SAND2017-10759C

Task F - Fluid Inclusion and Movement in Tight Rocks (FINITO)

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Sandia National Laboratories

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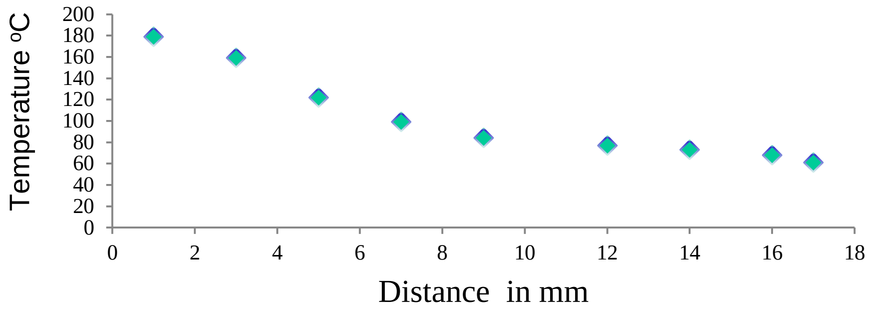
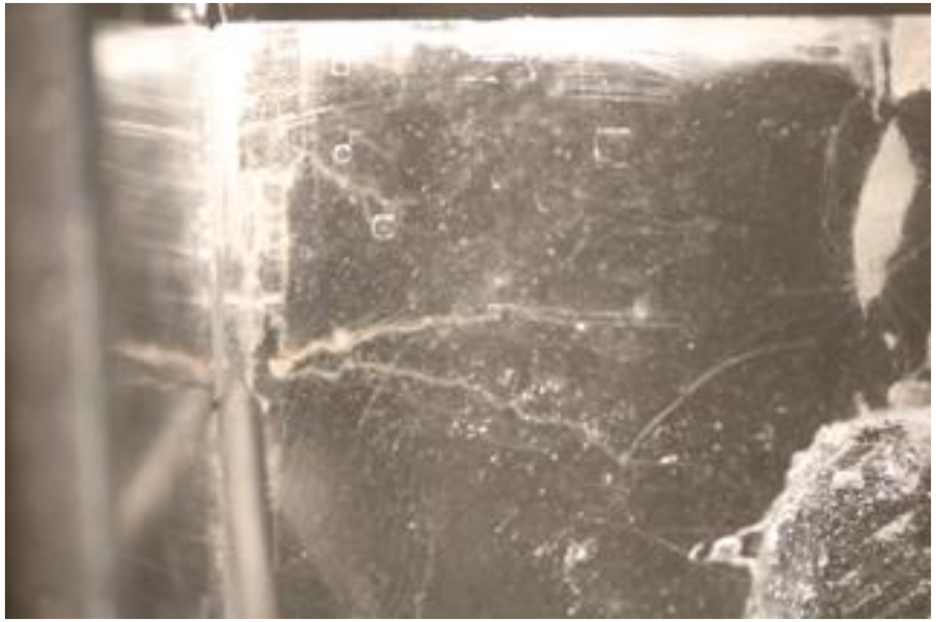
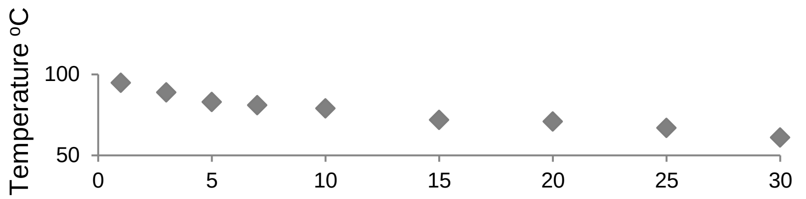
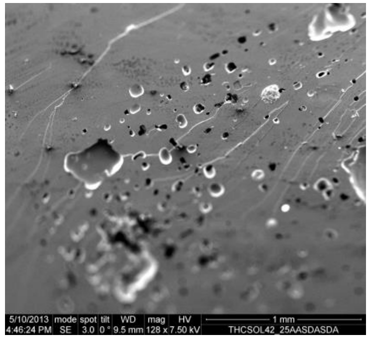
Observations: Temperature effect

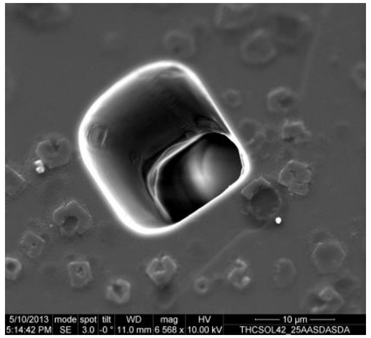




Caporuscio et al. (per. Comm.)

