The 2-region model
Development and properties

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Acknowledgements
The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme (FP7/2007-2011) under grant agreement n° 295487

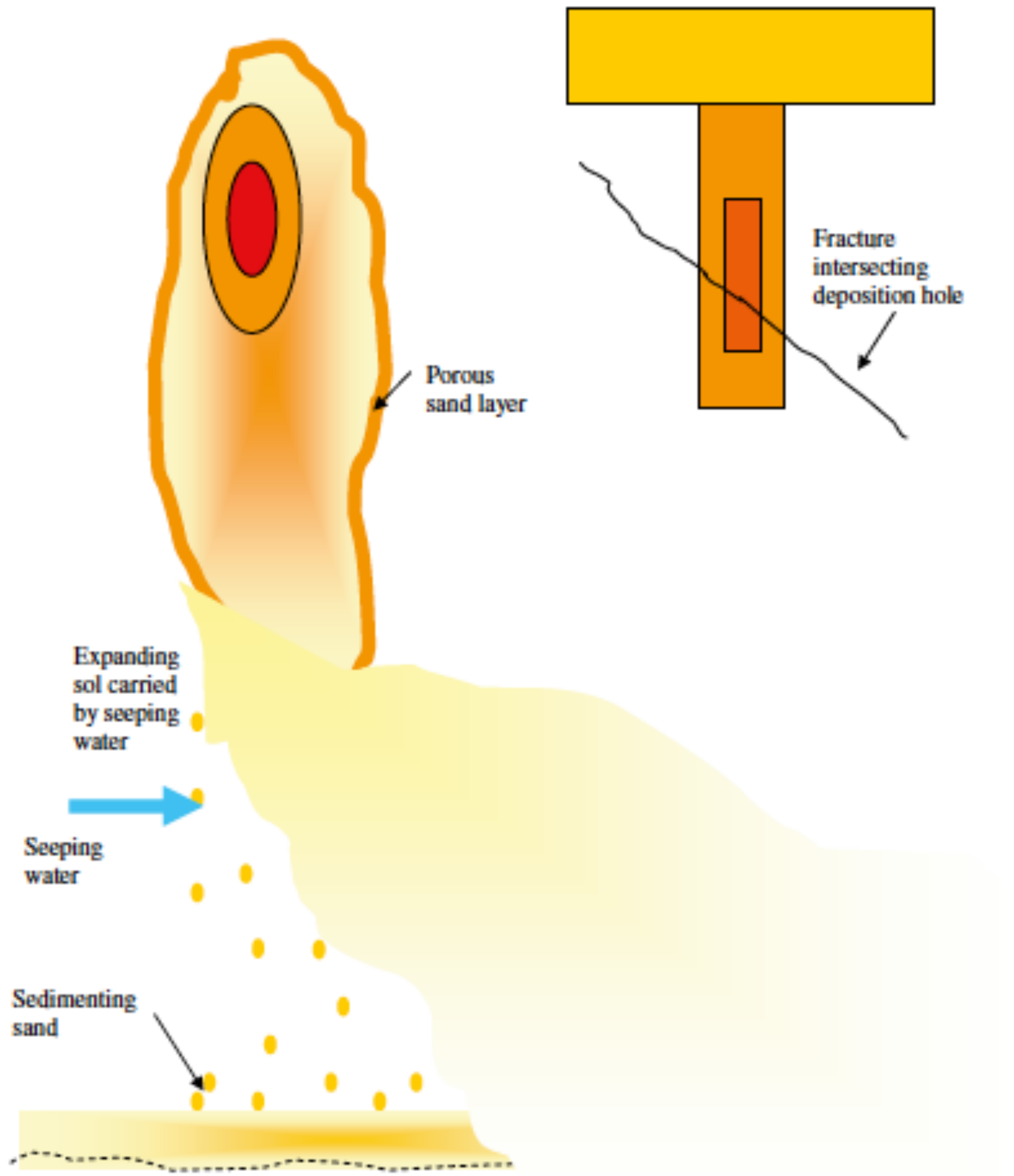


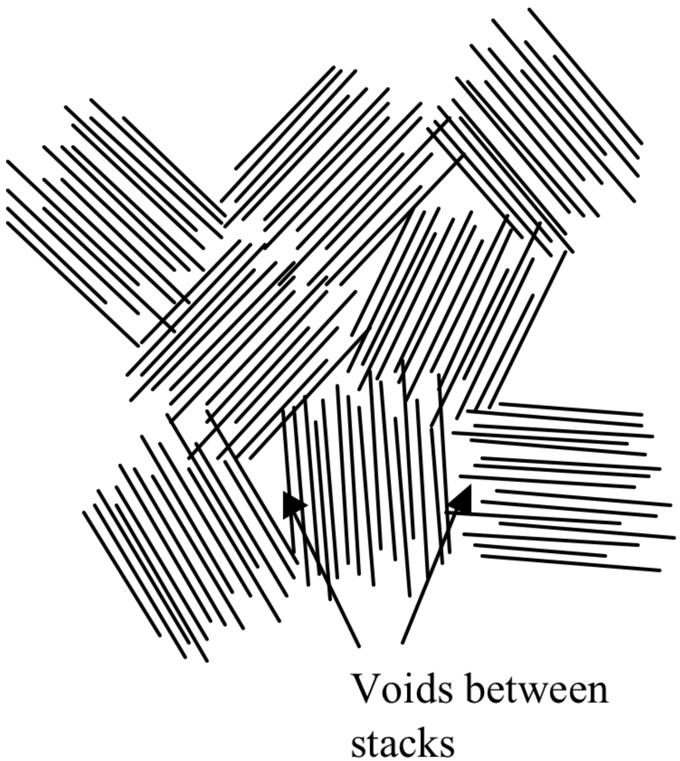
Figure 3-3. Cartoon of how a sand region could develop in the fracture around a deposition hole and that it may be breached and sediment away in the lower parts of the fracture.

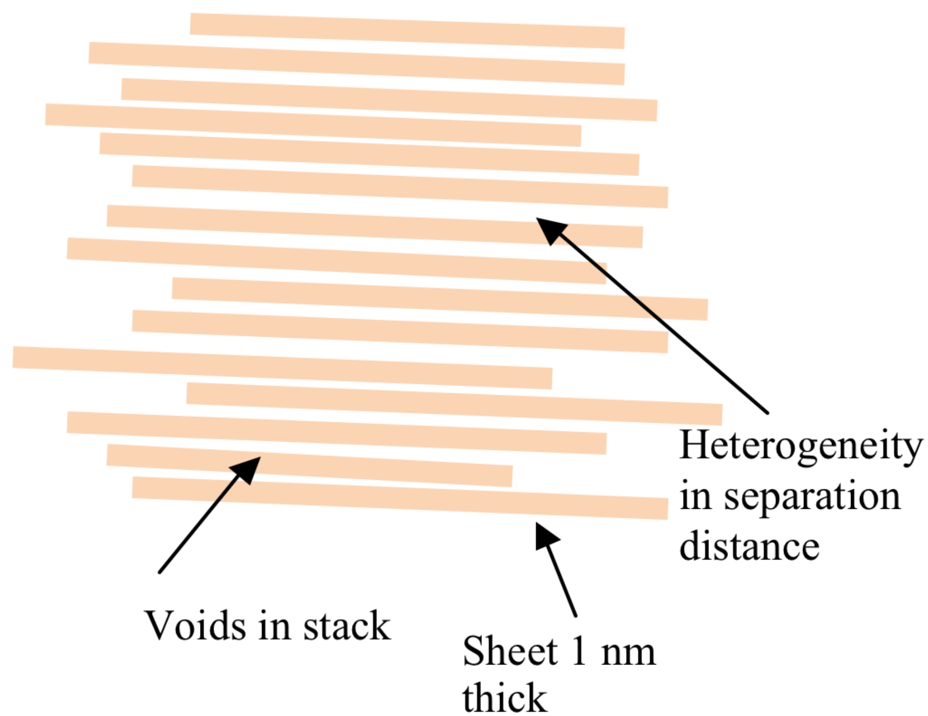
- Previous modeling using the “Dynamic clay expansion model” used FEM techniques

- Much to low resolution in the rim-zone where the “dramatic” changes occur

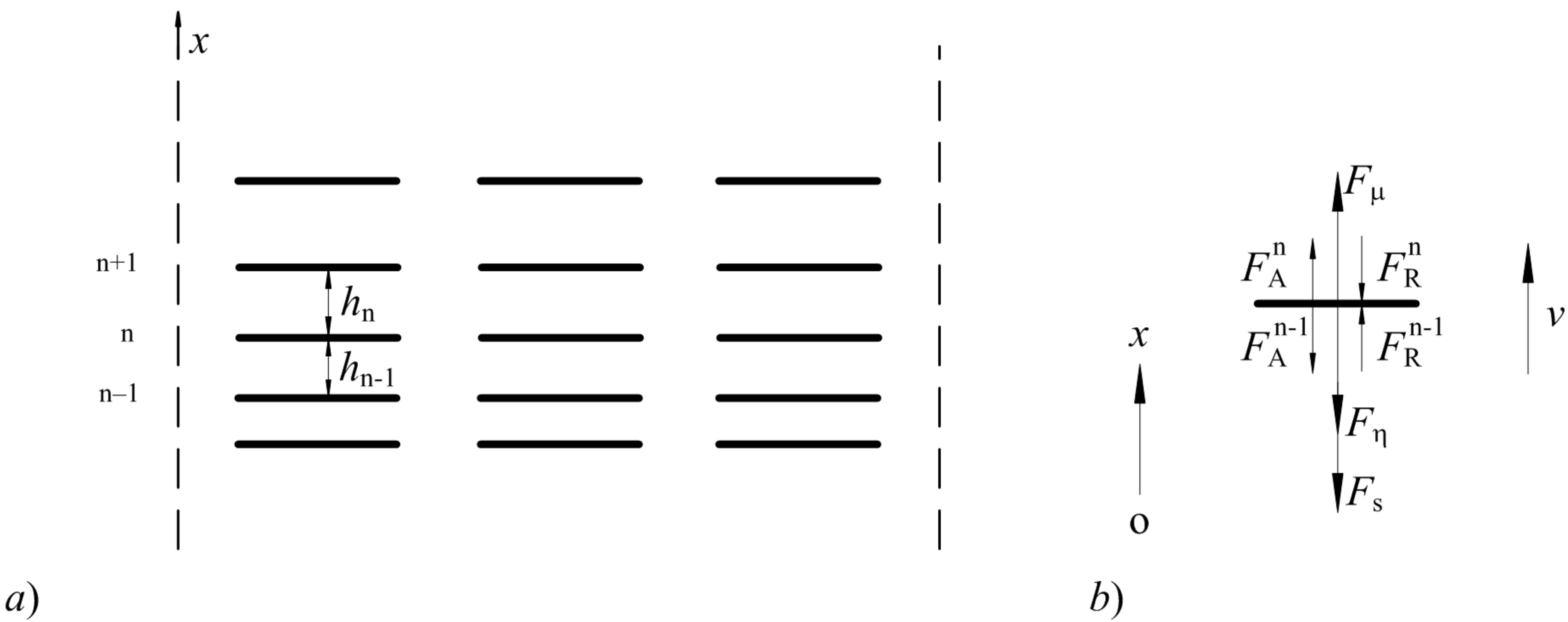
- Need to develop new model to resolve rim-zone

Expanding stacks, basis for our dynamic model for gel expansion





Swelling of parallel sheets

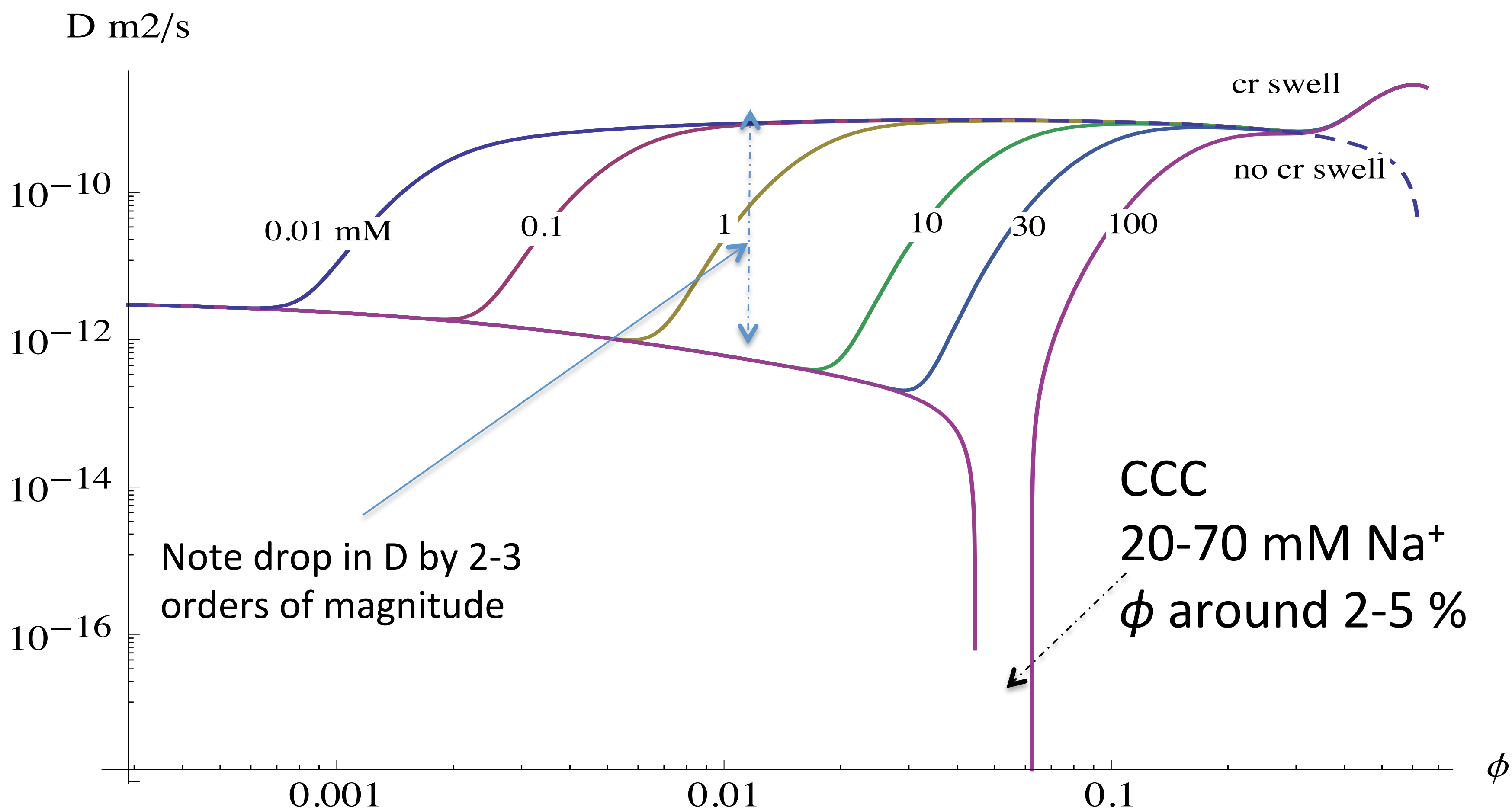


Dynamic expansion model

- Rate of expansion by force balance
- Expansive forces: thermal, osmotic
- Attractive forces: vdW
- Force restraining movement: friction in water

- Can be expressed as diffusivity $D(\phi , c_{ion})$

Diffusivity function



Swelling of Na exchanged bentonite in 0.5 mM $CaCl_2$ Validation- Experiments (NMR) and prediction

