41 GRC Annual Meeting, Salt Lake City
Reservoir Engineering/Reservoir Management/Modeling 1
October 3, 2017 at 8:20 a.m.

Estimation of Fracture Surface Area based on Tracer and Temperature Histories

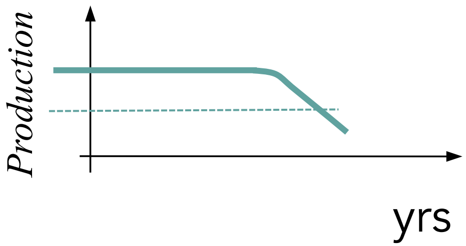
Anna Suzuki, Tohoku University (Japan)

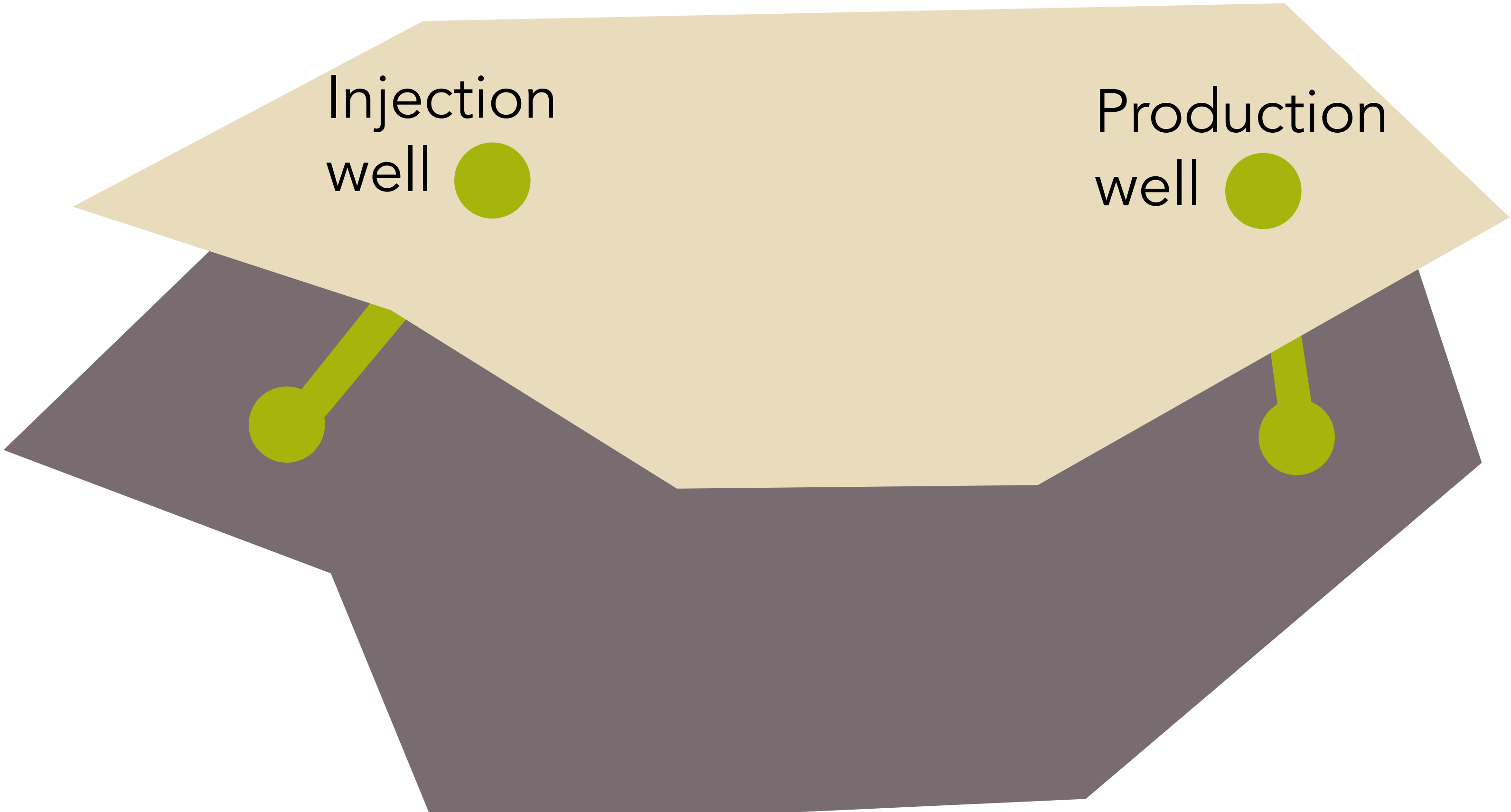
Shook, G. M., & Suzuki, A. (2017). Use of tracers and temperature to estimate fracture surface area for EGS reservoirs. Geothermics, 67, 40–47.