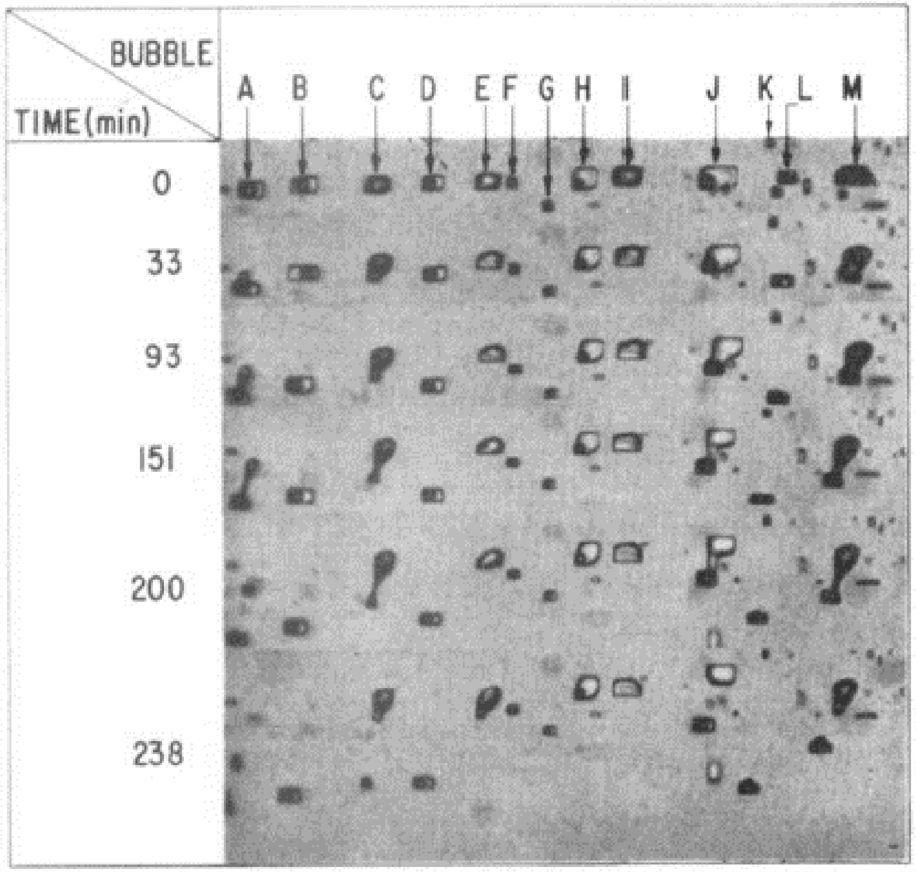


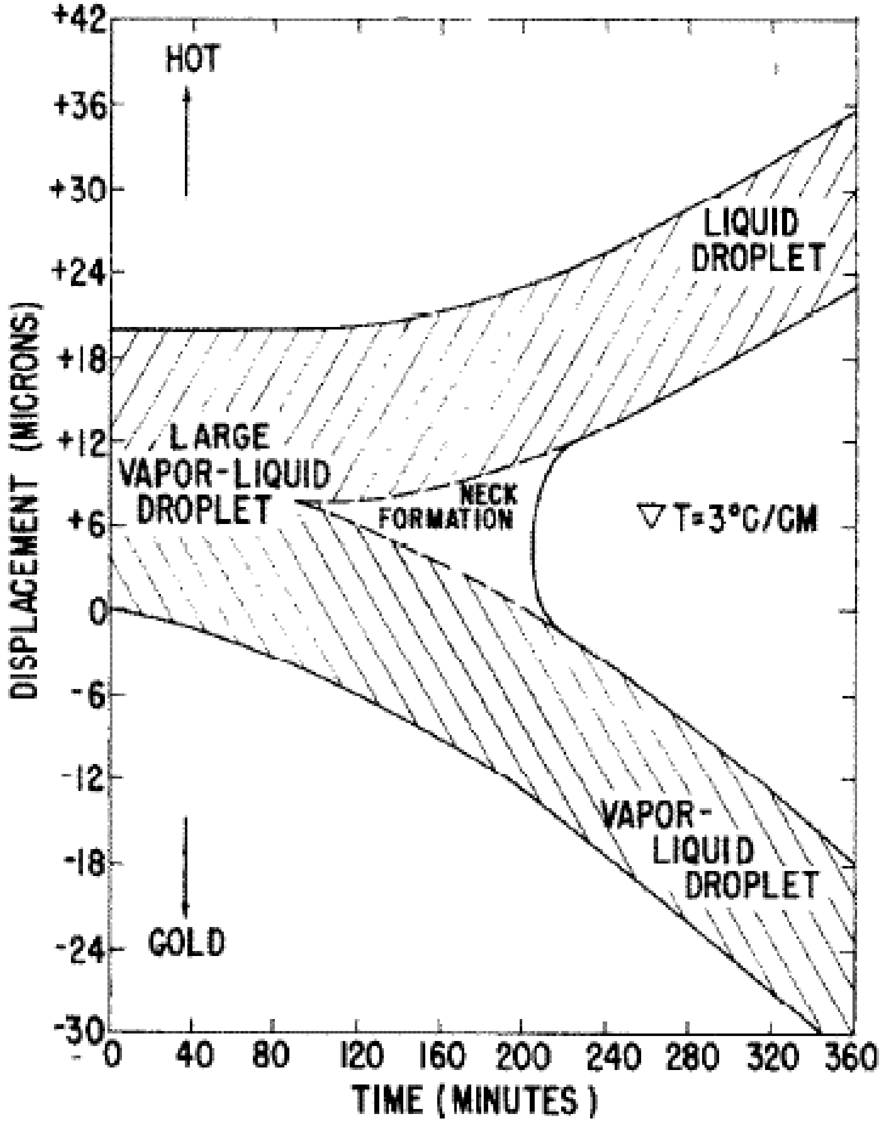




Interface instability and channeling

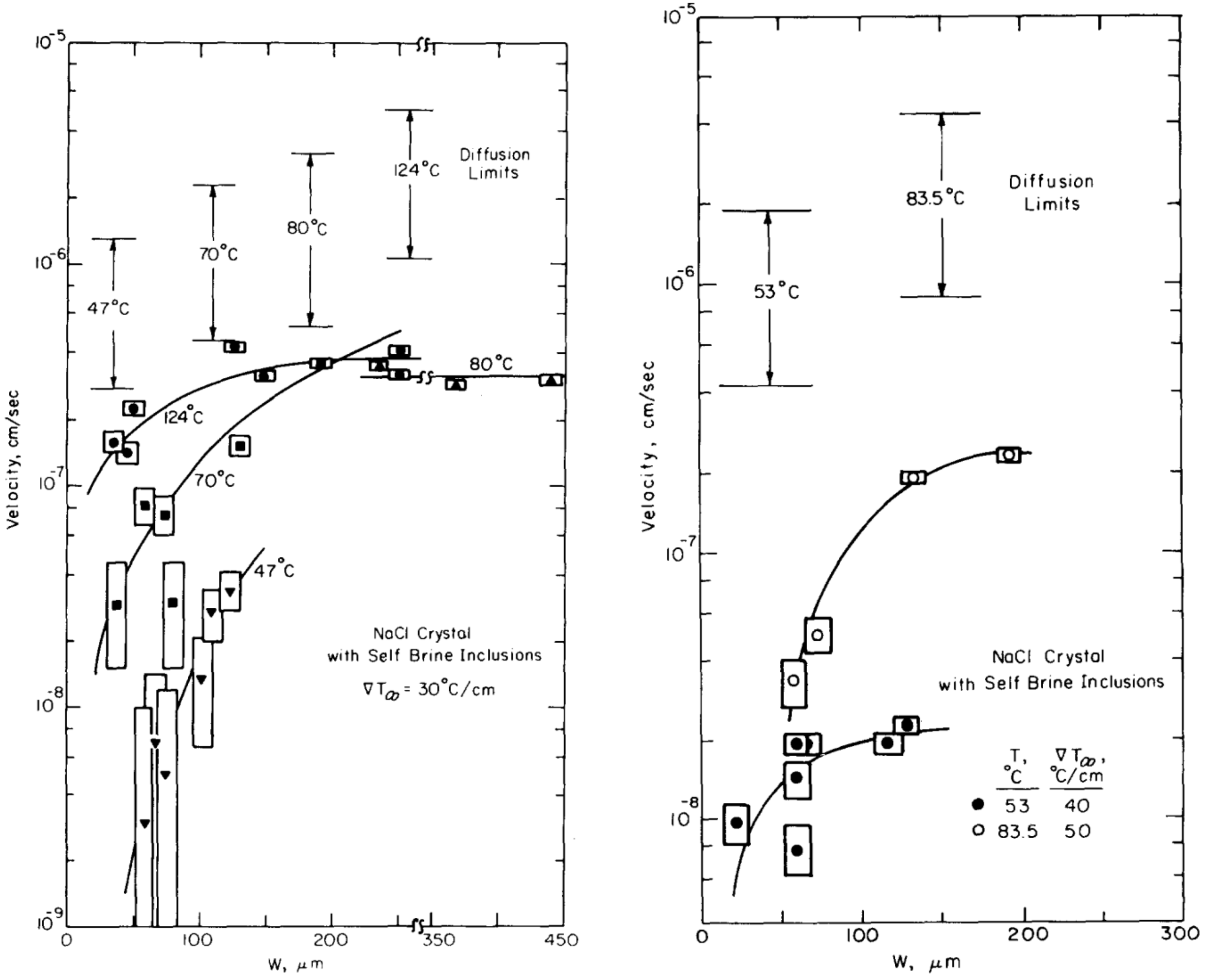
Observations: Biphase inclusions





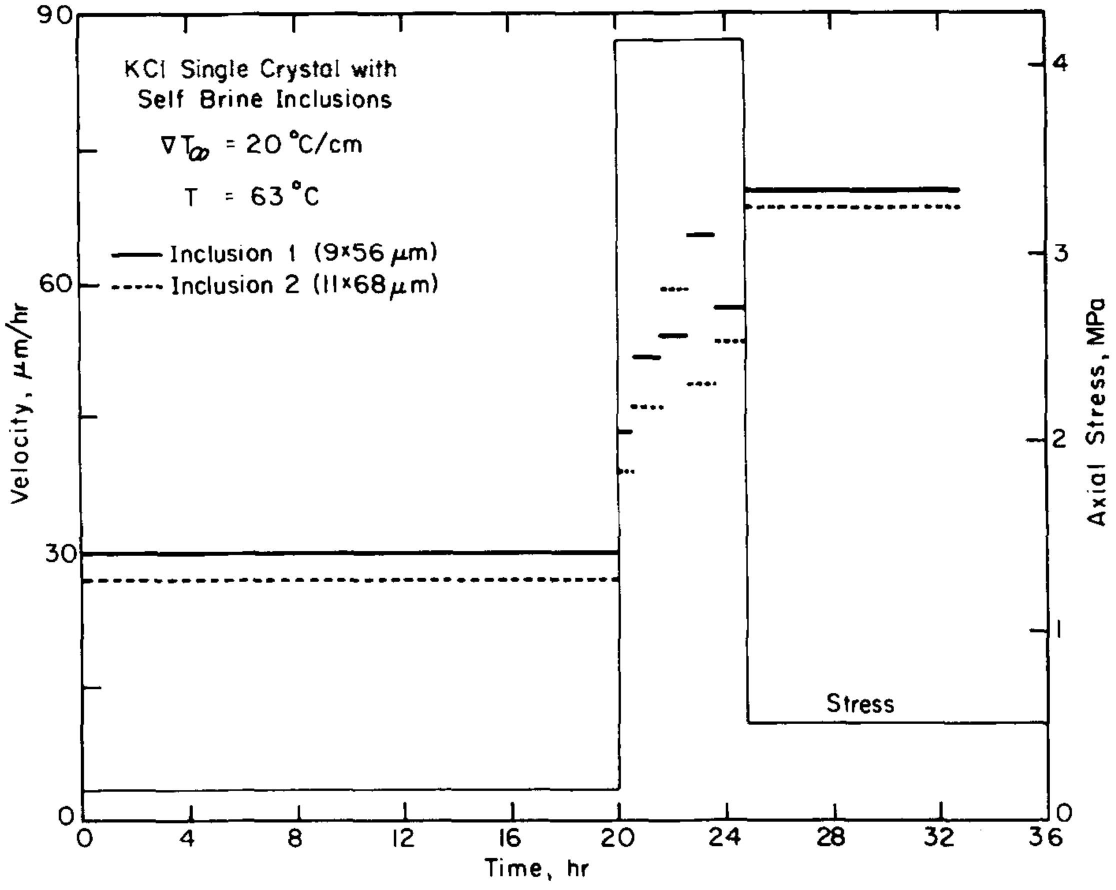
Anthony & Cline (1972)

