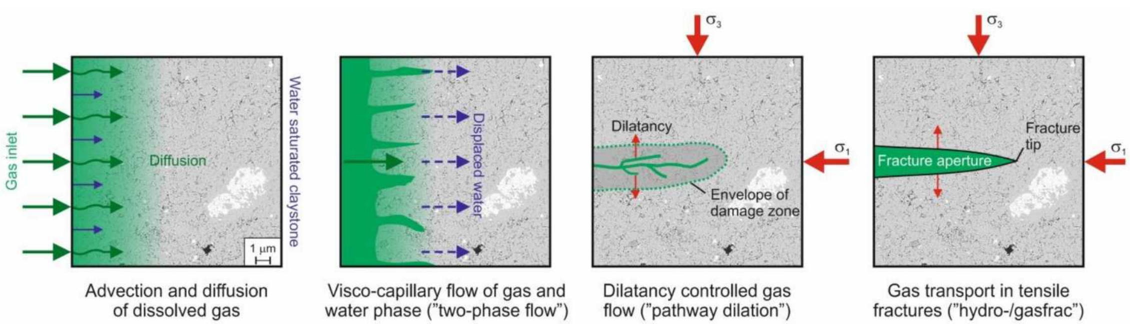
SAND2019-3867PE

DECOVALEX19 TASK A: modElliNg Gas INjection ExpERiments (ENGINEER)

DECOVALEX19
WORKSHOP 6
Seoul, R. of Korea
Oct. 16-19, 2018



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Yifeng Wang (SNL), Boris Faybishenko (LBNL), Jon Harrington (BGS)

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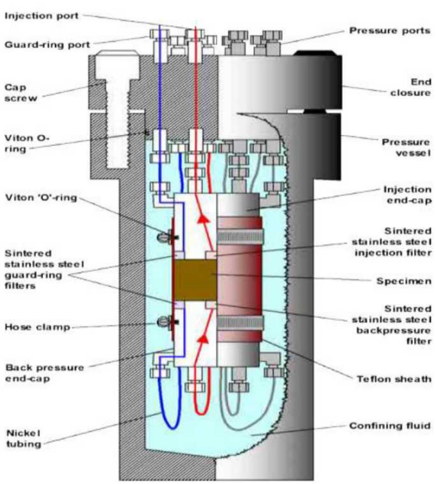
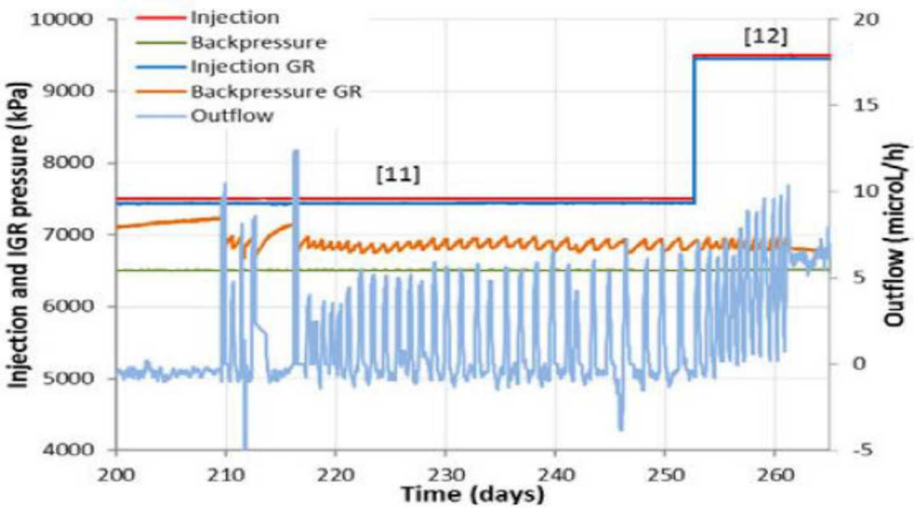
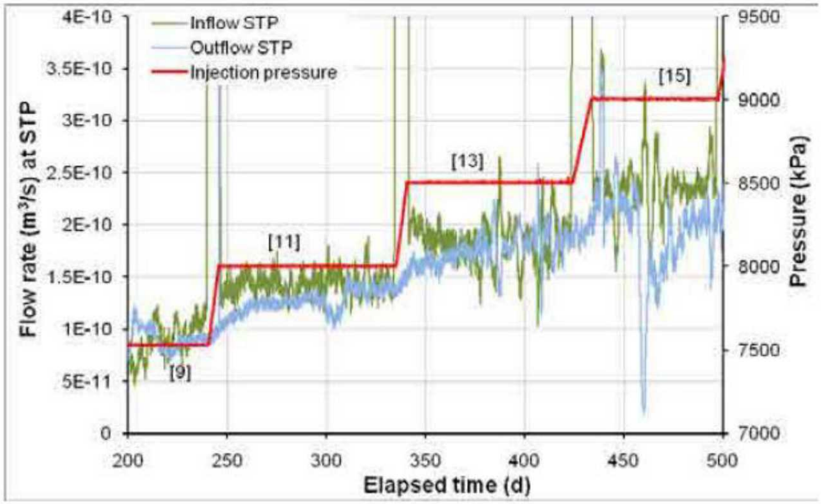
Observations







FORGE Report D4.17 (Harrington, 2013)

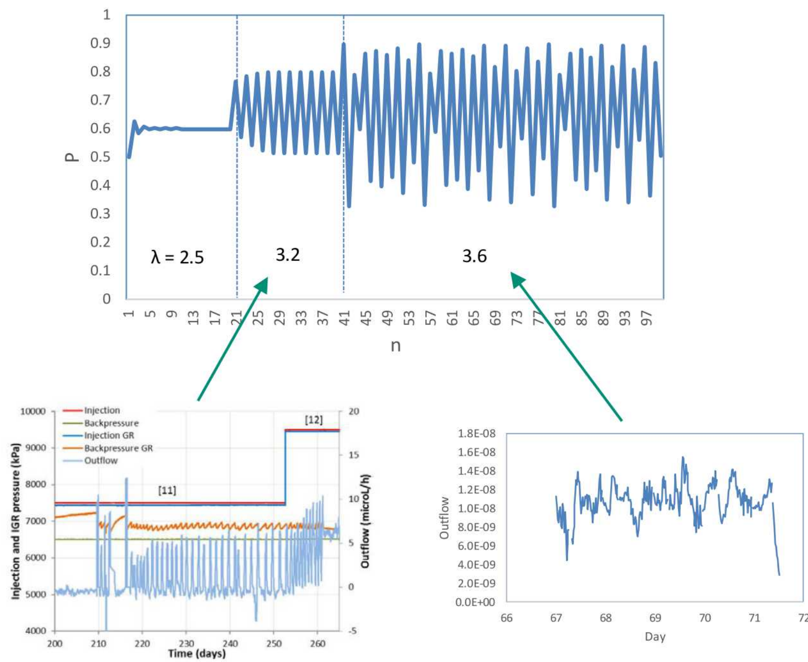
Bubble migration under a pressure gradient: Chaotic behavior