Injection strategy

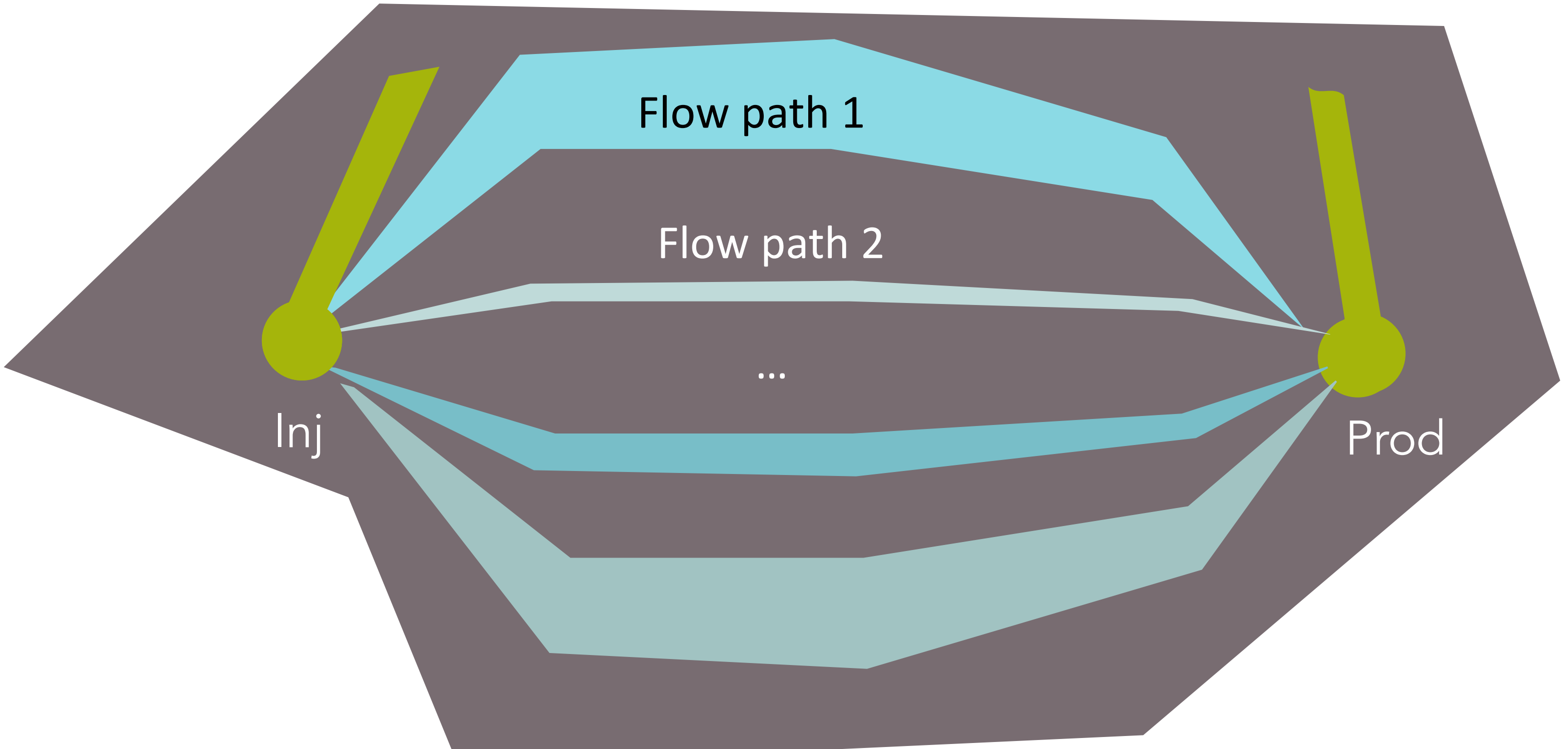
- Flow rate
- Temperature

Production prediction





II. TRACER TRANSPORT MODEL



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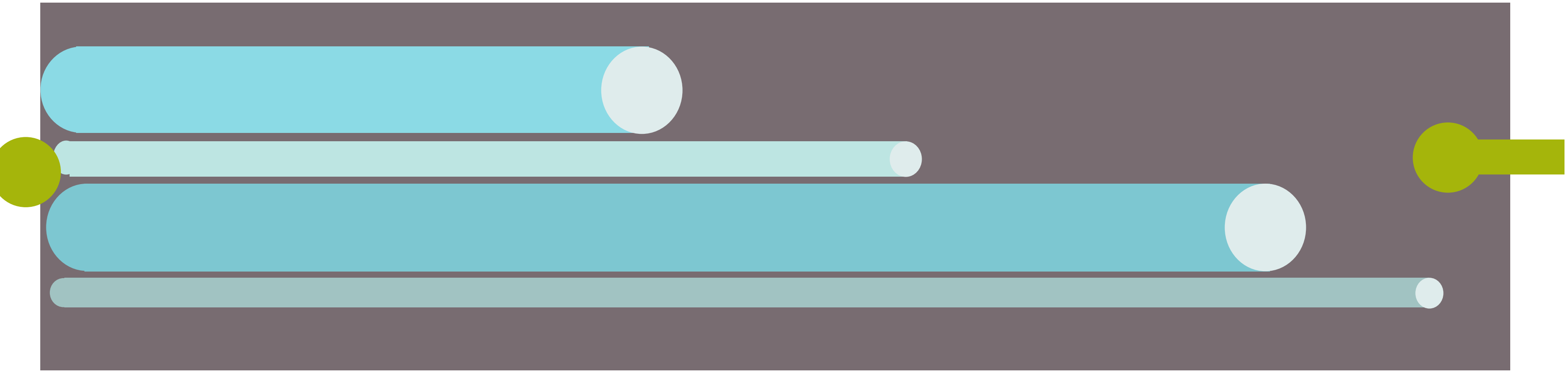
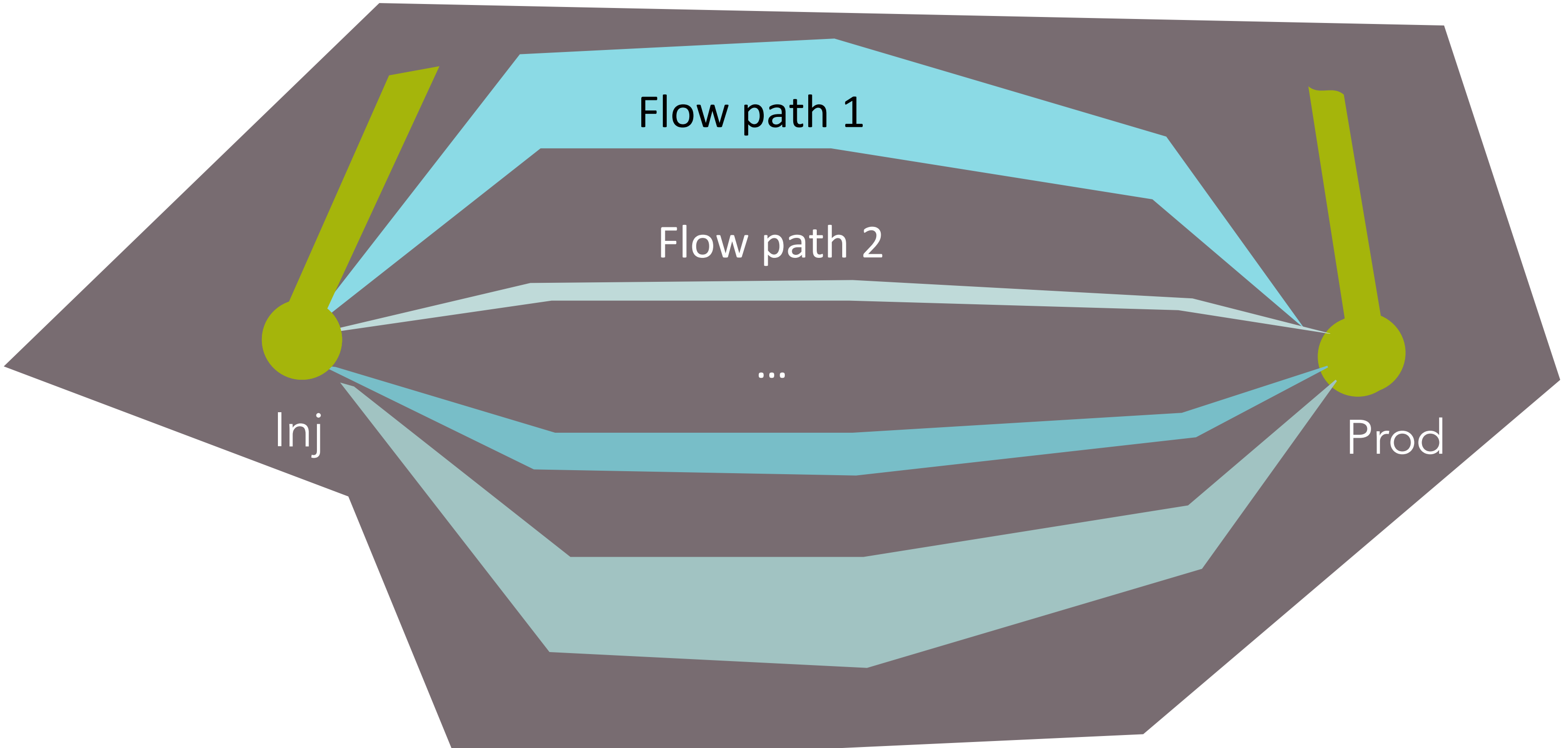
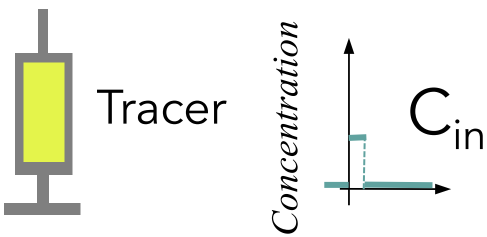
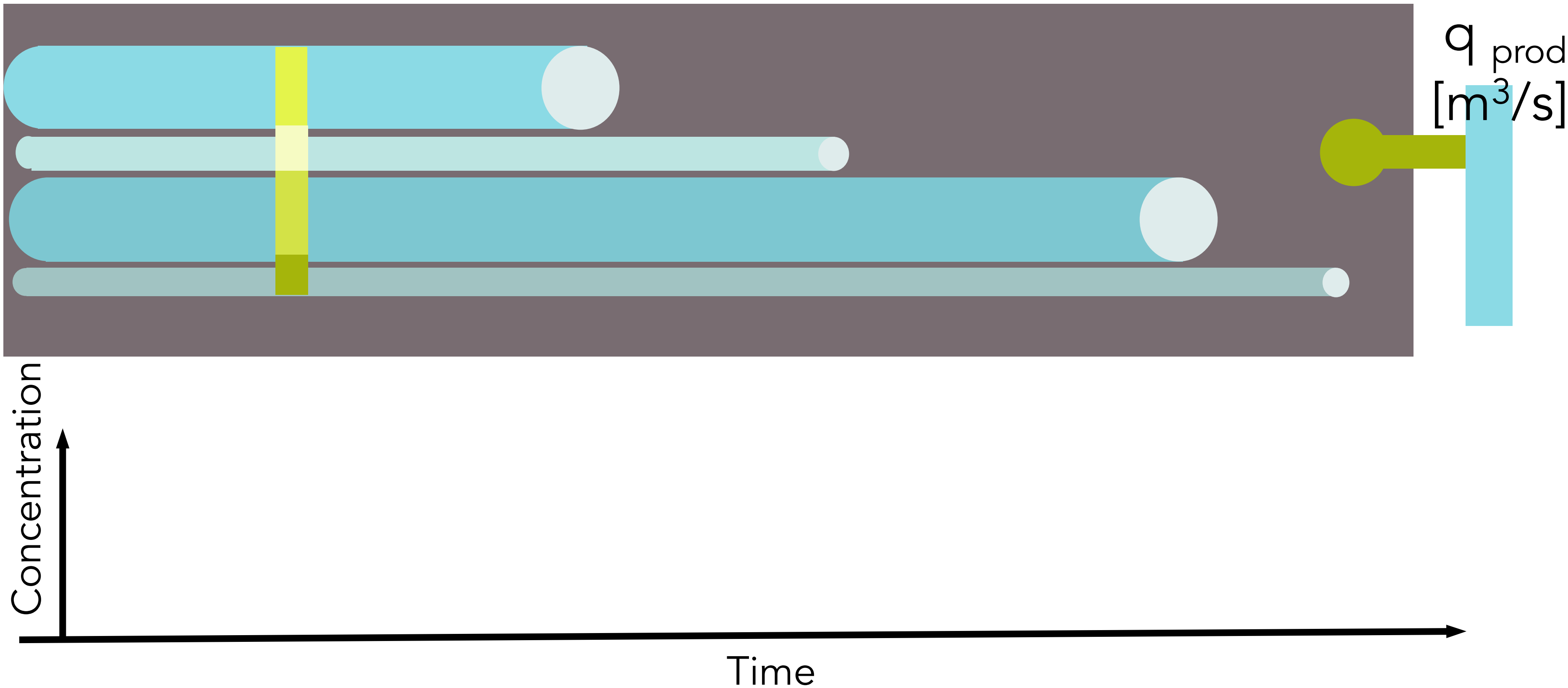




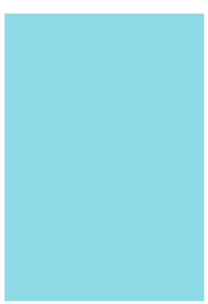
II. TRACER TRANSPORT MODEL

Flow rate at production well [m³/s] = Const.