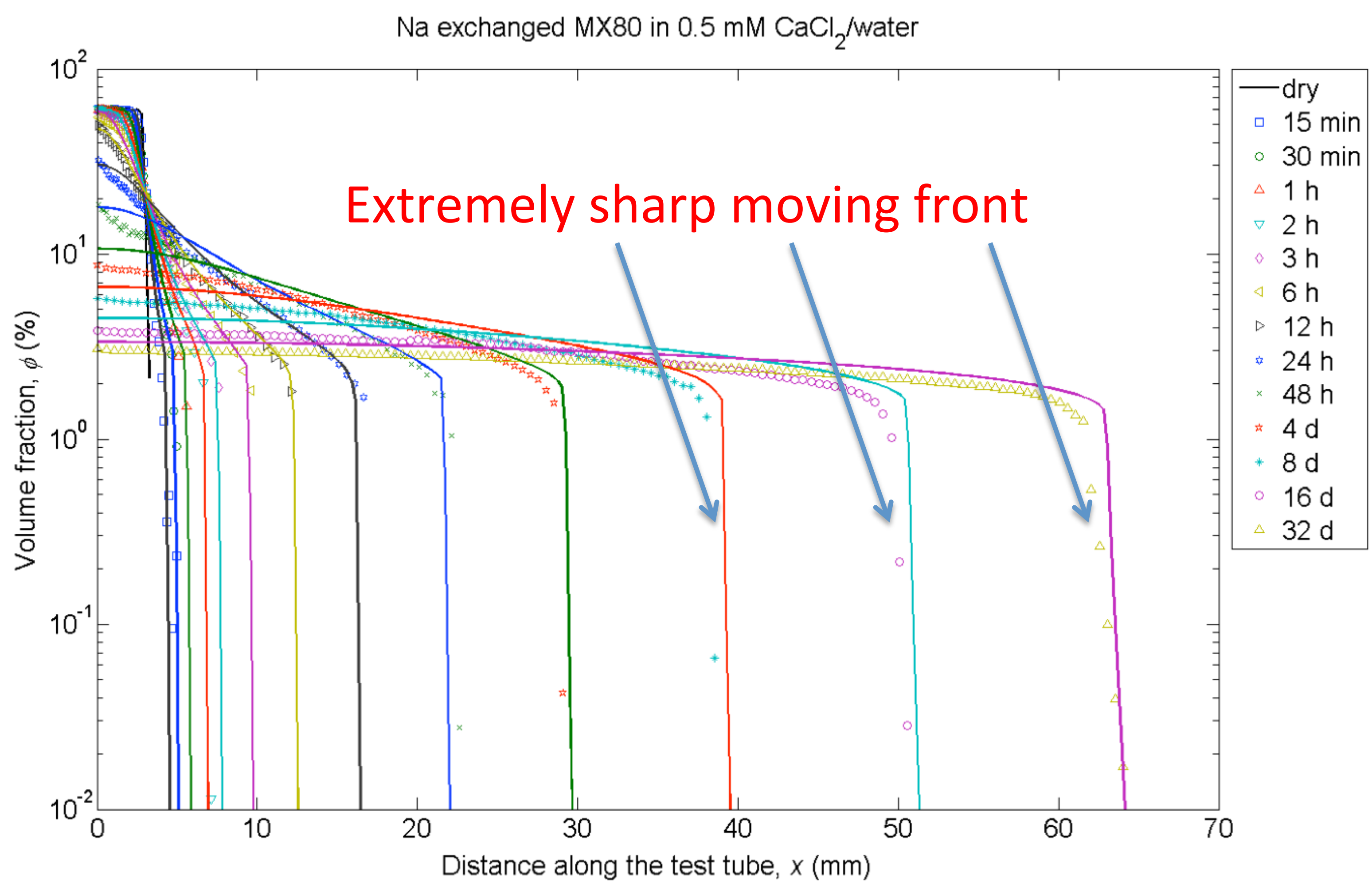
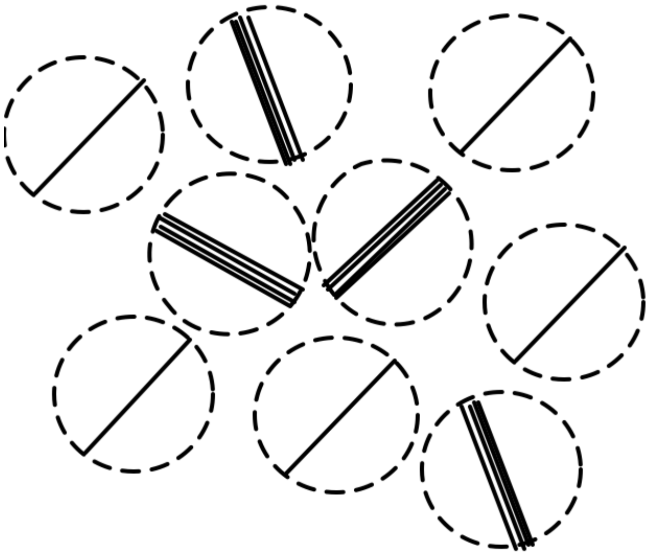
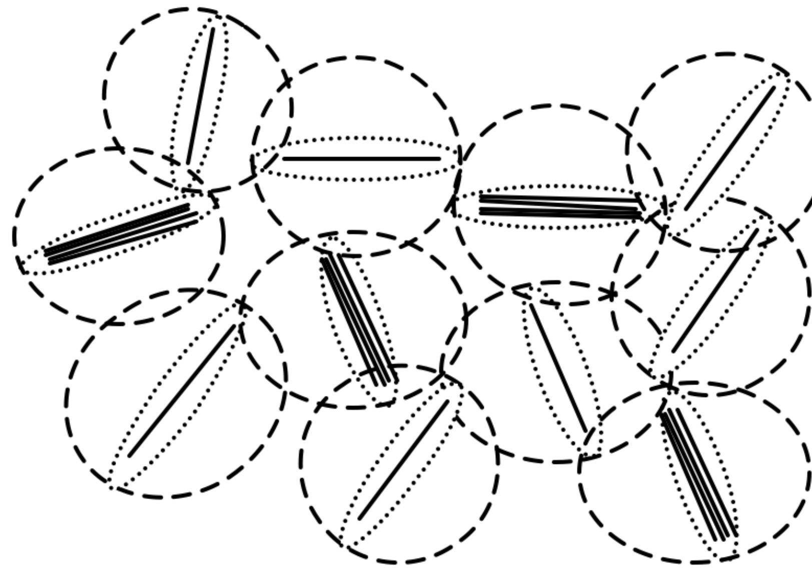


Figure 6.23. Sodium exchanged bentonite in 0.5 mM $CaCl_2$. Logarithmic scale

Co-volume notion- Rotation



Thin diffuse double layer,
co-volumes do not overlap

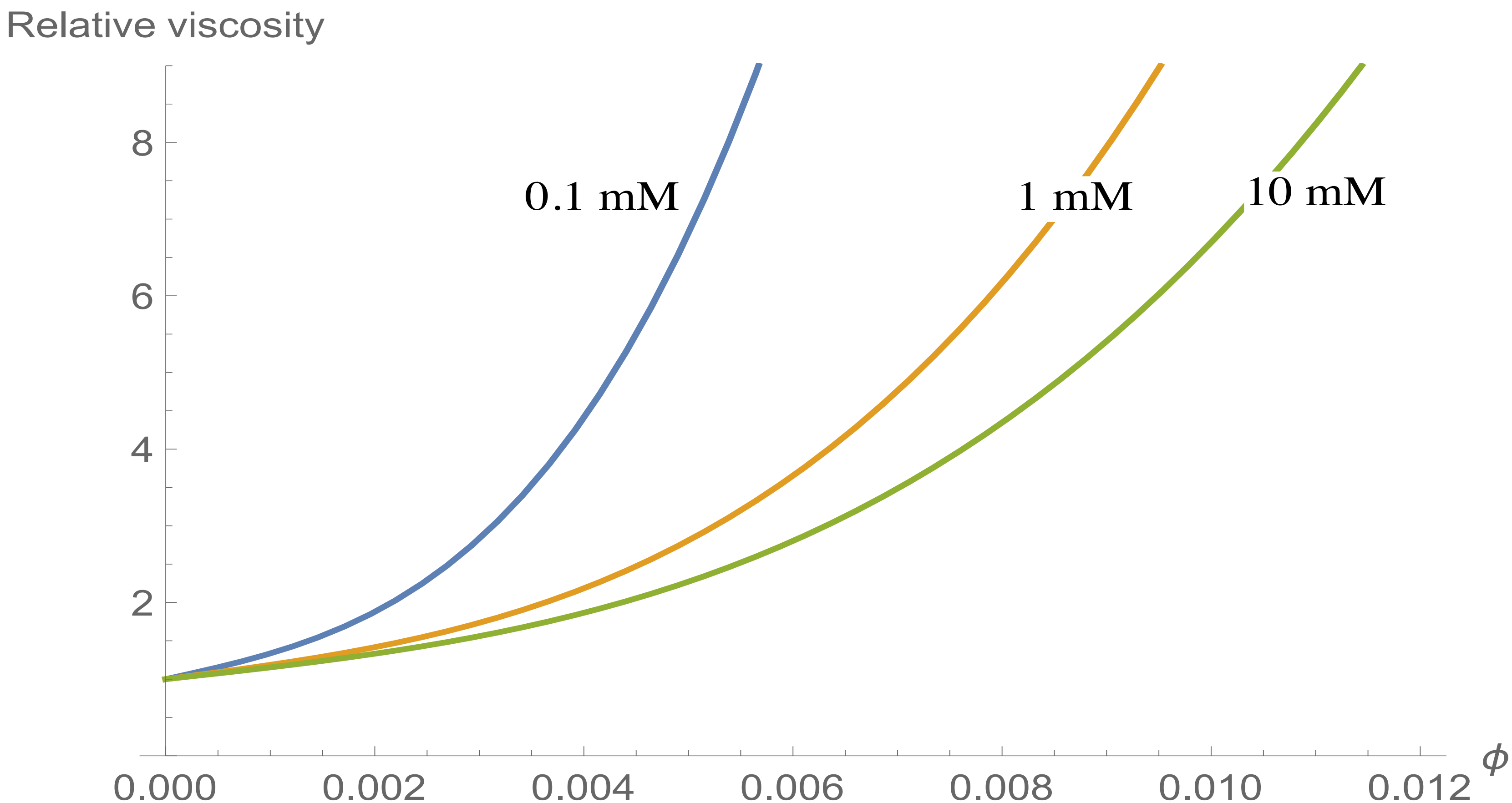


Large diffuse double
layer, co-volumes overlap

Used to determine viscosity of sol by fitting to experiments

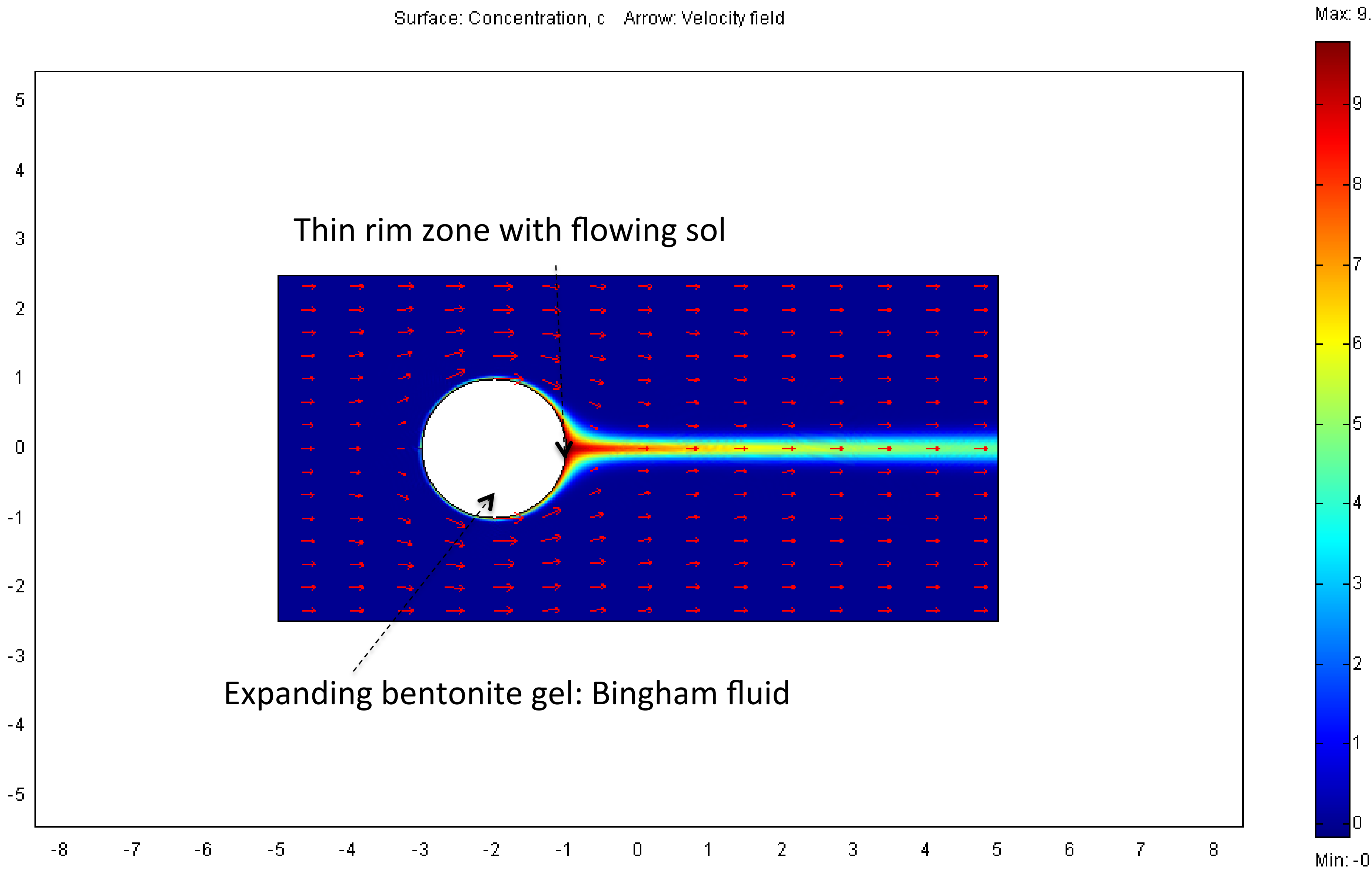
$$\eta_r = \frac{\eta}{\eta_w} = 1 + 1.022\phi_{cov} + 1.358(\phi_{cov})^3$$

Relative viscosity of sol

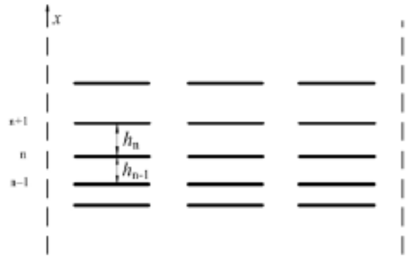


For ϕ > about 0.5- 1.2 gel is a Bingham body/fluid.
Does not flow at low shear forces such as caused by gravity or seeping water.

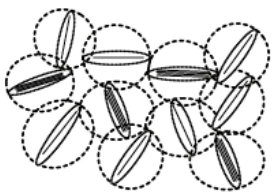
Erosion by sol loss to water



Dynamic model: Summary of processes

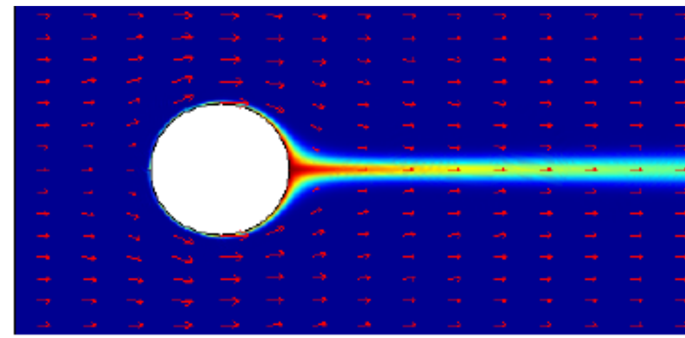


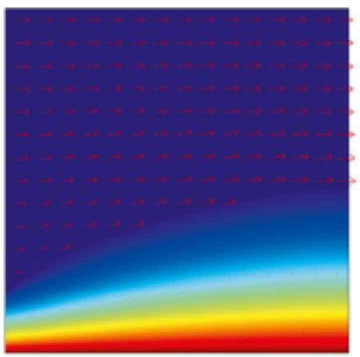
Expansion of
rigid gel.
Viscosity “
infinite



Large diffuse double
layer, co-volumes overlap

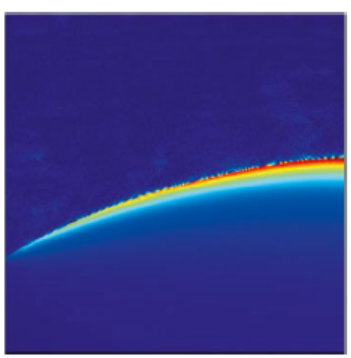
Starting
rotation.
Viscosity of sol
drops, Sol flows





Colloidal particles
diffuse into
seeping water.
Concentration
Picture of rim
zone

Viscosity of sol drops
from 10* water to
water in rim zone

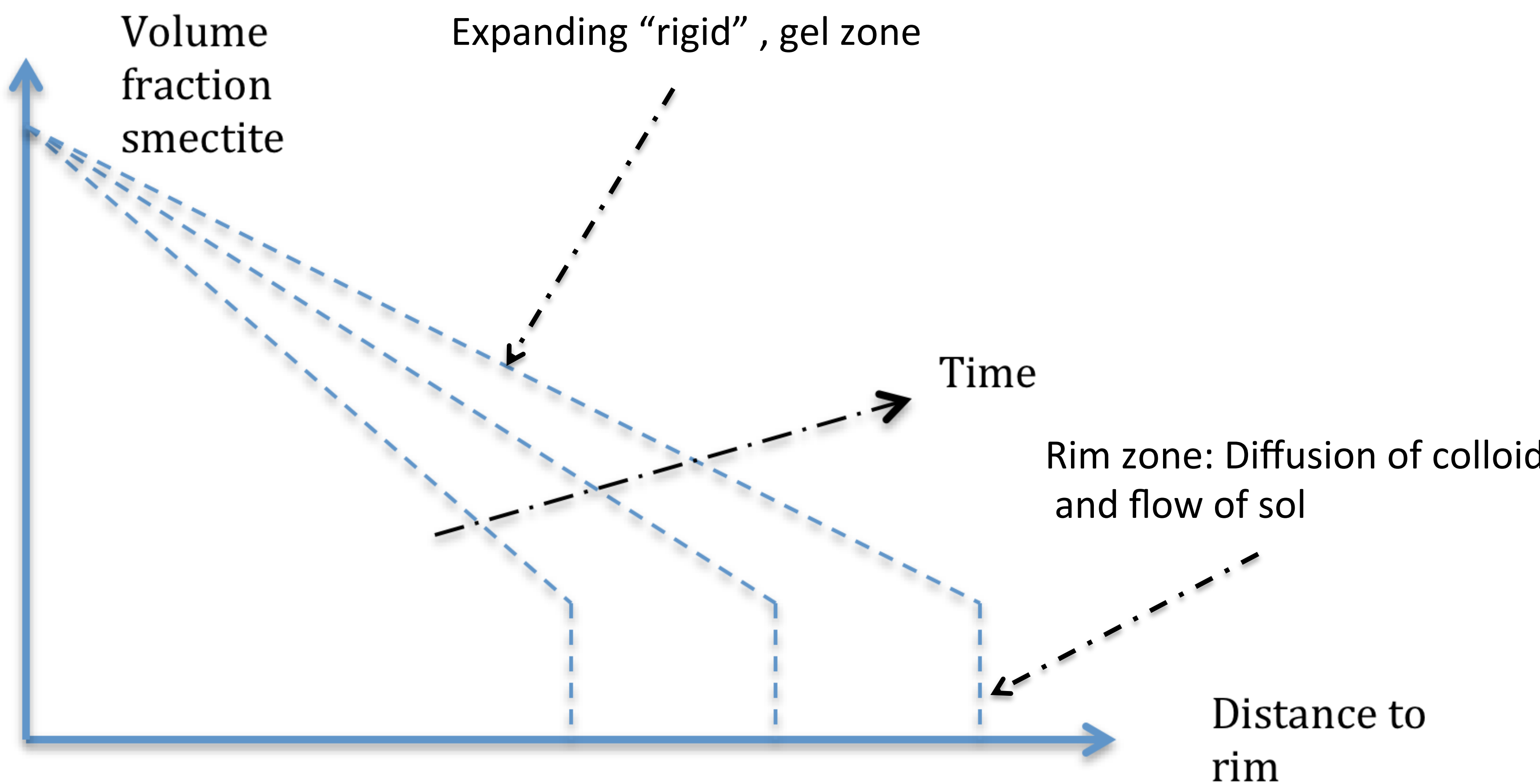


Most flux in thin zone

Sol flows.
Flux picture
of rim zone

Interface to rigid gel

Erosion front, rim, expands w. time. Standard finite element/volume/difference methods cannot follow this well



