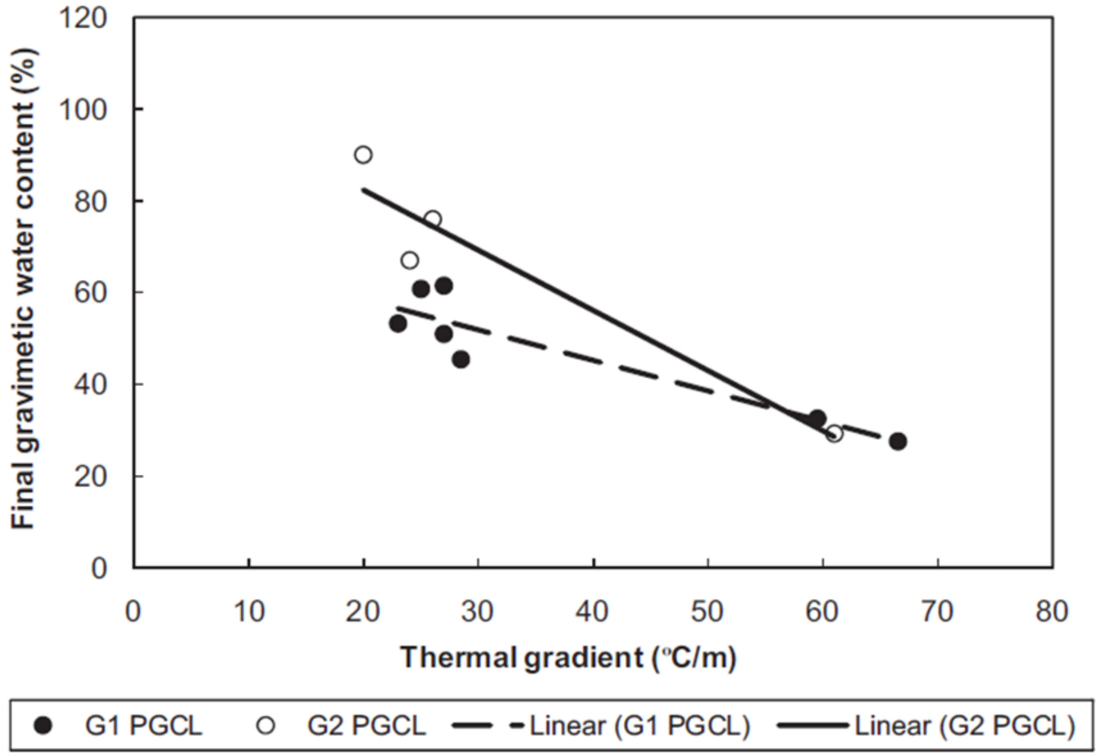
# Effect of thermal gradient:

**Solution:**

- Higher subgrade initial water content (the higher, the better)
- Using Multicomponent GCL to prevent moisture loss
- Minimise the thermal gradient (the lower, the better):



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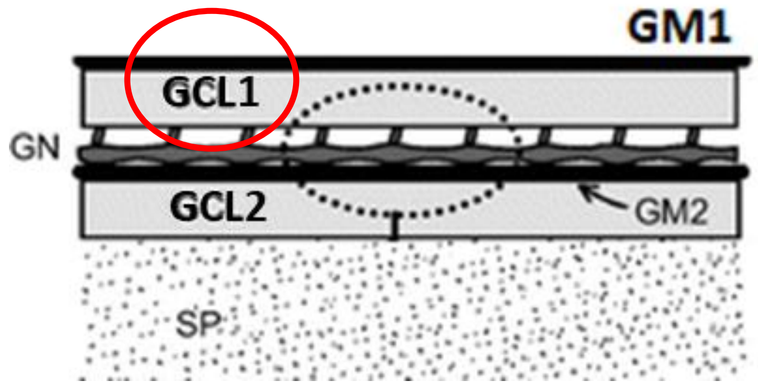
# Effect of thermal gradient in double composite liners:

Azad et al. (2012)

## GCL 1 (Primary):

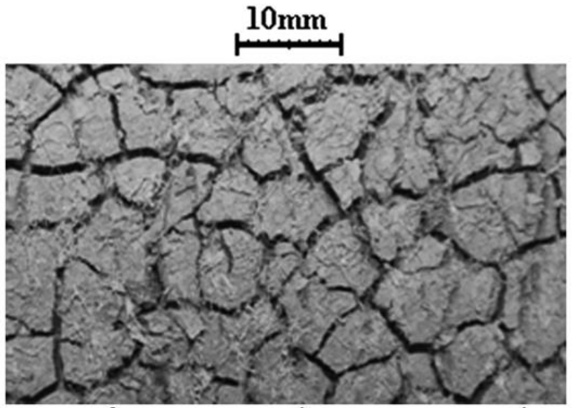
For to temperature > 40 degrees, GCL1 lost about 2/3$^{rd}$ of its moisture (into the geonet).

