Hydrodynamic scenario of the formation of natural hydrogen accumulation in underground reservoir

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Colloque Annuel du GdR CNRS HydroGEMM,

dédié à la mémoire de Michel Panfilov

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*This work was initiated by **Michel Panfilov** a couple of years ago, when he made calculations for the underground storage of hydrogen and its possible leakage through heterogeneous layers.*

In last months of his illness, he persistently asked to complete this work in the application for the natural hydrogen accumulatios.

So, this work was completed and simulated by me, my colleague from Lemta, Antonio Pereira, and student of ENSG, Cheikh Oumar Ba.

Irina Panfilov, 15.11.2023

Hydrogen emissions

H2 emissions are characterized by:

- circular areas : lakes or swamps
- white/blue colour of circles
- deforestation
- soil subsidence
- accelerated karst formation

Omsk region (Russia)

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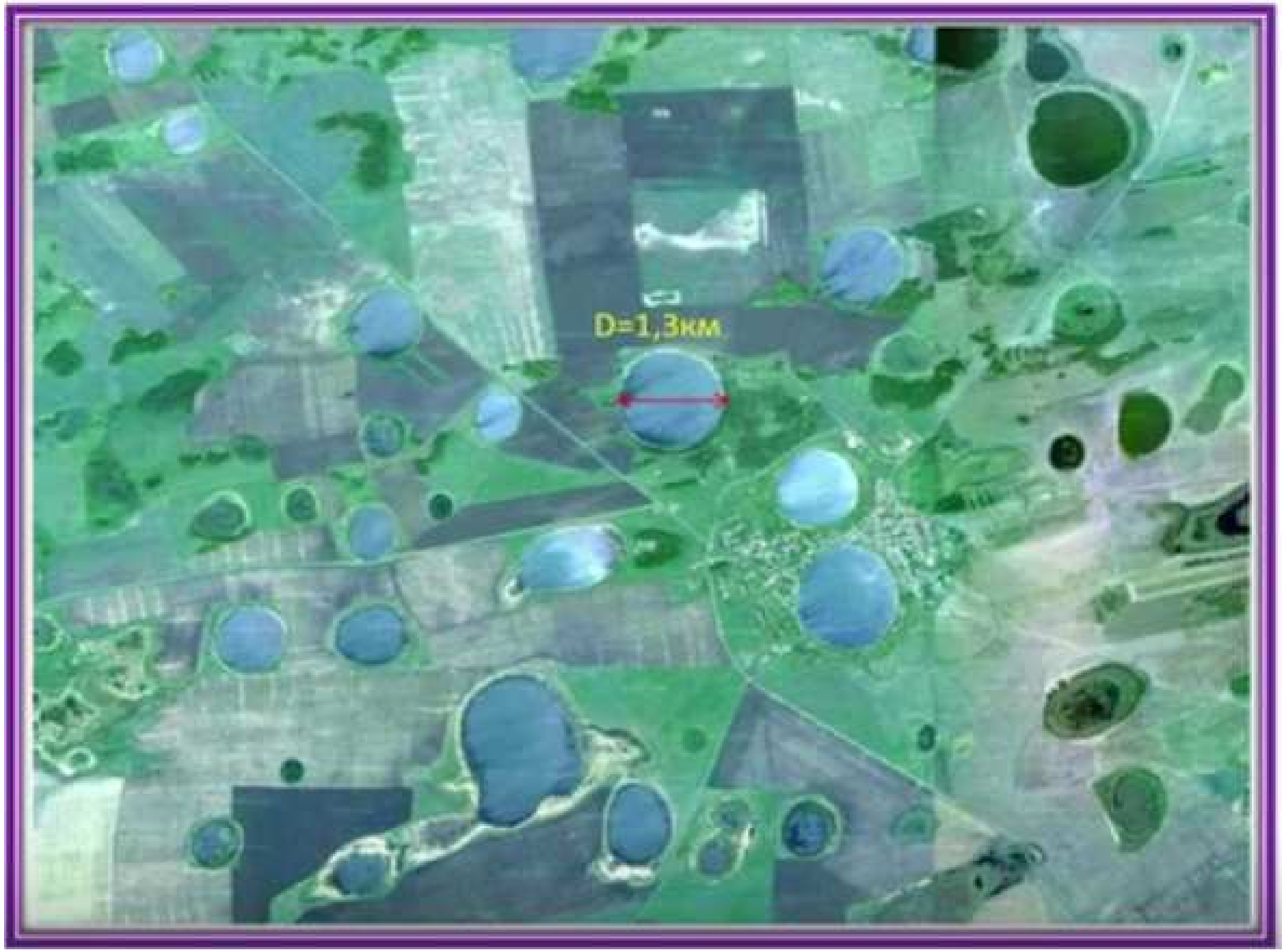
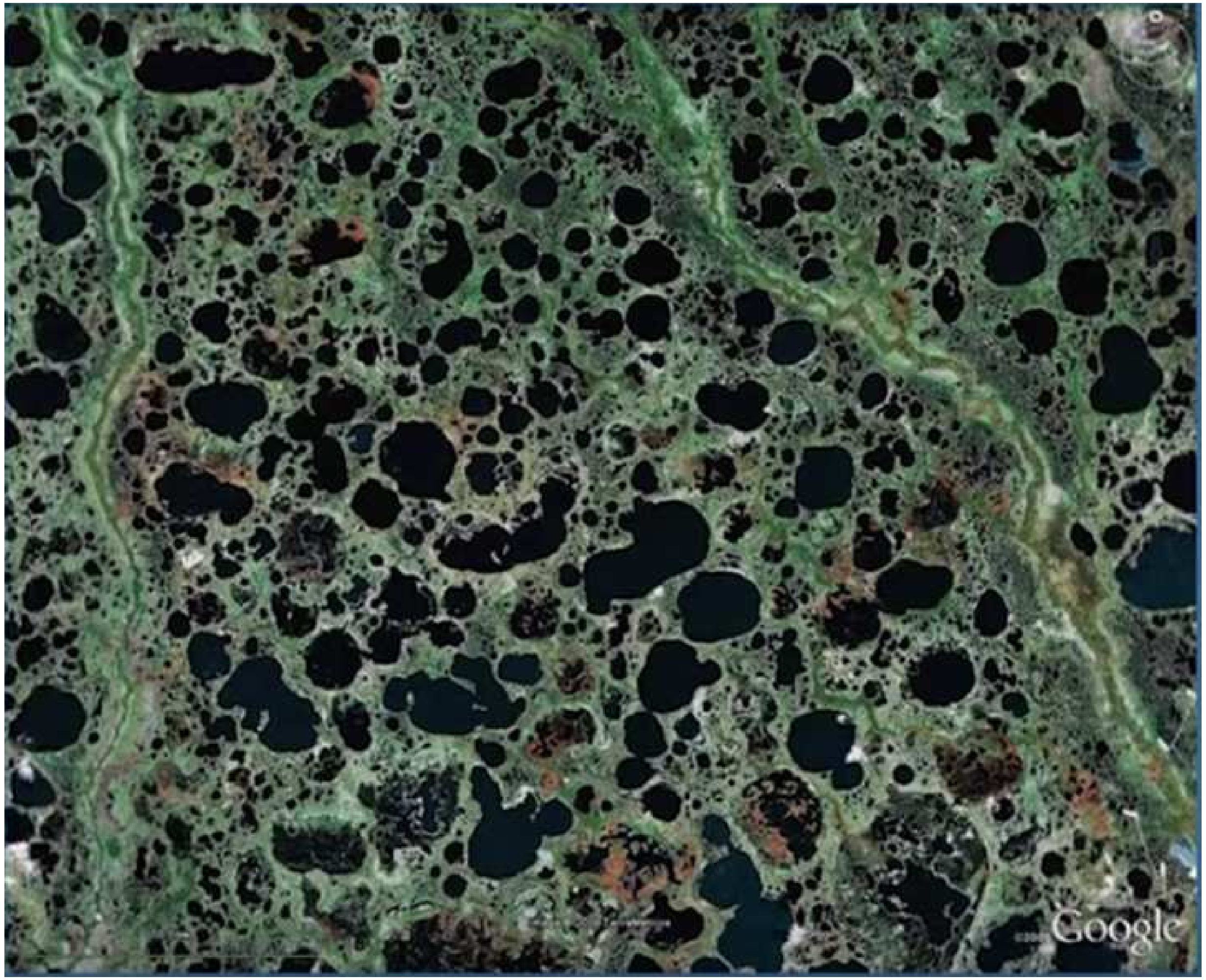
Kustanai region (Kazakhstan)