Two regions and models

- 1) The expanding gel up to the rim (sharp front)
- 2) The loss at the rim

- The the rim zone modelled w. technique that obviates discretization- can handle extremely sharp fronts

- Expansion of gel coupled to loss modelled by finite differences, constantly accounting for loss at the rim as the rim expands

Critical ϕ_{crit} to start flow

- $\phi < \phi_{crit}$ gel expands but cannot flow
- $\phi = \phi_{crit}$ gel flow but viscosity about 10*water
- $\phi < \phi_{crit}$ gel flow viscosity < 10*water

- A cylindrical gel expands symmetrically
- At rim $\phi = \phi_{crit}$ and smectite flows away as sol

Rim region model

"Un-wind" the rim zone from the rim of the expanding gel
Straighten it along an x-axis, with flow, diffusion in y-direction

$$N_{rim} = \rho_s \delta_{fr} \int_0^\infty u_x(y)\phi(y)dy = \rho_s \delta_{fr} u_o \int_0^\infty \frac{\phi(y)}{\eta_r(\phi(y))} dy \qquad (28)$$

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} = 0 \qquad (29)$$

$$\cancel{\frac{\partial \phi}{\partial t}} = \cancel{\frac{\partial}{\partial x}(D(\phi)\frac{\partial \phi}{\partial x})} + \frac{\partial}{\partial y}(D(\phi)\frac{\partial \phi}{\partial y}) - u_x \frac{\partial \phi}{\partial x} - \cancel{u_y \frac{\partial \phi}{\partial y}} \qquad (30)$$

After several simplifying assumptions (checked later for validity) (30) becomes

$$\frac{\partial}{\partial y}(D(\phi)\frac{\partial \phi}{\partial y}) = \frac{u_o}{\eta_r}\frac{\partial \phi}{\partial x} \qquad (31)$$

$$D_r(\phi)\frac{\partial^2 \phi}{\partial y^2} + \frac{dD_{rel}(\phi)}{d\phi}(\frac{\partial \phi}{\partial y})^2 = \frac{u_o}{D_o \eta_r(\phi)}\frac{\partial \phi}{\partial x} \qquad (35)$$

With Boltzmann transformation -> ODE in z

$$z = \frac{y}{2\sqrt{D_o x/u_o}} \tag{36}$$

(35) becomes

$$\eta_r(\phi) D_r(\phi) \frac{d^2\phi}{dz^2} + \eta_r(\phi) \frac{dD_r(\phi)}{d\phi} \left(\frac{d\phi}{dz}\right)^2 = -2z \frac{d\phi}{dz} \tag{37}$$

$$N_{rim} = \rho_s \delta_{fr} u_o \frac{dy}{dz} \int_0^\infty \frac{\phi(z)}{\eta_r(\phi(z))} dz = \rho_s \delta_{fr} 2\sqrt{D_o x u_o} \int_0^\infty \frac{\phi(z)}{\eta_r(\phi(z))} dz = \rho_s \delta_{fr} 2\sqrt{D_o x u_o} \times N_{rim}^{DL} \tag{41}$$

$$N_{rim} = \rho_s \delta_{fr} 2\sqrt{D_o x u_o} \times N_{rim}^{DL}$$

$$N_{rim}^{DL} = \int_0^\infty \frac{\phi(z)}{\eta_r(\phi(z))} dz \tag{42}$$

If $\eta_r = 1$ and $D = D_R = constant$

$$\phi(z) = \phi_R Erfc(z) \tag{43}$$

$$N_{rim}^{DL} = \frac{\phi_R}{\sqrt{\pi}} \sqrt{\frac{D_R}{D_o \eta_r}} \tag{44}$$

$$N_{rim} = \rho_s \delta_{fr} \phi_R \frac{2}{\sqrt{\pi}} \sqrt{D_R\, x\, u_o}$$

Smectite concentration profile and flux

Sharp concentration profile at front of smectite due to drop in Diffusivity

Flux of smectite at front

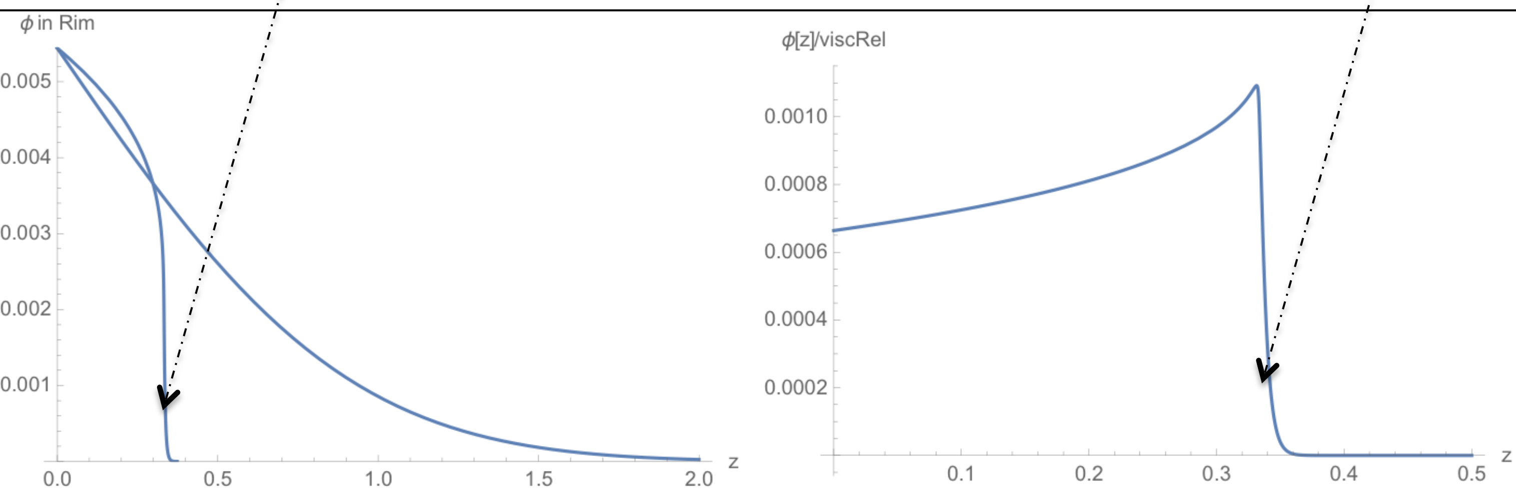


Figure 4a and b. 4a, left, Concentration profile in the rim-region , $\phi_{Cov} = 1.6$ *and c=0.1 mM monovalent ions. The drawn out curve is for constant D and viscosity. The other curve is for variable diffusivity. 4b shows a measure proportional to the smectite flux in rim-region.*

Rim region model, loss N_{rim} at x

$$N_{rim} = \rho_s \delta_{fr} 2\sqrt{D_o x u_o} \times N_{rim}^{DL}$$

$$N_{rim}^{DL} = \int_0^{\infty} \frac{\phi(z)}{\eta_r(\phi(z))} dz$$

From solution of
Rim zone model

If $\eta_r = 1$ and $D = D_R = constant$

$$N_{rim} = \rho_s \delta_{fr} \phi_R \frac{2}{\sqrt{\pi}} \sqrt{D_R\, x\, u_o}$$

Expanding rim model

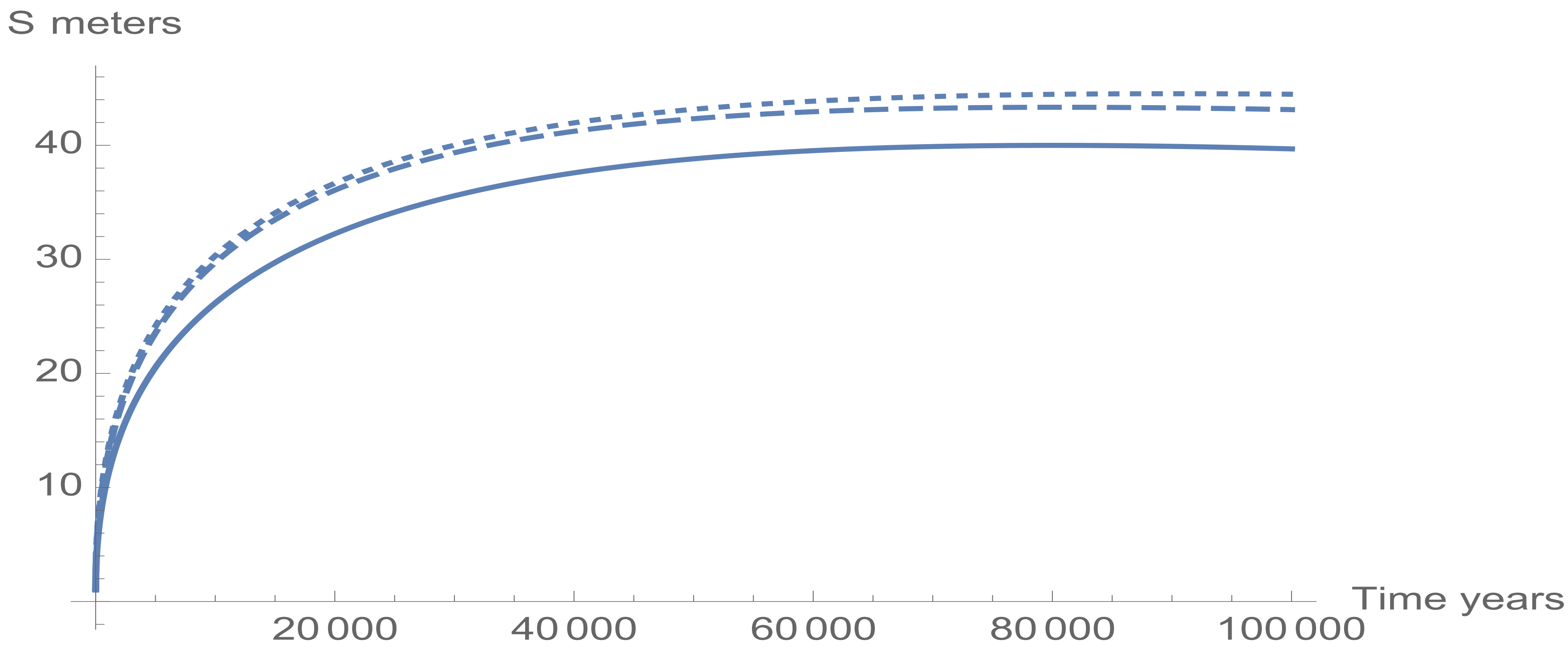
Rate of rim expansion from rim zone model (2)

$$\frac{\partial\ \phi}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(Dr\frac{\partial \phi}{\partial r}\right) - \frac{dr_R}{dt}\frac{\phi}{r_R - r_i}\left(1 + \frac{r - r_i}{r}\right)$$

Regular PDE for radial expansion   Impact of expanding rim

Expanding "universe", which exists between r_R and r_i
r_R can grow or shrink when source becomes exhausted

Expansion of rim, Loss at rim accounted for



Expansion of the rim-border for c=0.1 mM and $u_o=10^{-5}$ m/s, initial $\phi i=0.574$,

Compare old results I

Table 5. Loss of smecite for ion concentration 0.1 mM for different water velocities in 0.1 mm aperture fracture. N_{rim}^{DL} from Table 3, i.e. the y-component of the velocity is accounted for.

Water velocity m/s	*Mass eroded at rim at 10 000 years, kg. Old*	*Penetration depth, S, of rim at SS m Old*	*Mass eroded at rim at 10 000 years, kg.*	*Mass lost from deposition hole at 10 000 years, kg.*	*Penetration depth S of rim at 10 000 years m*
10^{-7}	43	7.0	7.6	140	34.2
10^{-6}	117	2.1	22	148	32.0
10^{-5}	292	0.5	144	172	14.7

Most mass lost from source due to expansion into fracture, not by erosion at low velocities

Compare old results II

Table 5. Loss of smecite for ion concentration 0.1 mM for different water velocities in 0.1 mm aperture fracture. N_{rim}^{DL} *from Table 3, i.e. the y-component of the velocity is accounted for.*

Water velocity m/s	*Mass eroded at rim at 10 000 years, kg. Old*	*Penetration depth, S, of rim at SS m Old*	*Mass eroded at rim at 10 000 years, kg.*	*Mass lost from deposition hole at 10 000 years, kg.*	*Penetration depth S of rim at 10 000 years m*
10^{-7}	43	7.0	7.6	140	34.2
10^{-6}	117	2.1	22	148	32.0
10^{-5}	292	0.5	144	172	14.7

Outlook

- Most mass is lost due to expansion into fracture
- This is occurs irrespective of ionic strength
- Starts “day 1”, does not need glacial water

- Floc formation is not considered
- Erosion by gravity is not considered

Bentonite swelling and erosion. The 2-region model. Modelling Schatz et al. (2012) experiments

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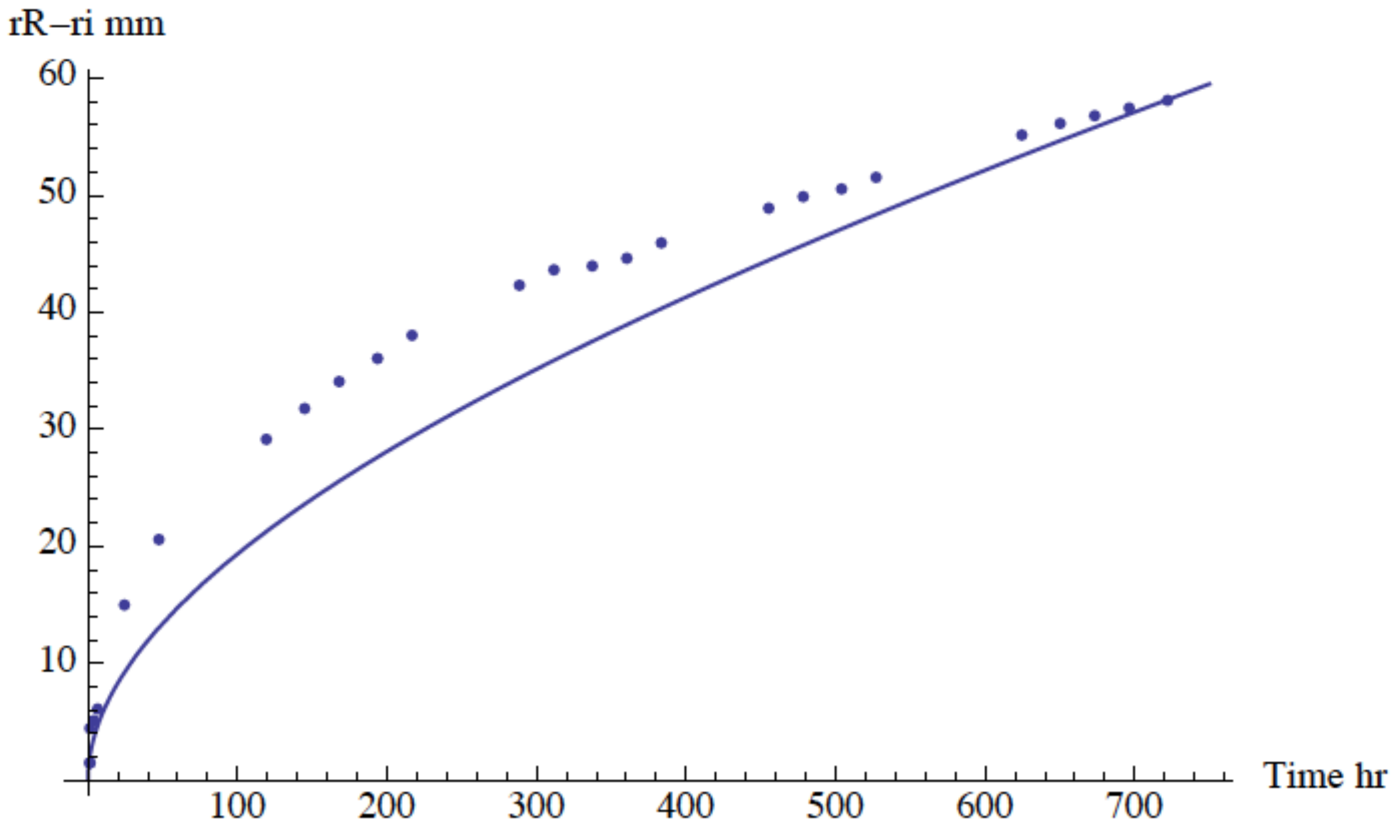
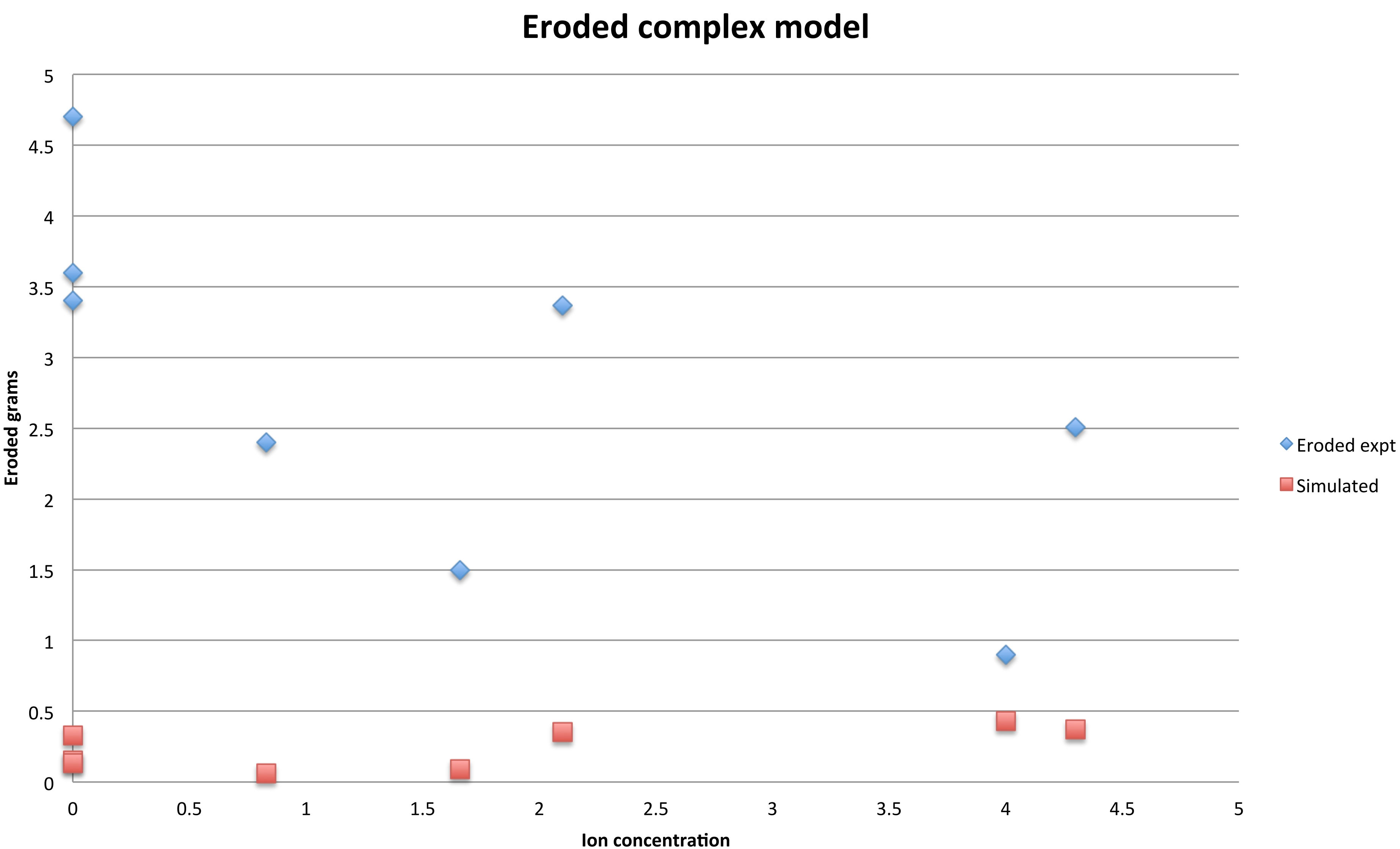
Schatz, T., Kanerva, N., Martikainen, J., Sane, P., Olin, M., Seppälä, A and Koskinen, K., 2012, Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44 (2012).