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

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

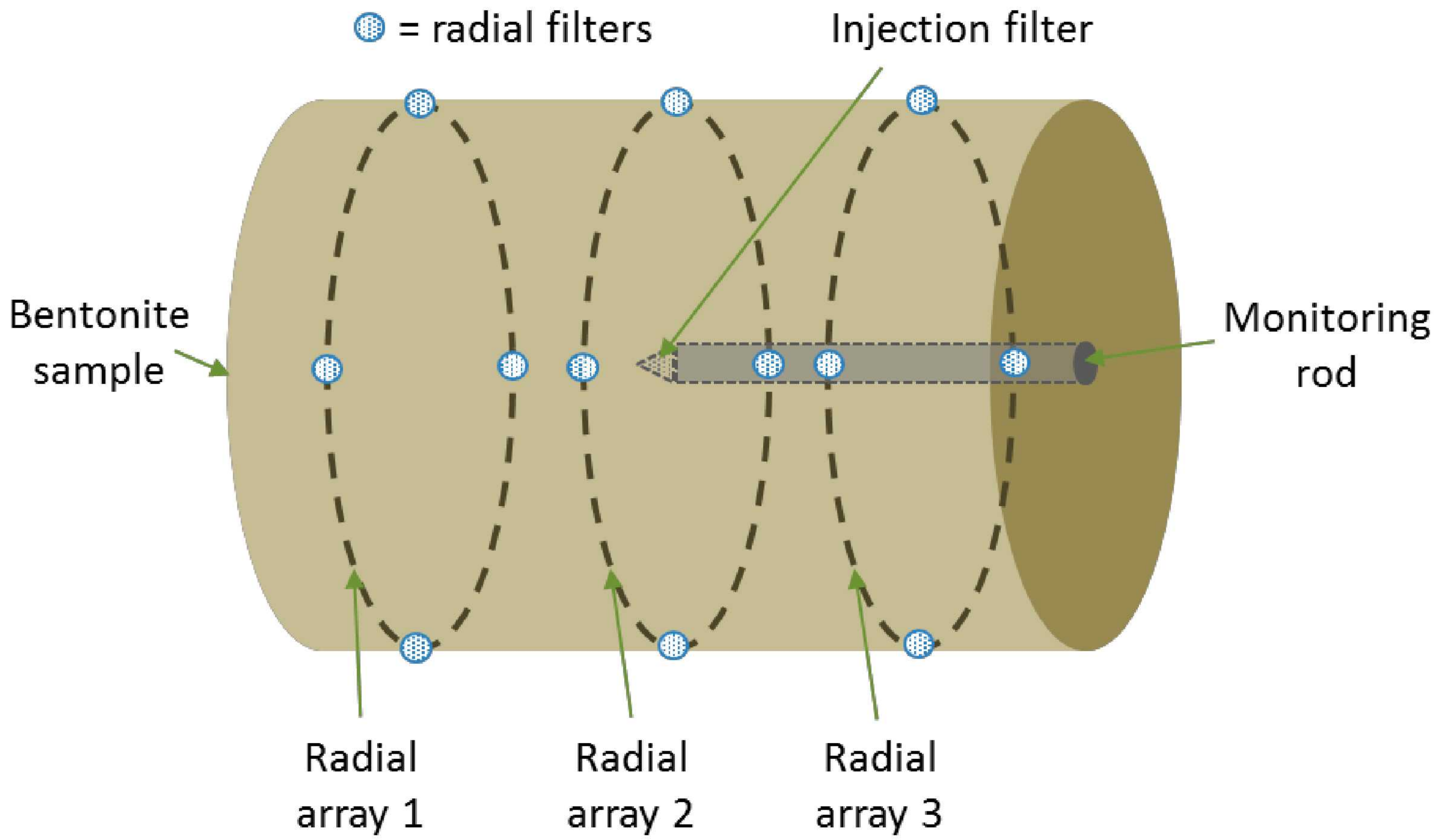
$$\lambda = 1 + \lambda_1 \Delta t$$

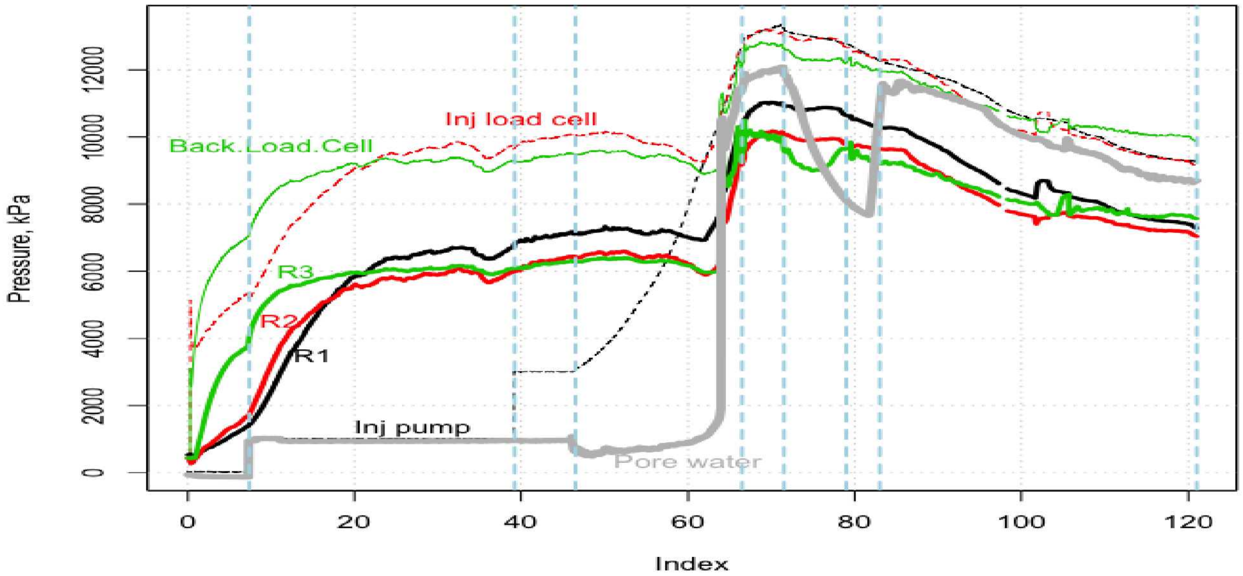
$$\boxed{p_{n+1} = \lambda p_n(1 - p_n)}$$