Accumulated production [m^3]



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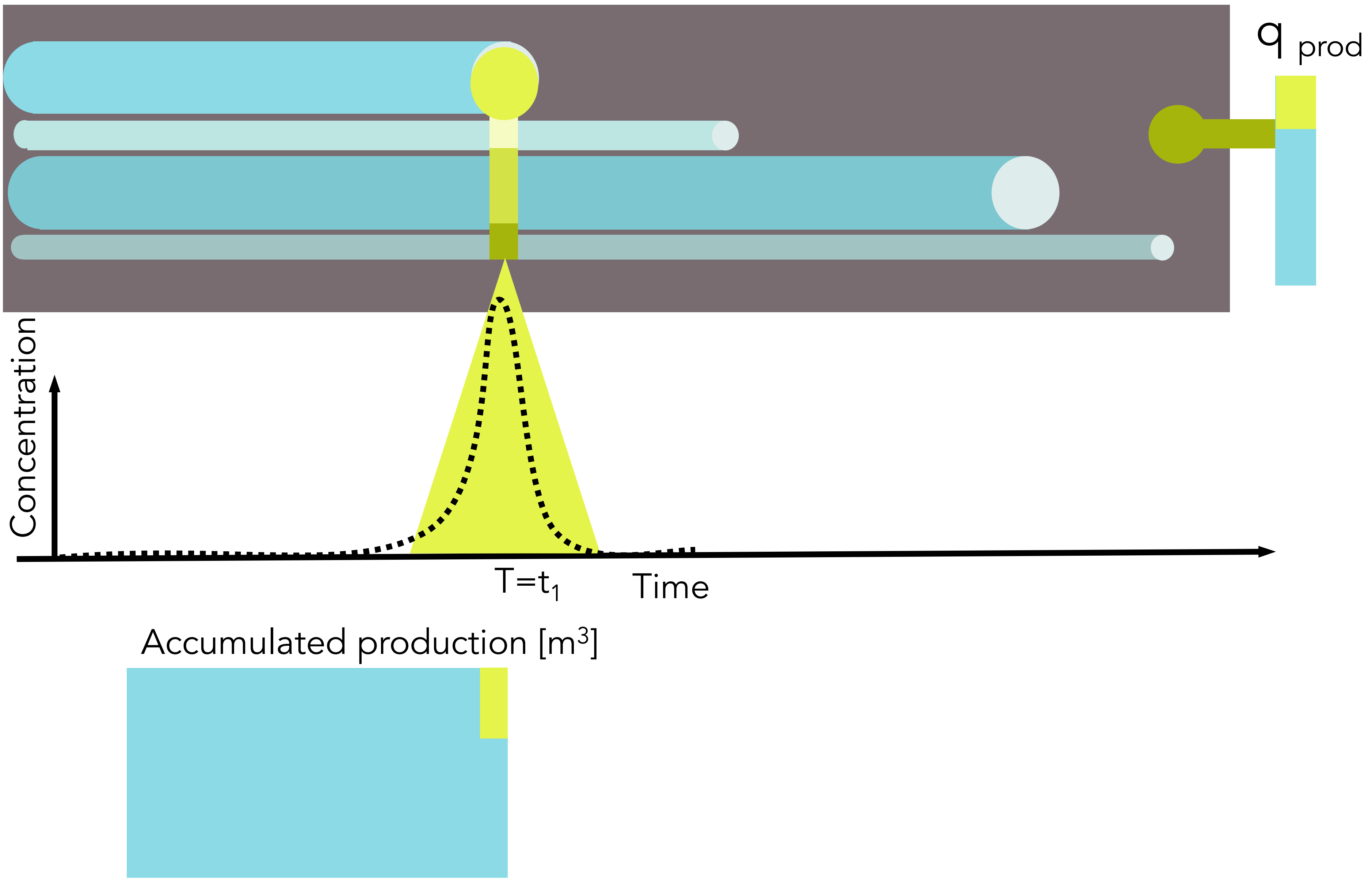