Just expansion no flow, DI water



Predicted erosion with 2-region model



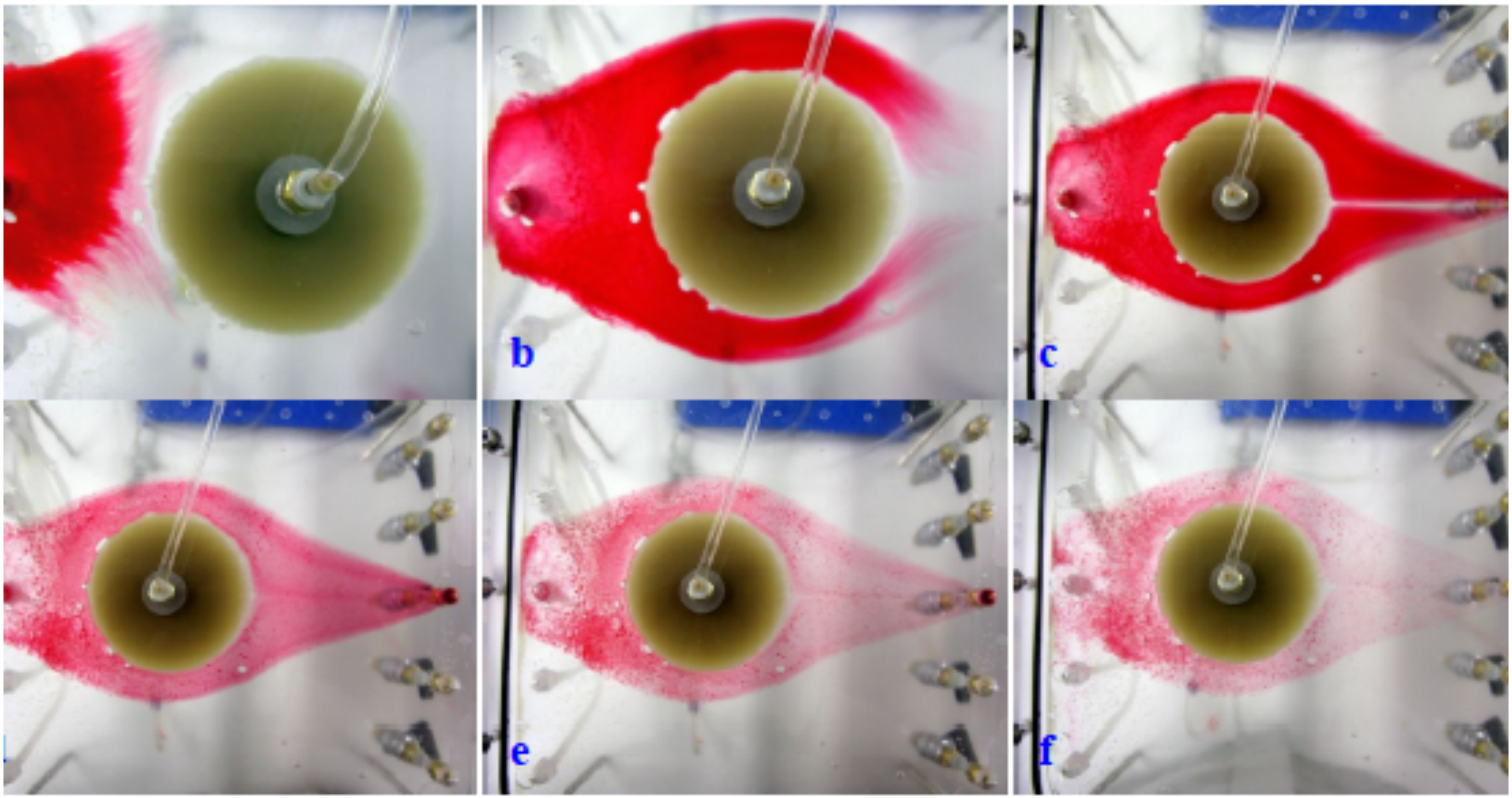
Obviously this is not a good prediction

Model is wrong or model does not account for some mechanism(s)

Agglomeration to flocs, Low ionic strength water

Schatz et al. (2012), Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44.

Expanded gel & flow pattern



Schatz et al. (2012), Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44.

Flocculation is observed

- The water with the flocs seem to flow as water
- Our basic Dynamic model does not account for this
- Our basic model suggest that the sol should be more viscous than water and move much slower
- The smectite concentration in flocs is larger than what our Diffusion+ Viscosity suggests

Comment on Dynamic model for gel expansion

- In our model the CCC results when attractive van der Waal forces equal thermal forces + osmotic forces

- The presence of other attractive force e.g. electrostatic edge to face forces will lower CCC (Hedström et al 2015)

Hedström M., Ekvy-Hansen E., Nilsson U., 2015, Montmorillonite phase behaviour Relevance for buffer erosion in dilute groundwater, SKB TR-15-07

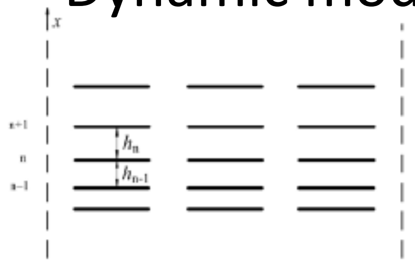
More on edge to face attraction

- CCC is lowered.
- Good as stable gel forms at lower c_{ion}
- Floc formation
- Bad because flocs are pulled off by gravity and possibly by shear from seeping water

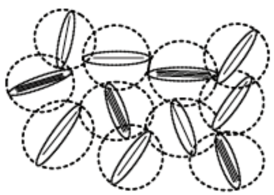
- Two region model is still valid for expansion but erosion model is not

Dynamic model

Dynamic model with floc formation

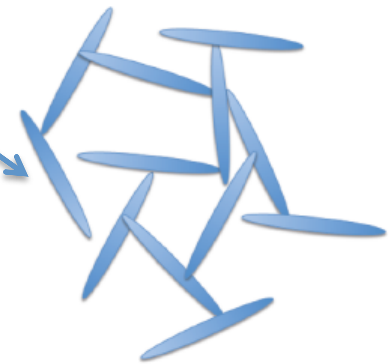


Expansion of
rigid gel.
Viscosity “
infinite

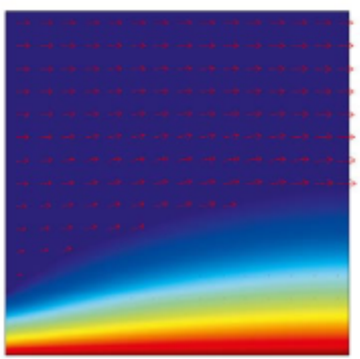


Large diffuse double
layer, co-volumes overlap

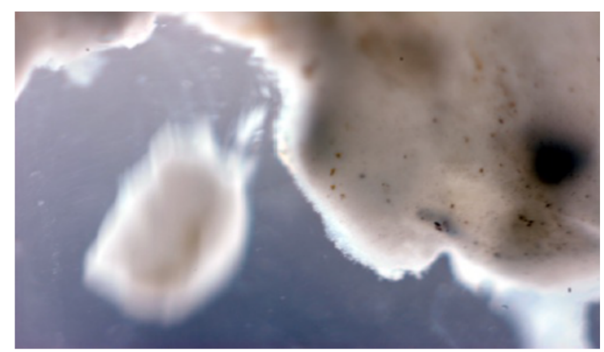
Starting
rotation.
Viscosity of
sol drops

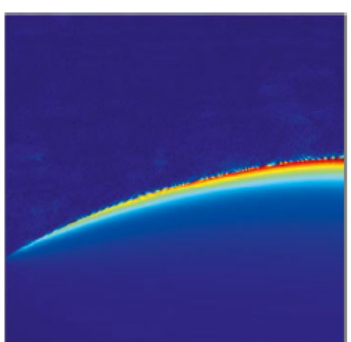


Flocs form. Can
sediment.
Floc slurry viscosity
near water.



Colloidal particles
diffuse into
seeping water.
Concentration
Picture of rim
zone





Sol flows.
Flux picture
Of rim zone

Rim zone model III

$$N_{rim} = \rho_s \delta_{fr} 2\sqrt{D_o x u_o} \times N_{rim}^{DL}$$

$$N_{rim}^{DL} = \int_0^\infty \frac{\phi(z)}{\eta_r(\phi(z))} dz$$

If $\eta_r = 1$ and $D = D_R = constant$

$$N_{rim} = \rho_s \delta_{fr} \phi_R \frac{2}{\sqrt{\pi}} \sqrt{D_R \, x \, u_o}$$

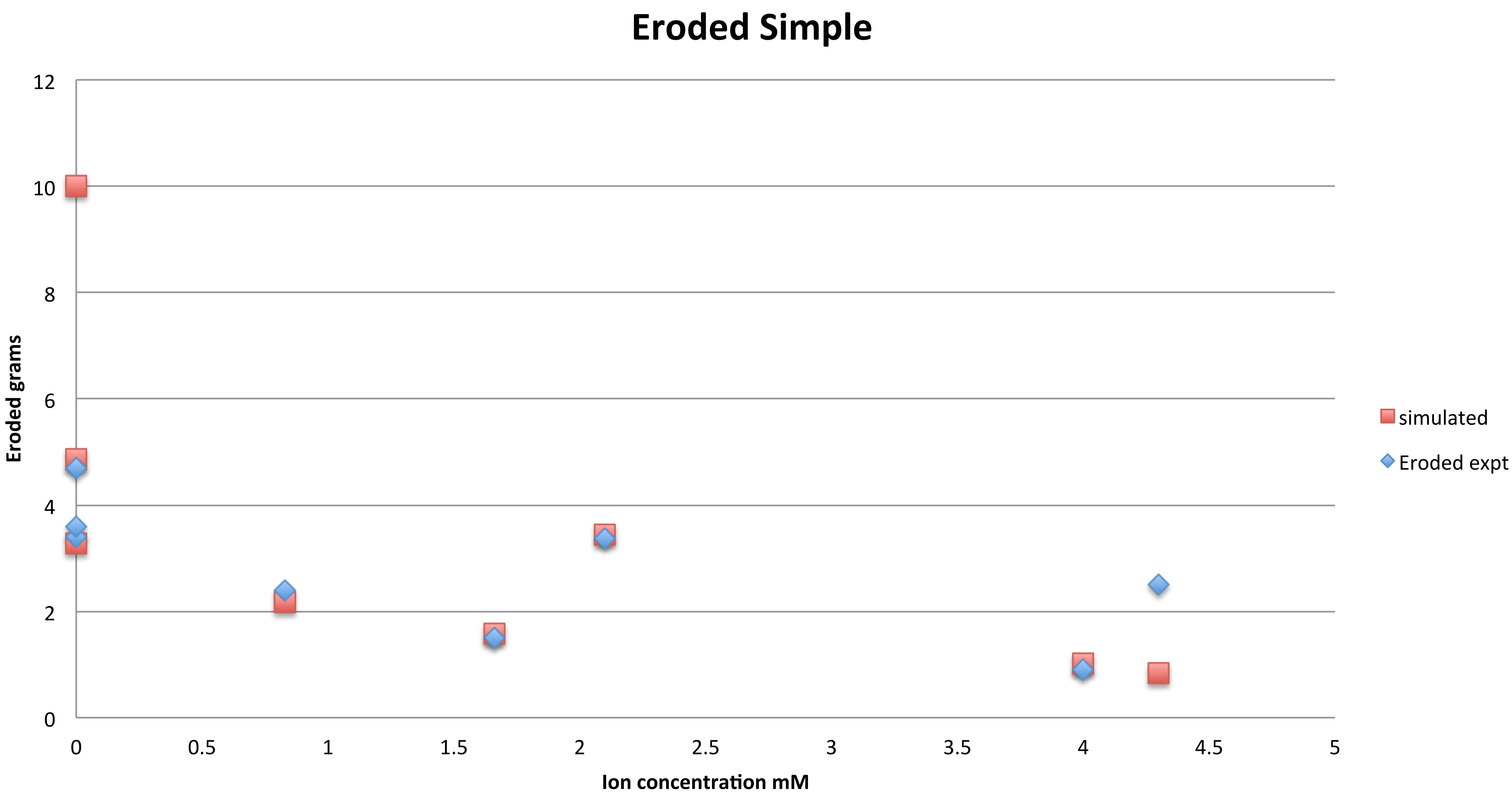
Changes and simplifications of model

- Floc slurry viscosity ≈ as water
- Volume fraction at rim ϕ_R indep. of ion conc.
- Loss rate expression simplifies to

$$N_{rim} = \rho_s \delta_{fr} \phi_R 2\sqrt{D_R r_R u_o}$$

But ϕ_R *now is an adjustable parameter,*
D_R *– diffusivity at rim- is still from Diffusivity function and it depends on* c_{ion}