Kogalym (Khanty-Mansiisk region - Russia)



Destruction of black earth soil in Lipetsk (Russia)

Panfilov's hypothesis of formation of natural H2 deposits

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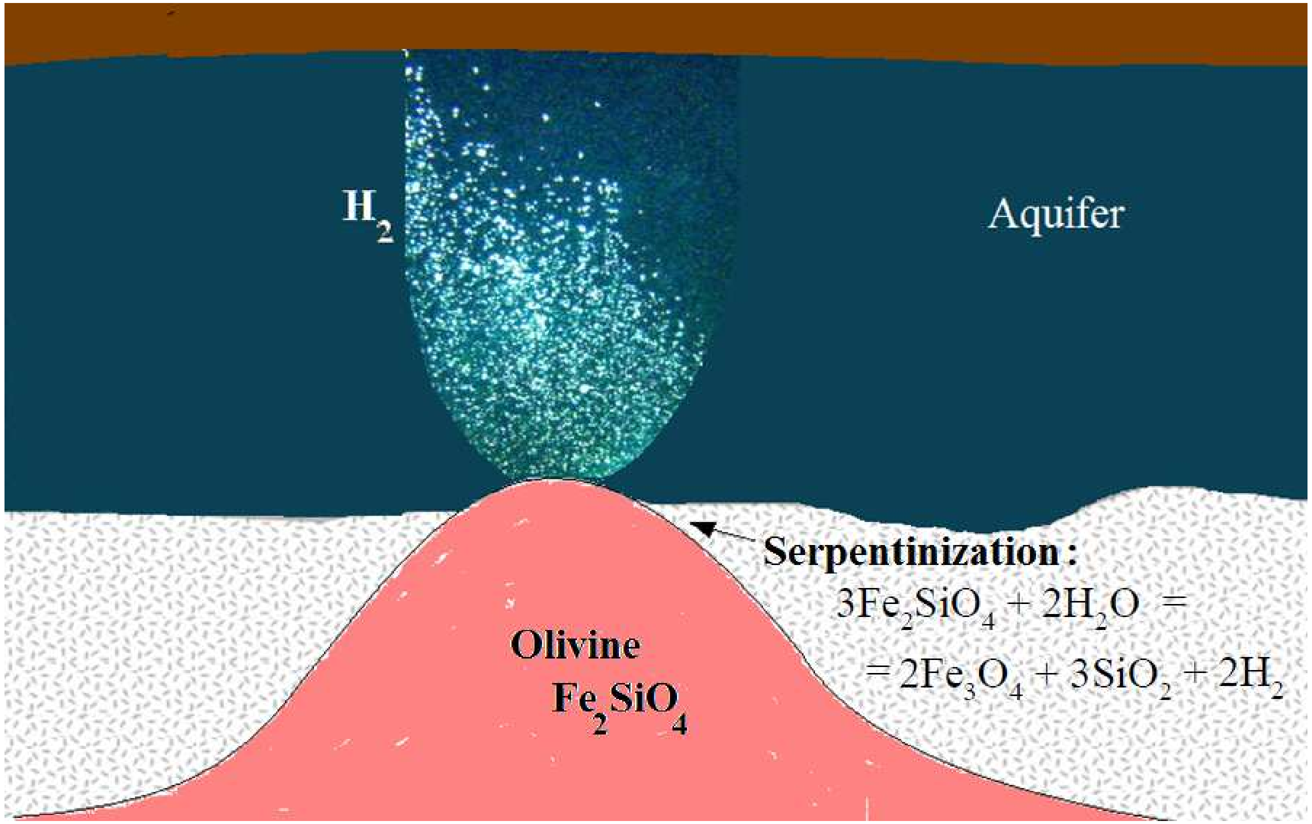
H2 genesis