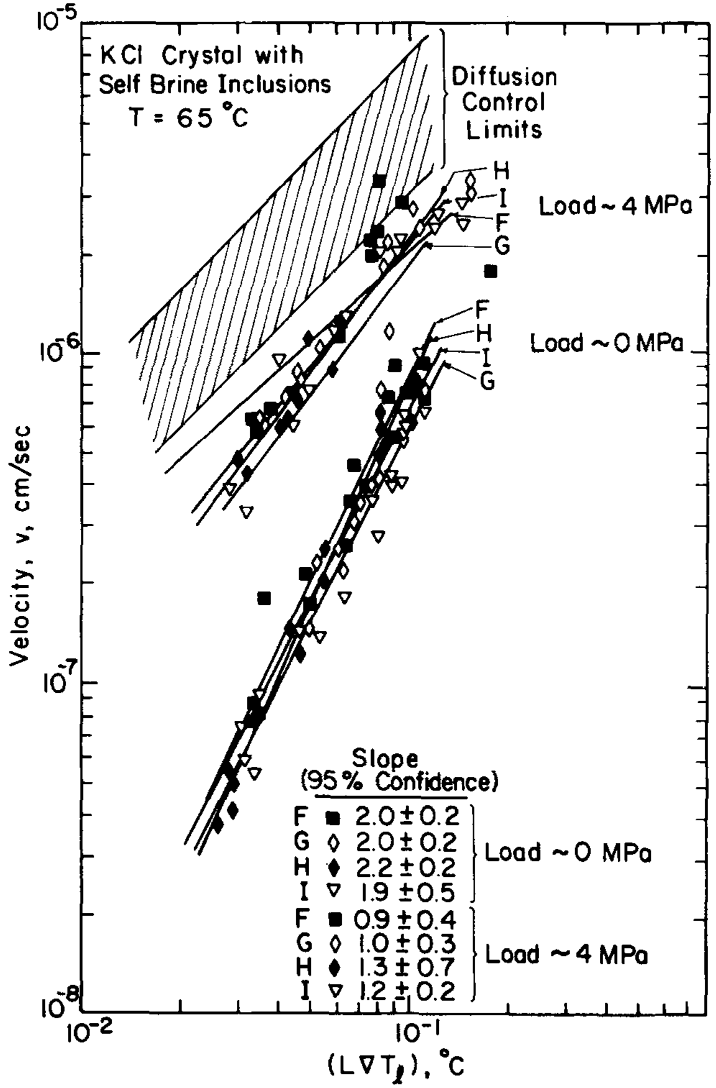
Observations: Size dependence



Olander et al. (1982)

Observations: Effect of stress





Olander et al. (1982)

Fluid inclusion migration under a thermal gradient

Within Ω:

$$\frac{\partial m}{\partial t} = D\nabla^2 m$$

$$\frac{\partial T}{\partial t} = \alpha$$

On Ω:

$$NaCl(s) \leftrightarrow NaCl(aq)$$

$$R_d = k(K_d - m)$$

$$K_d(T,\kappa) = K_d^0 e^{\frac{\Delta H_r}{RT}\left(\frac{T}{T_0}-1\right)-\frac{2\gamma V_m \kappa}{RT}}$$

Curvature effect

$$-D\vec{\nabla} m \cdot \vec{n} = R_d$$

Kinematics of Ω:

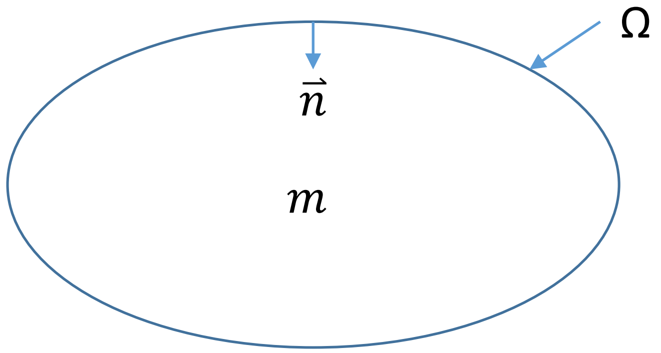
Ω(x, y, z, t) = 0

$$\vec{\nabla}\Omega \cdot \vec{V} + \frac{\partial \Omega}{\partial t} = 0$$

$$\vec{V} + V_0\vec{\imath} = -V_m R_d \vec{n}$$

$$\vec{n} = -\frac{\vec{\nabla}\Omega}{|\vec{\nabla}\Omega|}$$

$$\kappa = -\vec{\nabla} \cdot \vec{n}$$

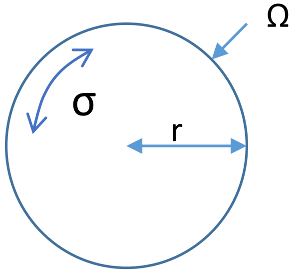


Questions:

- Steady state shape of a fluid inclusion?
- Morphological instability
- Dependence of inclusion movement on thermal gradient, size, solubility, etc.
- Effect on overall fluid movement

Moving boundary problem, level-set method for numerical solution

Model analysis

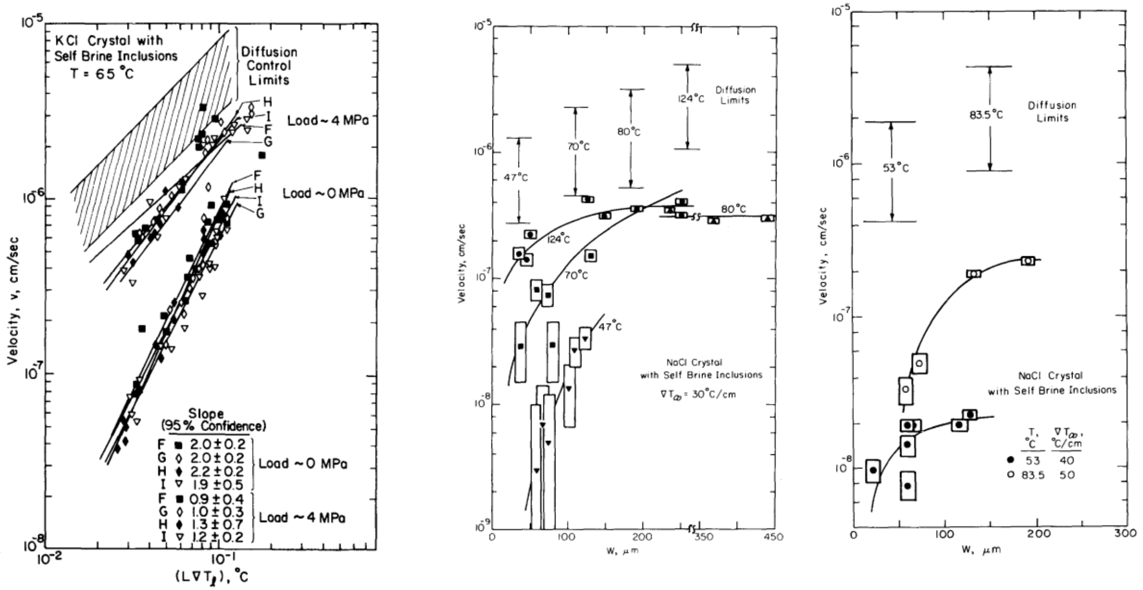


$$V_0 \approx \frac{V_m D K_d^0 \Delta H_r \alpha}{R T_0^2} e^{-\frac{2\gamma V_m}{R T_0 r}}$$

$$K_d^0 \propto e^{\frac{\Delta H_r}{R T_0} + \frac{\beta V_m \sigma^2}{R T_0}}$$

Wang (2017)

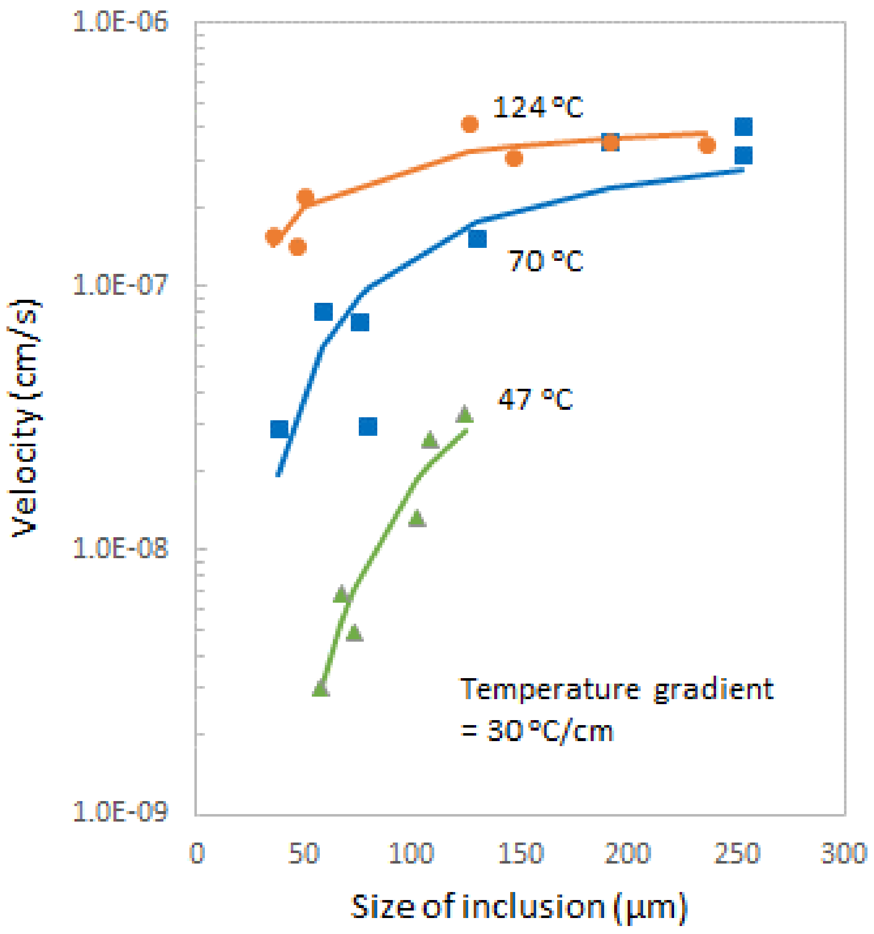
$$D \propto e^{\frac{\Delta E}{R T_0}}$$