Simulated erosion with Simple 2-region model ϕ_R=0.015



Also r_R, Extruded, Residual, Retained and Eroded masses agree quite well

Smectite loss by flocculation and gravity

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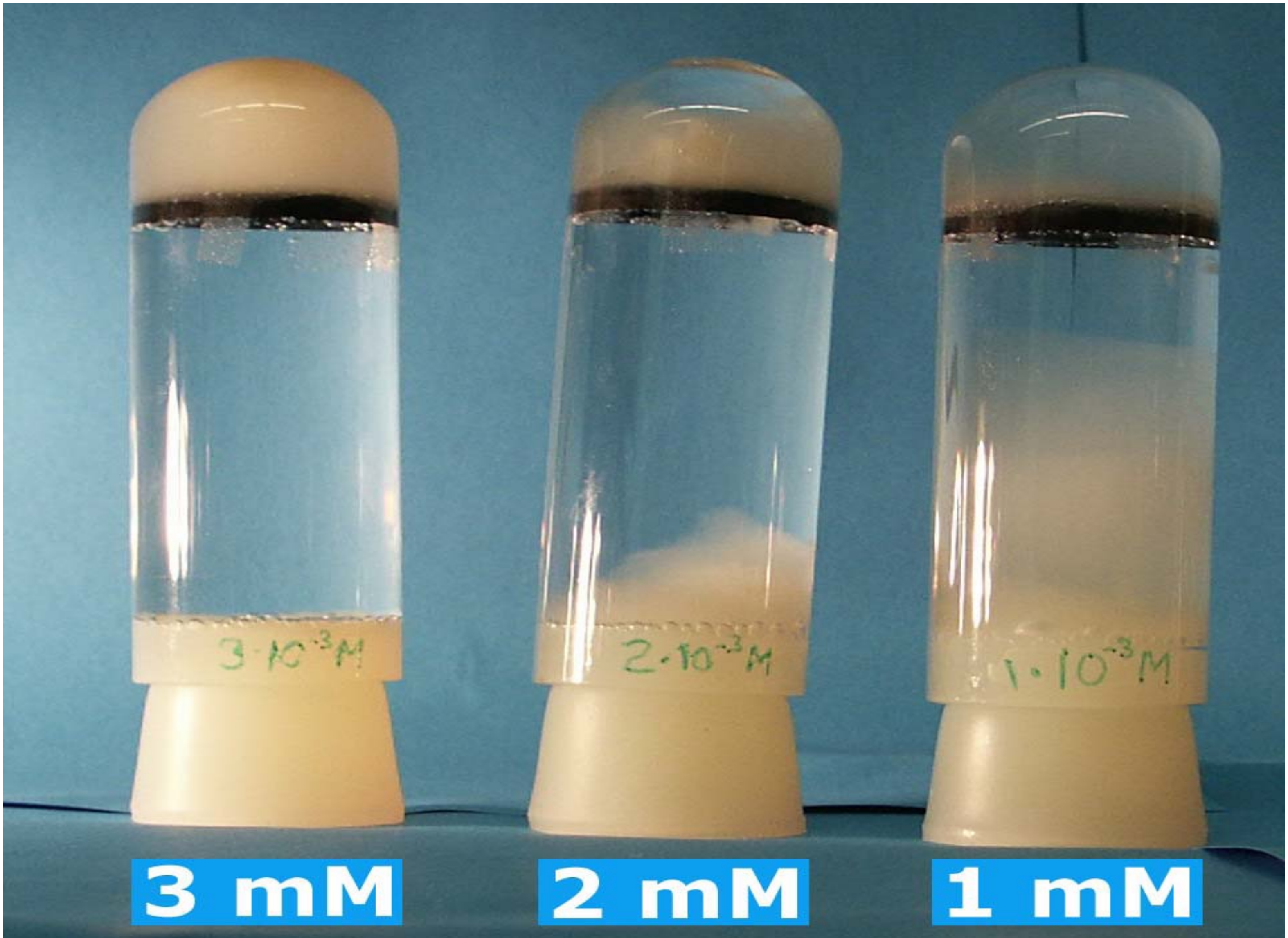
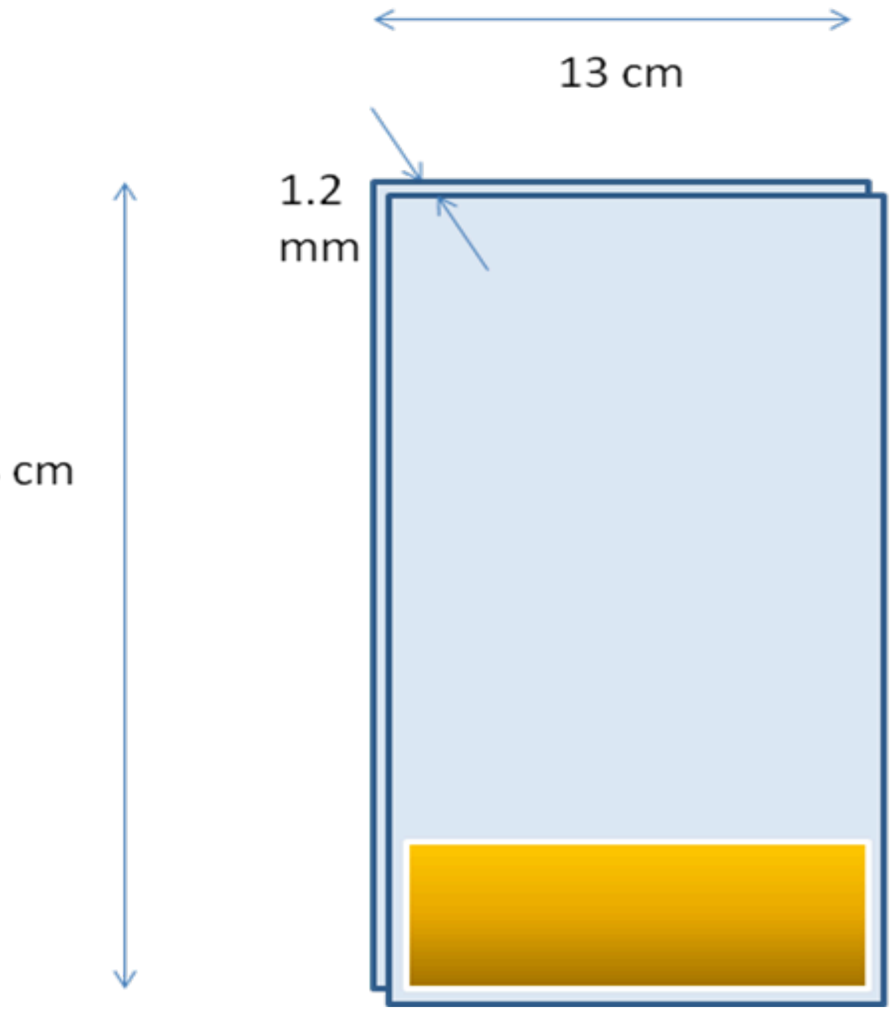
Flocs fall through fine filter, 10 μm



Experiments in slots



Plates glued together all around after filling clay and water

Swelling clay 0.1-2 g

Mx-80 in Di

Figure 4. ***24 hours later, detail of right hand corner. Dark spots are thought to be detritus material. The expanded gel is between ½ and 2 cm high and has a clay volume fraction of about 2 % on average.***

Neretnieks I., 2009, Some scoping erosion experiments in thin slits between glass plates, Chemical Engineering, Royal Institute of Technology, KTH, Stockholm, Sweden, Internal report.

Mx-80 in Di

Figure 5. ***The slit just turned upside down.***

Mx-80 in Di

Figure 6. Enlargement of the upside down turned slit 24 hours later. Gel is slowly pulled downward by gravity. Small gel blobs are released and very slowly move downward.

Detail of floc

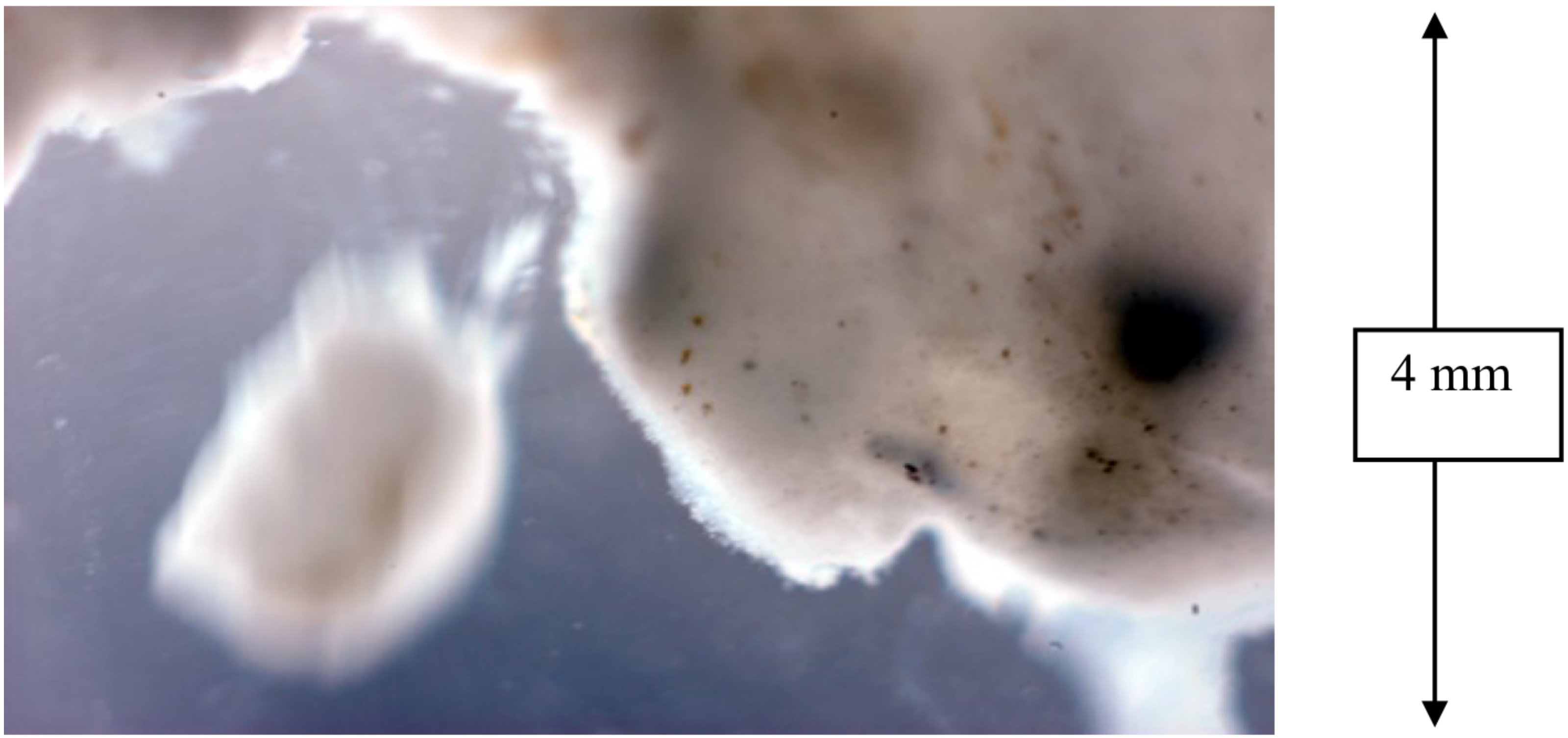


Figure 3. An enlarged detail of the hanging gel. The whole picture is 4 mm high. Large and small black particles are clearly seen.

Detail of hanging floc

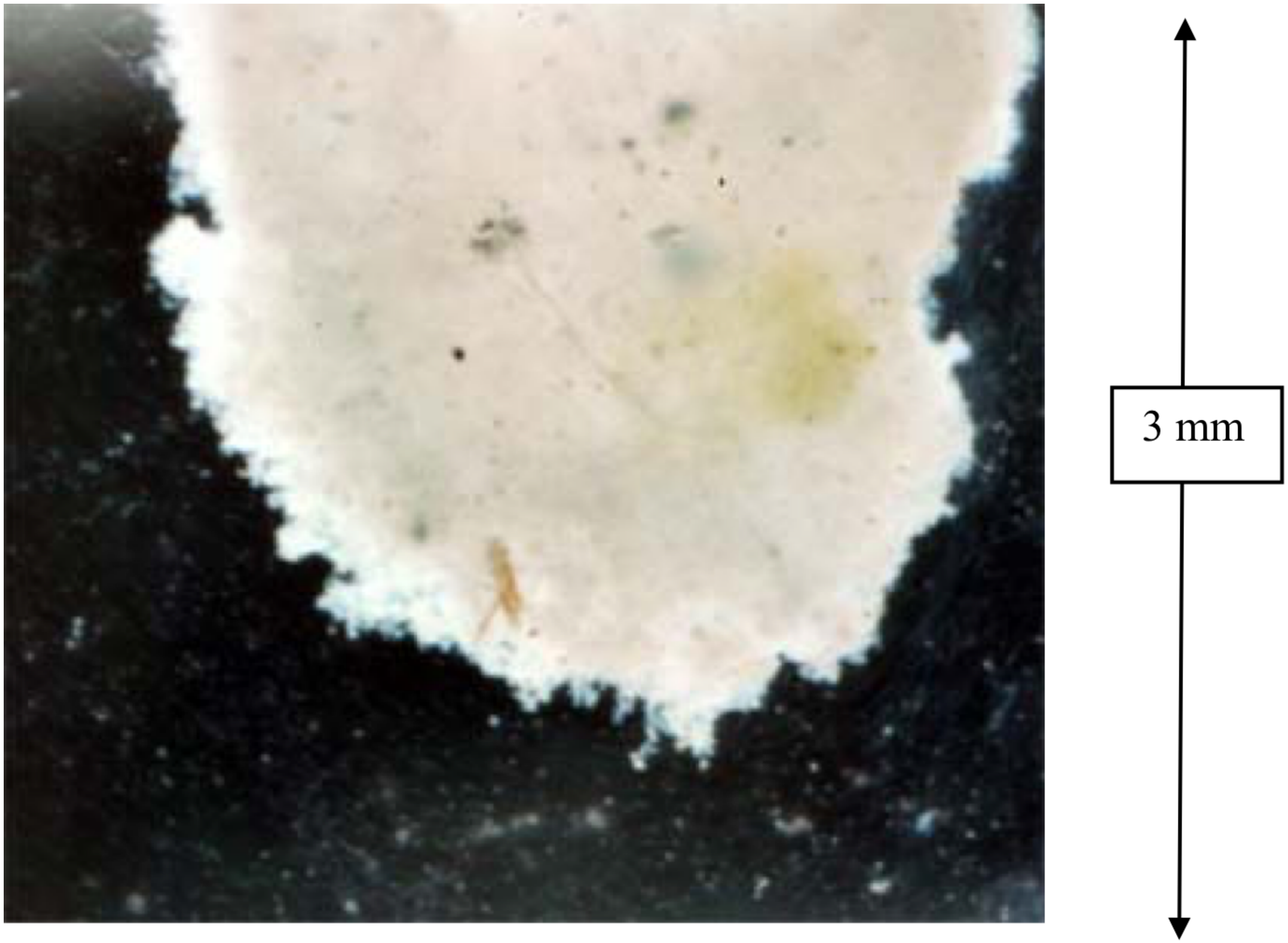


Figure 4. An enlarged detail of the hanging gel. The whole picture is 3 mm high. Small dark particles are clearly identifiable.

Mx-80 in Di

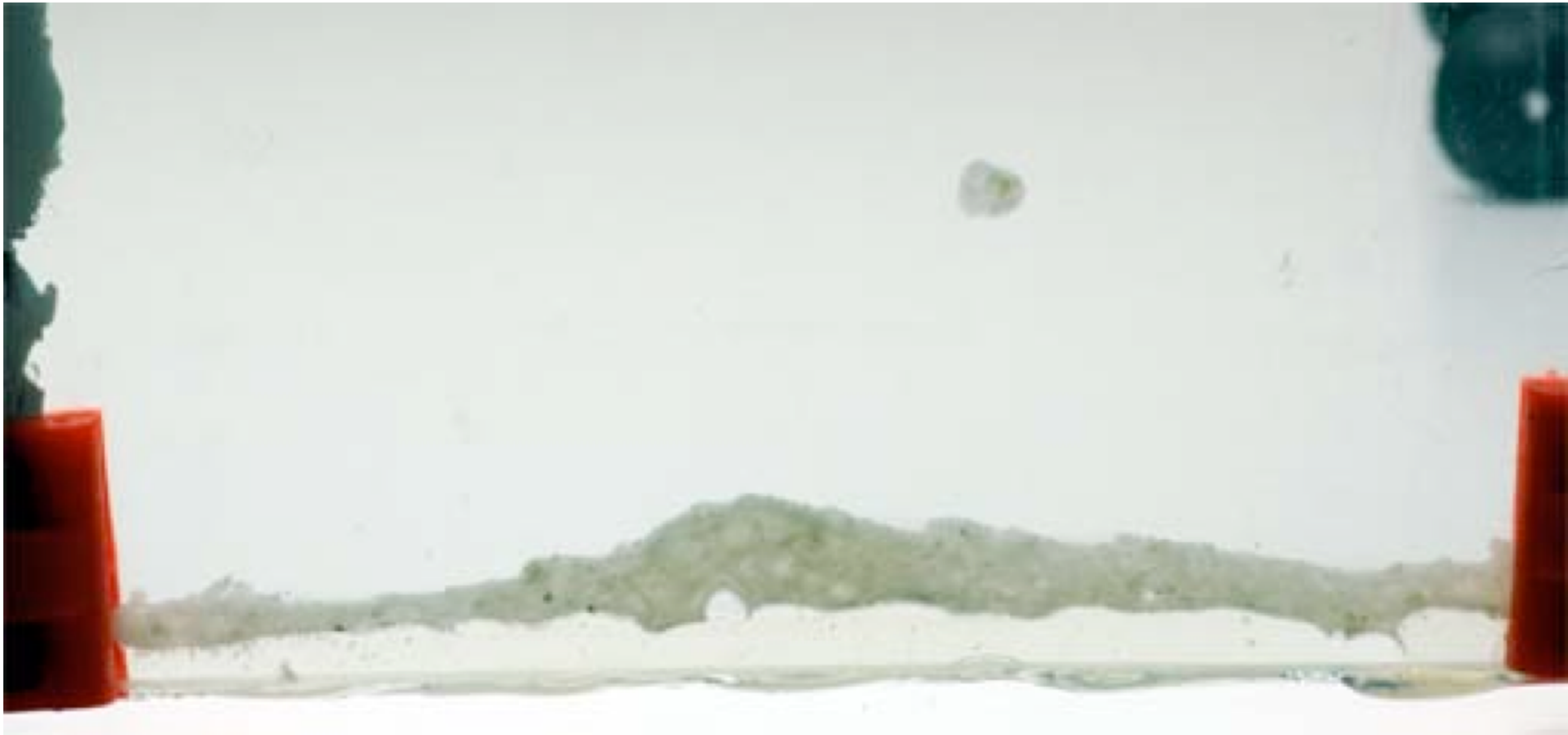


Figure 8. ***48 hours after turnover. Some gel has sedimented and is seen at the bottom of the slit. One small blob is very slowly sinking.***