Serpentinization: T=0 – 500 °C

Estimation of H2 flux

	Flux at the bottom $m^3/(s\cdot km^2)$	
Geological data:	0.005 - 0.015	$= (0.43 – 1)\cdot 10^4\ m^3/day/10\ km^2$
Hydrodynamics:	0.0043 - 0.042	$K=10^{-17} - 10^{-16}$ D (0.001 - 0.01 mD)
Diffusion trough water:	0.000003	
Diffusion through dense gas:	0.0005	

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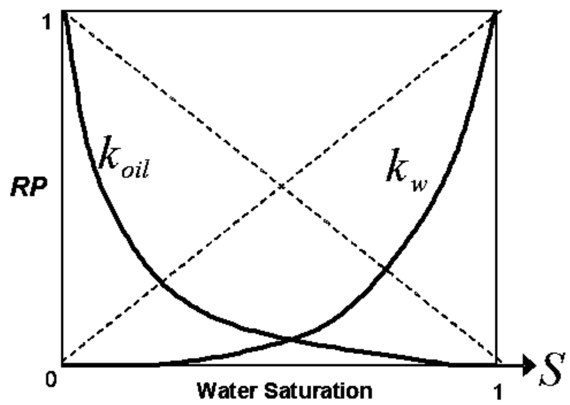
Buckley-Leverett model for 2 phase flow in homogeneous medium

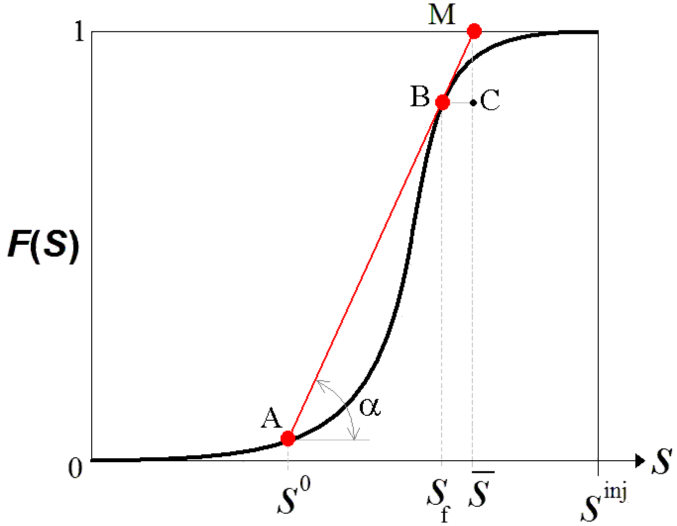


$$\frac{\partial s}{\partial t} + UF'(s)\frac{\partial s}{\partial x} = 0\,, \quad U\varphi = V_1 + V_2$$ total flow velocity

$$S\big|_{t=0} = S^0, \qquad S\big|_{x=0} = S^{\text{inj}}$$

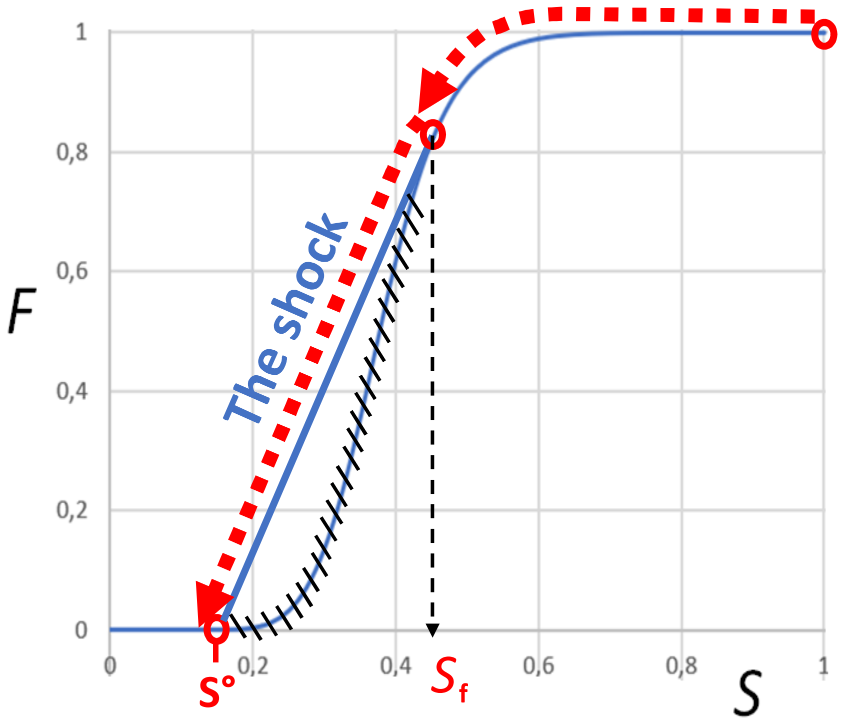
$$\vec{V}_i = \frac{K \cdot k_i(s)}{\mu_i} grad(P_i + \rho_i g z) \quad i = 1{,}2$$