Data from Olander et al. (1982)

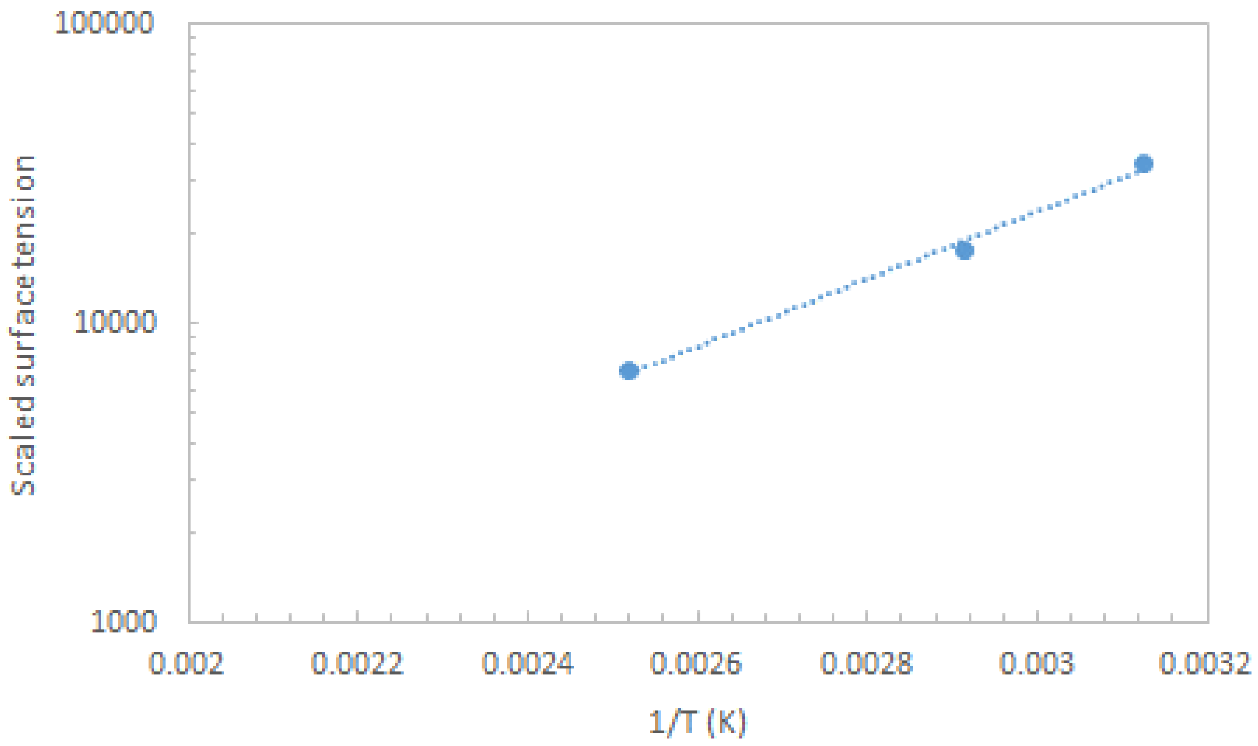
Model fitting

$$V_0 \approx \frac{V_m D K_d^0 \Delta H_r \alpha}{R T_0^2} e^{-\frac{2\gamma V_m}{R T_0 r}}$$



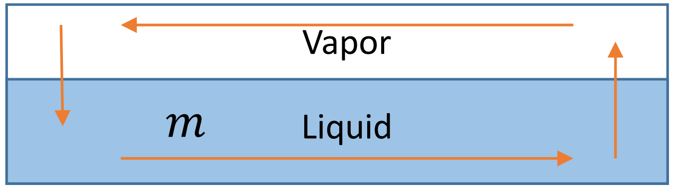
Data from Olander et al. (1982)

Model fitting (cont.)



Binary-phase inclusions

$$H_2O(l) \leftrightarrow H_2O(g)$$



$$T_0 - \frac{\Delta T}{2} \qquad T_0 \qquad T_0 + \frac{\Delta T}{2}$$

$$\rho_v(T) = \rho_v^0 e^{\frac{\Delta H_r^W}{RT}\left(\frac{T}{T_0}-1\right)}$$

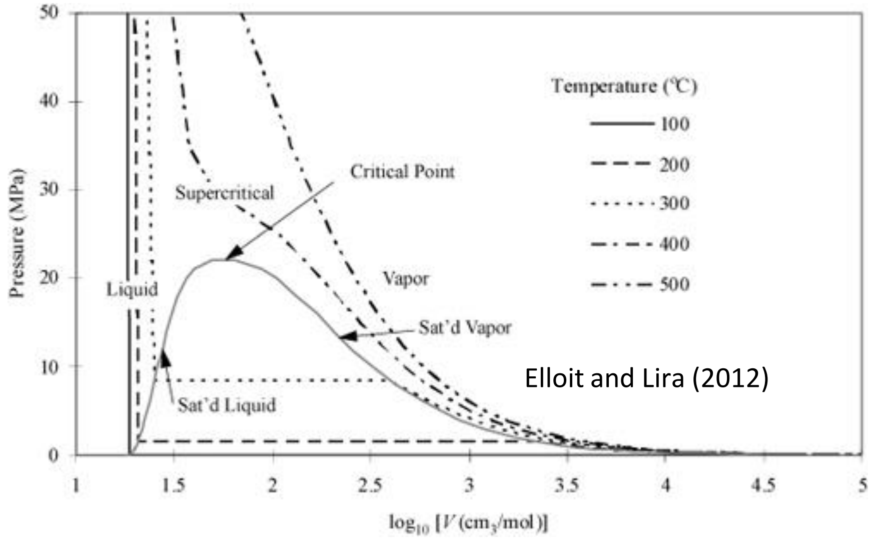
$$A_v D_v \frac{\partial \rho_v}{\partial x} = A_l V_l \rho_w$$

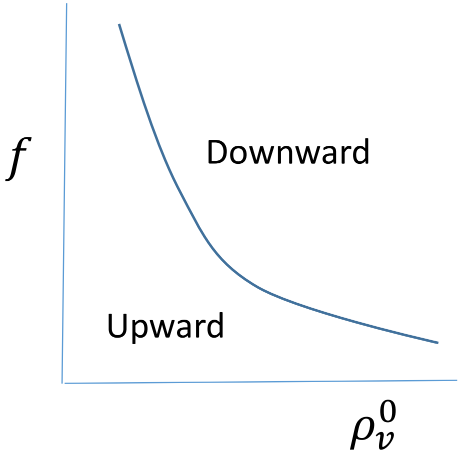
$$-D\frac{\partial M}{\partial x} + mV_l = 0$$

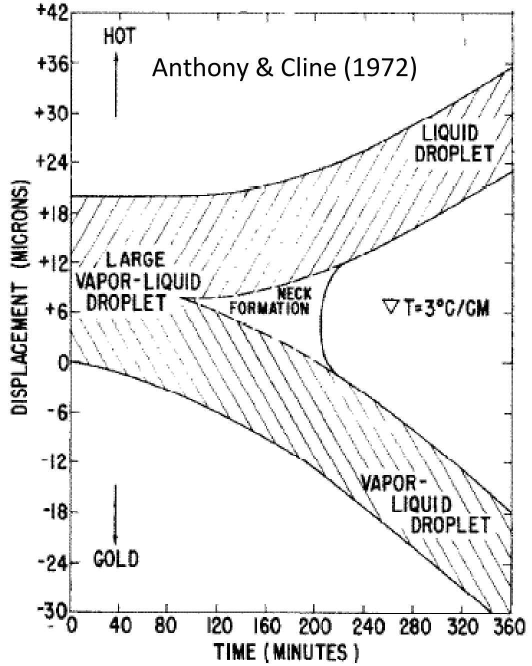
$$f = \frac{A_v}{A_l}$$

Bifurcation point:

$$f_c = \frac{D \Delta H_r \rho_w}{D_v \Delta H_r^W \rho_v^0(T_0)}$$

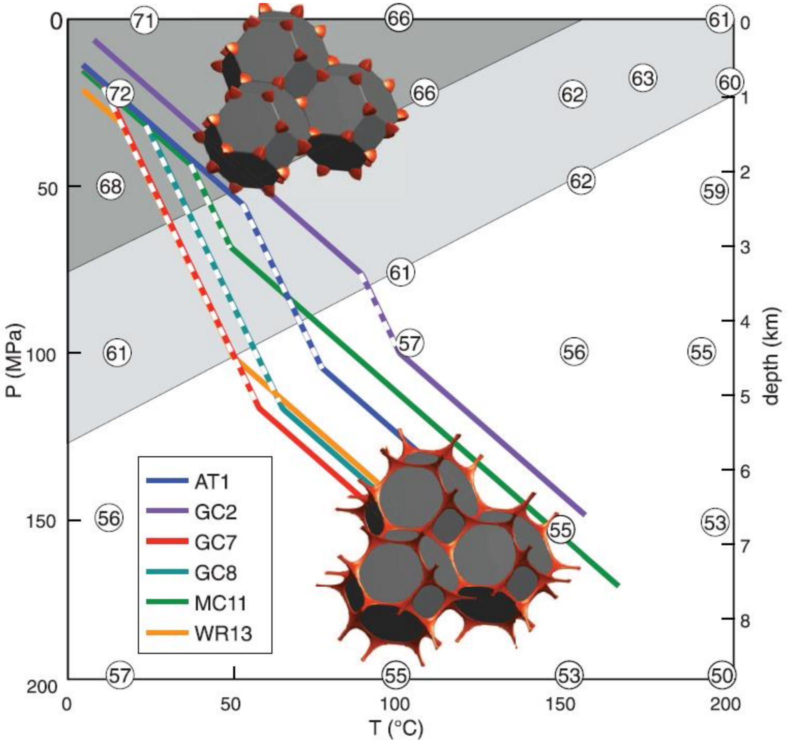






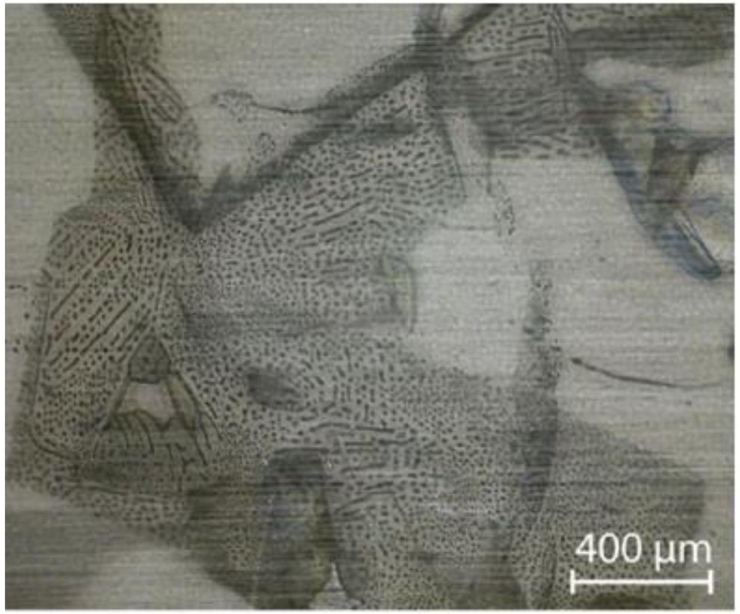
Work in progress

- Morphological instability and channeling
- Effect of stress on dihedral angle and percolation threshold; implications to field scale fluid flows
- Mechanism for the presence of fluid inclusions along grain boundaries
- Effect of stress on dihedral angles

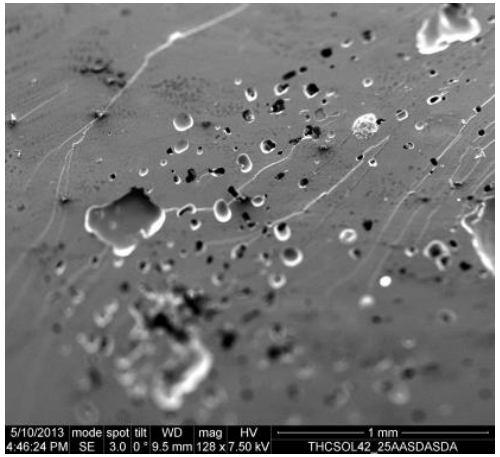


Ghanbarzadeh et al. (2015)

$$\theta = 2\cos^{-1}[\gamma_{ss}/(2\gamma_{sl})]$$



Thiemeyer et al. (2015)



Caporuscio et al. (per. Comm.)

Schedule

	1. year		2. year		3. year	
	1. workshop	2. workshop	3. workshop	4. workshop	5. workshop	6. workshop
WP - 1						
Literature recherche						
Process definition/description						
Conceptuel modeling						
WP - 2						
Upscalling study (microscale - macroscale)						
Mathematical formulation						
Programm developement						
WP - 3						
Modelling against observation						

TASK A: modElliNg Gas INjection ExpERiments (ENGINEER)

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SAND2017-4132PE

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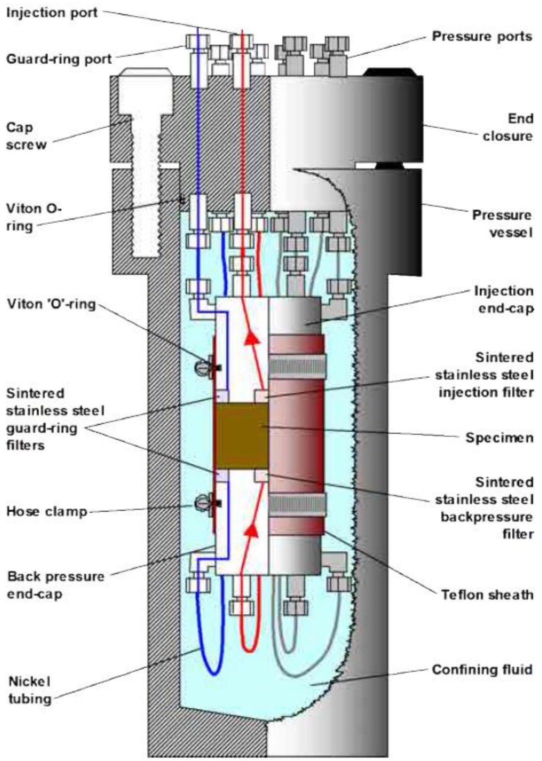
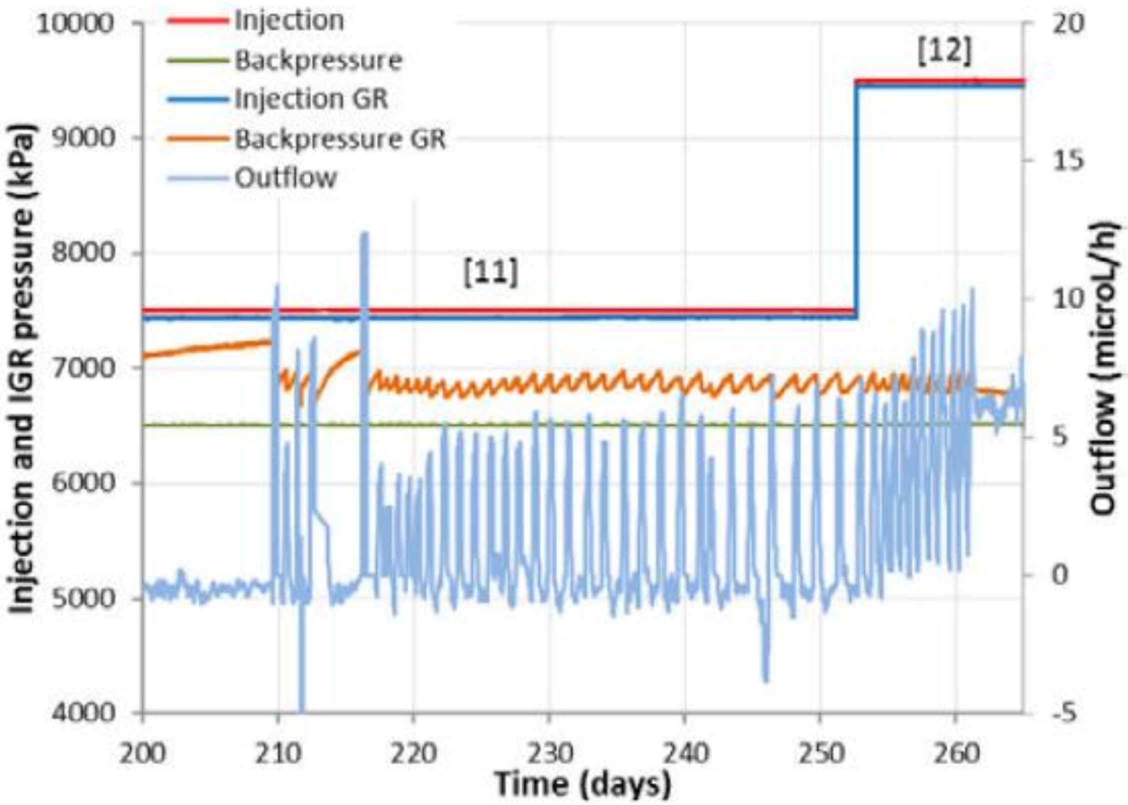
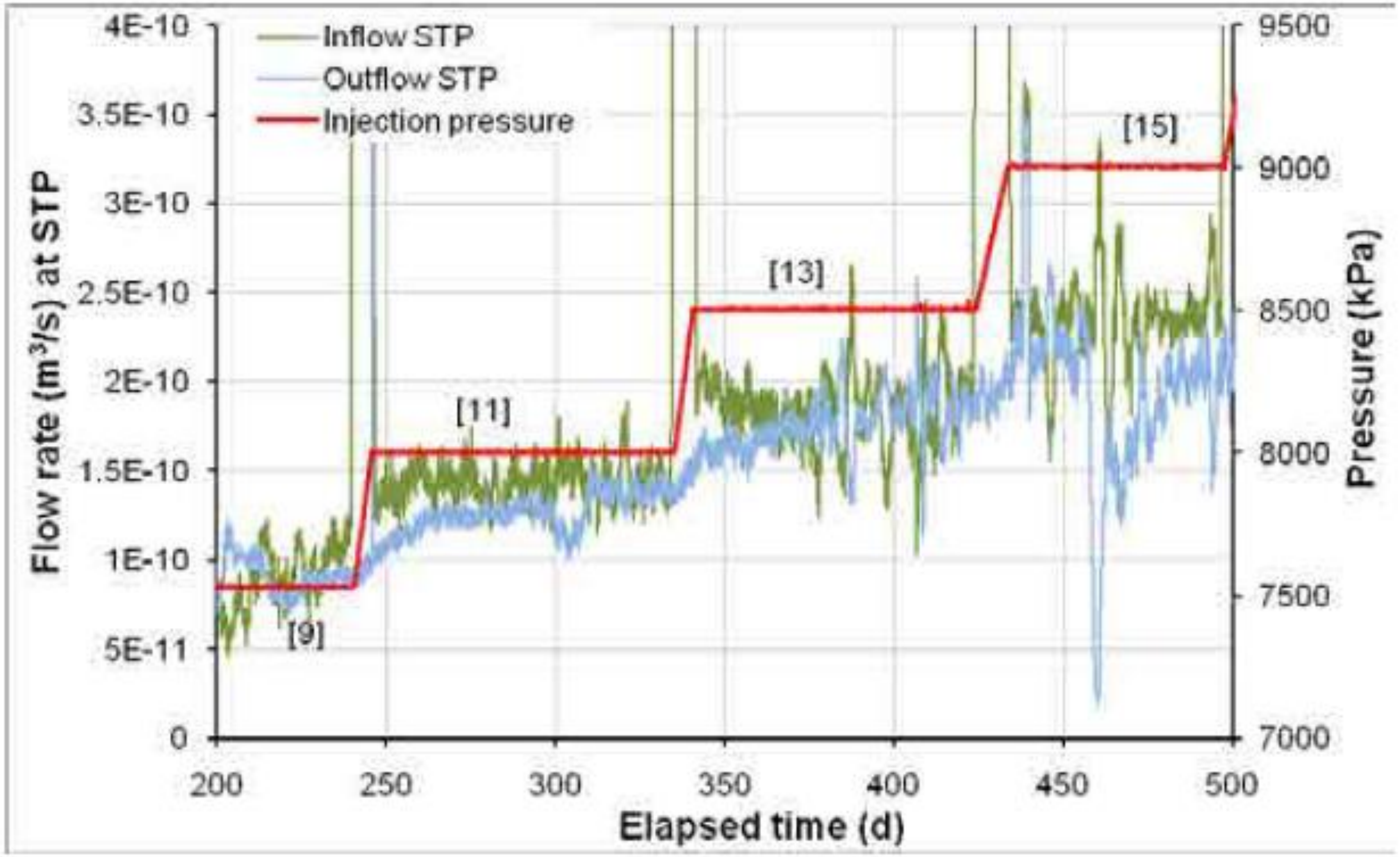
Dynamic behaviors of the system