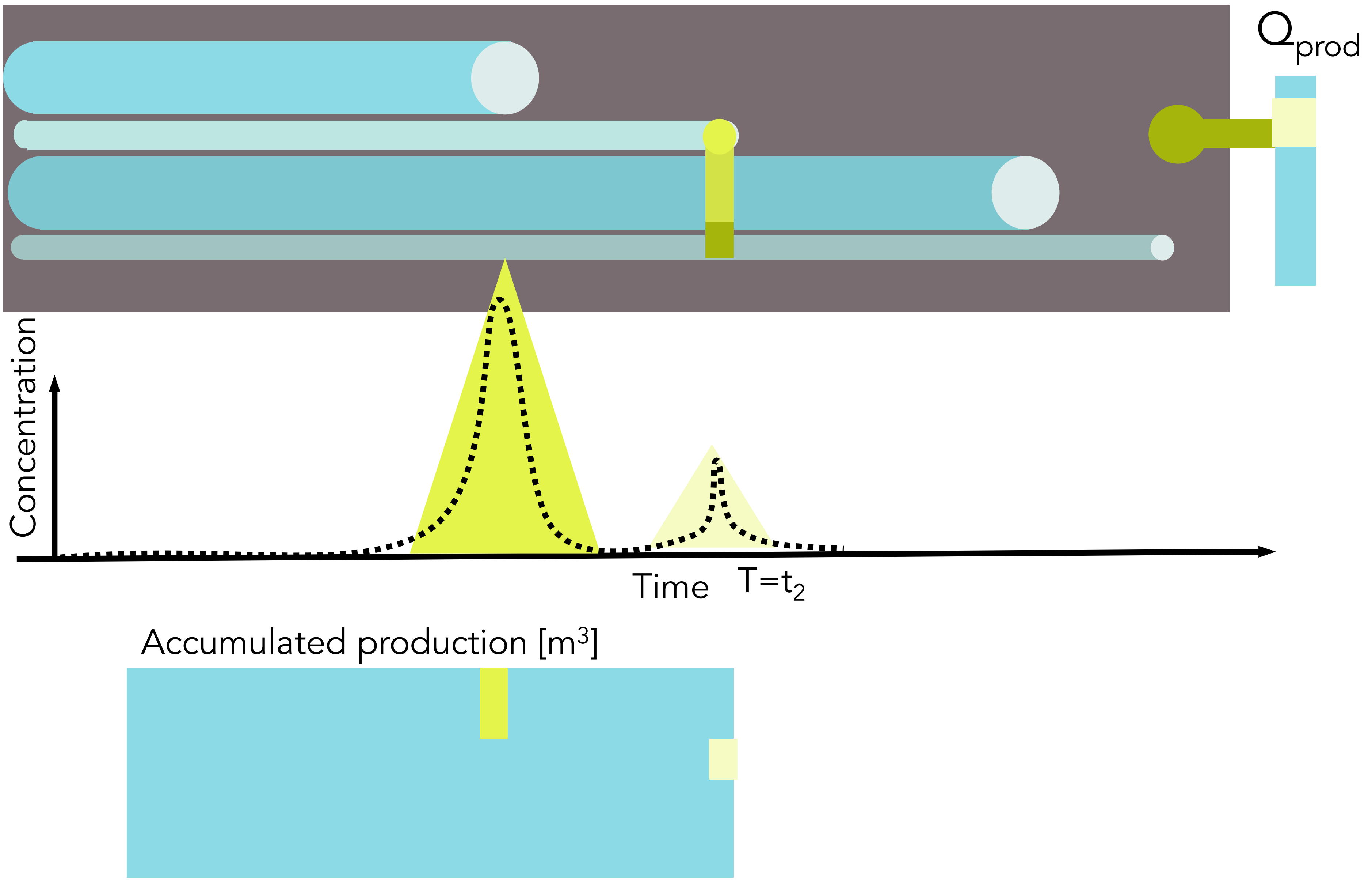
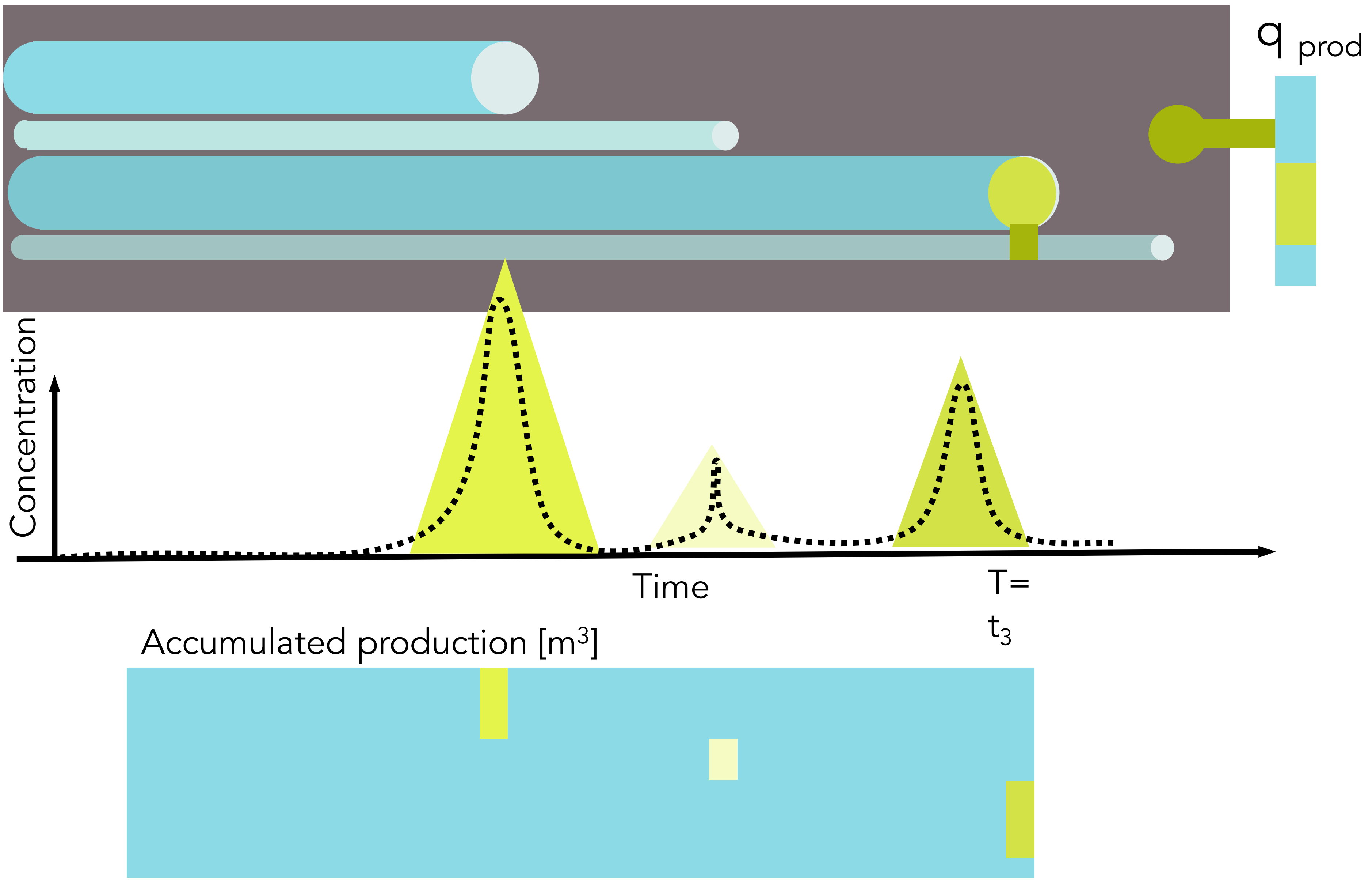
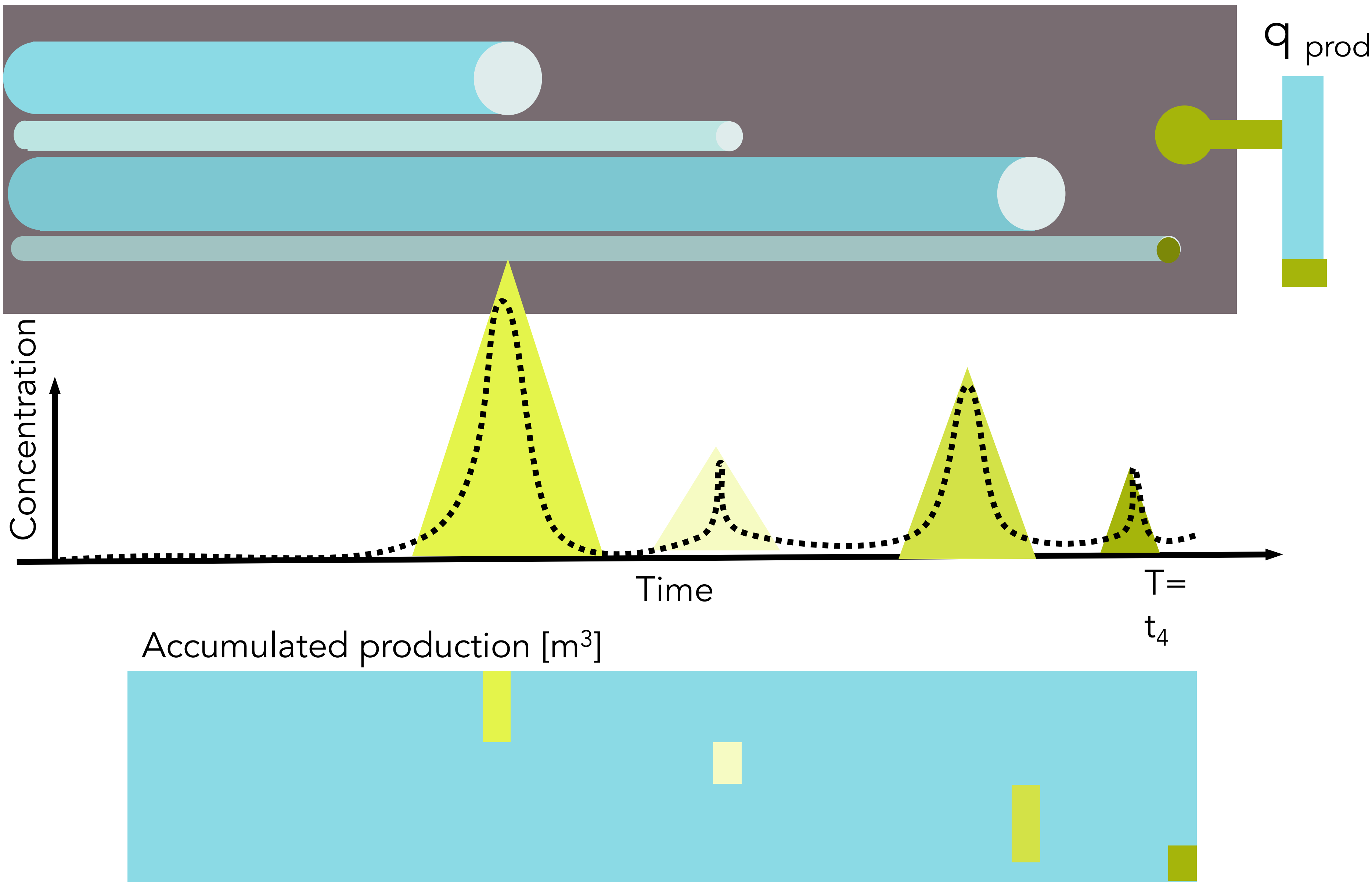
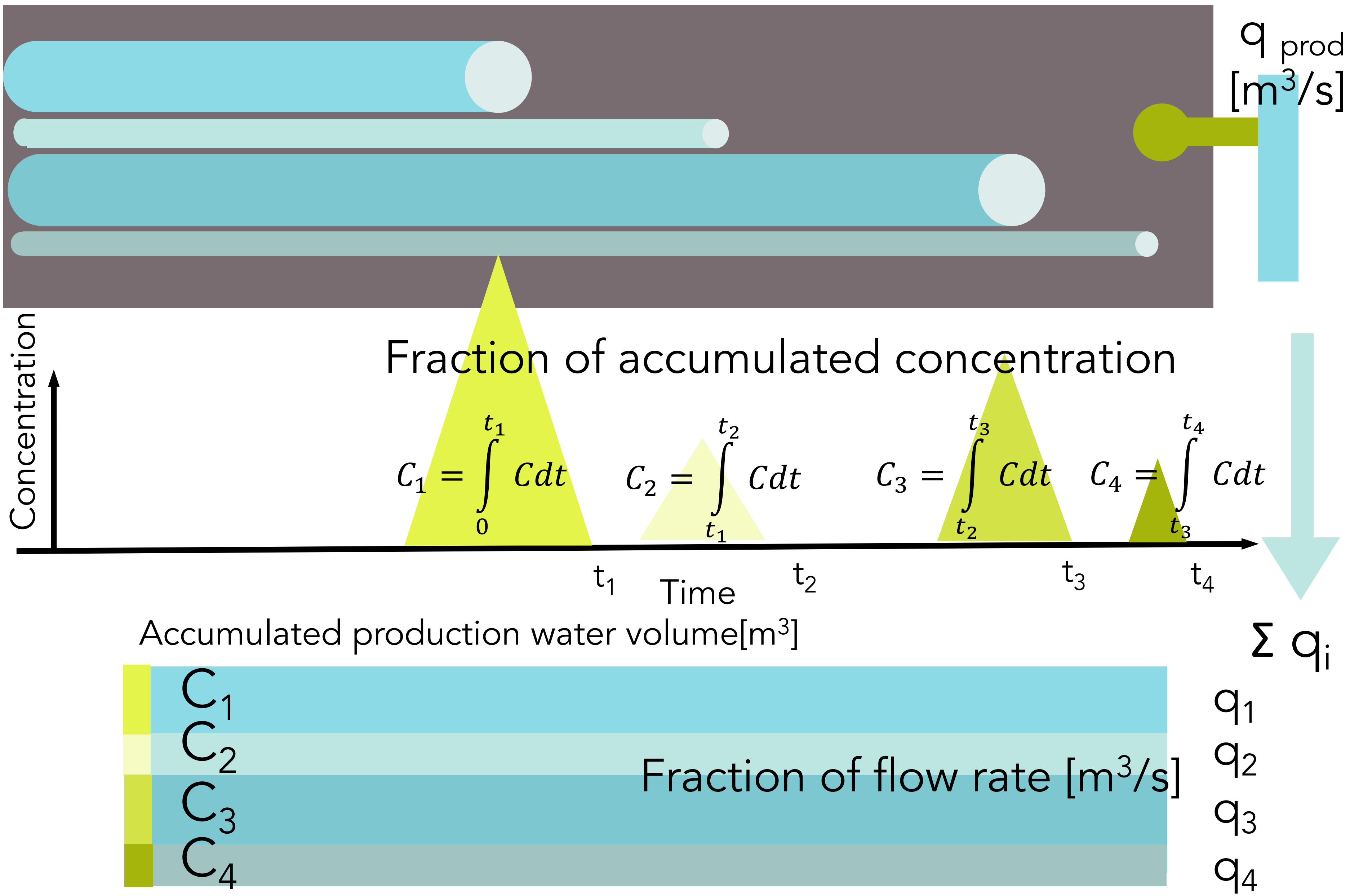