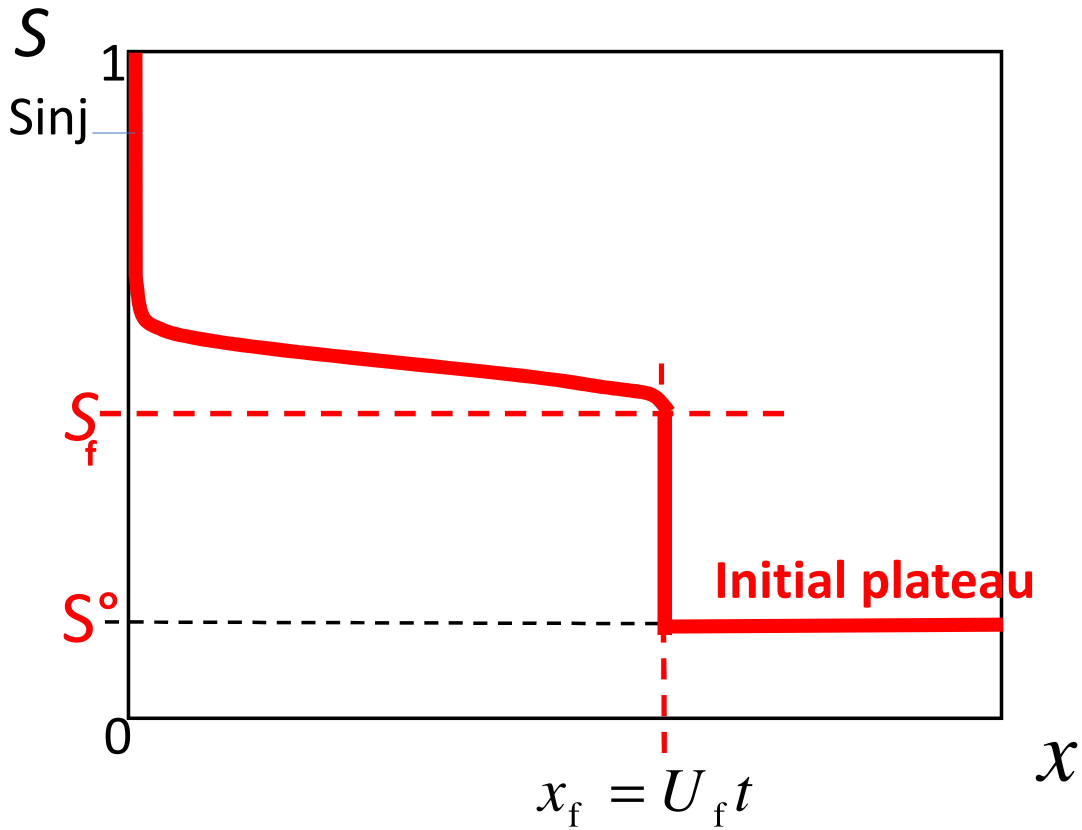
$$F(s) \equiv \frac{V_1}{V_1 + V_2} = \frac{k_1(s)}{k_1(s) + k_2(s)\bar{\mu}}$$ fractional flow, $\bar{\mu} \equiv \dfrac{\mu_1}{\mu_2}$



The solutions are totally determined by the function *F*(*s*)