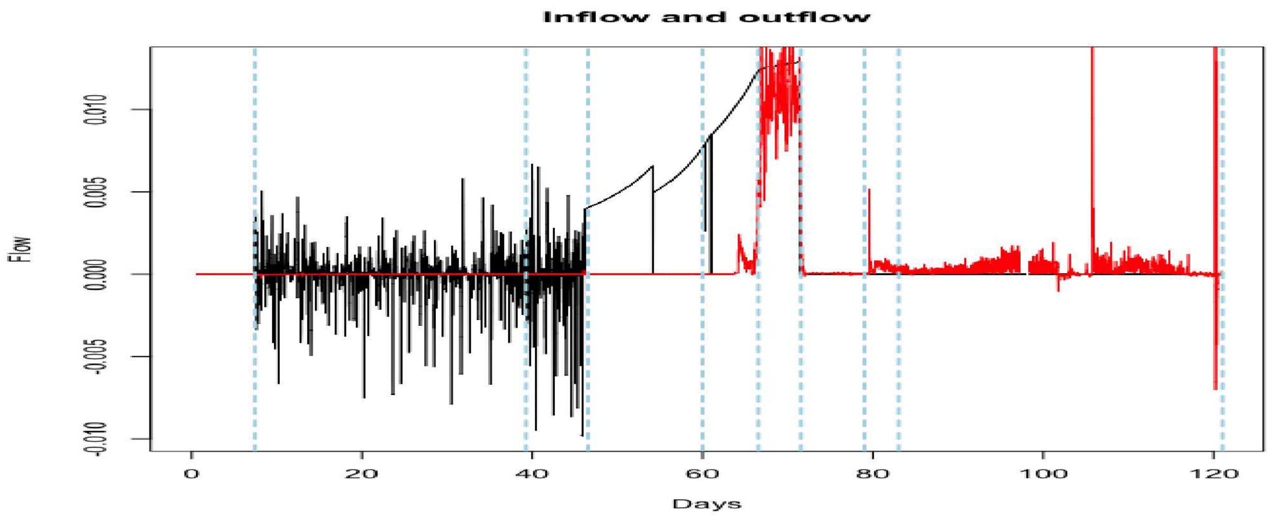


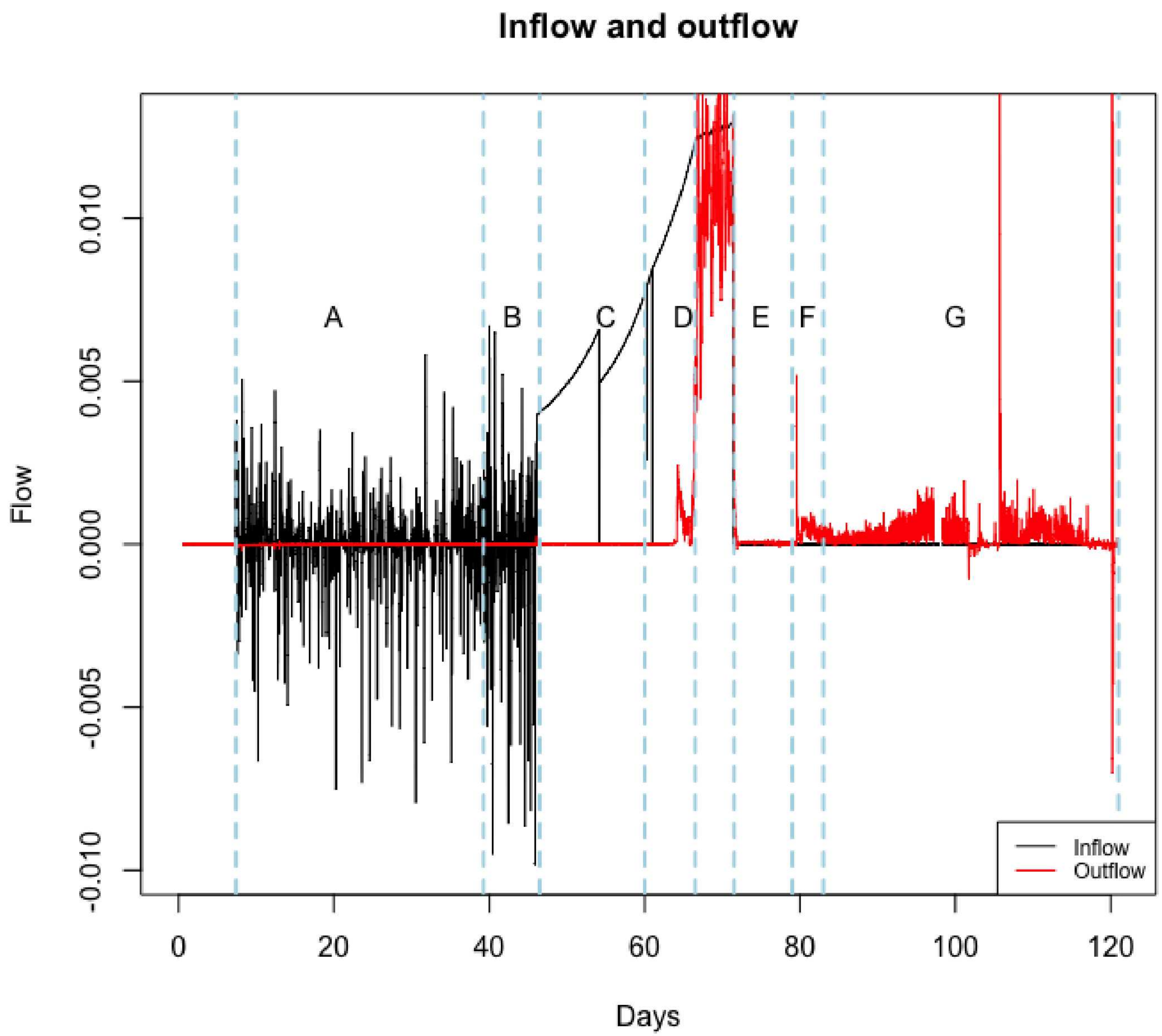
FORGE Report D4.17 (Harrington, 2013)

1D flow through saturated bentonite under constant volume boundary




Inj load cell
Back.Load.Cell
R3
R2
R1
Inj pump
Pore water
Pressure, kPa
Index


Inflow and outflow
Flow
Days


Inflow and outflow
A
B
C
D
E
F
G
Flow
0.010
0.005
0.000
-0.005
-0.010
0
20
40
60
80
100
120
Days
Inflow
Outflow

Time Series Decomposition

The additive model used is:
Y[t] = Trend [t] + Periodic [t] + Stochastic[t]

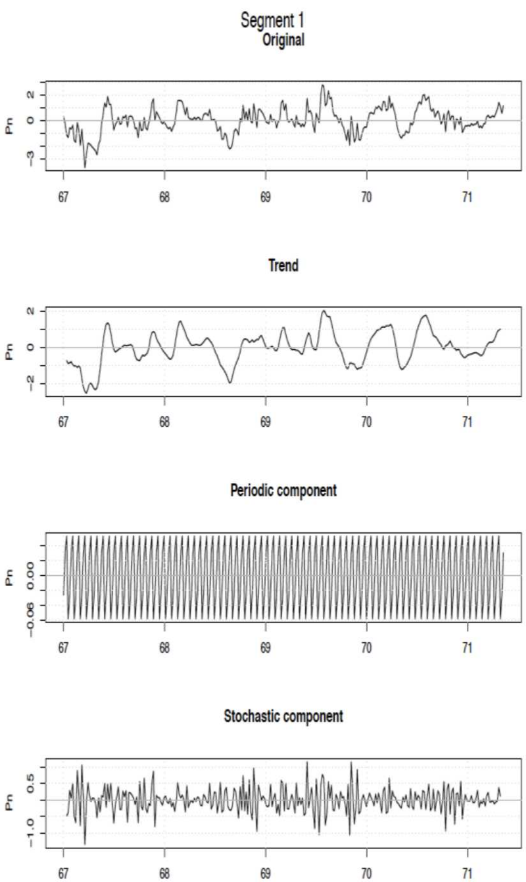
The multiplicative model used is:
Y[t] = Trend [t] * Periodic [t] * Stochastic [t]

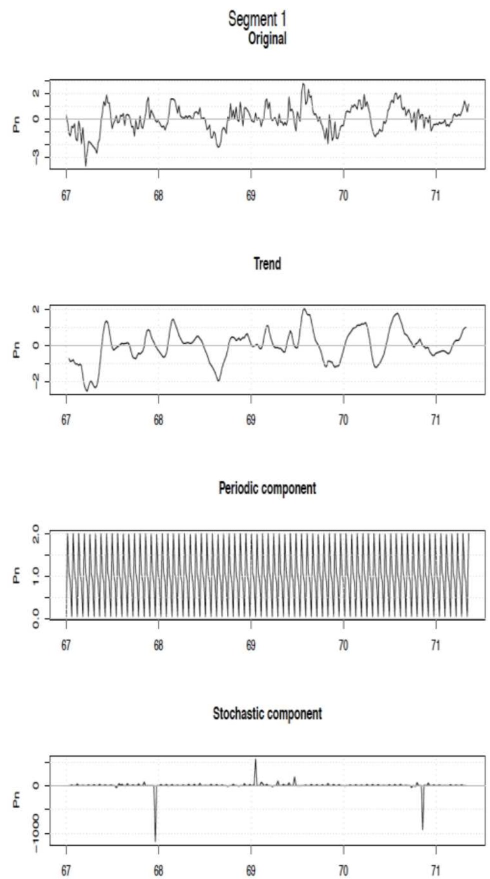
STL Model (Polynomial regression--variation of the additive model)