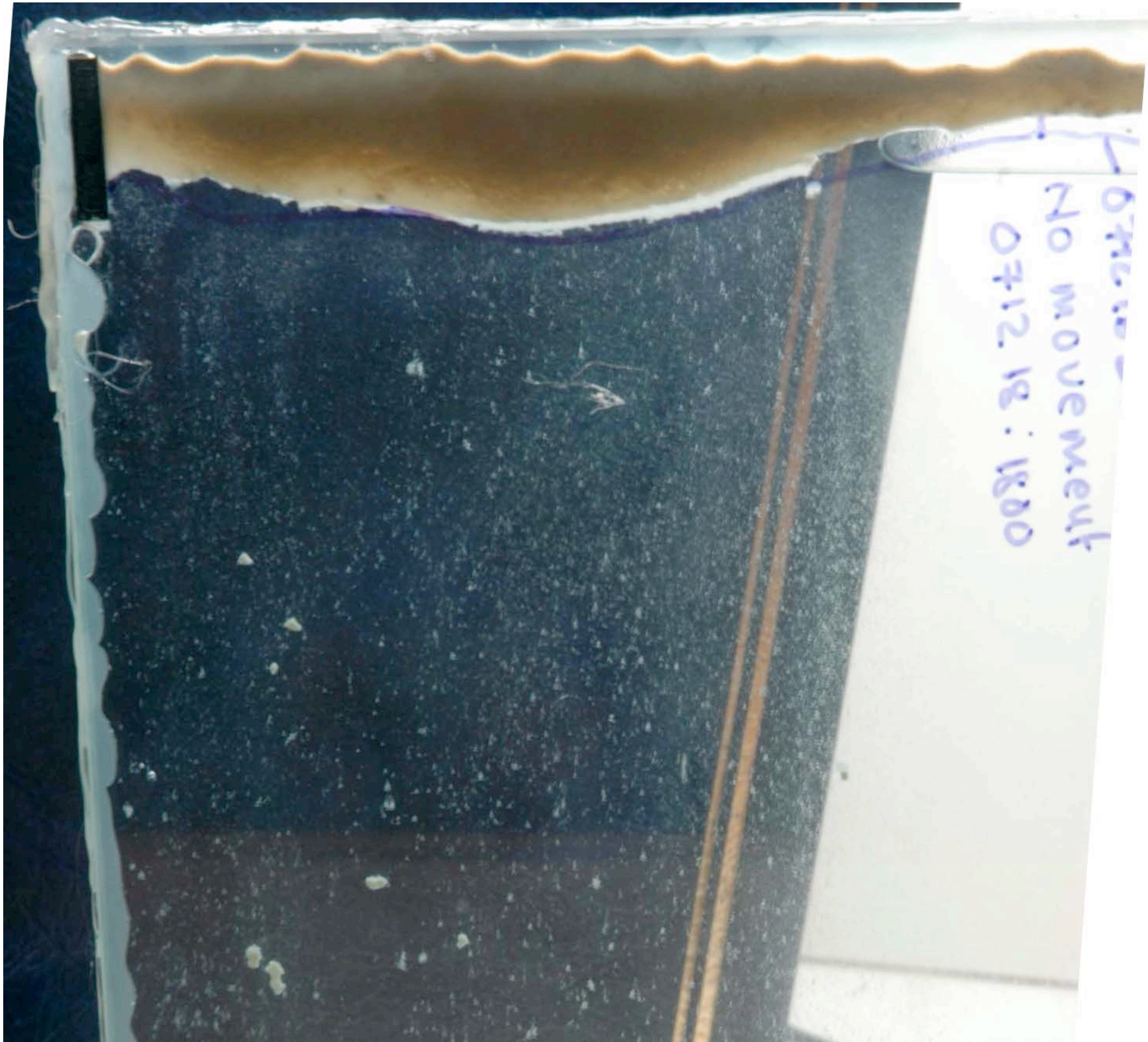
Estimated smectite flux, J_{Smec}, from Mx-80 in Di

- 0.106 g is slit 1.32 mm aperture and 0.13 m wide
- Released and sedimented in a few days
- $J_{Smec} \approx 10$ g/m^2/hr

- PA related
- Loss in 0.1 mm aperture 10 m wide expanded gel
- $N_{Smec} \approx 100$ g/yr (1000 kg/10 000 yrs)

Neretnieks I., 2009, Some scoping erosion experiments in thin slits between glass plates, Chemical Engineering, Royal Institute of Technology, KTH, Stockholm, Sweden, Internal report.

Ca smectite washed of detritus in Di



Ca smectite washed of detritus in Di

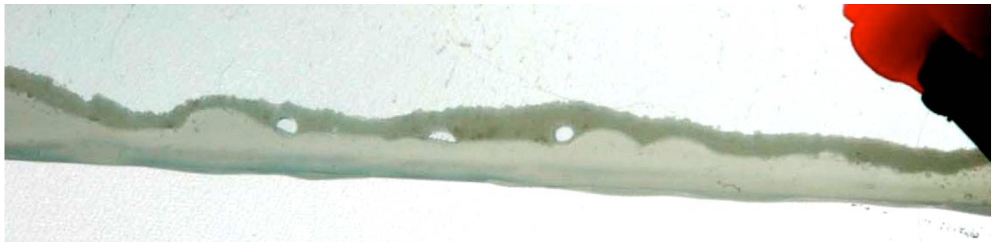


Figure 18   Small gel particles sedimented at bottom of slit.

An enlarged part of the sediment, 9 days after turnover is shown in figure 19.

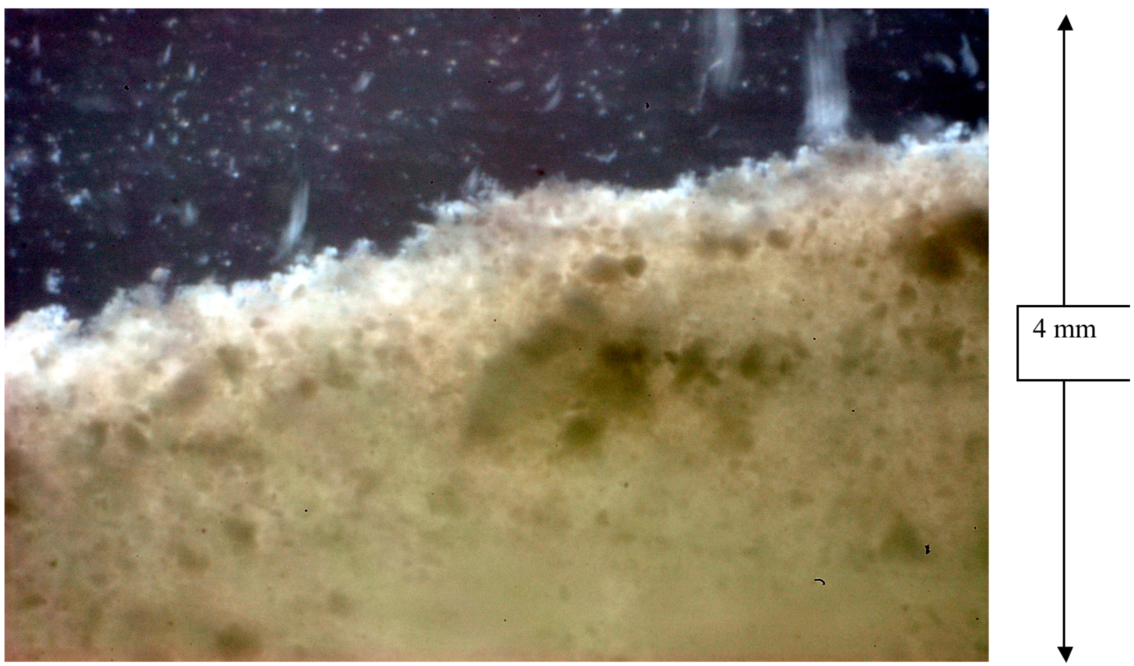


Figure 19   Enlargement of sediment after 9 days. Picture shows a 4 mm high section of the sediment.

Ca smectite washed of detritus in Di

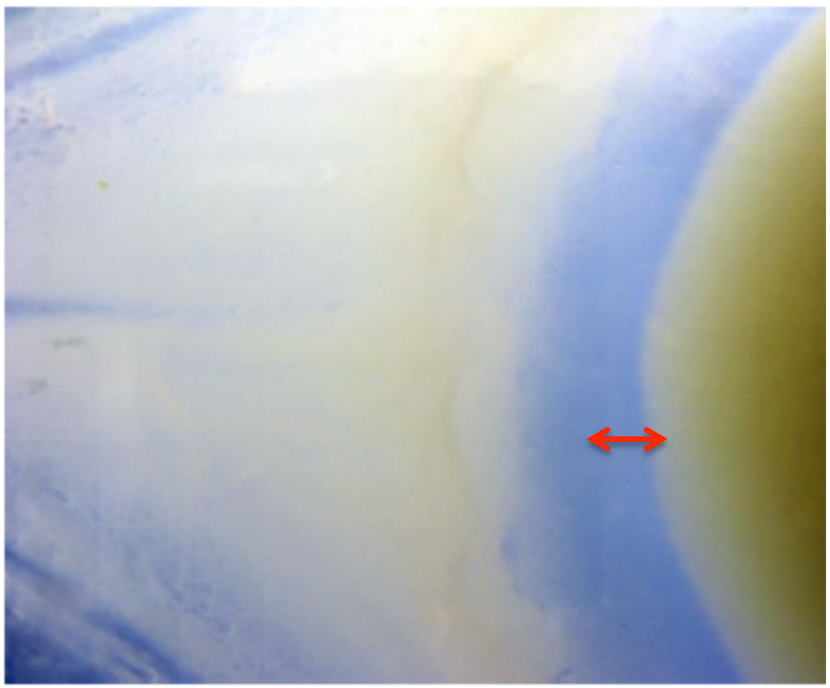
- After some initial loss the gel stabilised after ten days and did not release more particles

- A water sample taken after 3 months contained 0.76 mM Na, 1.02 mM Ca and 0.04 mM Mg.

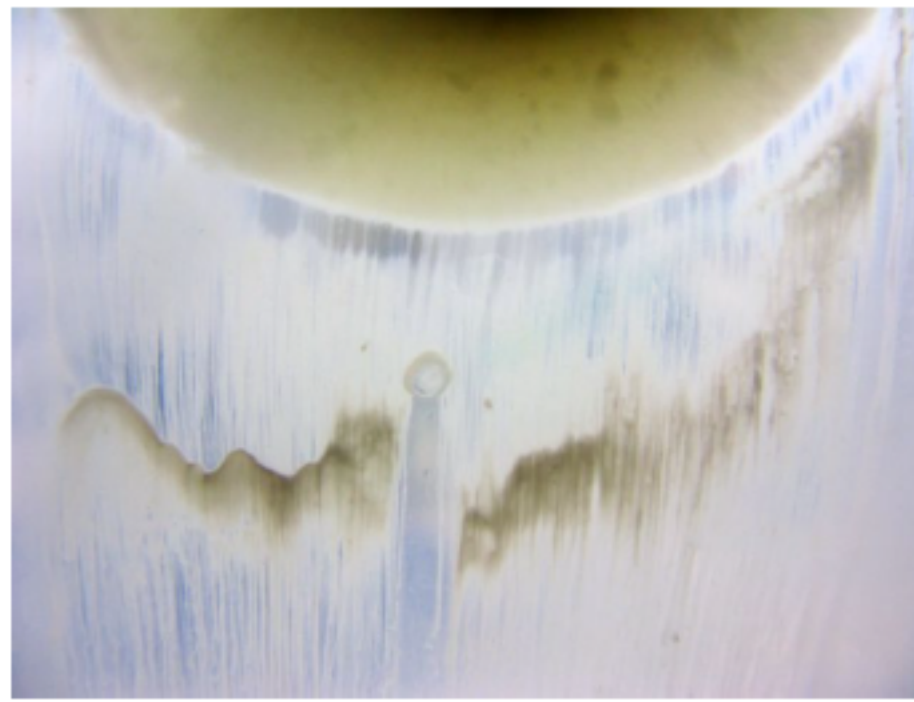
Schatz et al. (2012) erosion experiments

50/50 calcium/sodium montmorillonite in Di

Formation of flocs



Gravity pulling off flocs when slit is vertical



Schatz, T., Kanerva, N., Martikainen, J., Sane, P., Olin, M., Seppälä, A and Koskinen, K., 2012, Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44 (2012).

NaMt, DI water no flow

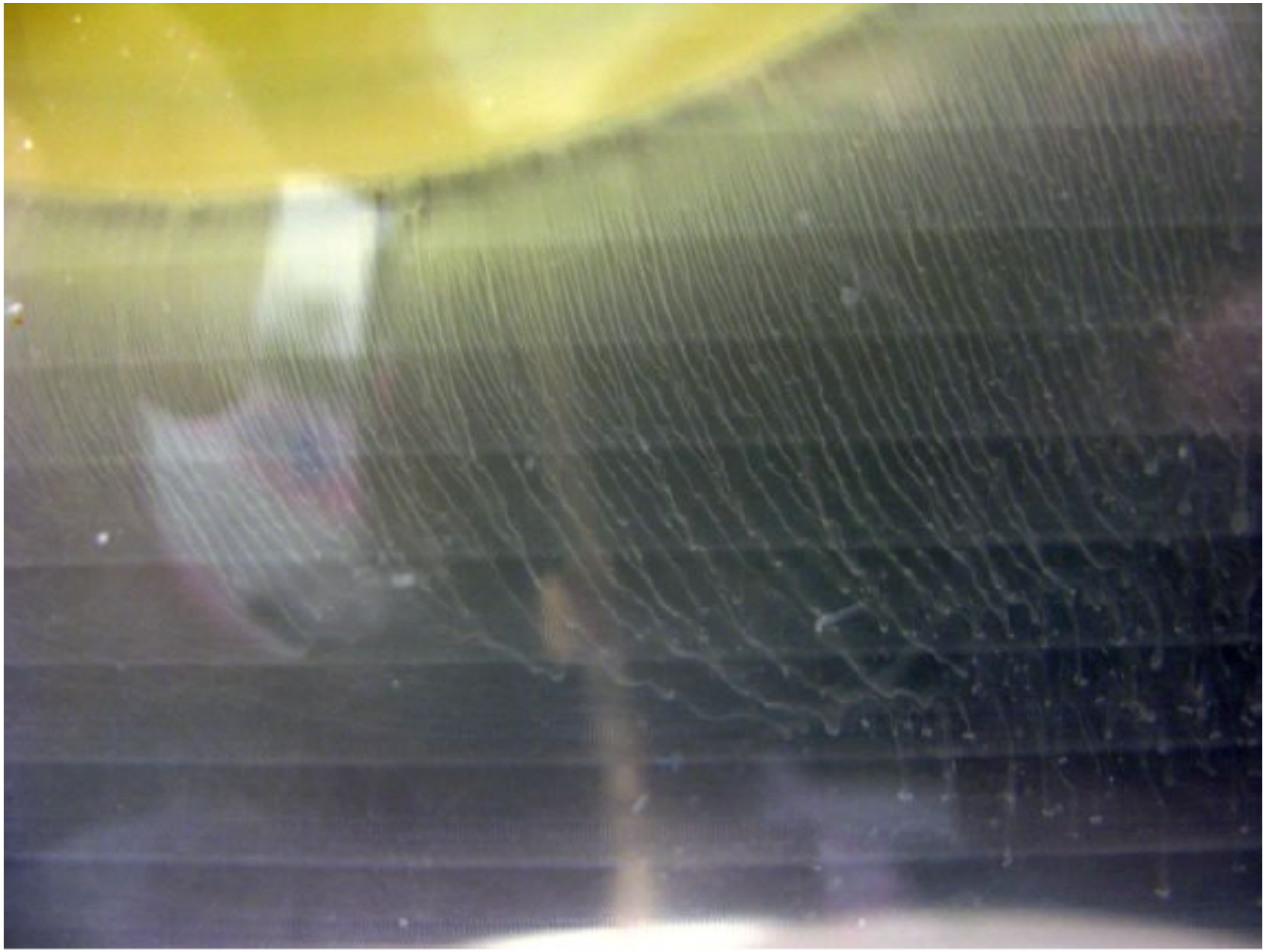


Figure 69. *Sedimentation of material strings at the extruded material/solution interface 1.5 h after rotation of test 11 from a horizontal to vertical fracture position.*

Schatz, T., Kanerva, N., Martikainen, J., Sane, P., Olin, M., Seppälä, A and Koskinen, K., 2012, Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44 (2012).

Some speculations on gel, stack and agglomerate formation

- Expansion phase: VolFrac <2-3 % Sheets parallel
- Wobble phase VolFrac around 1%, commencing rotation of sheets
- Floc formation phase: Edge to face attachment commences, loose flocs/agglomerates grow slowly to gel
- Maturation phase: Gel seeks lower energy minimum, stabilises increasingly.