Qprod
Concentration
Time
T=t2
Accumulated production [m3]

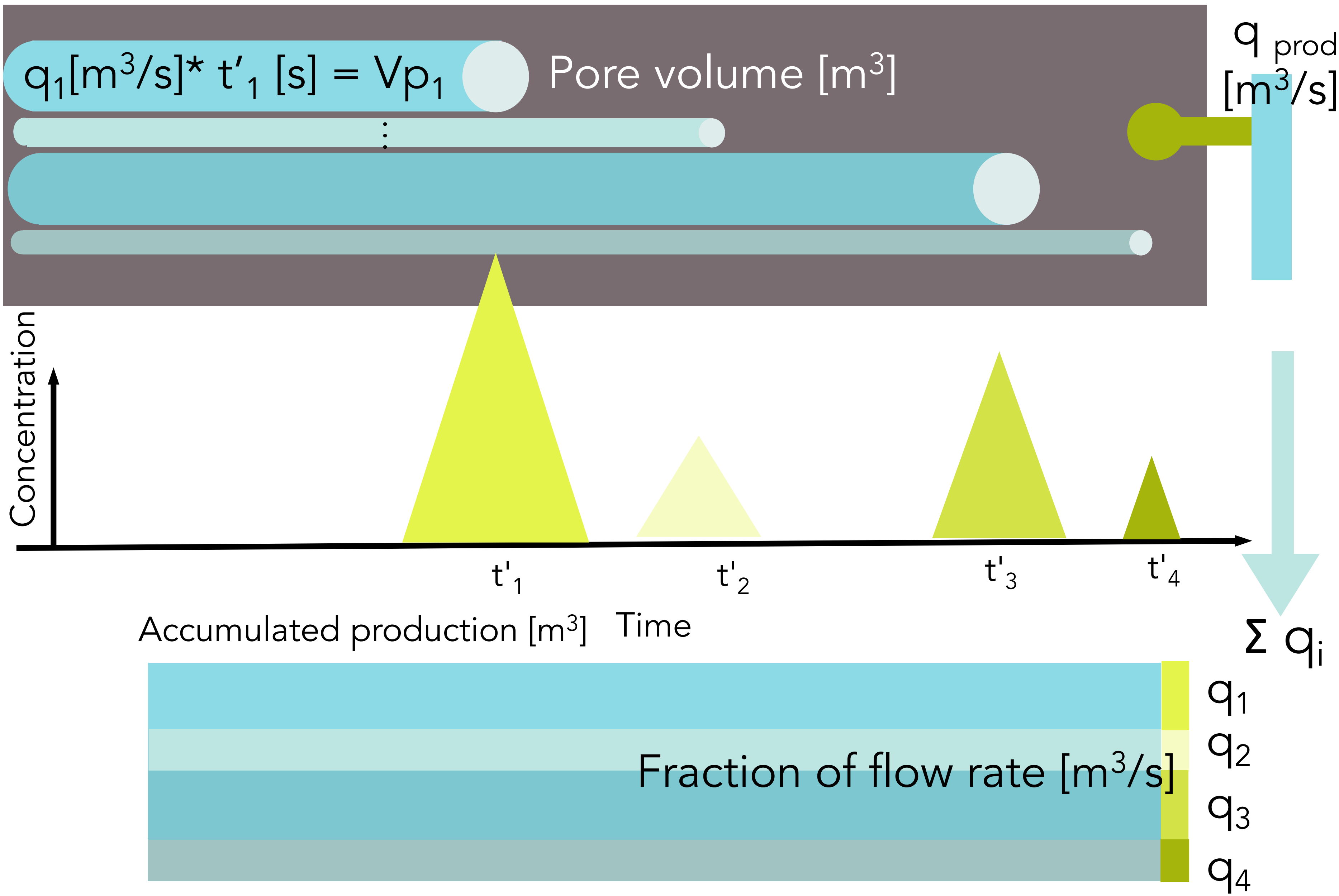
II. TRACER TRANSPORT MODEL




q prod
Concentration
Time
T=
t4
Accumulated production [m3]

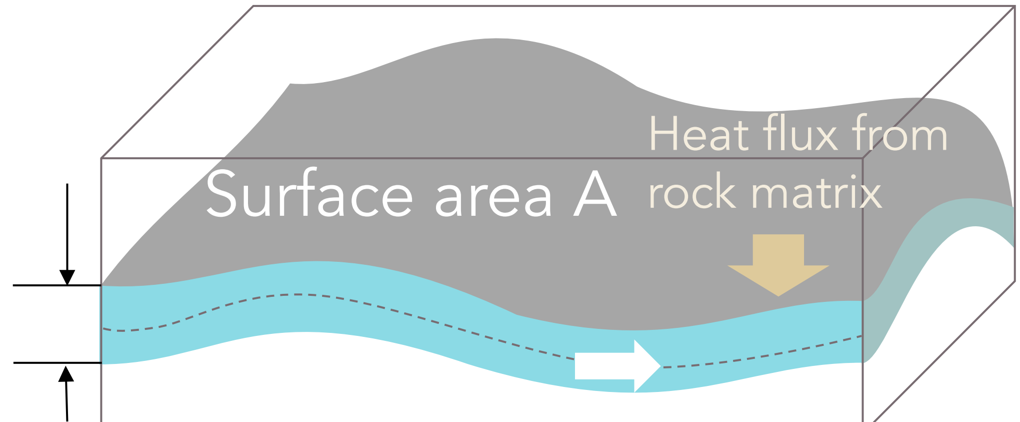


q prod [m3/s]
Concentration
Fraction of accumulated concentration
$C_1 = \int_0^{t_1} Cdt$
$C_2 = \int_{t_1}^{t_2} Cdt$
$C_3 = \int_{t_2}^{t_3} Cdt$
$C_4 = \int_{t_3}^{t_4} Cdt$
t1
Time
t2
t3
t4
Accumulated production water volume[m3]
Σ qi
C1
C2
C3
C4
Fraction of flow rate [m3/s]
q1
q2
q3
q4



q1[m3/s]* t'1 [s] = Vp1
Pore volume [m3]
q prod [m3/s]
Concentration
t'1
t'2
t'3
t'4
Accumulated production [m3]
Time
Σ qi
Fraction of flow rate [m3/s]
q1
q2
q3
q4

III. HEAT TRASFER MODEL



b aperture << L

Heat transfer equation (Gringarten and Sauty, 1975)

$$\frac{b}{2}(\rho C_p)_T \frac{\partial T_w}{\partial t} + \frac{q}{2}(\rho C_p)_w \frac{\partial T_w}{\partial S} - K_R \frac{\partial T_R}{\partial z}\bigg|_{z=b/2} = 0$$

Accumulation

Convection

Heat flux from rock matrix

$$\frac{(\rho C_p)_R}{K_R}\frac{\partial T_R}{\partial t} - \frac{\partial^2 T_R}{\partial z^2} = 0$$

III. HEAT TRASFER MODEL

Analytical solution in Gringarten and Sauty (1975)

$$\frac{T_I - T_w(t)}{T_I - T_J} = erfc\left[\frac{(\rho C_p)_w^2}{K_R(\rho C_p)_R}\left(\frac{q}{S}\right)^2\left\{t - \frac{(\rho C_p)_T}{(\rho C_p)_w}\frac{bS}{q}\right\}\right]^{-1/2}$$

Aperture [m]

Rock properties

Flow rate [m^3/s]

One side of surface area [m^2]

Pore volume $V_p = bWL\phi = bS\phi$

Surface area $A = 2S$

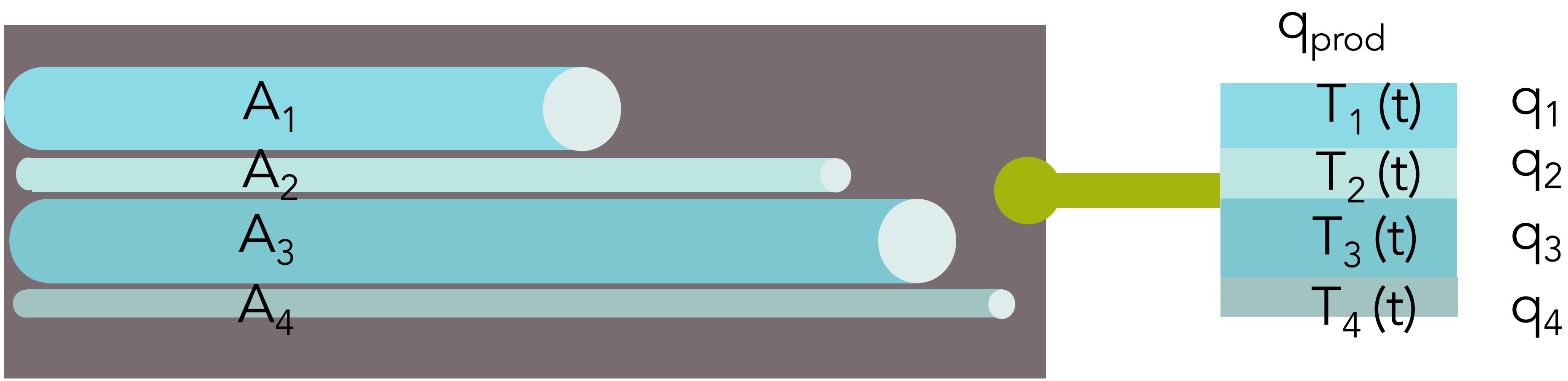
Surface area [m^2]

Flow rate [m^3/s]

Pore volume [m^3]

$$T = T_I - (T_I - T_J)erfc\left[\frac{1}{(\rho C_p)_w}\frac{A}{2q}\sqrt{K_R(\rho C_p)_R}\frac{1}{\left(t - \frac{(\rho C_p)_T}{(\rho C_p)_w}\frac{V_p}{\varphi q}\right)^{1/2}}\right]$$

$$T = T(A, Vp, q, t)$$

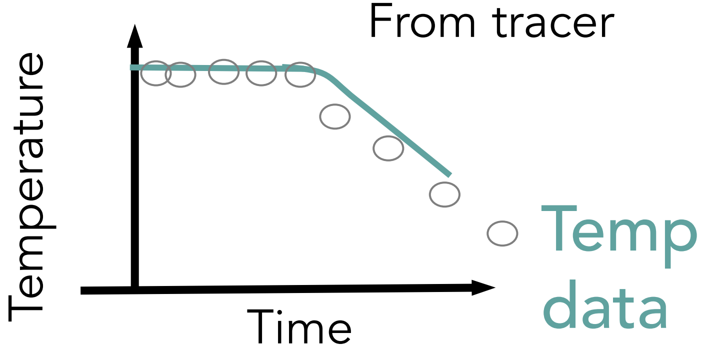


Flow rate-averaged temperature

$$T_{prod}(t) = \frac{\Sigma\, Ti\,(t) * qi}{\Sigma\, q_i}$$

$$T_{prod}(t) = T_{prod}(A_i, Vp_i, q_i, t) \quad \text{for } i = 1, \ldots, \#\text{flowpath}$$