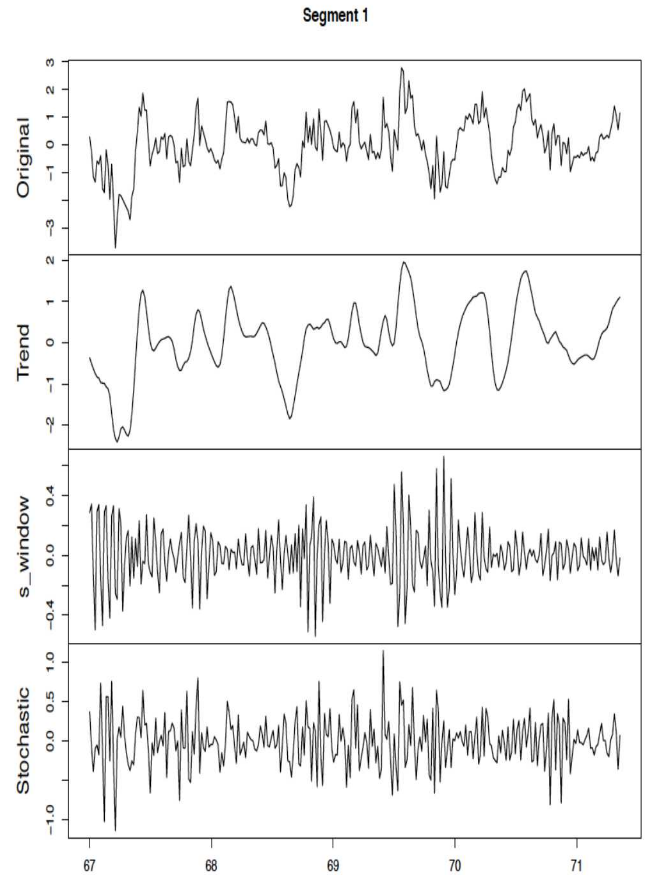
There are three components of a time series:

- trend of the overall changing
- Periodic component
- Stochastic -- error/residual/irregular component not explained by the trend or the periodic value

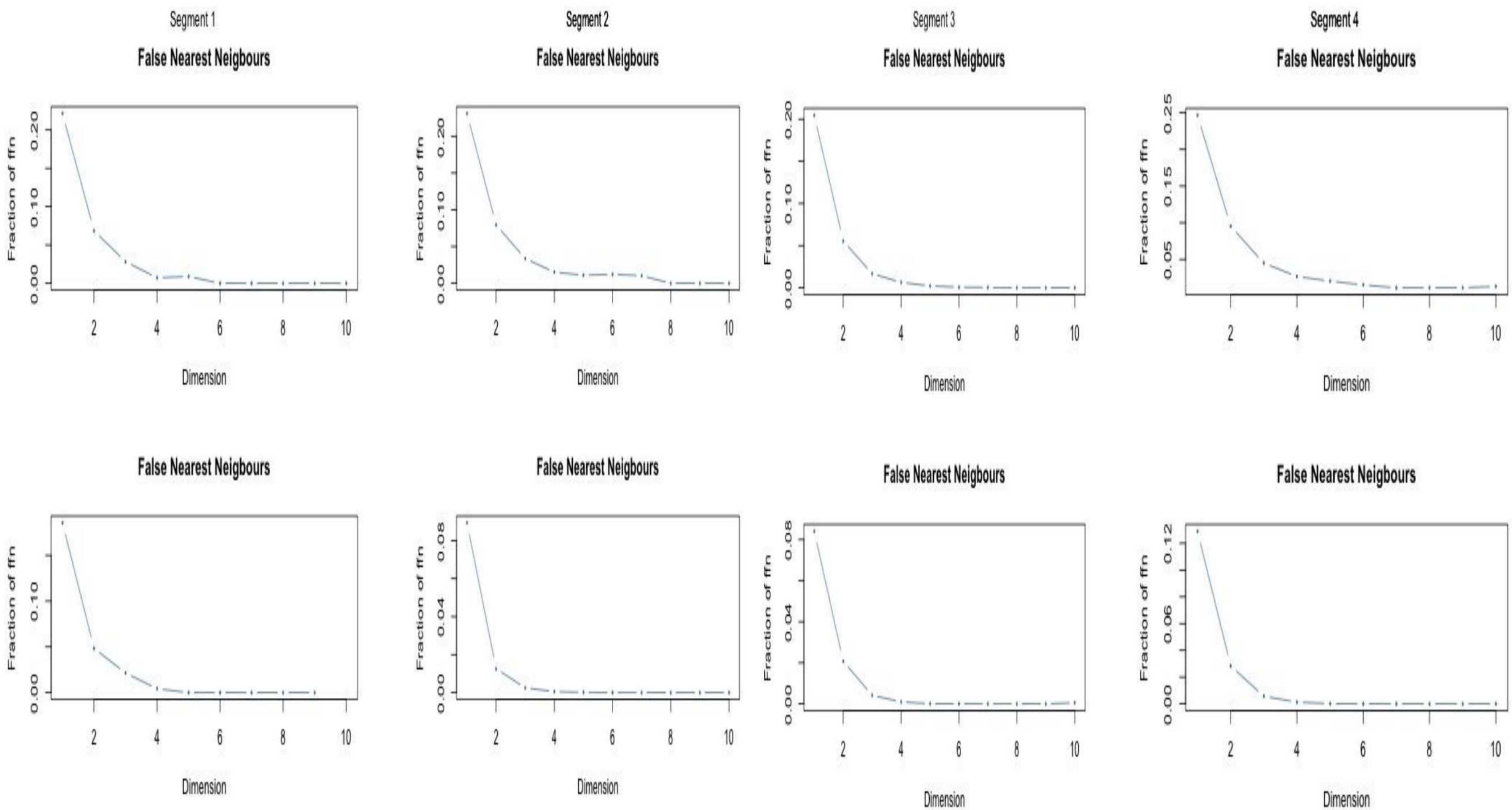
Graphical Comparison of Decomposition Models: Segment 1







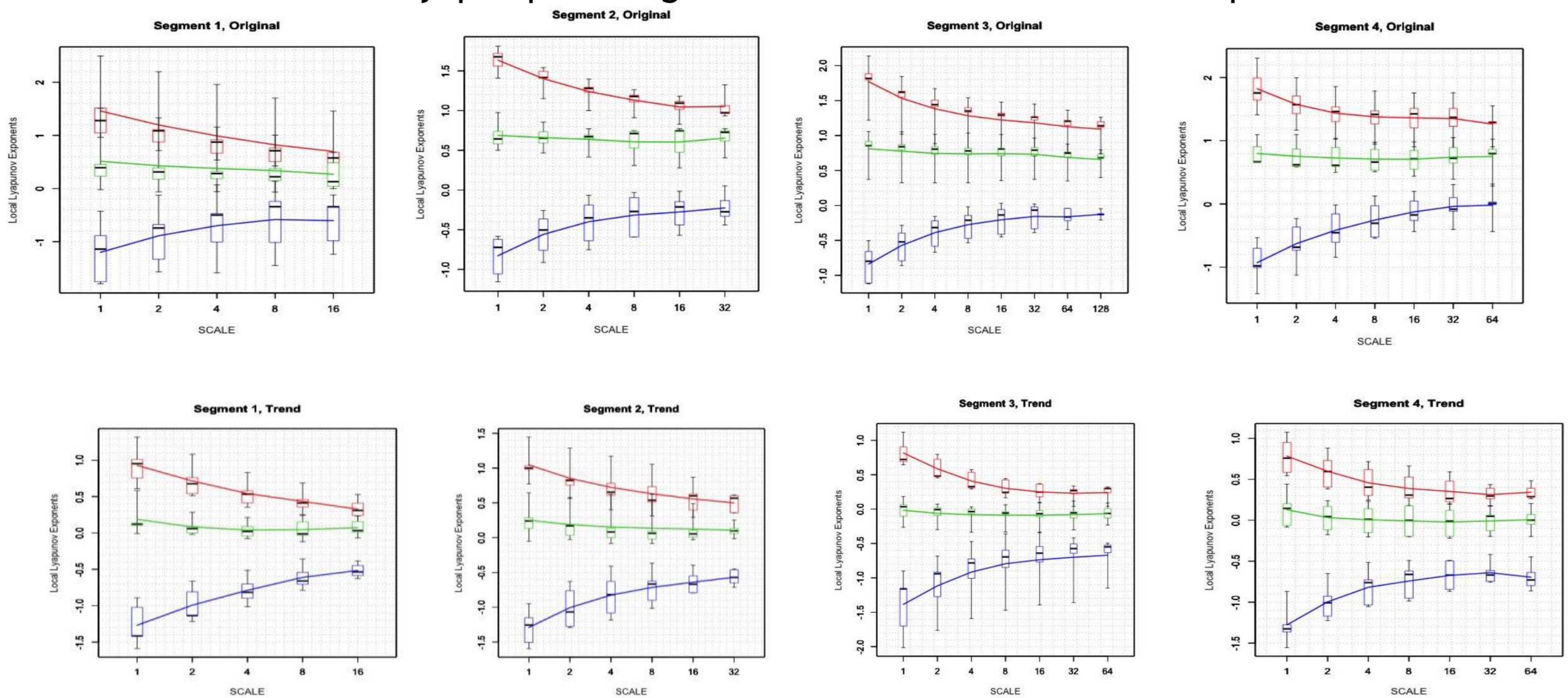
Global Embedding Dimension calculated using the False Nearest Neighbors Method