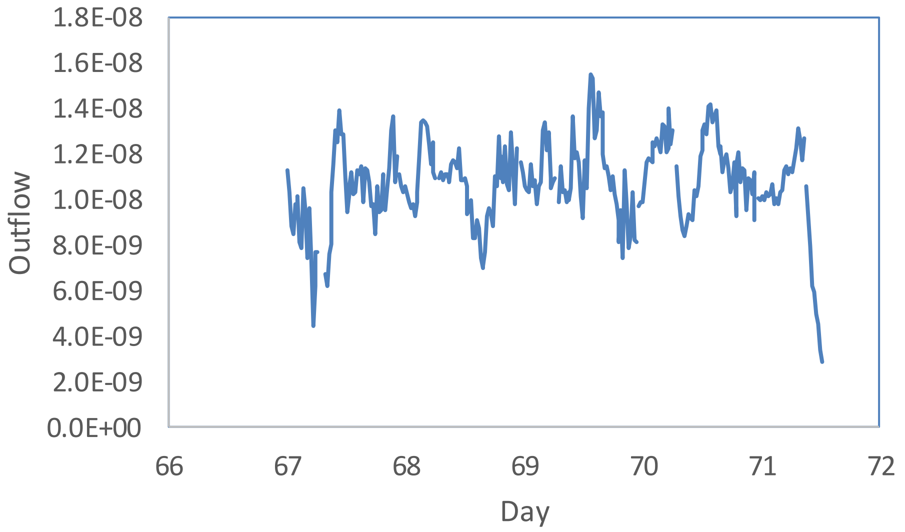
FORGE Report D4.17 (Harrington, 2013)

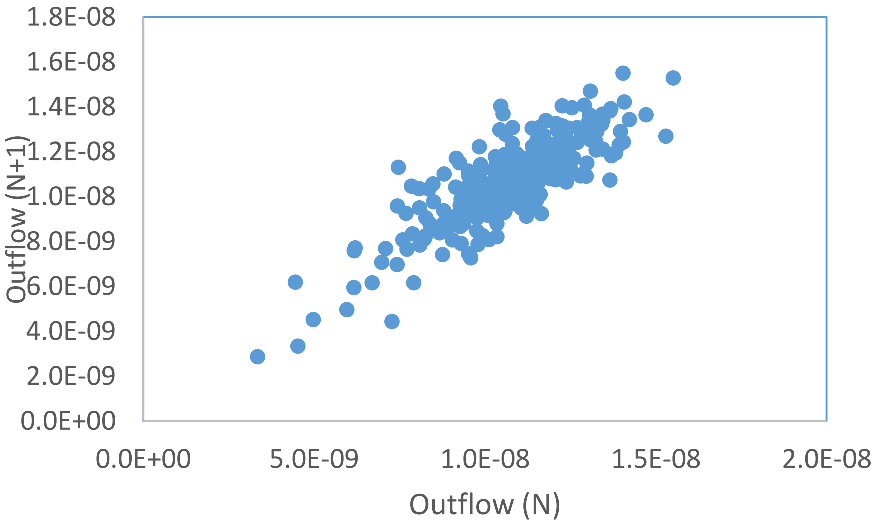
Dynamic behaviors of the system (cont.)



FORGE Report D4.17 (Harrington, 2013)

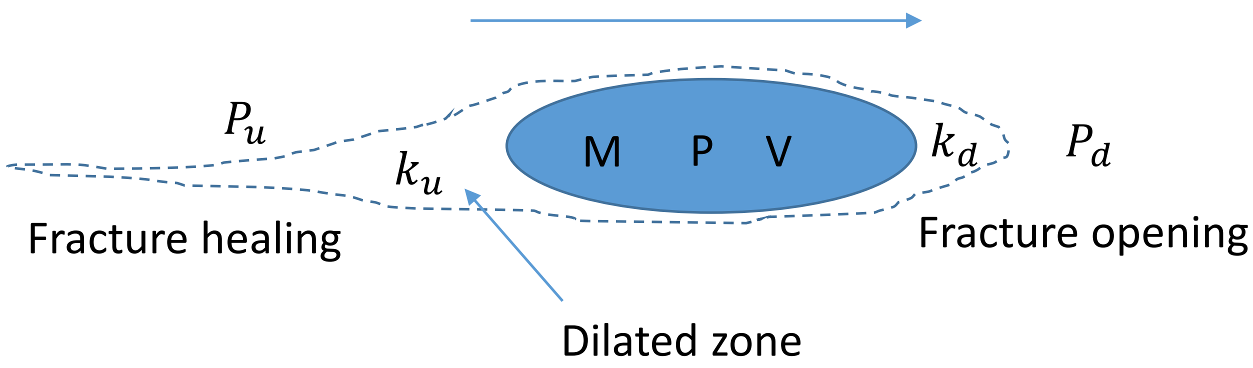
Time series analysis: Delay Coordinate embedding (DCE) method





- Differentiate from chaotic behaviors from random (white noise) variations.
- Provide an insight about the dimensionality of the systems (number of controlling variables).
- Limitation: Require sampling at equal time steps.
- Original data (not averaged).