Construction of analytical solution

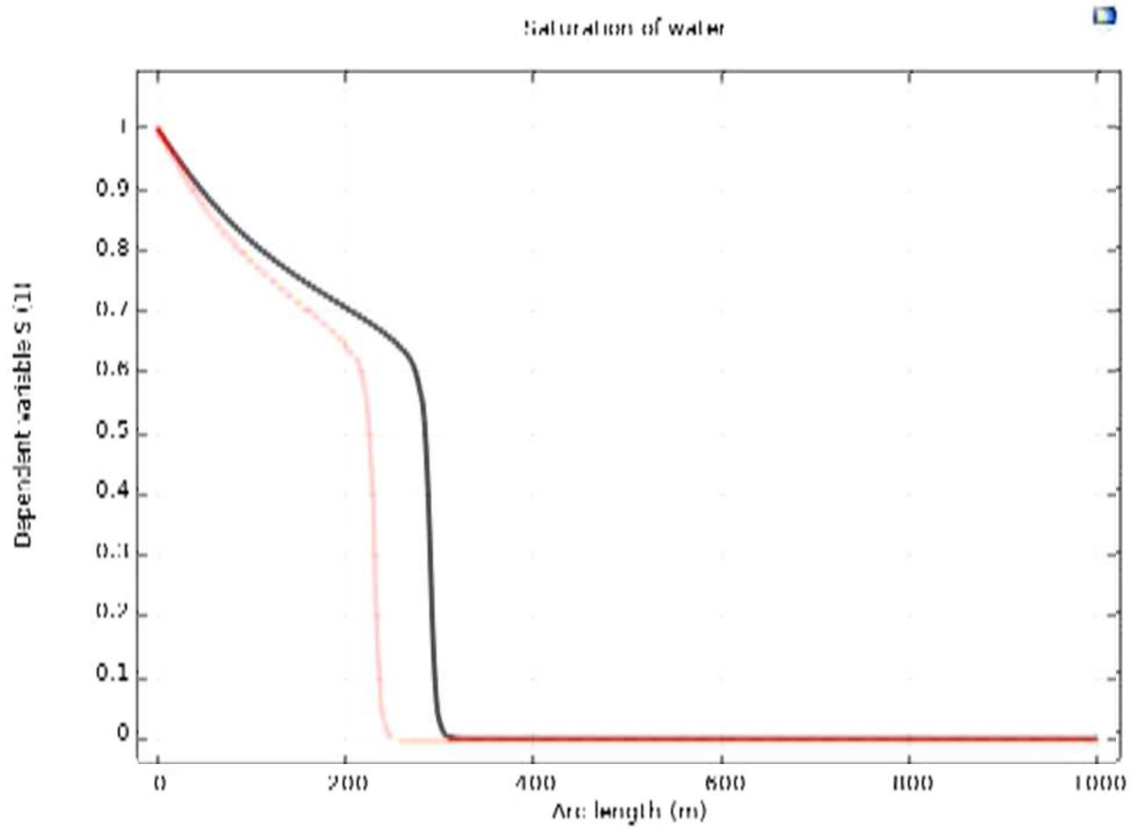




The implicit equation which determines the saturation S(x,t) :

$$x = U \cdot F'(s) \cdot t + x0$$

Buckley-Leverett model for homogeneous medium



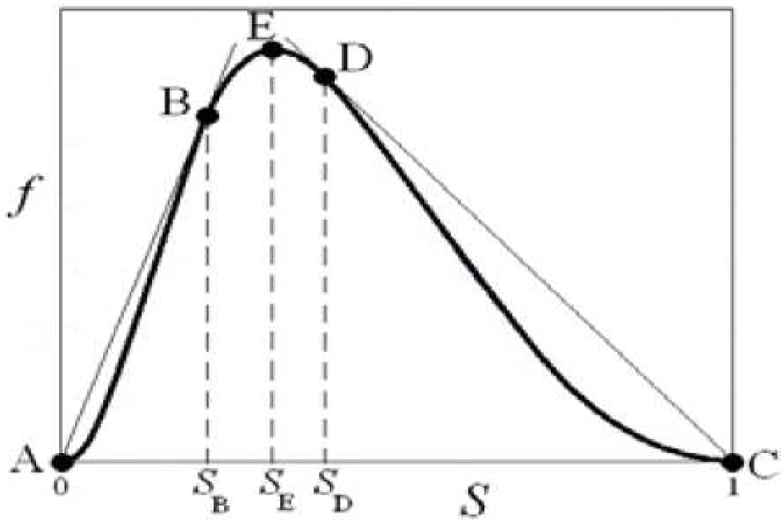
Demonstration of numerical simulation

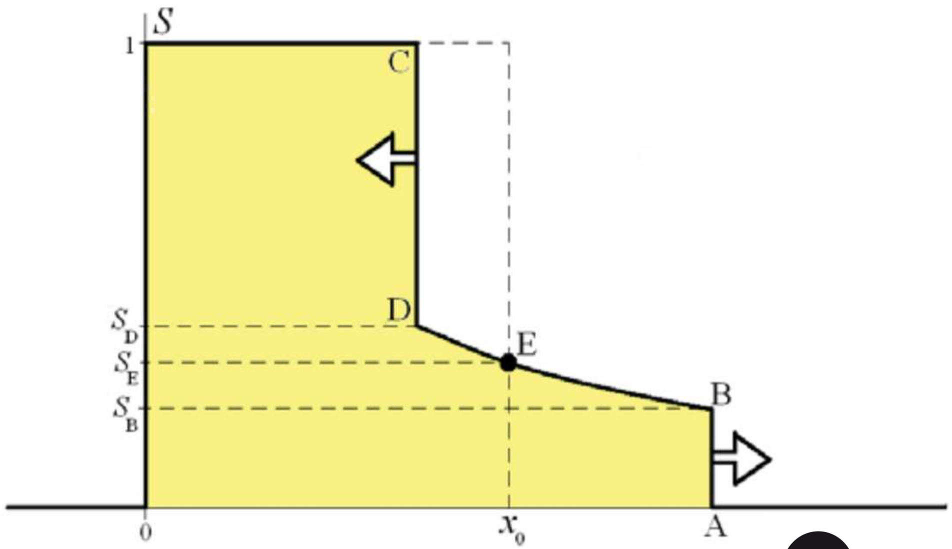
Buckley-Leverett model of segregation

$$\frac{\partial s}{\partial t} + \beta \frac{\partial f(s)}{\partial x} = 0, \qquad U = 0$$