=> Deep cracks in GCL1 for top temperature > 40 degrees




After cracking, the GCL1 rehabilitation and performance (e.g. K value) depends on:

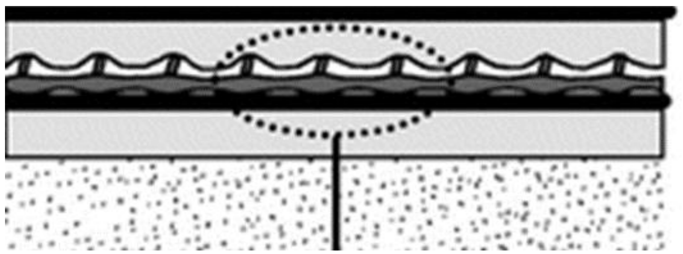
- The leaked liquid from a hole in the GM1 to rehydrate the GCL
- The confinement

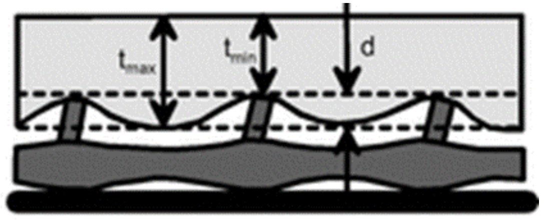


GCL 1 after removing the cover geotextile

Other risks?

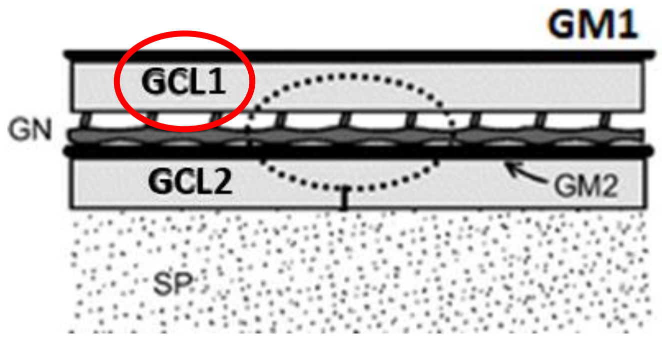
- Intrusion of the GCL into the geonet
- Reduction of geonet capacity
- Risk of bentonite erosion in the long term





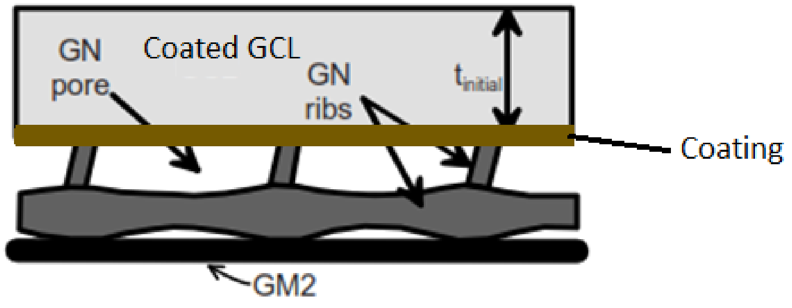
Deformed shape

# Effect of thermal gradient in double composite liners:




**Solution:**

- Minimising the thermal gradient (The lower, the better)
- Trying to keep GCL1 hydrated
- High GCL1 initial water content
- Using multicomponent GCL for GCL1 with Coating/film facing the geonet (Ref.: GRI-GCL5)
  - GCL will not loos moisture
  - No GCL intrusion into the GN
  - No GCL erosion




Multicomponent GCL



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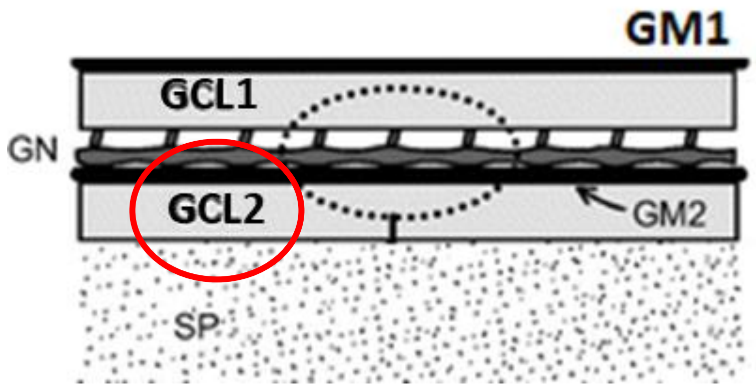
# Effect of thermal gradient in double composite liners:

Azad et al. (2012)

## GCL 2 (Secondary):

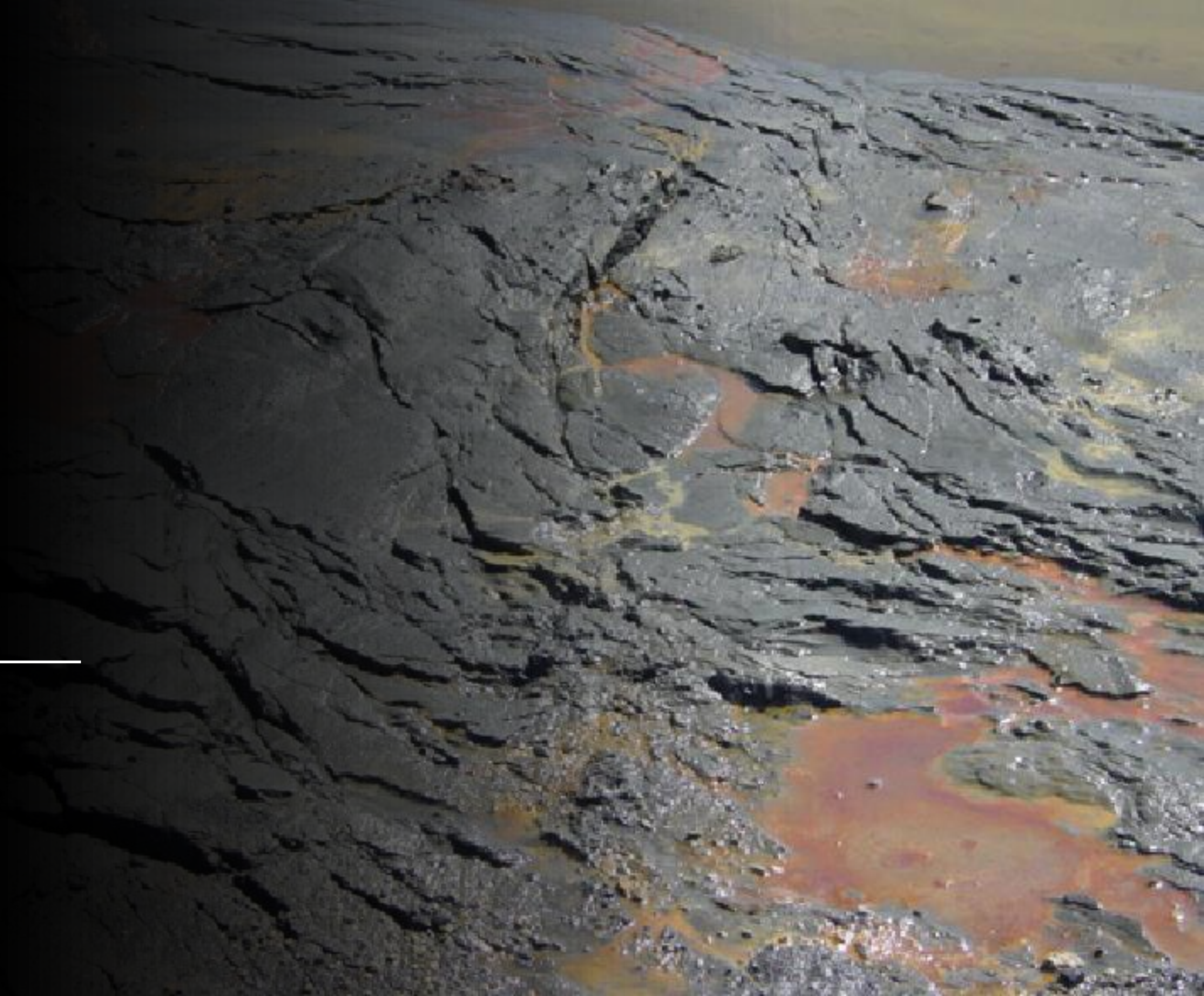
Cracks occurred for high top temperature (> 45 degrees) and low initial subgrade water content




Solution:

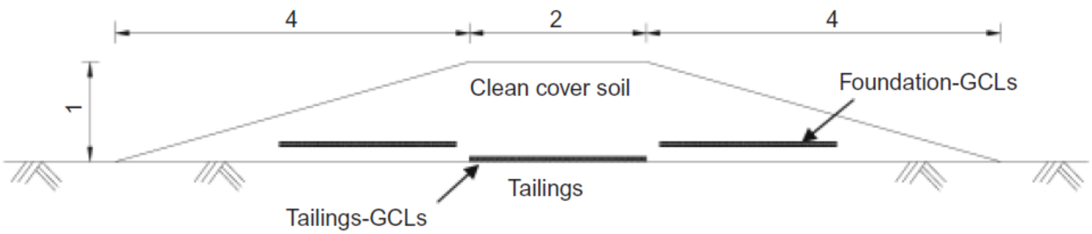
- Higher subgrade initial moisture content
- Thicker Geonet for leak detection (Bouazza et al. 2017)- Larger gap can reduce the heat flow to the bottom liner and subgrade
- The coating in GCL1 can reduce the heat as well

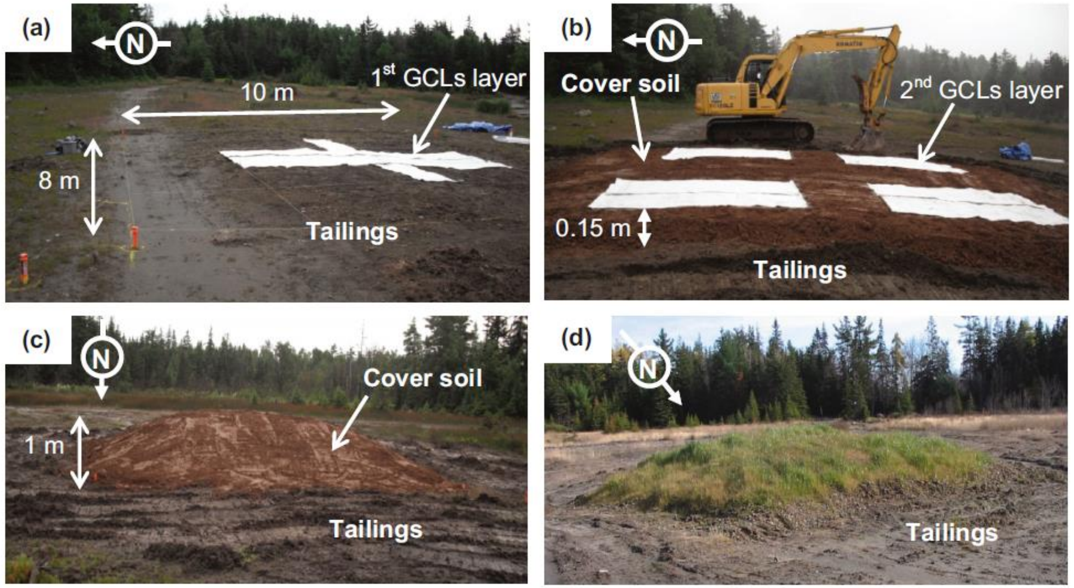
# GCL and Arsenic Rich Tailings



# GCL and Arsenic Rich Tailings

- Hosney and Rowe (2013, 2014)




| Parameter | GCL A | GCL B | GCL C |
|---|---|---|---|
| Avg. bentonite mass/area (g/m²) | | | |
| Measured | 4491 (SD, 401; $n$ = 14) | 5009 (SD, 336; $n$ = 14) | 5238 (SD, 608; $n$ = 14) |
| MARV[a] | 3660 | 4340 | 3660 |
| Carrier GTX | | | |
| Type | W[c] | NWSR[c] | W/P[c] |
| Mass (g/m²) | 123 (SD, 13; $n$ = 4) | 253 (SD, 23; $n$ = 4) | 125 (SD, 12; $n$ = 4) |
| Cover GTX | | | |
| Type | NW[c] | NW[c] | NW[c] |
| Mass (g/m²) | 231 (SD, 17; $n$ = 4) | 235 (SD, 15; $n$ = 4) | 232 (SD, 19; $n$ = 4) |
| Structure | | | |
| Needle punched | Yes | Yes | Yes |
| Thermally treated | Yes | Yes | Yes |

[c]NW, nonwoven geotextile; NWSR, nonwoven scrim reinforced geotextile; W, woven geotextile; W/P, woven geotextile with a thin polypropylene film.