From tracer

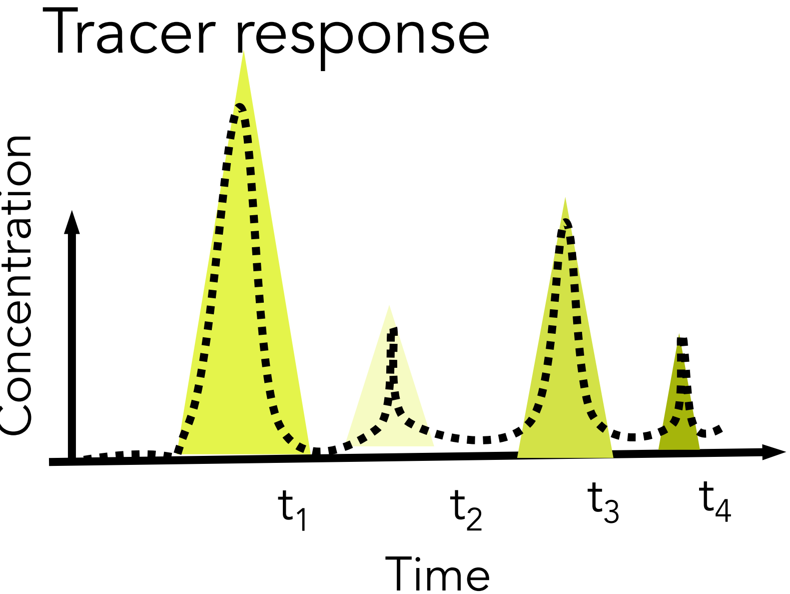


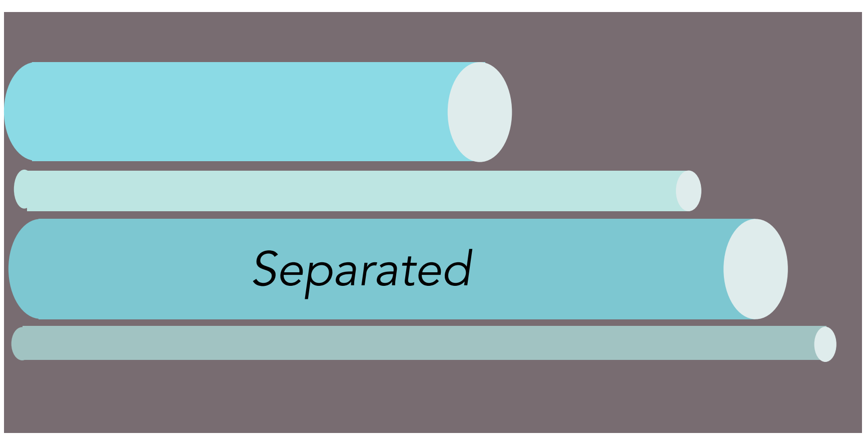
Optimization

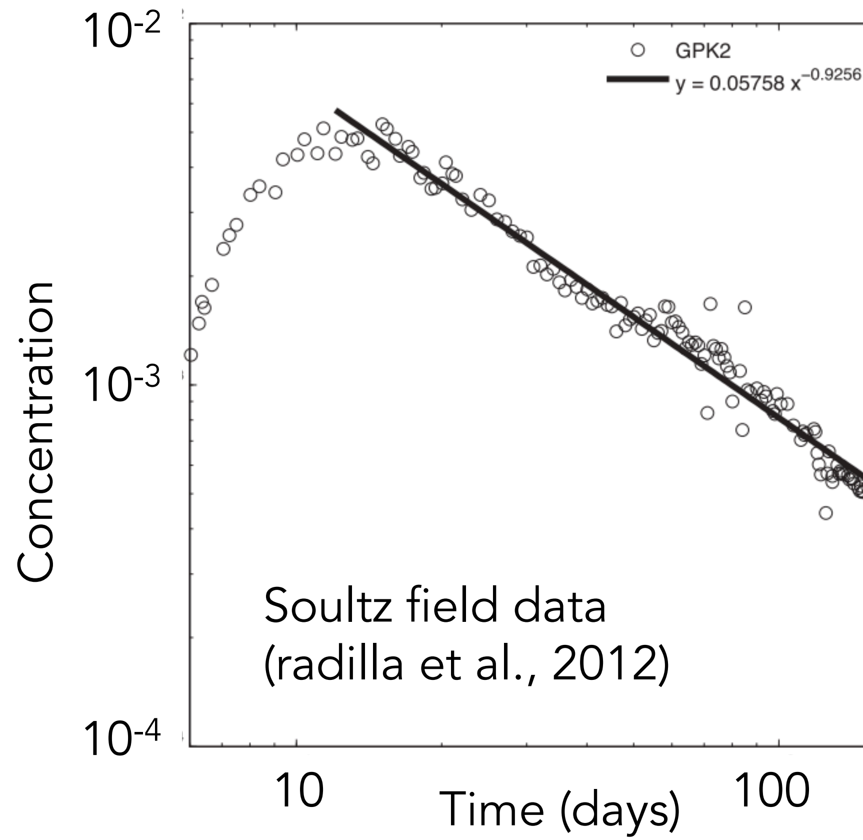
$$OBJ = \Sigma_{t=0}^{N_t} \frac{|Data(\tau_t) - Tw(\tau_t, \Sigma_{j=1}^{4} A_j)|}{Data(\tau_t)}$$