Edge to face attraction

- Controversial and disputed idea that smectite edges can be positively charged
- Recent experiments by Hedström et al, 2015 clearly show that this occurs even at neutral pH
- Explains why very lose gels can form and that flexible flocs can be formed and be stable

Hedström M., Ekvy-Hansen E., Nilsson U., 2015, Montmorillonite phase behaviour Relevance for buffer erosion in dilute groundwater, SKB TR-15-07

Expanding stacks and gel formation

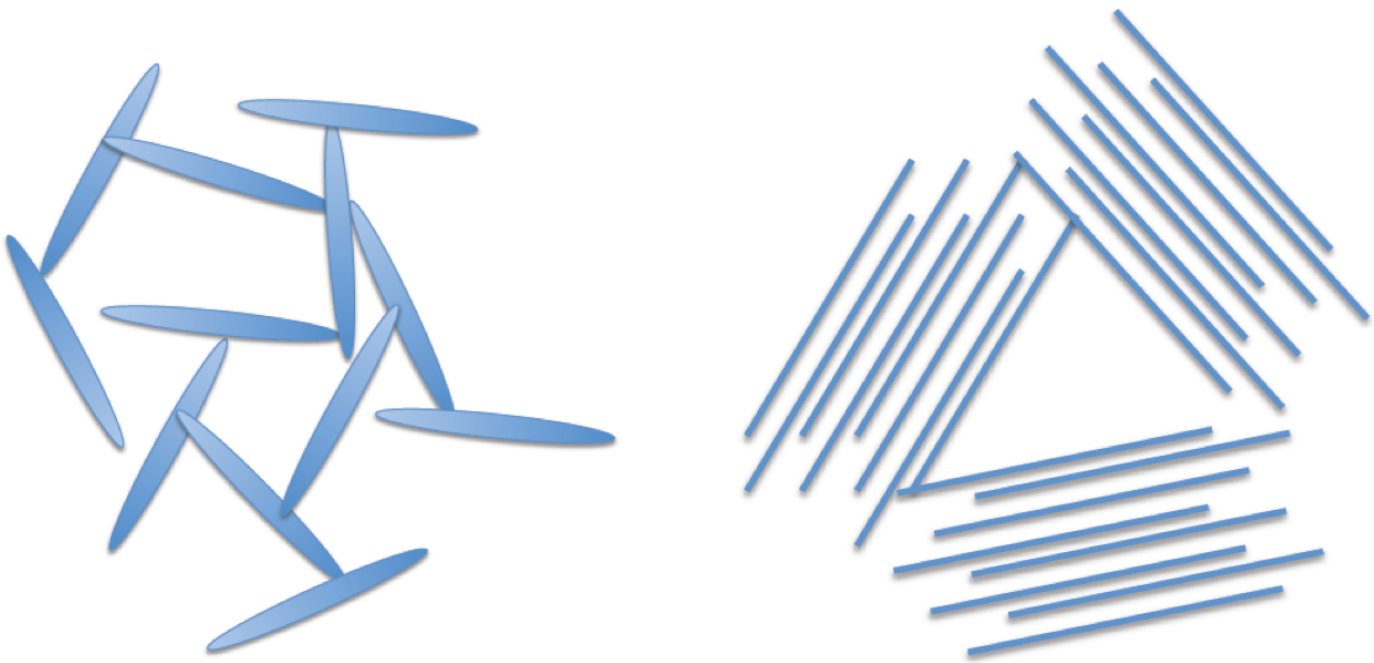
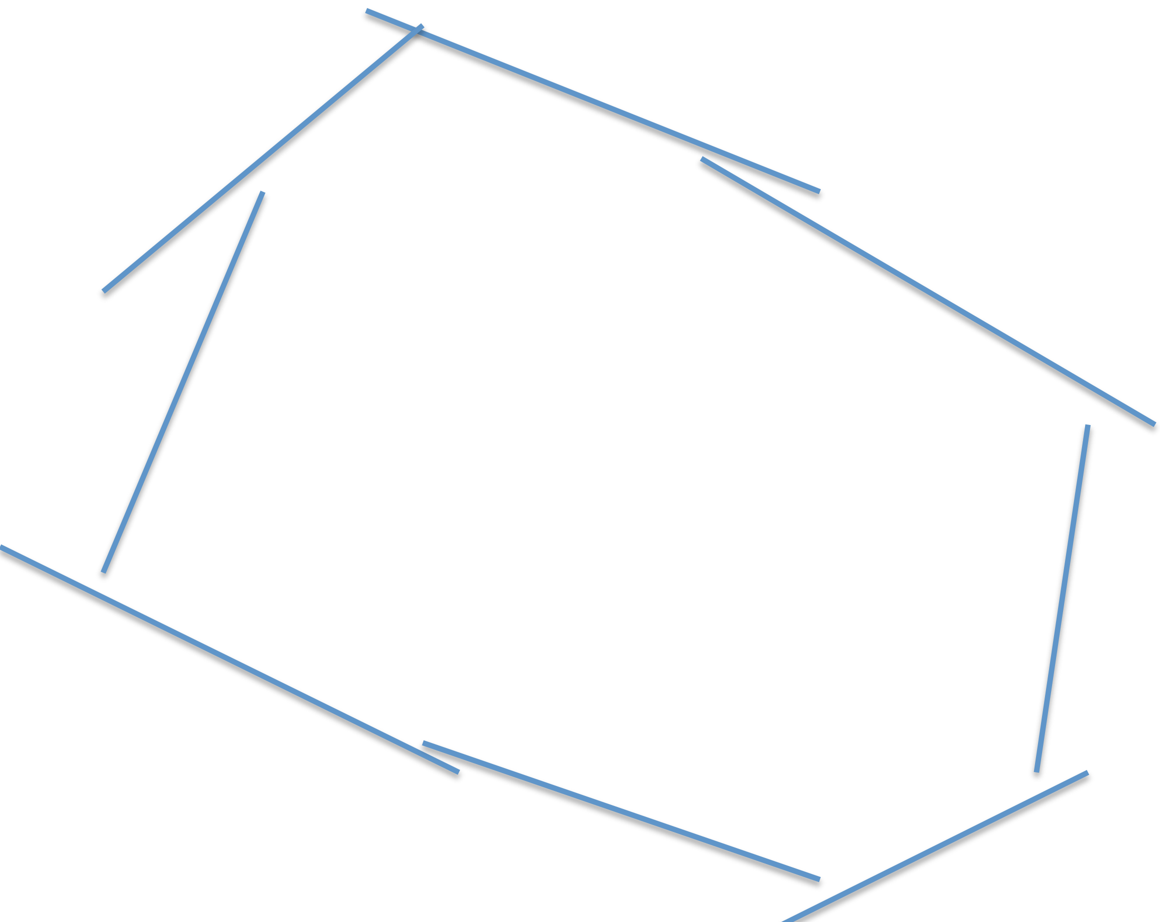


Figure 10. Two different forms of agglomerates in the AF. At left, "house of cards" structure, at right, still expanding stacks.

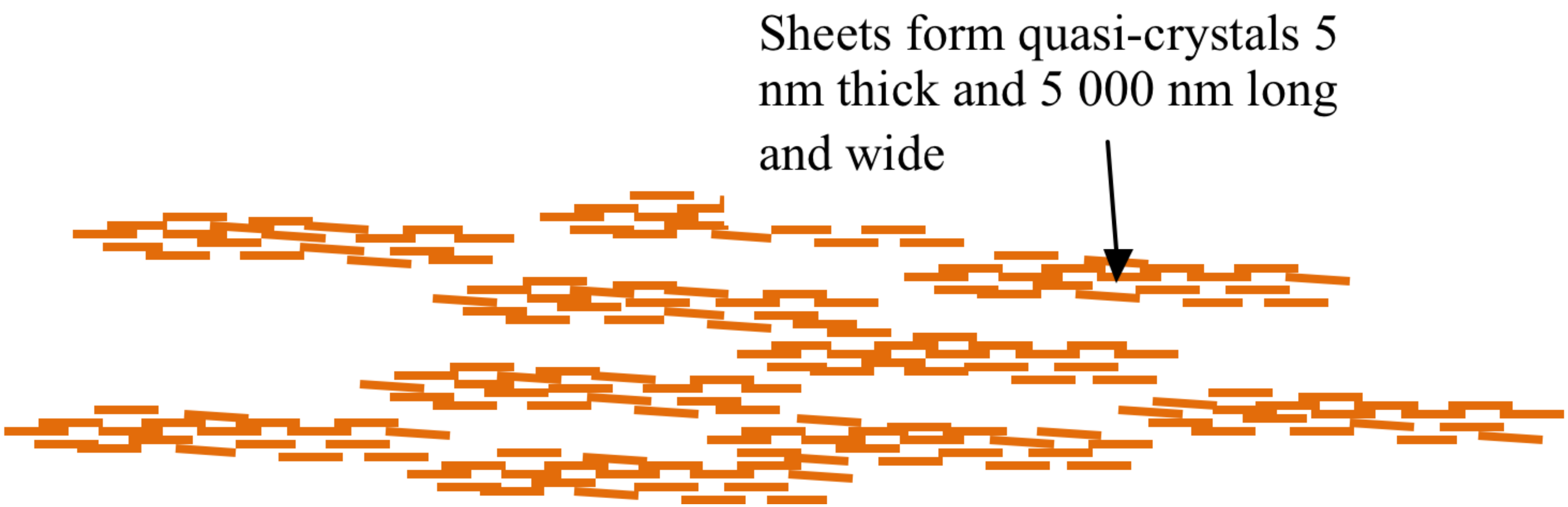
Illustration of space filling gel by face to edge attraction (2D)



Stable gels with < 0.001 vol % have been observed

Hedström M., Ekvy-Hansen E., Nilsson U., 2015, Montmorillonite phase behaviour Relevance for buffer erosion in dilute groundwater, SKB TR-15-07

Conceptualisation of "quasi-crystals" of individual Ca smectite sheets arranged in a configuration that makes it possible to have a high solid volume fraction when compacted but may allow swelling between the quasi-crystals. Based on Kjellander et al. (1988) description.

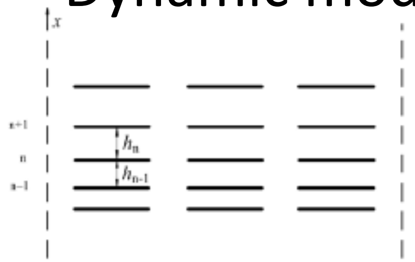


Can such "sheets" in turn form 3D structures?

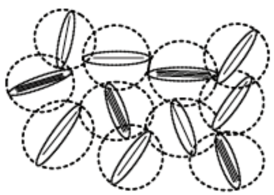
Kjellander R., Marcelja S., Quirk, JP, 1988, attractive double-layer interactions between calcium clay particles, Journal of Colloid and Interface Science, 126 (1)

Dynamic model

Dynamic model with floc formation

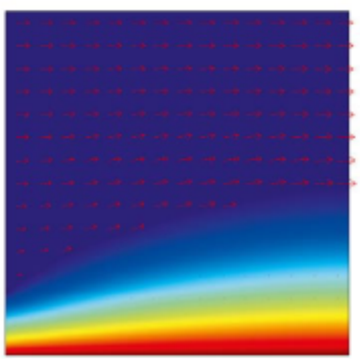


Expansion of rigid gel.
Viscosity “ infinite

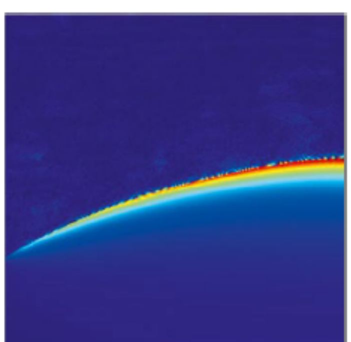


Large diffuse double layer, co-volumes overlap

Starting rotation.
Viscosity of sol drops

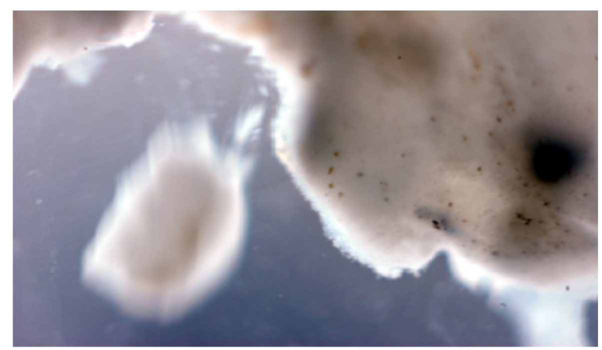


Colloidal particles diffuse into seeping water.
Concentration Picture of rim zone



Sol flows.
Flux picture
Of rim zone

Flocs form. Can sediment.
Floc slurry viscosity near water.



Quantification of smectite loss by gravity from experiments

“For a sloped fracture, the sol is constantly removed due to gravity “ (…)

“Using the example above of a clay paste with diameter of 2 m and a fracture aperture of 1 mm, the erosion from a sloped fracture (slope angle 45 degrees) amounts to approximately 1 kg/yr under glacial water conditions. Similar erosion rates was found in the experiments on sloped fractures performed at B +Tech (T. Schatz…)“

Compare Neretnieks observations in slit (Earlier slide)

Loss in 1 mm aperture 2 m wide expanded gel N_{Smec} ≈ 0.2 kg/yr

Hedström M., Ekvy-Hansen E., Nilsson U., 2015, Montmorillonite phase behaviour
Relevance for buffer erosion in dilute groundwater, SKB technical report TR-15-07, available at www.SKB.se

Neretnieks I., 2009, Some scoping erosion experiments in thin slits between glass plates, Chemical Engineering, Royal Institute of Technology, KTH, Stockholm, Sweden, Internal report.

Limits for smectite loss by gravity

- A limiting mechanism could be the rate at which the flocs can be carried away downward in the fracture
- Small flocs as spheres when d< fracture aperture
- Large flocs as coin-like flocs when d> fracture aperture

Model w. small spheres

Sedimentation rate of spheres, Stokes law

$$v_{sph} = \frac{2}{9\mu_W} r_{sph}^2 \left(\varrho_{sph} - \varrho_W\right) g$$

$$\varrho_{sph} = \phi\, \varrho_{smec} + (1 - \phi)\, \varrho_w$$

$$\varrho_{\#} = \frac{1}{r_{sph}^3 n_{rS,v}\, n_{rS,h}^2}$$

$$N_{smec} \propto \frac{1}{n_{rS,v}\, n_{rS,h}^2}\, r_{sph}^2 \delta W_{AF}$$

Maximum loss as spheres

Largest sphere diam = aperture

Note cubic dependence on aperture

$$N_{smec} = fr\,\frac{\pi\delta^3}{108\mu_W}\left(\varrho_{sph} - \varrho_W\right)g\phi\varrho_{smec}W_{AF}$$

fr is fraction of maximum # of spheres per volume

Model with Coins- Friction against walls

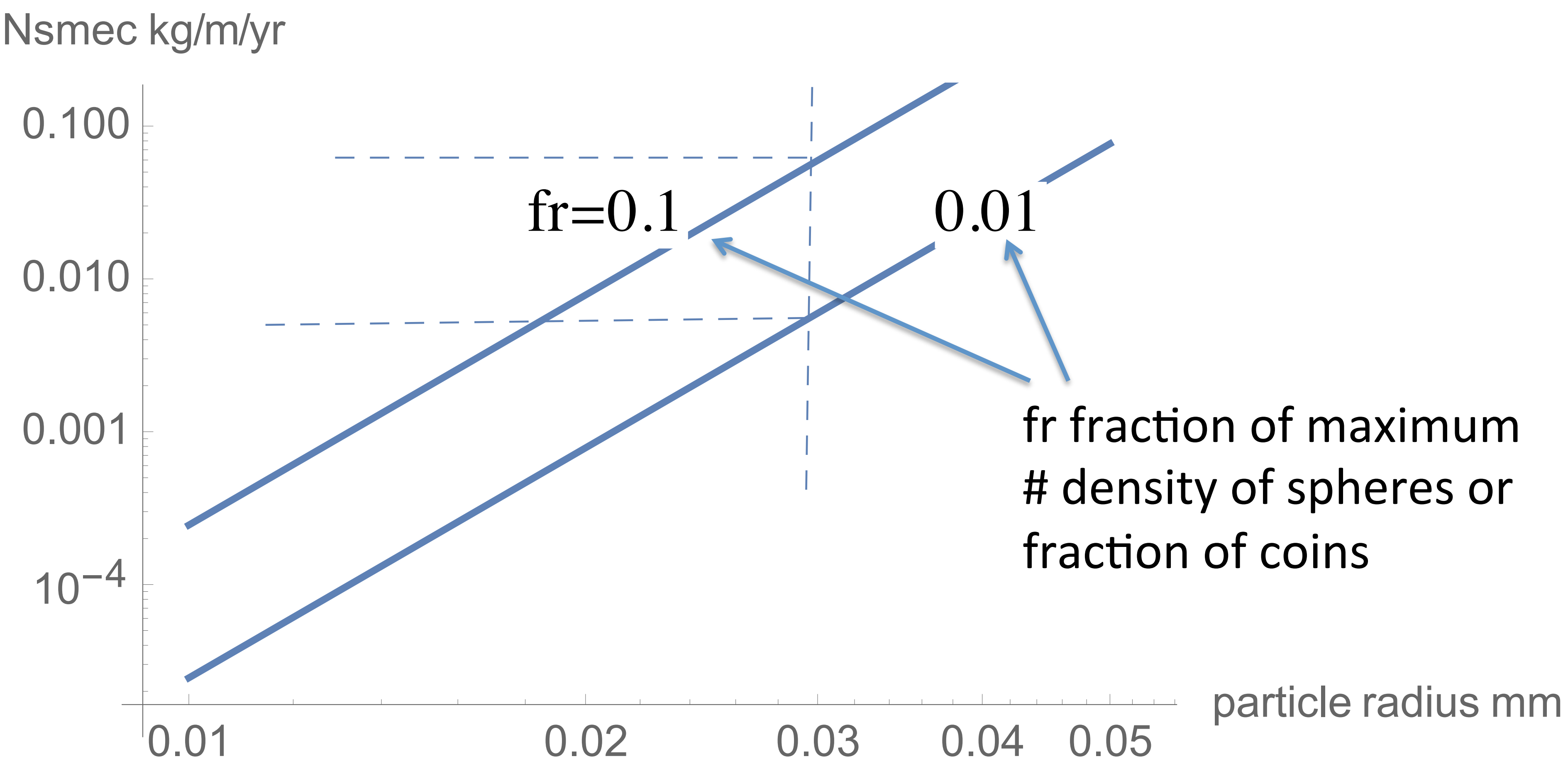
Sedimentation rate of “coin” or viscous agglomerate fluid AF, -> Cubic law

$$N_{smec,max,coin} = \frac{\pi\delta^3}{12\mu_{agg}}(\varrho_{sph} - \varrho_W) g \phi \varrho_{smec} W_{AF}$$