$$f(s) \equiv F(s) k_g(s)$$

$$\beta \equiv \frac{gK(\rho_w - \rho_g) \sin \alpha}{\mu_g}$$





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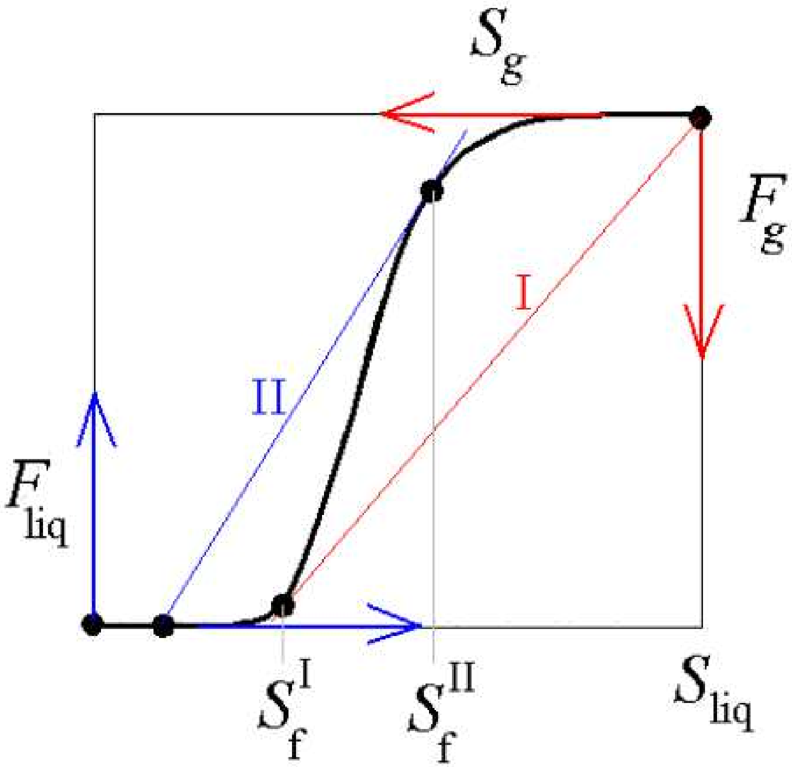
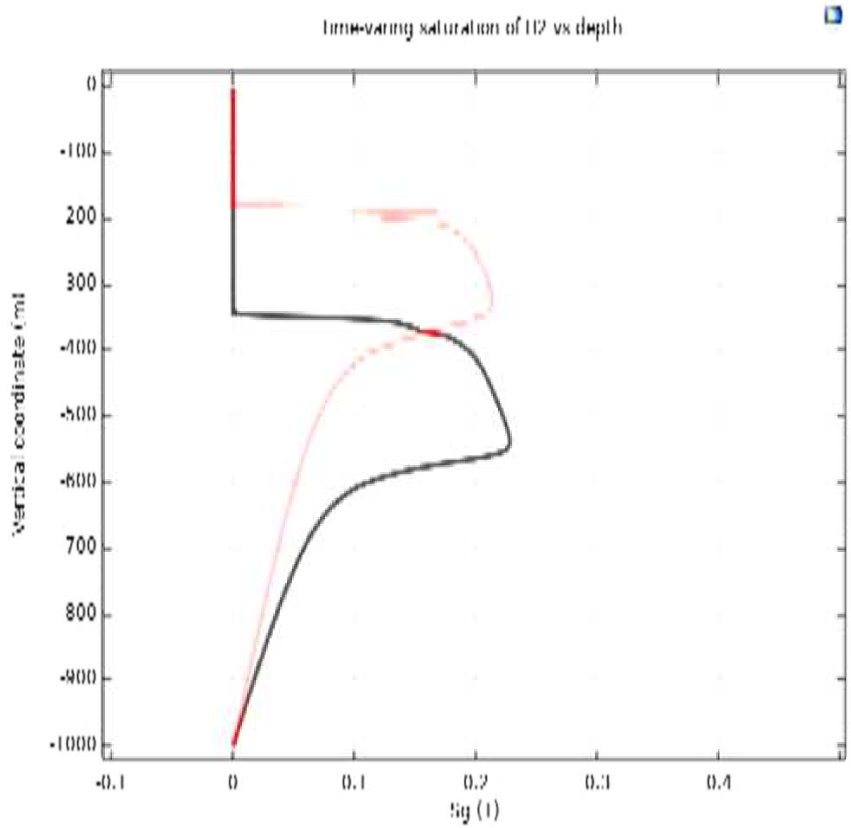
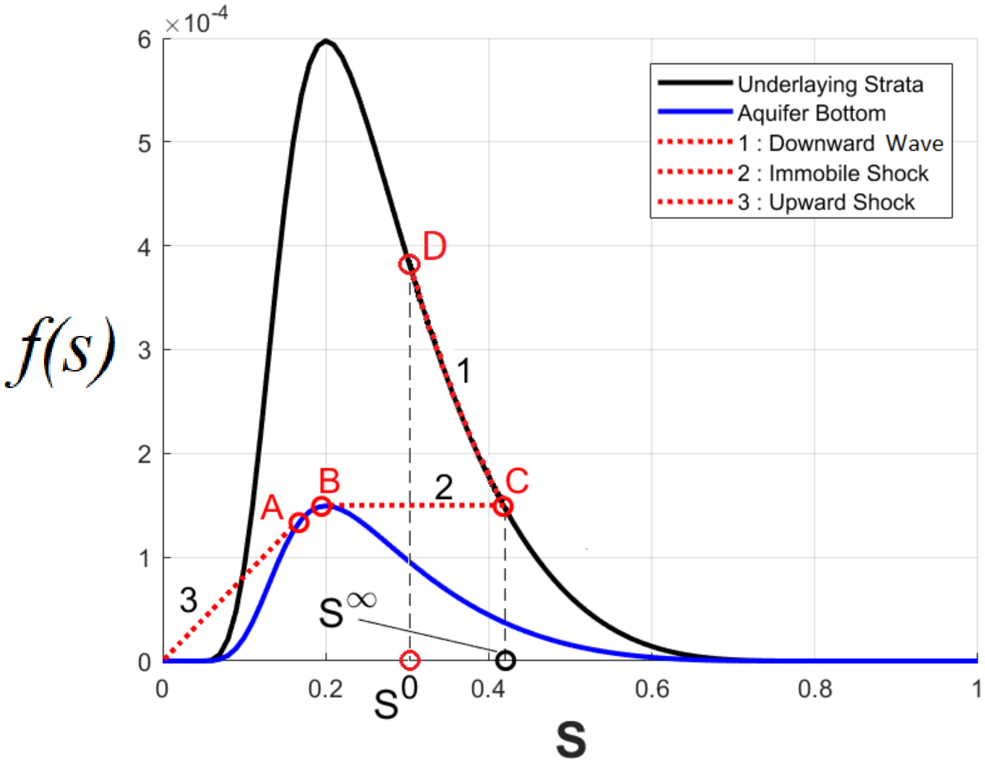
Model of rising of finite volume of gas