Embedding dimension of all time series trends is 4, which is a diagnostic feature of low-dimensional chaos.

Calculations of the spectrum of 3 Local exponents Lyapunov

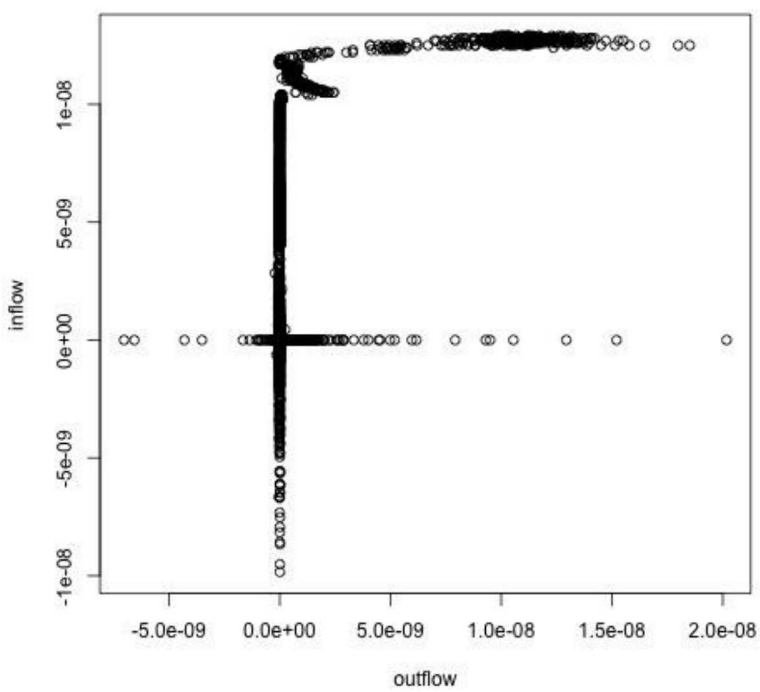
No zero Lyap exp for original data – there is a random component

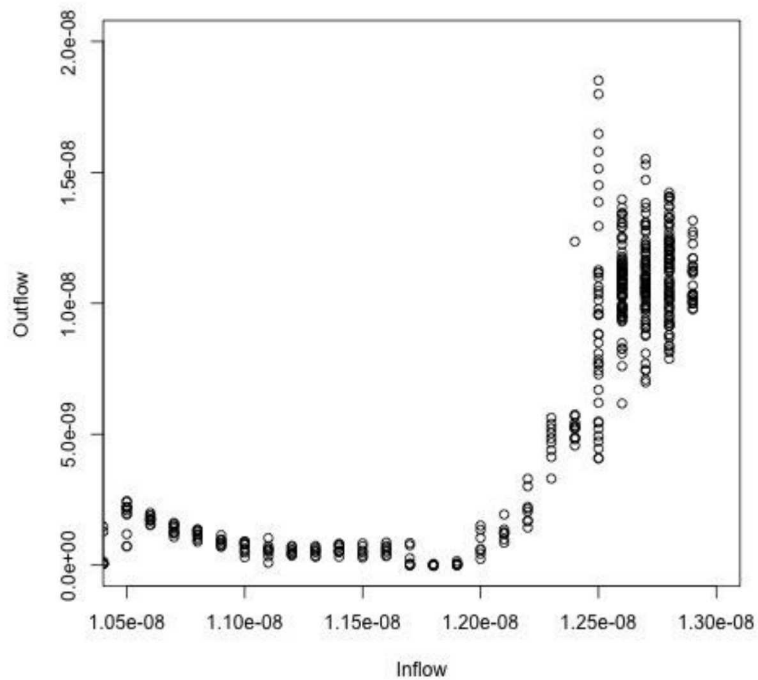


All time series contain a positive Lyapunov exponents, which is a typical feature of deterministic chaos.
Trends have 1 exponents ~0, and the sum of Lyapunov exponents is <0, which are typical features of deterministic chaos. (Calculations will be performed with 4 Local Lyapunov exponents).

All diagnostic parameters indicate that all time series data are deterministic chaotic.

Correlation between parameters

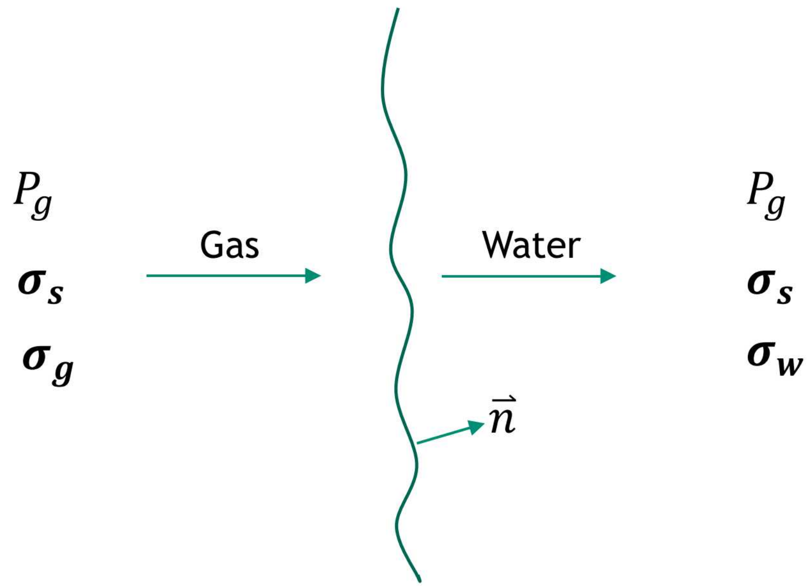




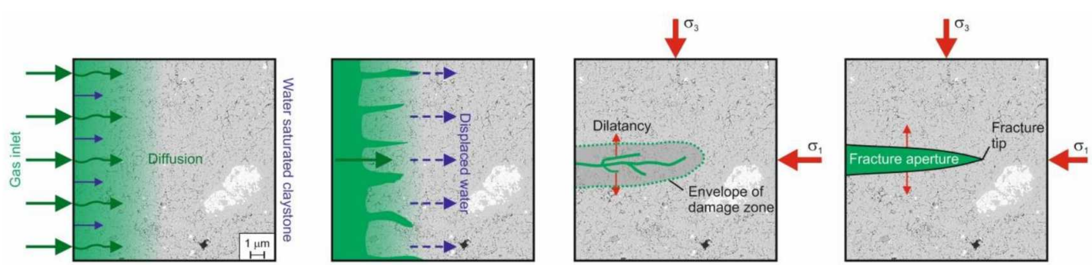
Instability of immiscible fluid invasion in deformable media: Model formulation