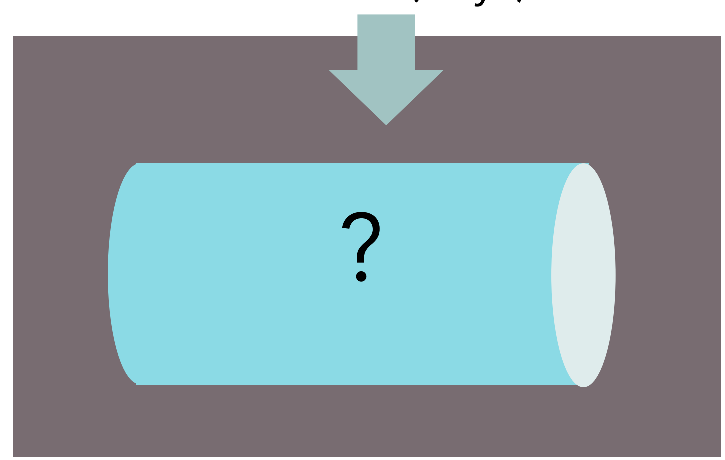
Estimated surface area = ΣA_i

IV. NEW POINT FROM PREVIOUS STUDY

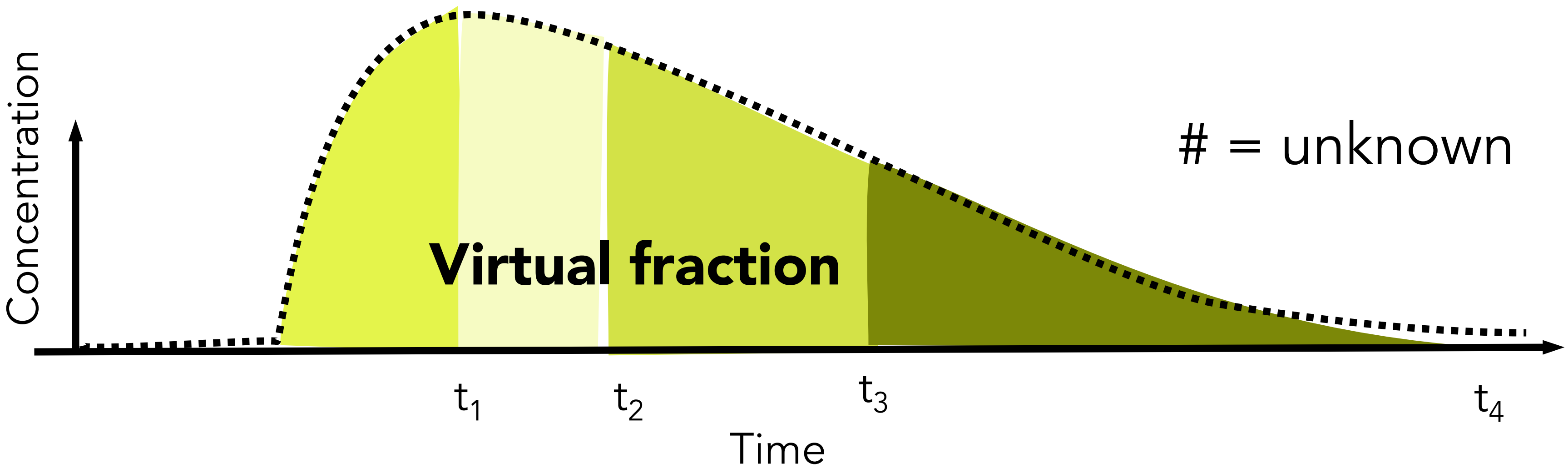








Tracer response



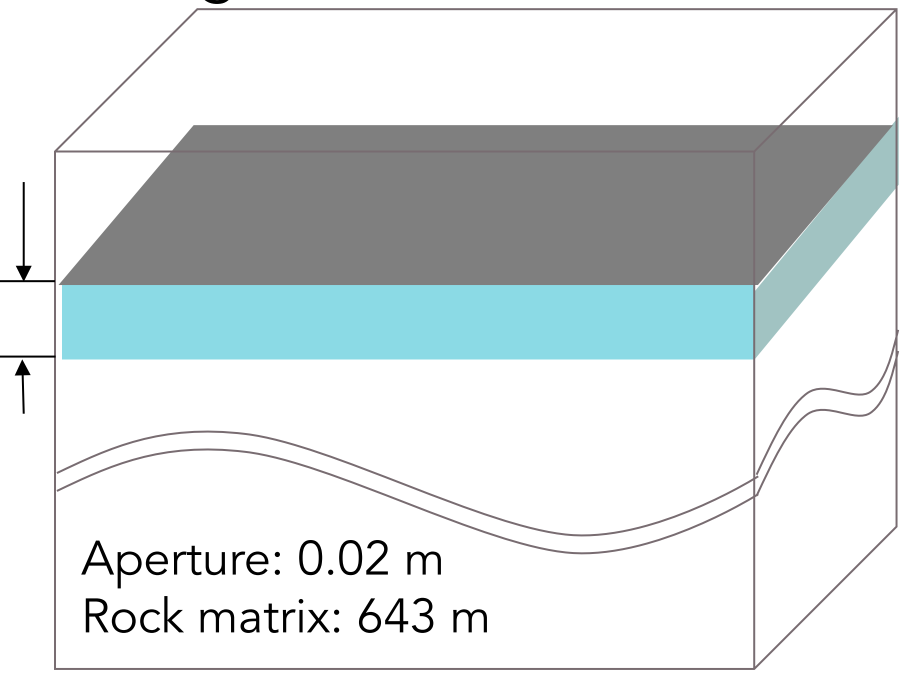
e.g. # = 4

$q_1 = q_2 = q_3 = q_4$ $(q_{prod} = \Sigma\, q_i)$

$A_1 \quad A_2 \quad A_3 \quad A_4$

Estimated surface area $= \Sigma\, A_j$

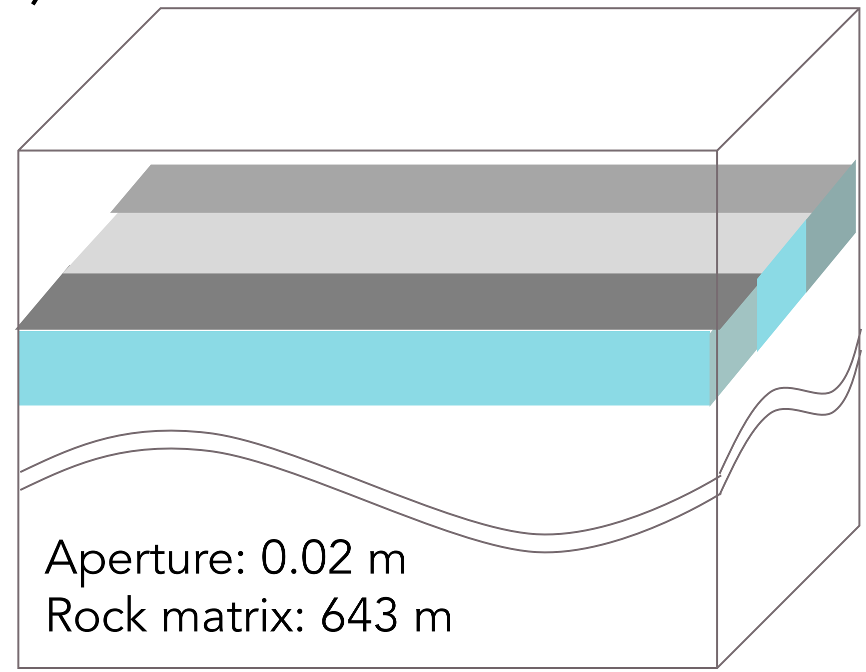
1) Single fracture



Fracture
- Permeability: 10 Darcy
- Porosity: 0.9

Simulation : TOUGH2

2) Three fractures

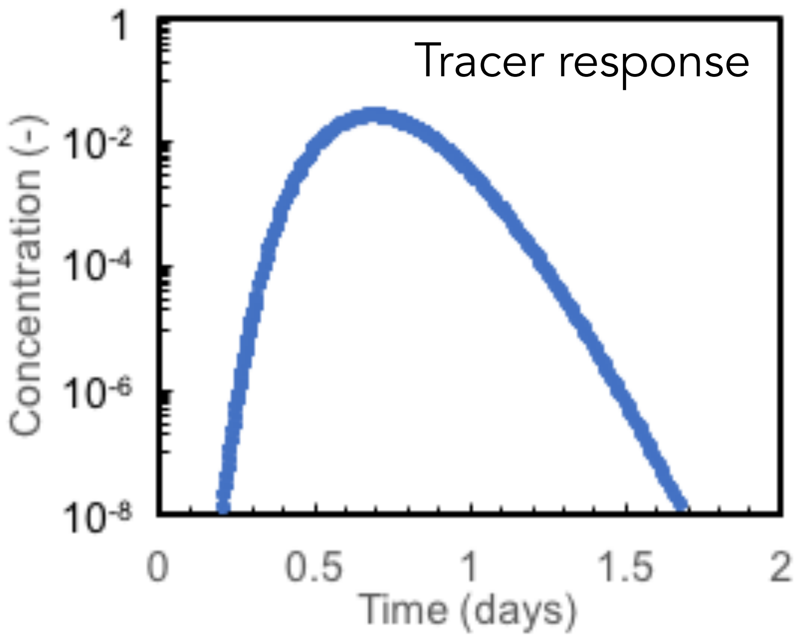


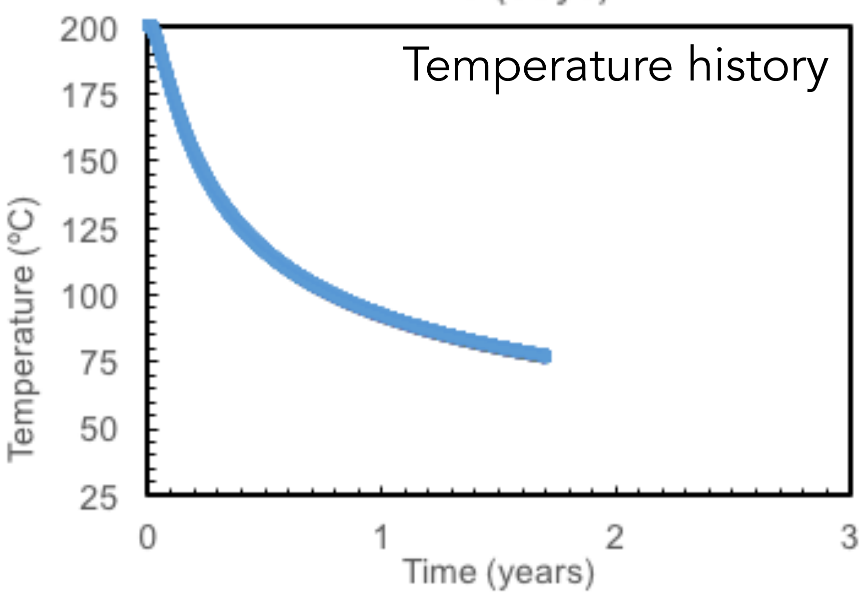
Damage zone 1
- Permeability: 4 Darcy
- Porosity: 0.75

Fracture
- Permeability: 10 Darcy
- Porosity: 0.5

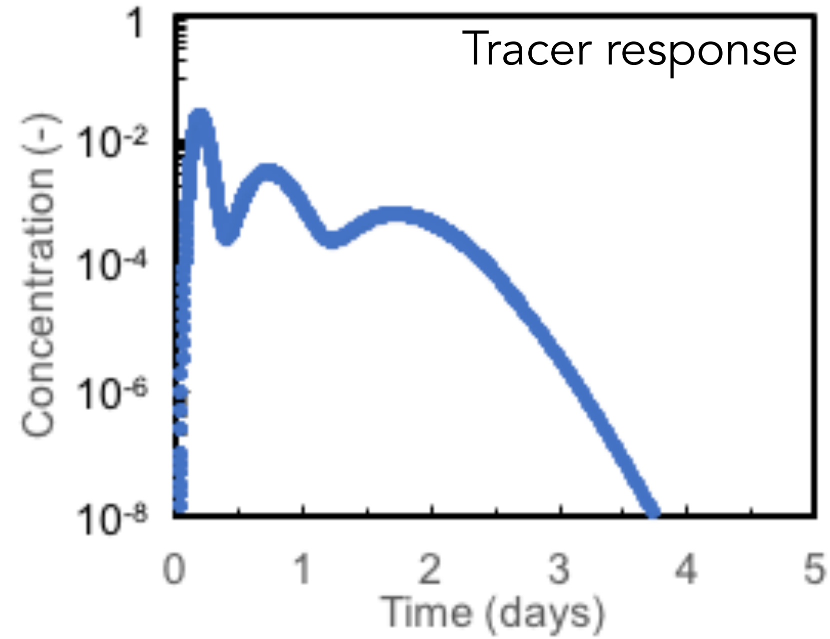
Damage zone 2
- Permeability: 2 Darcy
- Porosity: 0.96