Bubble migration under a pressure gradient



$$\frac{dM}{dt} = k_u(P_u - P) - k_d(P - P_d)$$

$$k_u = k_u^0 P \qquad k_d = k_d^0 P \qquad M = \frac{PV}{RT}$$

Continuous logistic equation

$$\frac{dP}{dt} = \lambda_1 P\left(1 - \frac{P}{K}\right)$$

$$\lambda_1 = \frac{\left(k_u^0 P_u + k_d^0 P_d\right)RT}{V} \qquad \lambda_2 = \frac{\left(k_u^0 + k_d^0\right)RT}{V} \qquad K = \frac{\lambda_1}{\lambda_2}$$

Delay logistic equation

$$\frac{dP}{dt} = \lambda_1\left(1 - \frac{P}{K}\right)\int_{-\infty}^{t} G(t-s)p(s)ds$$

$$\frac{dP}{dt} = \lambda_1\left(1 - \frac{P}{K}\right)\int_{-\infty}^{t} \alpha e^{-\alpha(t-s)}p(s)ds$$

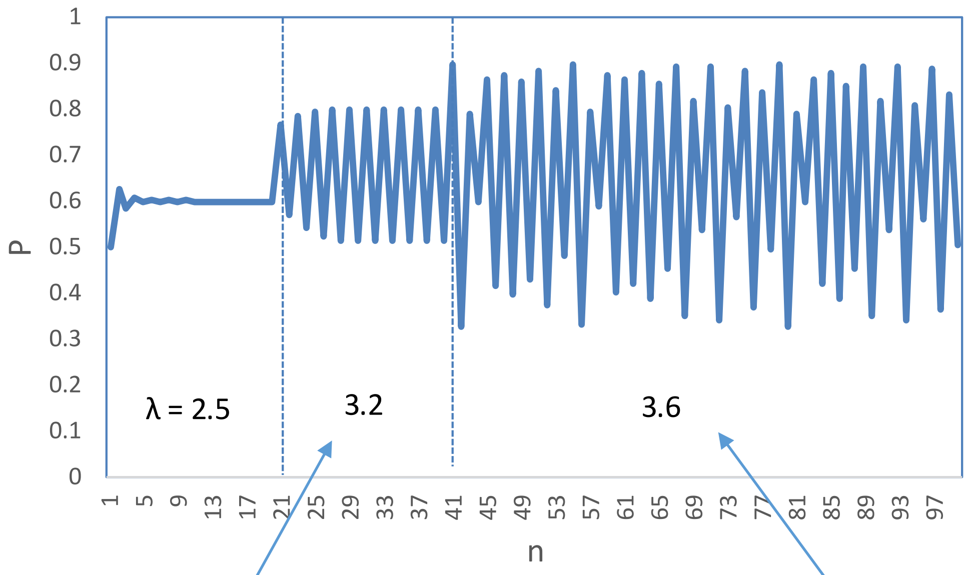
Logistic map: An illustration

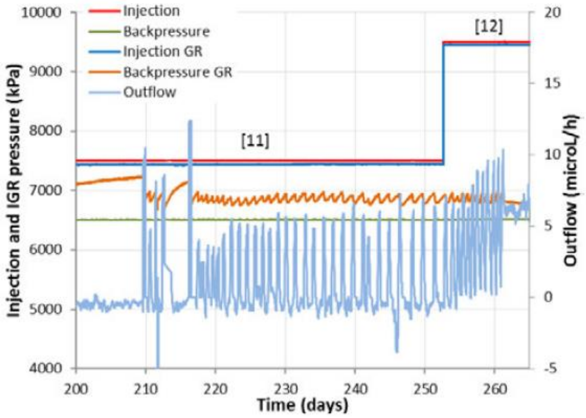
$$\frac{dP}{dt} = \lambda_1 p \left(1 - \frac{P}{K}\right)$$

$$P_{n+1} = P_n + \lambda_1 P_n \left(1 - \frac{P}{K}\right) \Delta t$$

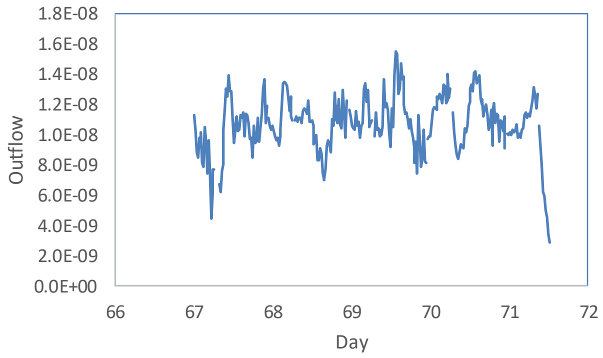
$$\lambda = 1 + \lambda_1 \Delta t$$

$$\boxed{p_{n+1} = \lambda p_n (1 - p_n)}$$

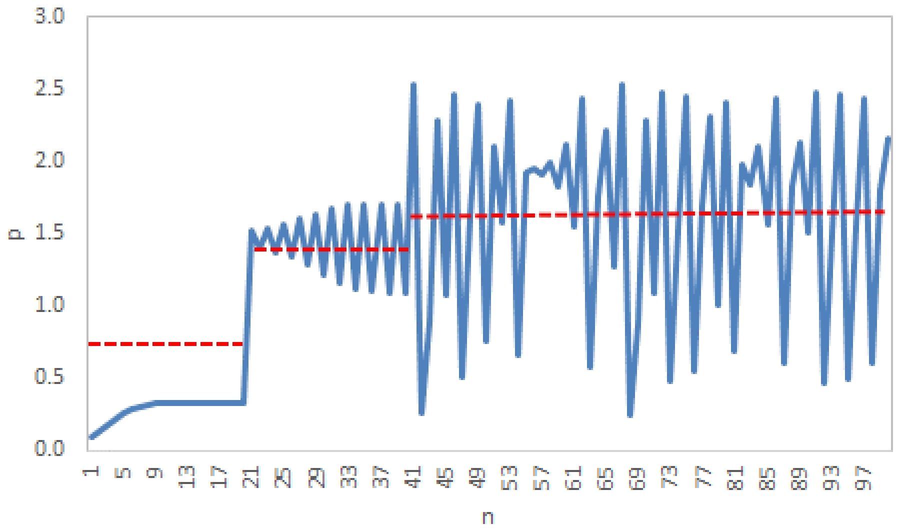




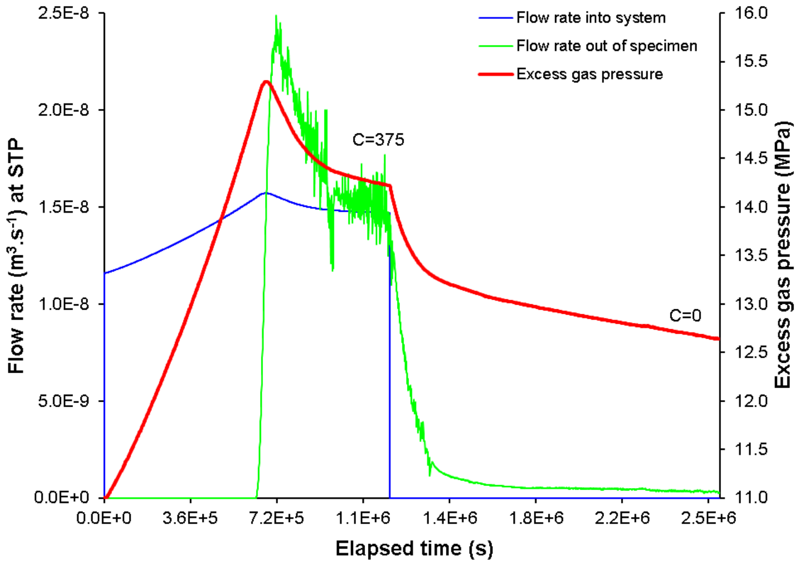
FORGE Report D4.17 (Harrington, 2013)