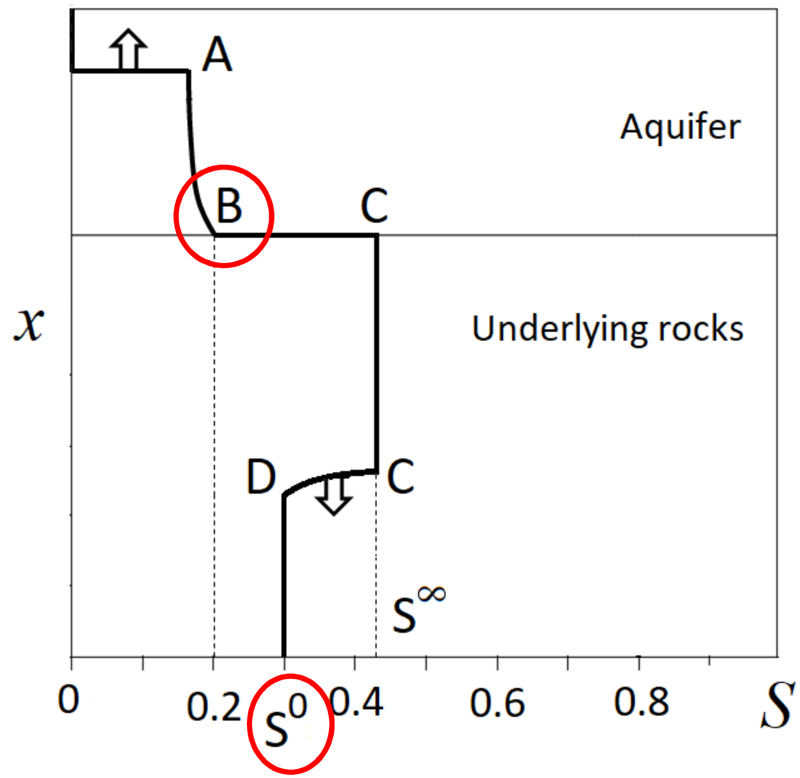
Panfilov M. Physico-chemical fluid dynamics in porous media.
Wiley-VCH, 2019