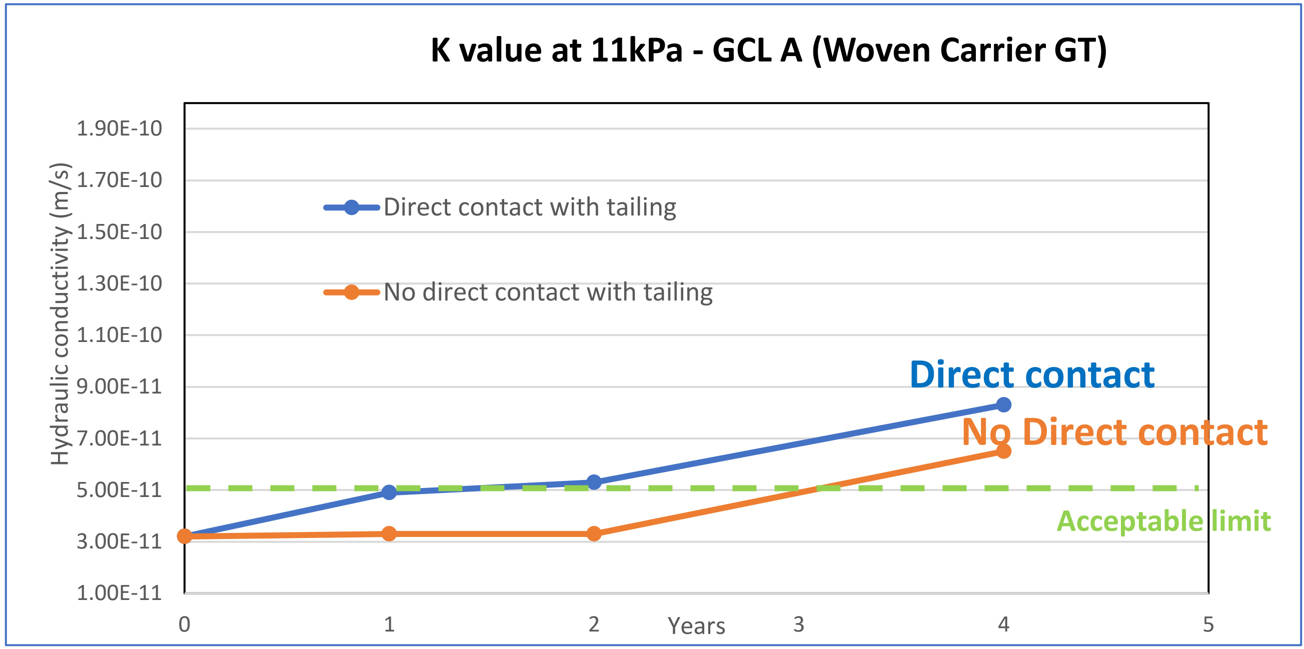
**GCL A: Woven carrier GT**

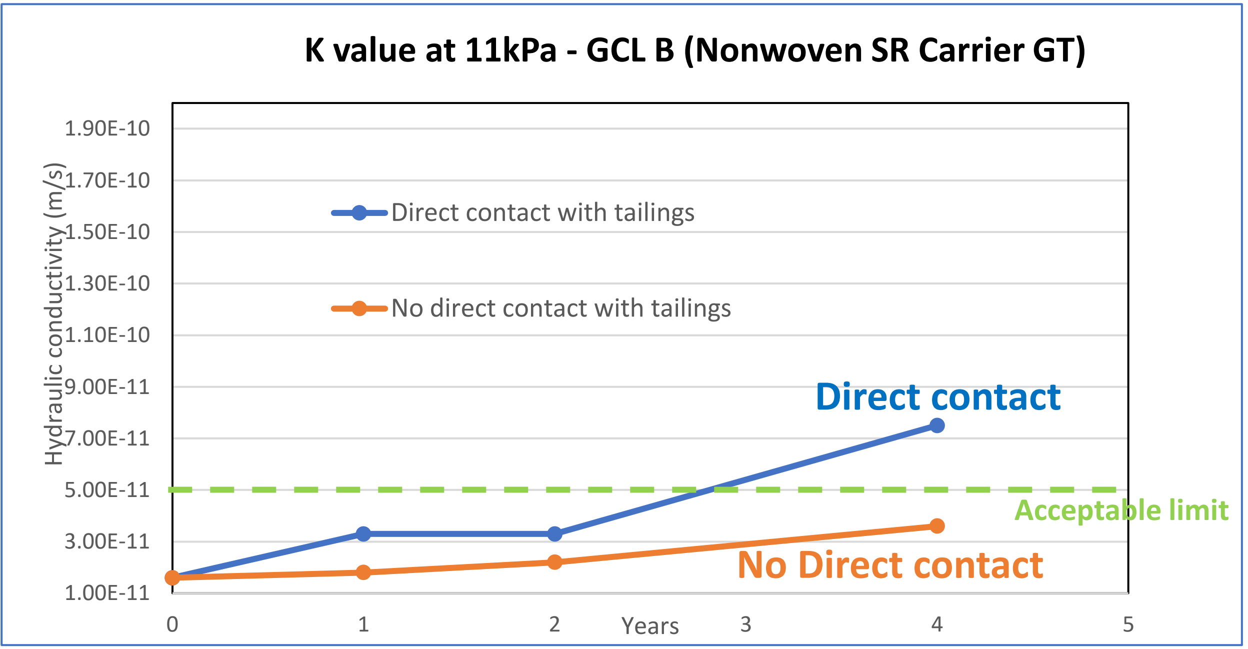
**GCL B: Non-Woven Scrim Reinforced (SR) carrier GT**