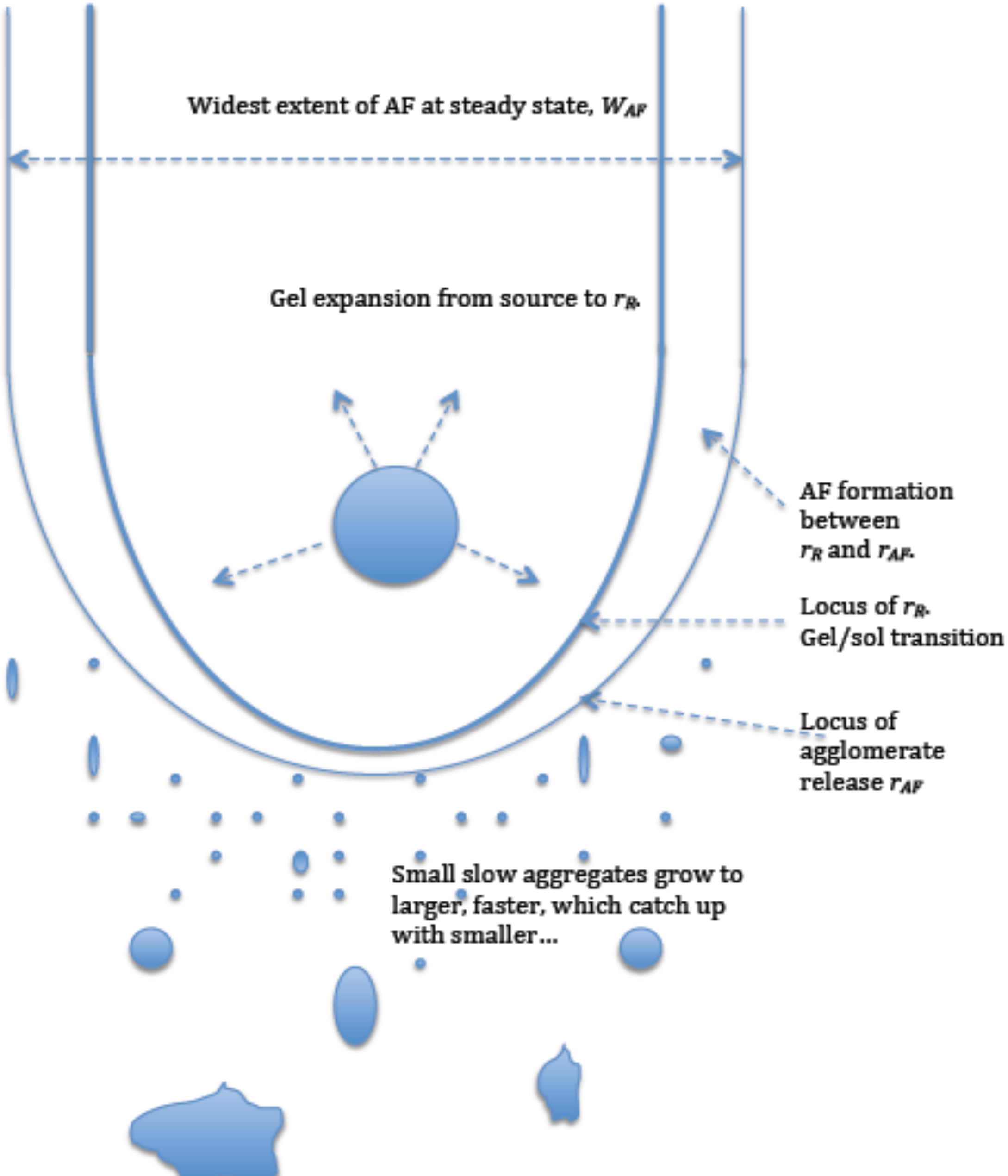
“Coin” filling whole width of source W_{AF}

$$\mu_{agg} \cong 10 * \mu_W$$

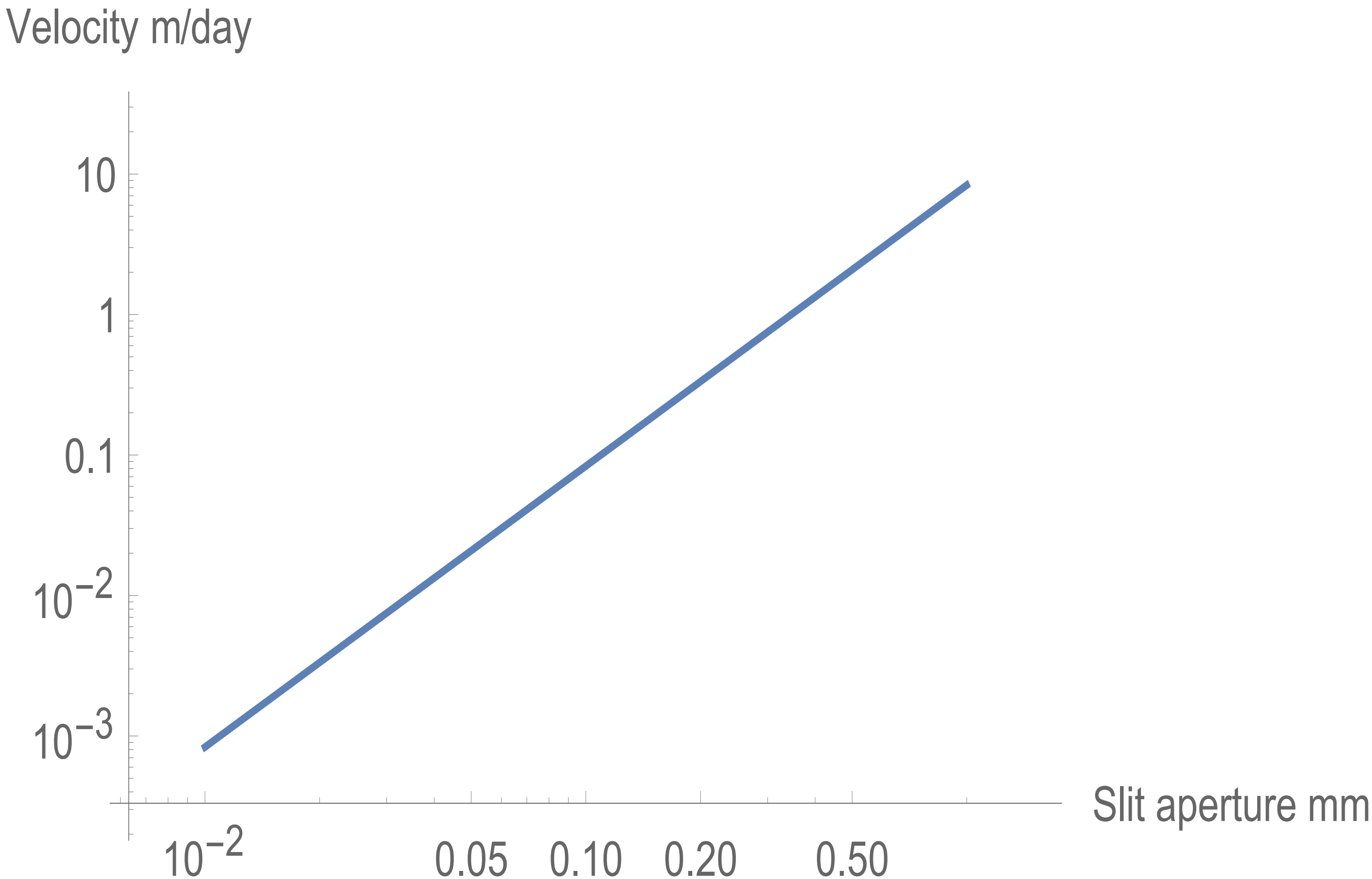
Note enormous impact of particle size 0.1 mm aperture



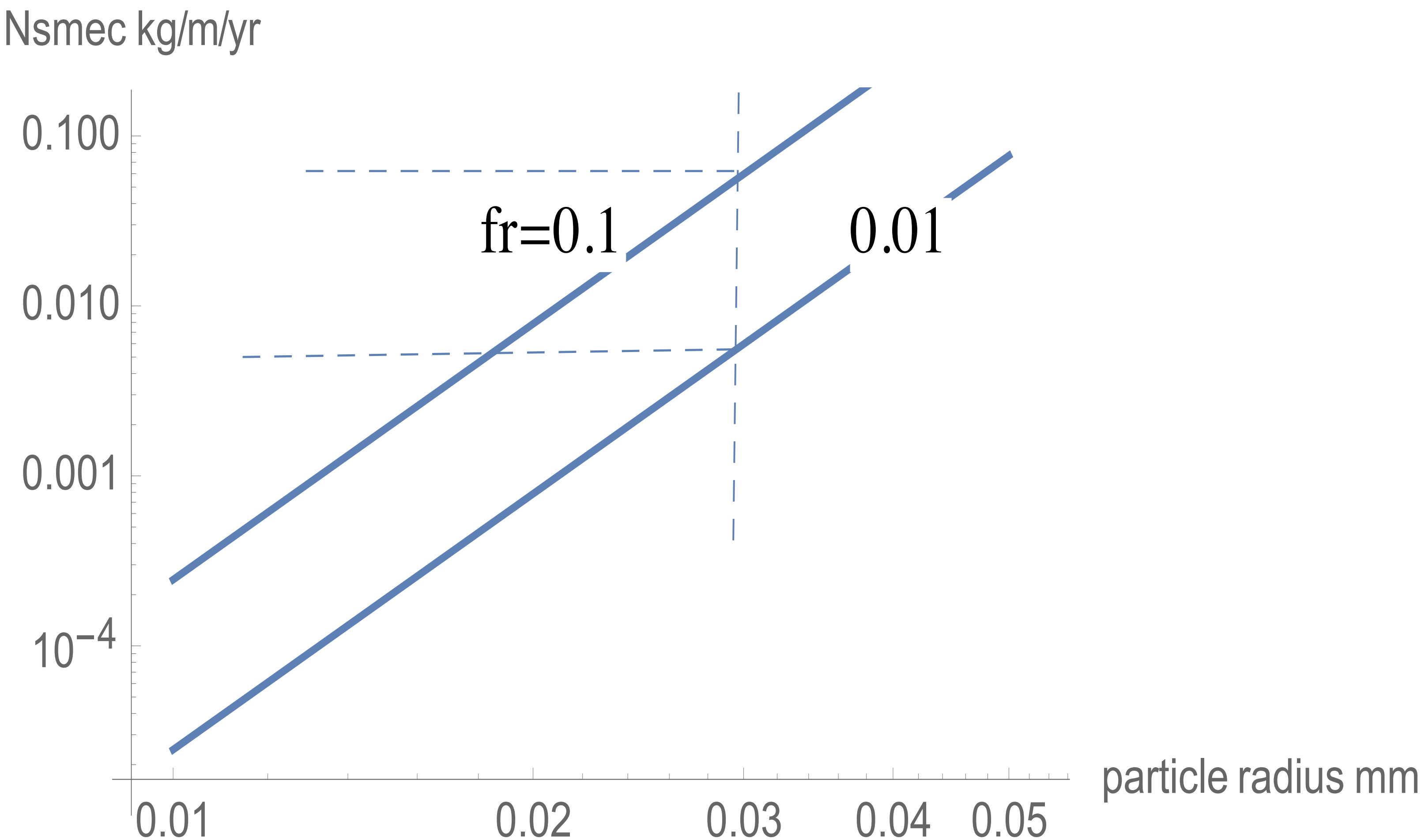
Loss of smectite by floc sedimentation



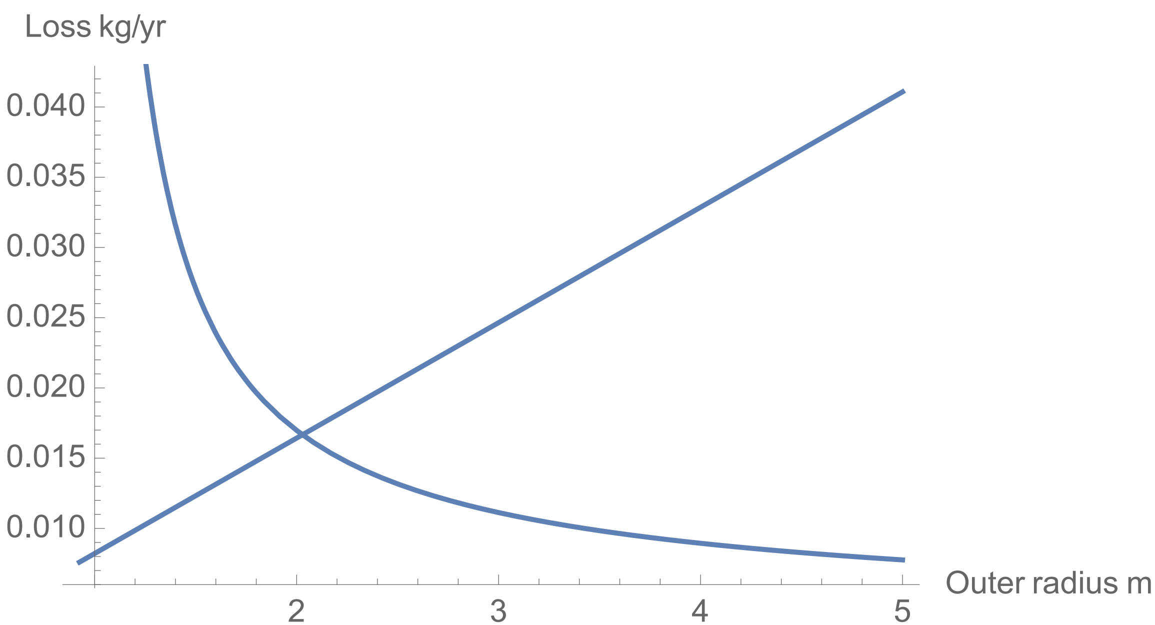
Sedimentation velocity of large coin-like agglomerates with 1% by volume smectite in a vertical slit vs. slit aperture.



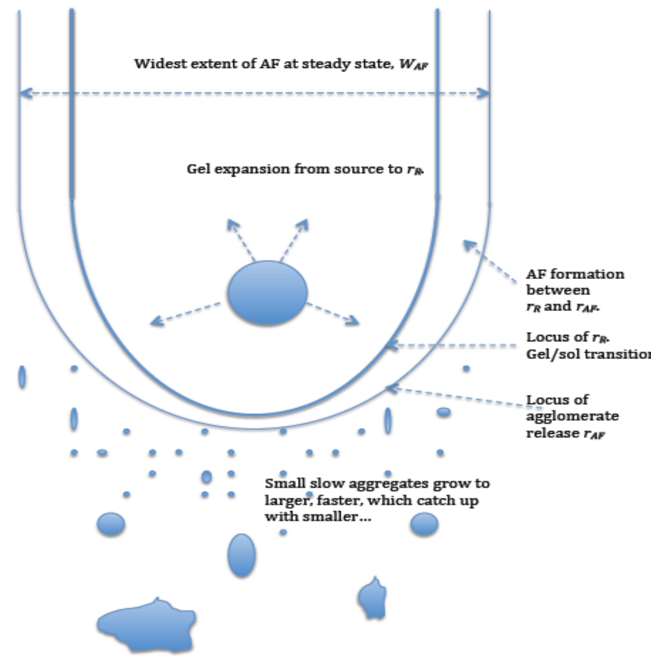
Rate of mass loss vs. particle radius for two different fr-factors in a 0.1 mm aperture fracture



Stabilisation of width of expansion



Aperture 0.1 mm, fr=0.01



Rate of loss from deposition hole N_{PSS} (curved line) and rate of loss by sedimentation N_{smec} (straight line) as function of the radius to the rim

Outlook

- The model sets an upper bound of loss if rate of generation and release of agglomerates is UNLIMITED
- It is not. We must study rate of generation

$$N_{smec} \propto \frac{r_{sph}^2}{n_{rS,v}\, n_{rS,h}^2}$$

Model suggests that

$$N_{smec} \propto \frac{\delta^3}{\mu_{agg}}$$

Some queries I

Where does the bentonite end up?

Example 100 kg bentonite loss

Agglomerate volume fraction of bentonite= 0.01
Rock porosity of fractures 10^{-4}

Fills 38 000 m^3 rock
A cube with 34 m sides

Could this be used as an argument against large loss?

Some queries II

- Where does the detritus end up?
- What does the detritus do to the loss of smectite?

Some references on erosion modelling and background reports

SKB reports can be freely downloaded from www.SKB.se
Posiva reports can be freely downloaded from www.Posiva.fi
The reports marked yellow summarise modelling approaches

Liu, L., 2010. Permeability and expansibility of sodium bentonite in dilute solutions. Colloids Surf. A: Physicochem. Eng. Aspects 358 (1–3), 68–78.

Liu L. Neretnieks I., Moreno L., Permeability and expansibility of natural bentonite MX-80 in distilled water, Physics and Chemistry of the Earth 36 (2011) 1783–1791

Liu L., 2011, A model for the viscosity of dilute smectite gels, Physics and chemistry of the earth, 36, p 1792-1798

Liu L., 2013, Prediction of swelling pressures of different types of bentonite in dilute solutions, Colloids and Surfaces A: Physicochem. Eng. Aspects 434 (2013) 303– 318

Liu, L., Moreno, L., Neretnieks, I., 2009a. A Dynamic force balance model for colloidal expansion and its DLVO-based application. Langmuir 25 (2), 679–687.

Liu, L., Moreno, L., Neretnieks, I., 2009b. A novel approach to determine the critical coagulation concentration of a colloidal dispersion with plate-like particles. Langmuir 25 (2), 688–697.

Liu L., Neretnieks I., Moreno L., 2011, Permeability and expandability of natural bentonite MX-80 in distilled water. Physics and Chemistry of the Earth, 36, p 1783-1791

Moreno L., Neretnieks I., Liu L., 2010, modelling of bentonite erosion SKB TR-10-64.

Moreno L., Neretnieks I., Liu L., 2011, Erosion of sodium bentonite by flow and colloid diffusion, Physics and chemistry of the earth, 36, p 1600-1606

Neretnieks, I., Liu, L., Moreno, L., 2009. Mechanisms and Models for Bentonite Erosion. Swedish Nuclear Fuel and Waste management Co., Technical report, SKB TR-09-35

Neretnieks I., Liu L., Moreno, L., 2010, Mass transfer between waste canister and water seeping in rock fractures. Revisiting the Q-equivalent model, Swedish Nuclear Fuel and Waste management Co., Technical report, SKB TR-10-42

Schatz, T., Kanerva, N., Martikainen, J., Sane, P., Olin, M., Seppälä, A and Koskinen, K., 2012, Buffer Erosion in Dilute Groundwater. Posiva Report 2012-44 (2012).

Reports submitted to BELBaR 2015

1) Bentonite expansion and erosion- Development of a two-region model by Ivars Neretnieks, Luis Moreno and Longcheng Liu

2) Evaluation of some erosion experiments by the two-region model by Ivars Neretnieks, Luis Moreno and Longcheng Liu

3) Release and sedimentation of smectite agglomerates from bentonite gel/sol by Ivars Neretnieks

Thank you for your attention