Domain I: Gas + bentonite

Domain II: Water + bentonite



F(x, y, z, t) = 0



Advection and diffusion of dissolved gas

Visco-capillary flow of gas and water phase ("two-phase flow")

Dilatancy controlled gas flow ("pathway dilation")

Gas transport in tensile fractures ("hydro-/gasfrac")

Model formulation: Domain II

Continuity for mass:

$$\frac{\partial(\phi\rho_w)}{\partial t} + \nabla\cdot\left(\phi\rho_w\vec{V}_w\right) = 0$$

$$\frac{\partial[(1-\phi)\rho_s]}{\partial t} + \nabla\cdot[(1-\phi)\rho_s\vec{V}_s] = 0$$

Continuity for momentum:

$$\vec{I} + \nabla\cdot[(1-\phi)\boldsymbol{\sigma_s}]=0$$

$$-\vec{I} + \nabla\cdot(\phi\boldsymbol{\sigma_w})=0$$

$$\vec{I} = \frac{\mu_w}{k}(\vec{V}_w - \vec{V}_s) - P_w\nabla\cdot$$

Constitutive relationship:

$$\sigma_{w_{ij}} = -P_w\delta_{ij} + \mu_w\left(\frac{\partial V_{wi}}{\partial x_j} + \frac{\partial V_{wj}}{\partial x_i}\right)$$

$$\sigma_{s_{ij}} = -P_w\delta_{ij} + \zeta\delta_{ij}\frac{\partial V_{sl}}{\partial x_l} + \eta\left(\frac{\partial V_{si}}{\partial x_j} + \frac{\partial V_{sj}}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial V_{sl}}{\partial x_l}\right)$$

Model formulation: Domain I

Continuity for mass:

$$\frac{\partial(\phi\rho_g)}{\partial t} + \nabla\cdot\left(\phi\rho_g\vec{V_g}\right) = 0$$

$$\frac{\partial[(1-\phi)\rho_s]}{\partial t} + \nabla\cdot[(1-\phi)\rho_s\vec{V_s}] = 0$$

Continuity for momentum:

$$\vec{I} + \nabla\cdot[(1-\phi)\boldsymbol{\sigma_s}]=0$$

$$-\vec{I} + \nabla\cdot\left(\phi\boldsymbol{\sigma_g}\right)=0$$

$$\vec{I} = \frac{\mu_g}{k}(\vec{V_g} - \vec{V_s}) - P_g\nabla\cdot$$

Constitutive relationship:

$$\sigma_{g_{ij}} = -P_g\delta_{ij} + \mu_g\left(\frac{\partial V_{gi}}{\partial x_j} + \frac{\partial V_{gj}}{\partial x_i}\right)$$

$$\sigma_{s_{ij}} = -P_g\delta_{ij} + \zeta\delta_{ij}\frac{\partial V_{sl}}{\partial x_l} + \eta\left(\frac{\partial V_{si}}{\partial x_j} + \frac{\partial V_{sj}}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial V_{sl}}{\partial x_l}\right)$$

$$P_g = \frac{RT}{\phi M_g}\rho_g$$

Model formulation: At water-gas interface F(x, y, z, t)=0

$$\sigma_g \cdot \vec{n} = \sigma_w \cdot \vec{n} + (\sigma^* \nabla \cdot \vec{n} + P_c)\vec{n}$$

$$[(1-\phi)\sigma_s \cdot \vec{n}]_-^+ = \phi(\sigma^* \nabla \cdot \vec{n} + P_c)\vec{n}$$

$$P_c = \frac{2\sigma\cos(\theta)}{r}$$

$$\vec{V}_w = \vec{V}_g$$

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

$$\vec{n} = \frac{\nabla F}{|\nabla F|}$$

DECOVALEX19 TASK F: Fluid Inclusion and Movement in Tight Rocks (FINITO)

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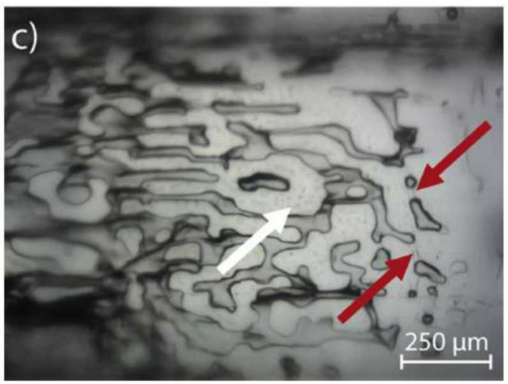

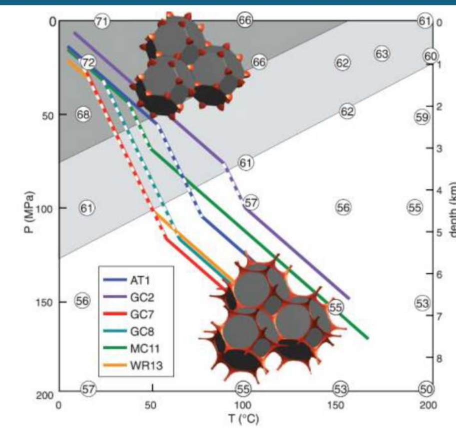

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Yifeng Wang (SNL), Hua Shao (BGR) and others

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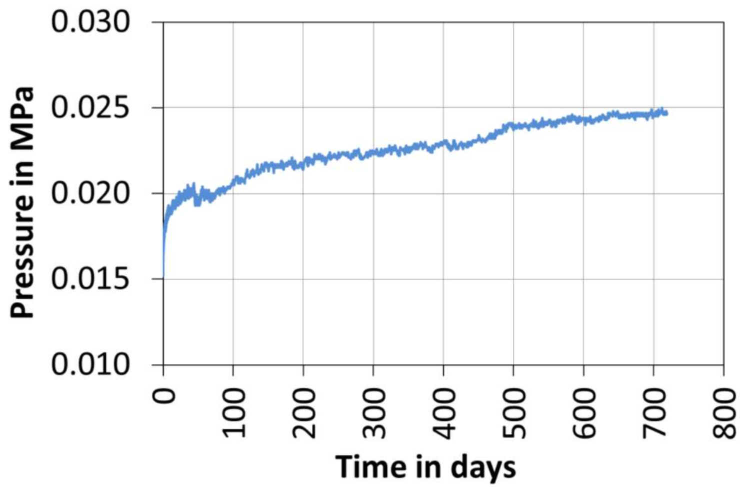
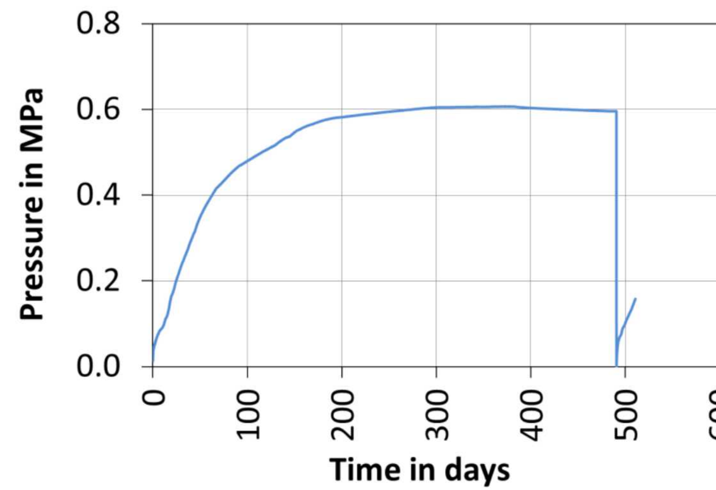
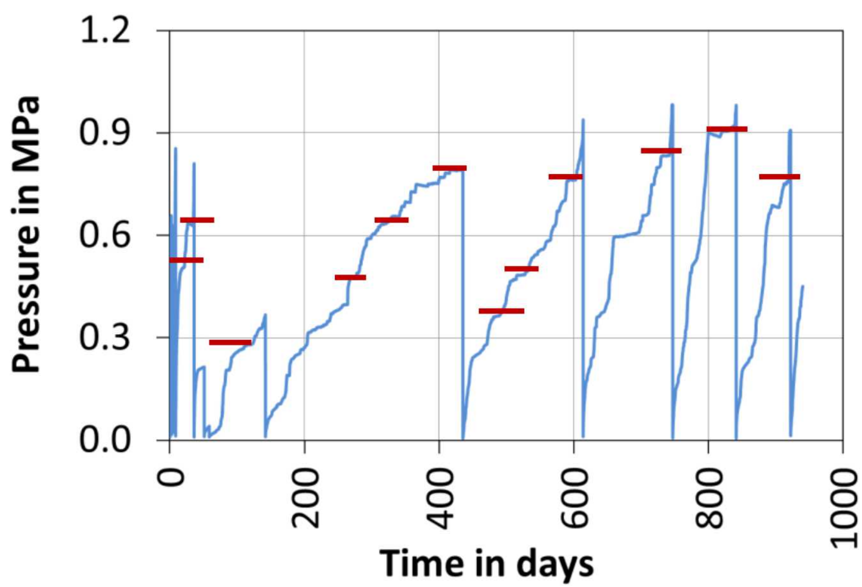
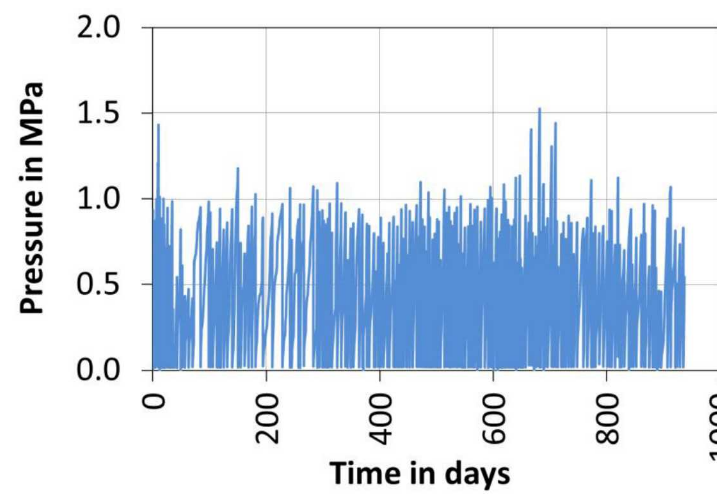
Possible chaotic behaviors of fluid release from rock salt