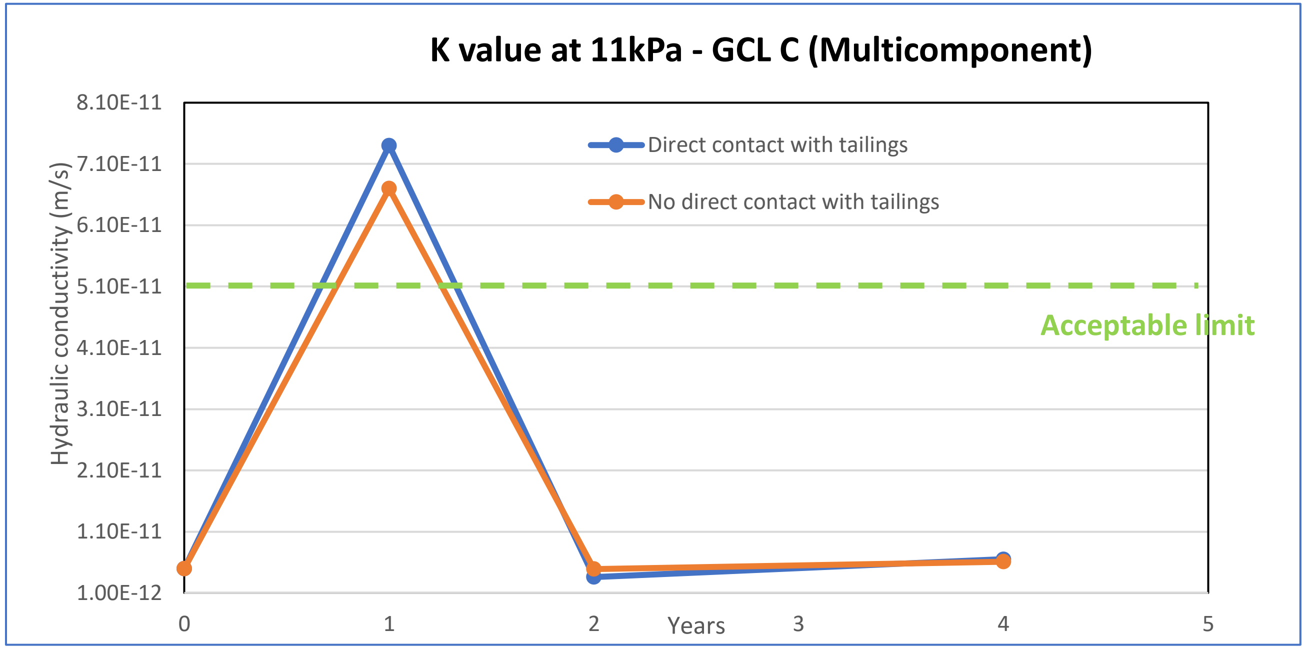
**GCL C: Multicomponent (thin film attached) carrier GT**

# Effect of GCL type:

After Hosney and Rowe (2013, 2014)