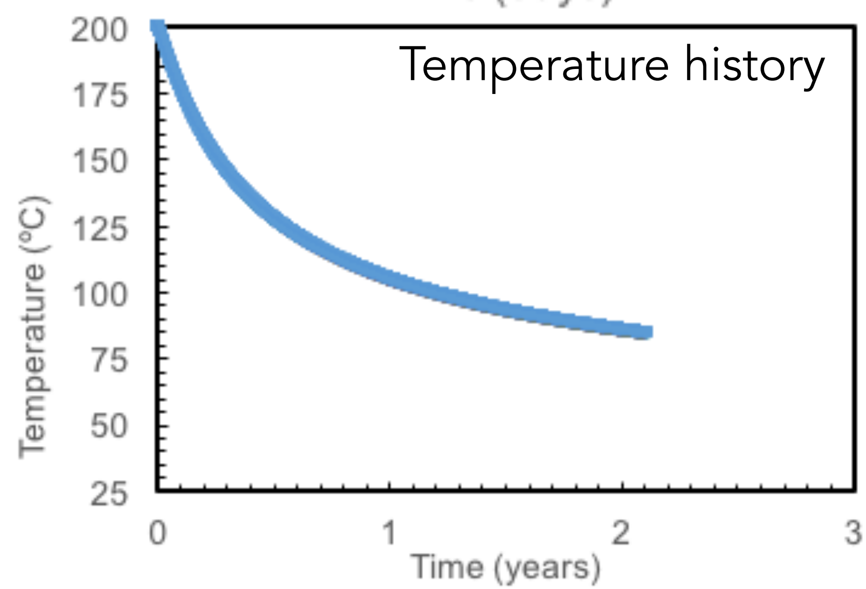
1) Single fracture



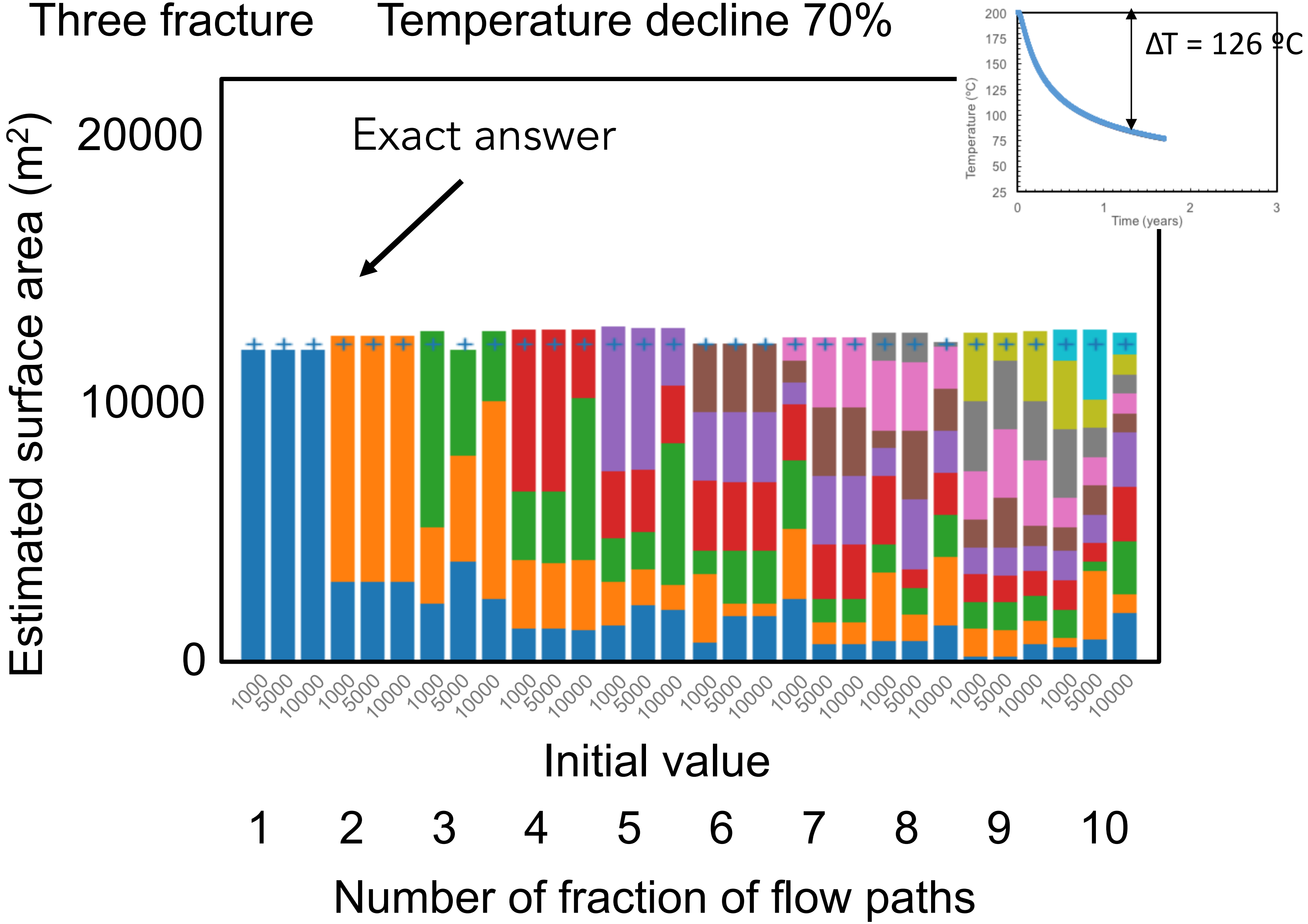


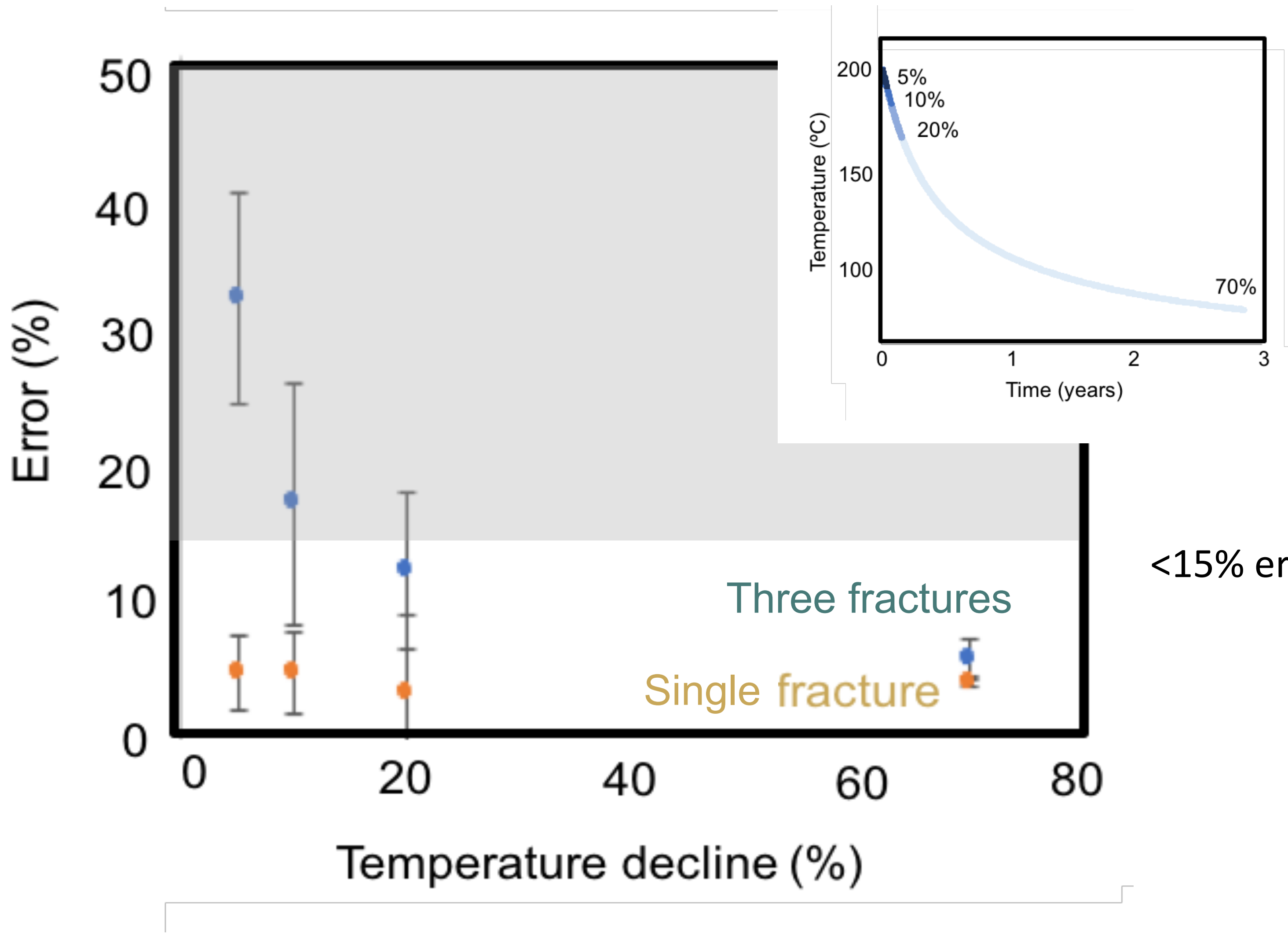
2) Three fractures





Three fracture Temperature decline 70%





<15% error!

Temperature decline should be acquired for future design!

VI. CONCLUSION

1. We propose a method to estimate fracture surface area based on tracer and temperature histories.

2. This method does not need a fracture aperture.

3. Virtual fractions of flow paths would help even though the number of paths is unknown.

4. Temperature decline of only 20% provides 15% error of estimation for fracture surface area.

Acknowledgement:
- Mike Shook
- JSPS KAKENHI Grant Number 717H049760, K17K190840