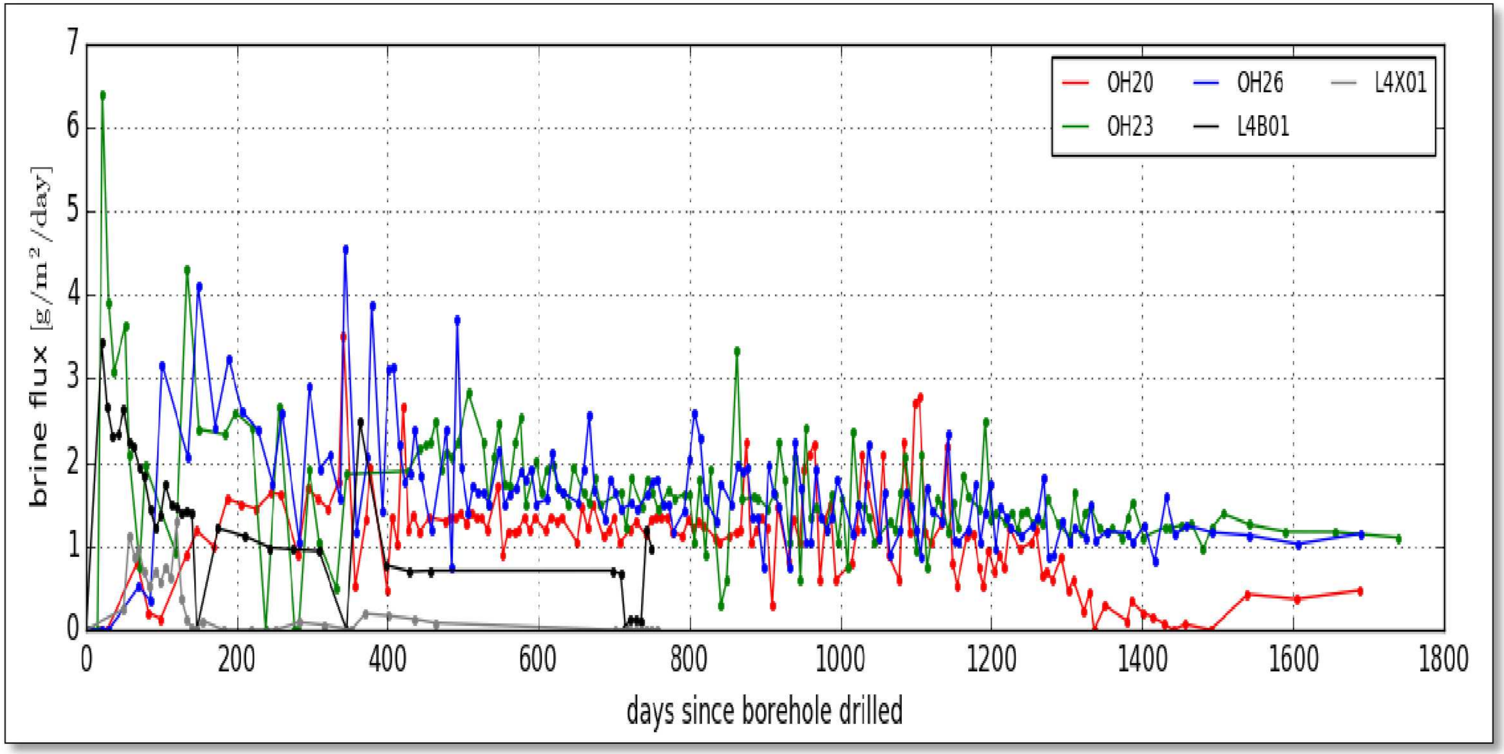






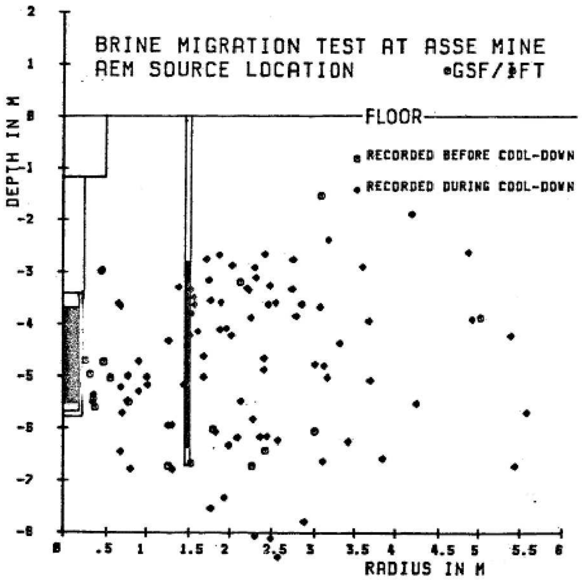


1997 WIPP Unheated Brine Inflow Study



Beauheim et al. (1997)

More observations



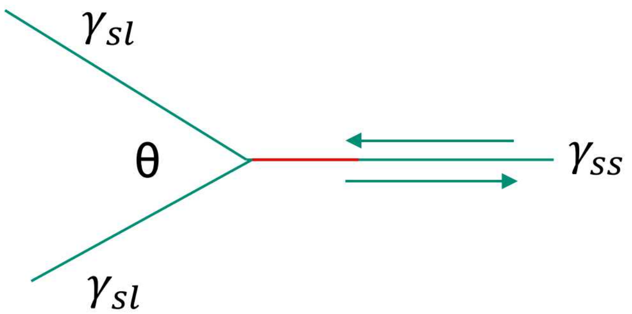
Rothfuchs et al. (1988)

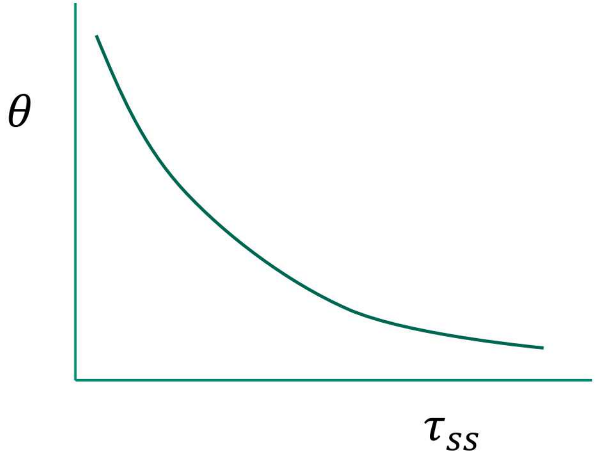
Patches of brine are also chemically isolated.