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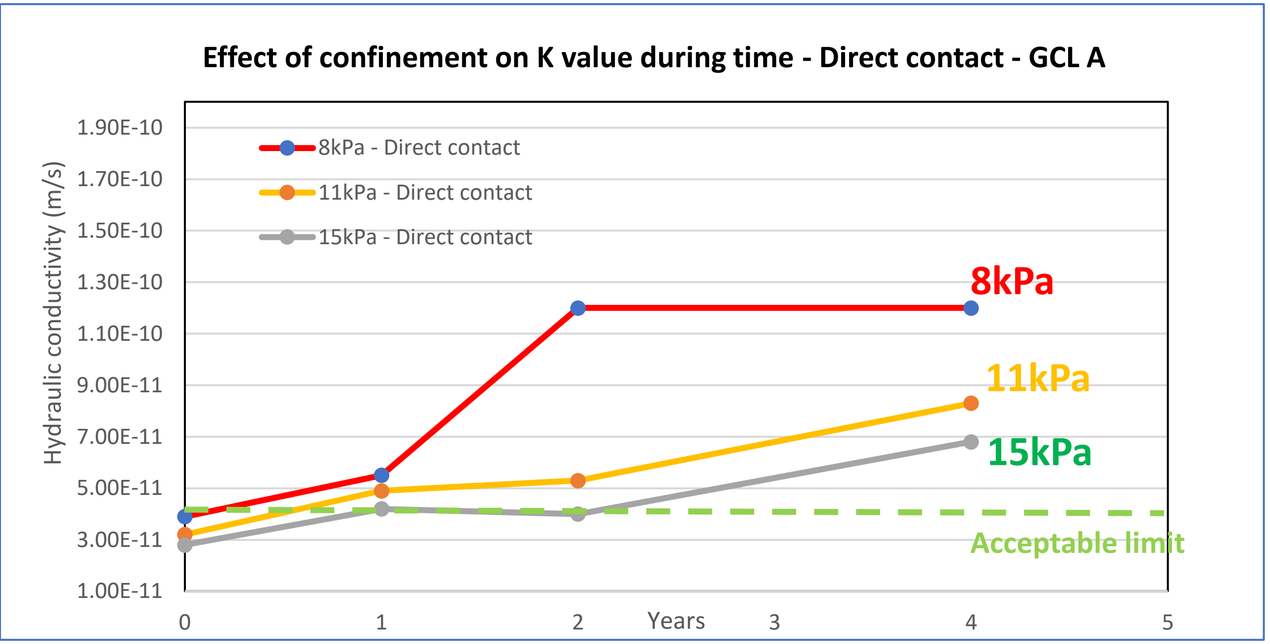
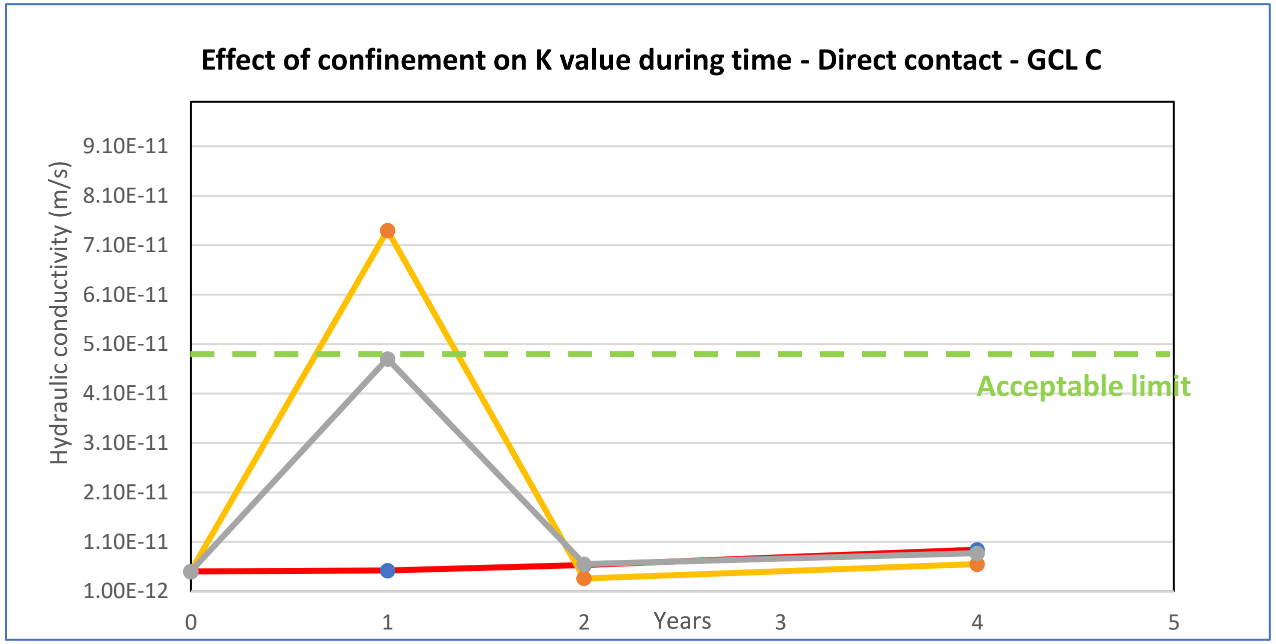
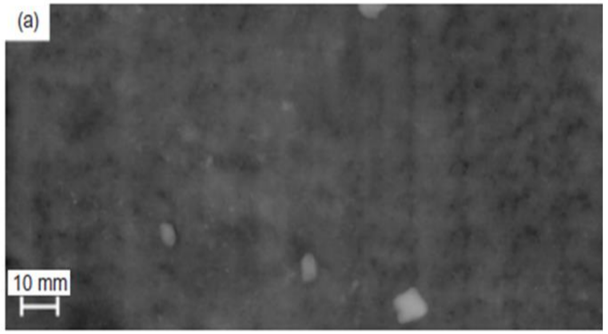
# Effect of confinement:

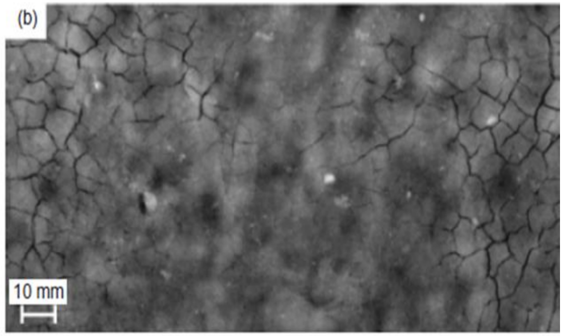
After Hosney and Rowe (2013, 2014)




After 4 yrs with **15kPa**




After 4 yrs with **11kPa**



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# Effect of GCL on Arsenic emission from tailings

After Hosney and Rowe (2013, 2014):

**Arsenic concentration in cover soil**

| GCL | Soil directly below GCL | Stress (kPa) | Arsenic concentration: Porewater (mg/L) 1 year | Porewater (mg/L) 2 years | Solid phase (mg/kg) 1 year | Solid phase (mg/kg) 2 years |
|---|---|---|---|---|---|---|
| A : **Woven carrier GT** | | | | | | |
| | Tailings | 8 | 3 | 2 | 29.4 | 35.5 |
| | | 11 | 4 | 3 | 27.8 | 30.0 |
| | | 15 | 3 | 6 | 26.9 | 30.9 |
| B : **Non-Woven Scrim Reinforced (SR) carrier GT** | | | | | | |
| | Tailings | 8 | 2 | 2 | 14.3 | 23.8 |
| | | 11 | 2 | 3 | 14.1 | 20.8 |
| | | 15 | 3 | 3 | 15.6 | 24.2 |
| C : **Multicomponent (thin film attached) carrier GT** | | | | | | |
| | Tailings | 8 | <0.03 | <0.03 | 7.5 | 7.8 |
| | | 11 | <0.03 | <0.03 | 6.5 | 6.9 |
| | | 15 | <0.03 | <0.03 | 5.4 | 8.7 |

**Note:** Each data point for virgin GCLs is an average of three measurements.

- Arsenic emission is reduced with increase in the GCL hydration/degree of saturation.
- Multicomponent GCL had highest reduction in Arsenic emission.

# Lessons learned (Jo et al., 2001):

- Tailings chemistry can affect the performance of the GCL. GCL should not be in direct contact with tailings unless it is a multicomponent GCL.

- Arsenic emission from tailings can be reduced by higher GCL degree of saturation and using multicomponent GCLs

# Summary:

- The **chemistry** of **both** the **pore water in the subgrade** and **final permeant**, along with **subgrade water content** (and of course confinement) will all affect the final hydraulic conductivity of the GCL in many practical situations.

- The higher the cations concentration in the subgrade, the lower the performance of the GCL.

- For single-species, the GCL performance depends on the type of the cations and concentration of cation (to a certain level).

- For multispecies inorganic salt solutions, **Ionic Strength** and the **relative abundance of monovalent and divalent cations (RMD)** in the permeant solution were found to influence the swell of the bentonite, and the hydraulic conductivity of GCLs.

- Higher RMD results in more swell and less hydraulic conductivity (Positive effect), Higher Ionic Strength results in less swell and higher hydraulic conductivity (negative effect)

# Summary:

- Thermal gradient between two sides of the lining system can result in desiccation cracking, even under high confinement, and even if the high temperature is maintained for relatively short time.
- For double composite liners, desiccation cracking of the primary GCL is more critical as the GCL is sitting on a geonet, and also is not in contact with moisture.
- Solution to thermal gradient desiccation cracking can be: higher subgrade initial water content, minimise the thermal gradient, or using Multicomponent GCL to prevent moisture loss
- Tailings chemistry can affect the performance of the GCL. GCL should not be in direct contact with tailings unless it is a multicomponent GCL.
- Arsenic emission from tailings can be reduced by higher GCL degree of saturation and using multicomponent GCLs



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# Thank you


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