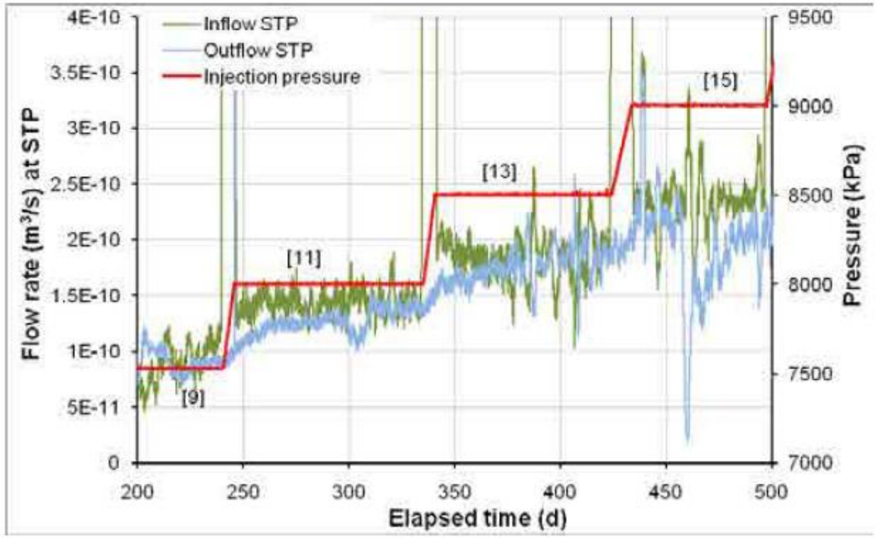


Qualitative comparison with experimental observations



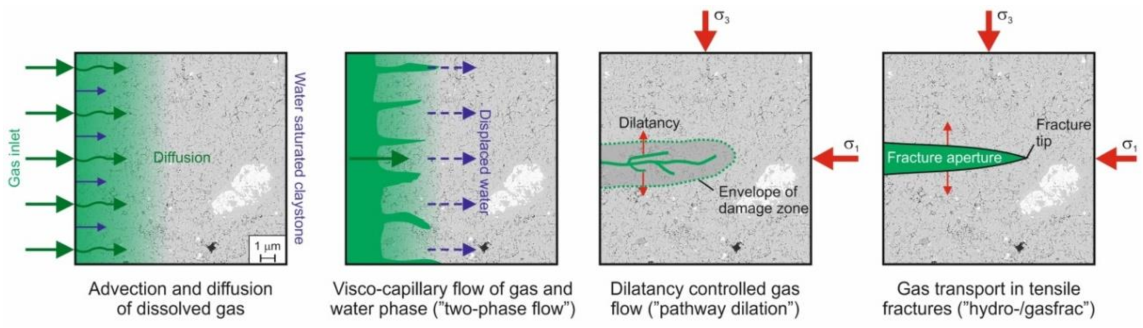
Parameters λ and K are proportional to the injection pressure and the ability of material for local dilation.



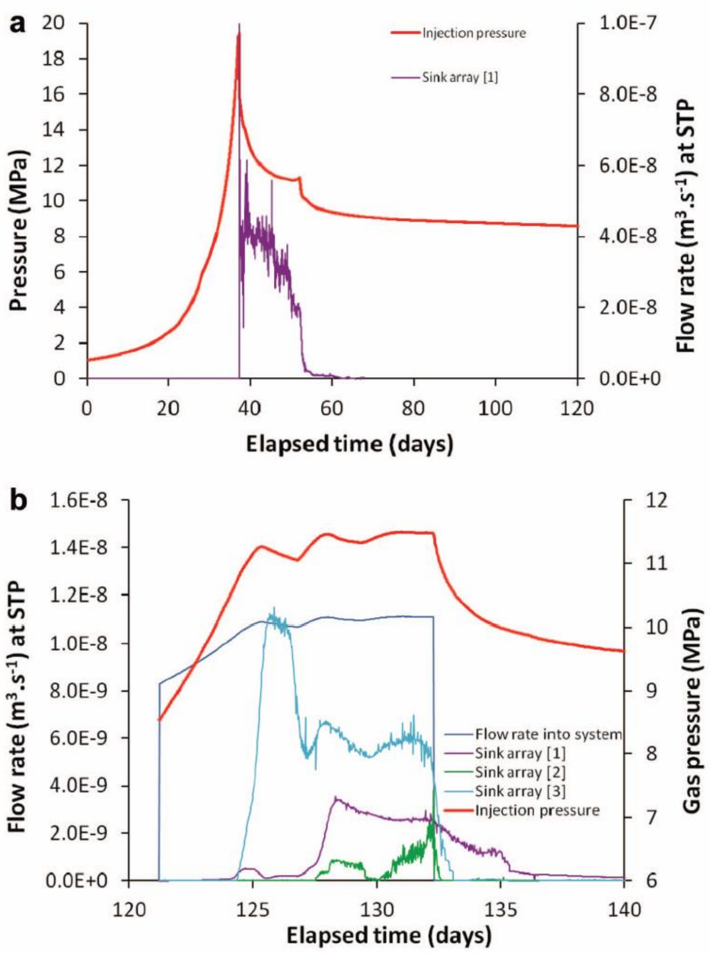


FORGE Report D4.17 (Harrington, 2013)

Infiltration instability: How many channels would develop within a given system?



Harrington & Tamayo (2016)



Graham et al. (2012)

In clay-rich system considerable evidence exists suggesting gas flow is accompanied by the creation of preferential pathways and dilation of the clay

- Channeling of gas percolation front
- Instability of the movement of individual gas bubbles

Linear instability analysis

Viscoelastoplastic model
(Yarushina et al, 2015)

$$\frac{\partial(1-\varphi)}{\partial t} + \nabla_j\left((1-\varphi)v_j^s\right) = 0$$

$$\frac{\partial\varphi}{\partial t} + \nabla_j\left(\varphi\ v_j^f\right) = 0$$

$$\varphi\left(v_i^f - v_i^s\right) = -\frac{k}{\eta_f}\left(\nabla_i p^f + g\rho^f \hat{z}^i\right)$$

$$\nabla_j \bar{\sigma}_{ij} - g\bar{\rho}\hat{z}^i = 0.$$

$$p_e = -\eta_\varphi \dot{\varphi}$$

$$p_e = \bar{p} - p^f = \left(p^s - p^f\right)(1-\varphi)$$

+

Immiscible two-phase flow
(Riaz & Tchelepi, 2004)

$$\mathbf{u}_w = -\frac{k\,k_{r_w}}{\mu_w}(\nabla P_w + \rho_w \mathbf{g}),$$

$$\mathbf{u}_n = -\frac{k\,k_{r_n}}{\mu_n}(\nabla P_n + \rho_n \mathbf{g}),$$

$$\frac{\partial S_w}{\partial t} + \nabla \cdot \mathbf{u}_w = 0,$$

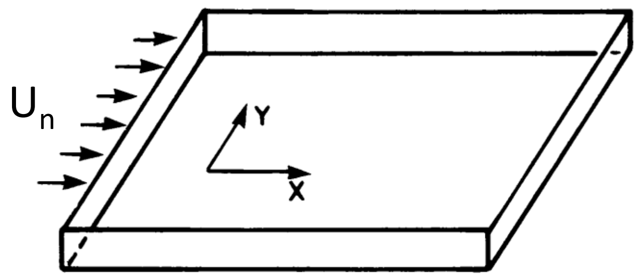
$$\frac{\partial S_w}{\partial t} - \nabla \cdot \mathbf{u}_n = 0,$$

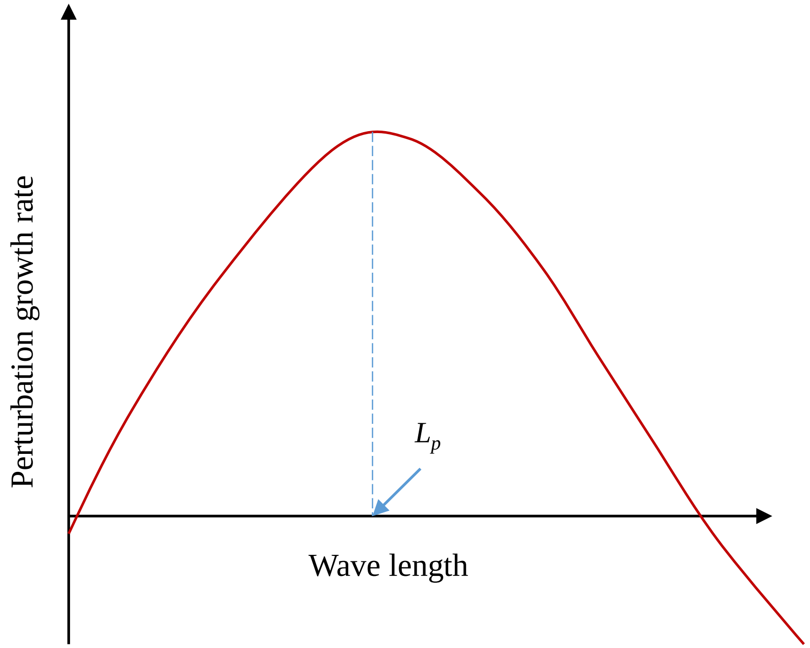
$$\mathbf{u}_t = \mathbf{u}_w + \mathbf{u}_n,$$

$$P_c = P_n - P_w,$$

$$\frac{dP_c}{dS_w} = \sqrt{\frac{\phi}{k}}\,\gamma_{nw}\cos\theta,$$

Not a simple coupling.
Additional terms need to be formulated.





Schedule

Activity	Spring 2016	Autumn2016	Spring 2017	Autumn 2017	Spring 2018	Autumn 2018	Spring 2019	Autumn 2019
Stage1: 1D flow (laboratory)	Wksp 1	Wksp 2						
Stage 2: Spherical flow (laboratory)			Wksp 3	Wksp 4				
Interim reporting								
Stage 3: Field scale flow					Wksp 5	Wksp 6		
Stage 4: Gas flow in natural clay							Wksp 7	Wksp 8
Final Reporting								

Next steps

- Complete the mathematical formulation and analysis for single bubble movement.
- Complete delay coordinate embedding (DCE) analysis.
- Complete the formulation for the channeling of a gas percolation front.
- Consider how to incorporate the instability analysis into a 2D or 3D continuum model.