Shear-induced brine localization and episodic release

$$\cos\left(\frac{\theta}{2}\right) = \frac{\gamma_{ss}}{2\gamma_{sl}}$$

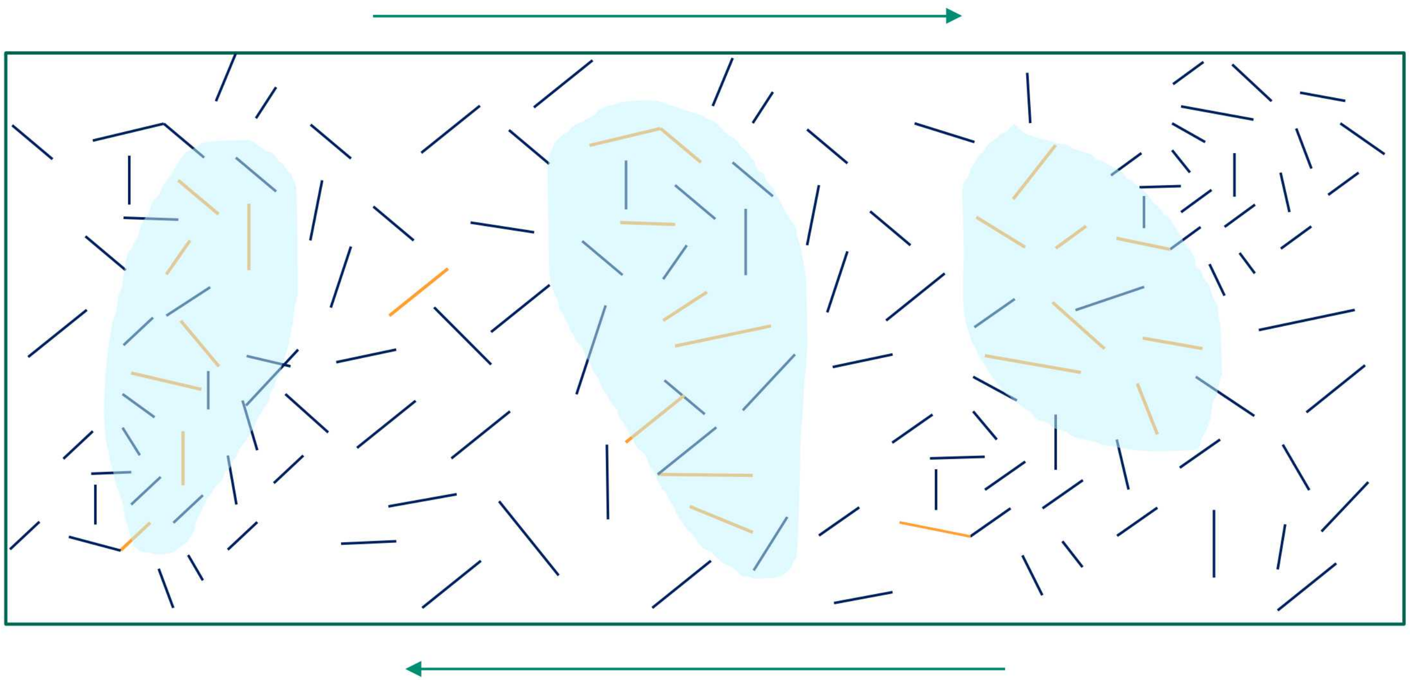
$$\gamma_{ss} = \gamma_{ss}^{0} + k_{ss}\tau_{ss}^{2}$$





- Draw water into grain boundary.
- Weaken the boundary.

Positive feedback



$$I = \frac{1}{3}\sigma_{ii}$$

$$J = \frac{1}{6}[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2] + \sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2$$

Shear-induced dilatancy force = $\frac{1}{2} R_d \varepsilon_t^2 E$

Mathematical model

$$\frac{\partial \phi}{\partial t} = \nabla \cdot (kf\phi^2 \nabla P)$$

Continuity for brine

$$\frac{\partial \phi}{\partial t} = \lambda[\frac{R_d E}{2G_d^2}\tau^2 + P - I - (\phi - \phi_0)E]$$

Shear induced dilatancy

$$f = \frac{\alpha\tau^n\phi^m}{1 + \alpha\tau^n\phi^m}$$

Fraction of weaken grain boundaries

$$\tau = \frac{G_d\sqrt{J}}{G_d - (f + \beta\nabla^2 f)(G_d - G_w)}$$

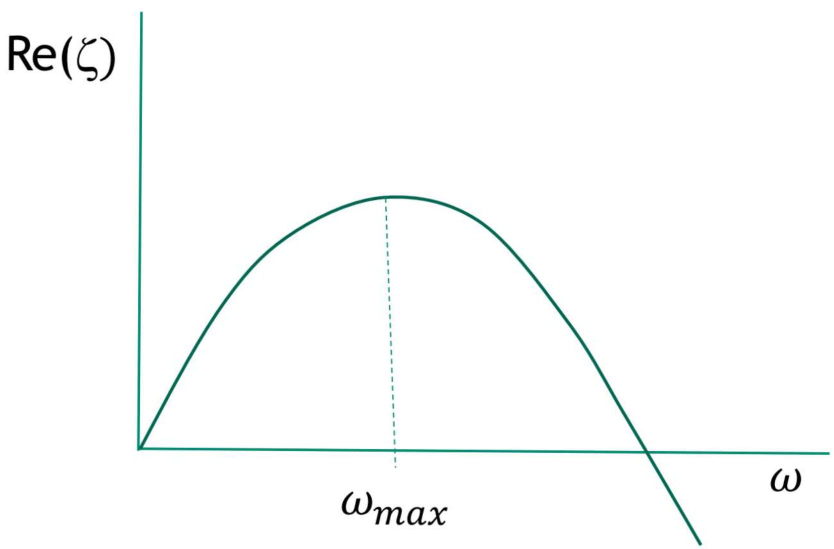
Stress partitioning

Linear stability analysis

$$\delta\phi = \hat{\phi} e^{i\omega x + \zeta t} \qquad \delta f = \hat{f} e^{i\omega x + \zeta t}$$

$$\delta p = \hat{p} e^{i\omega x + \zeta t} \qquad \delta\tau = \hat{\tau} e^{i\omega x + \zeta t}$$

$$\zeta = \frac{2\lambda m \tau_s^3 (1-g) f_s (1-f_s) \phi_s (1-\beta\omega^2)\omega^2 - \lambda K \phi_s^2 \omega^2 + 2\lambda\mu\phi_s q\omega i}{\lambda\mu + \phi_s^2\omega^2}$$



New mechanism for brine migration

- Episodic release
- Brine localization
- Heterogenous brine chemistry
- Acoustic emission
- Effect of stress
- Brine migration rate
- Bed salt vs. domal salt