Buckley-Leverett model in heterogeneous medium



H. P. Langtangen, A. Tveito, R. Winther, Instability of Buckley-Leverett flow in heterogeneous media, 9, 165-185, 1992.

$K_{aq} < K_{un}$



S = gas saturation

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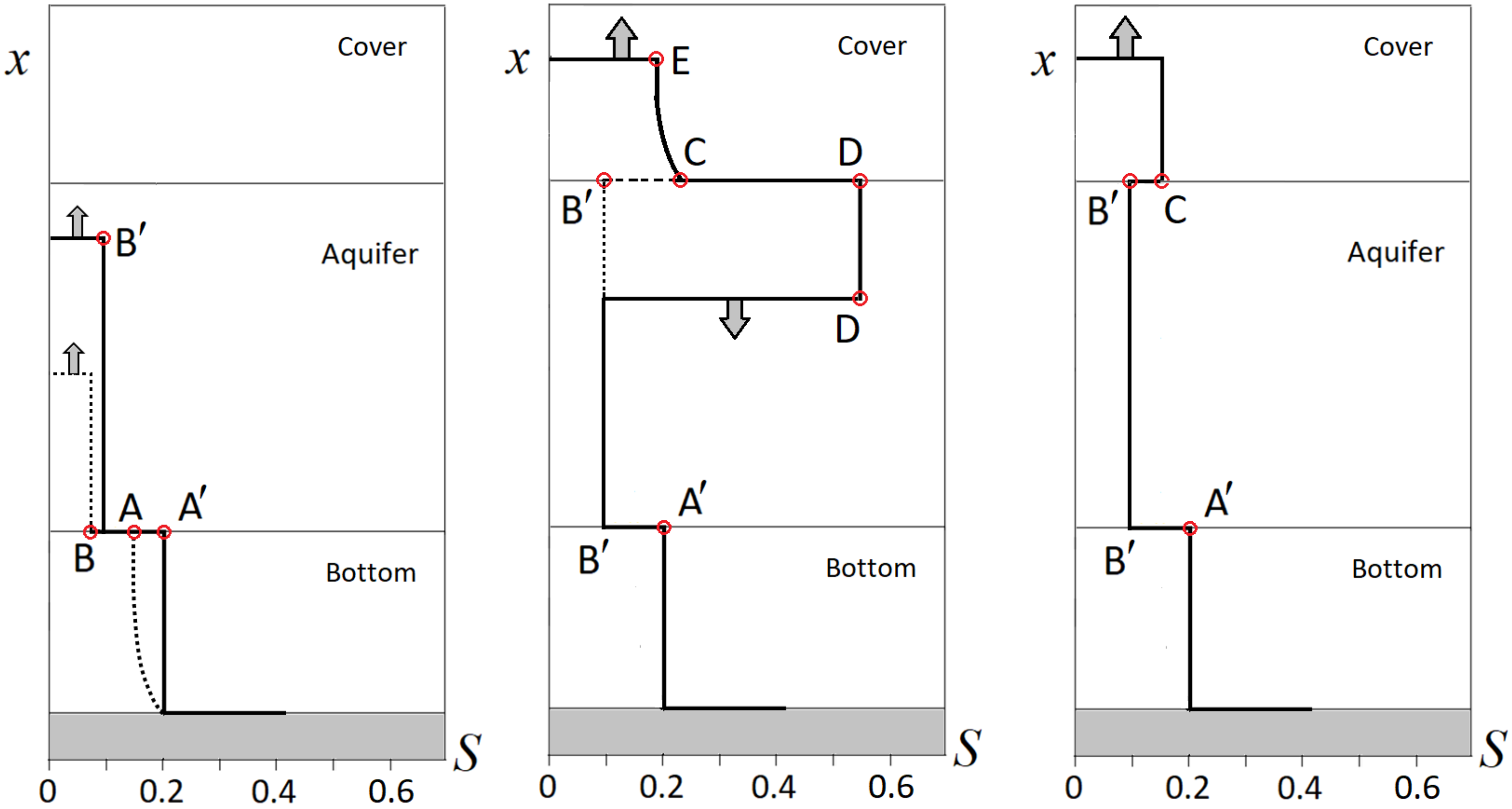
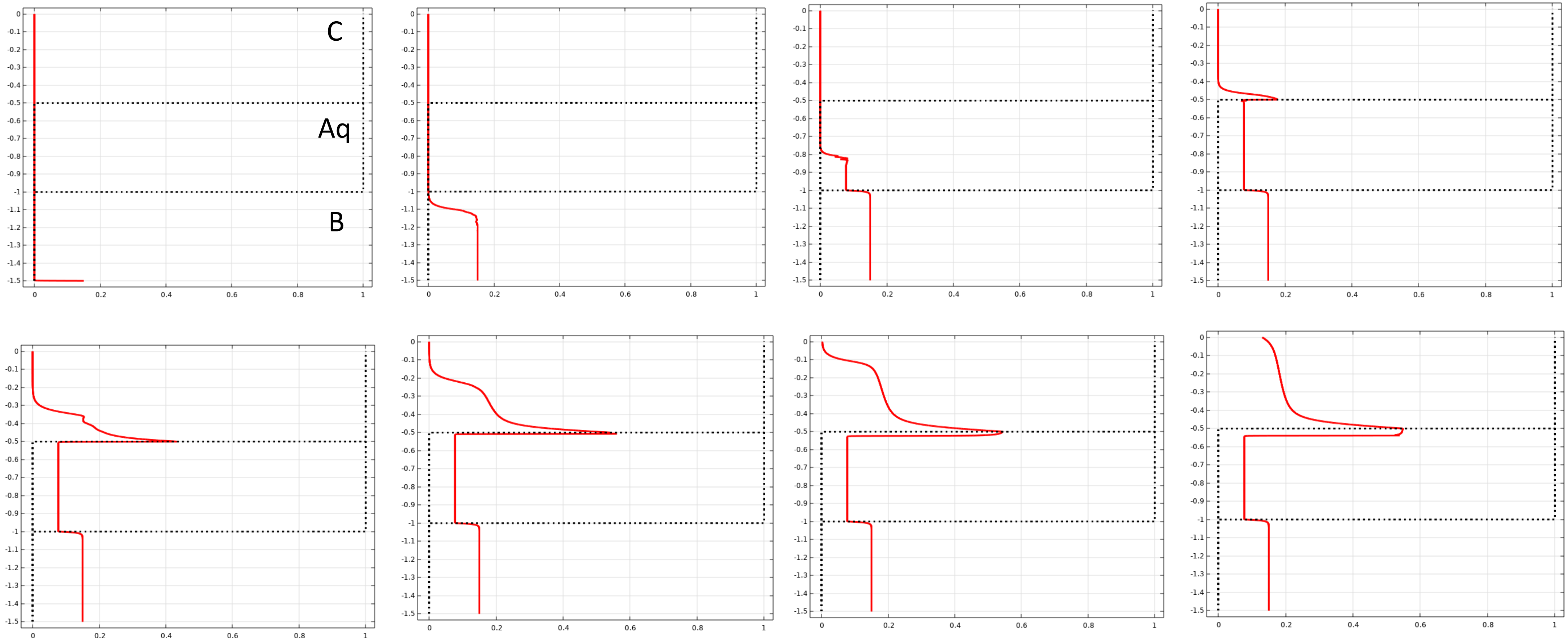
Hydrodynamic scenarios of hydrogen upflow



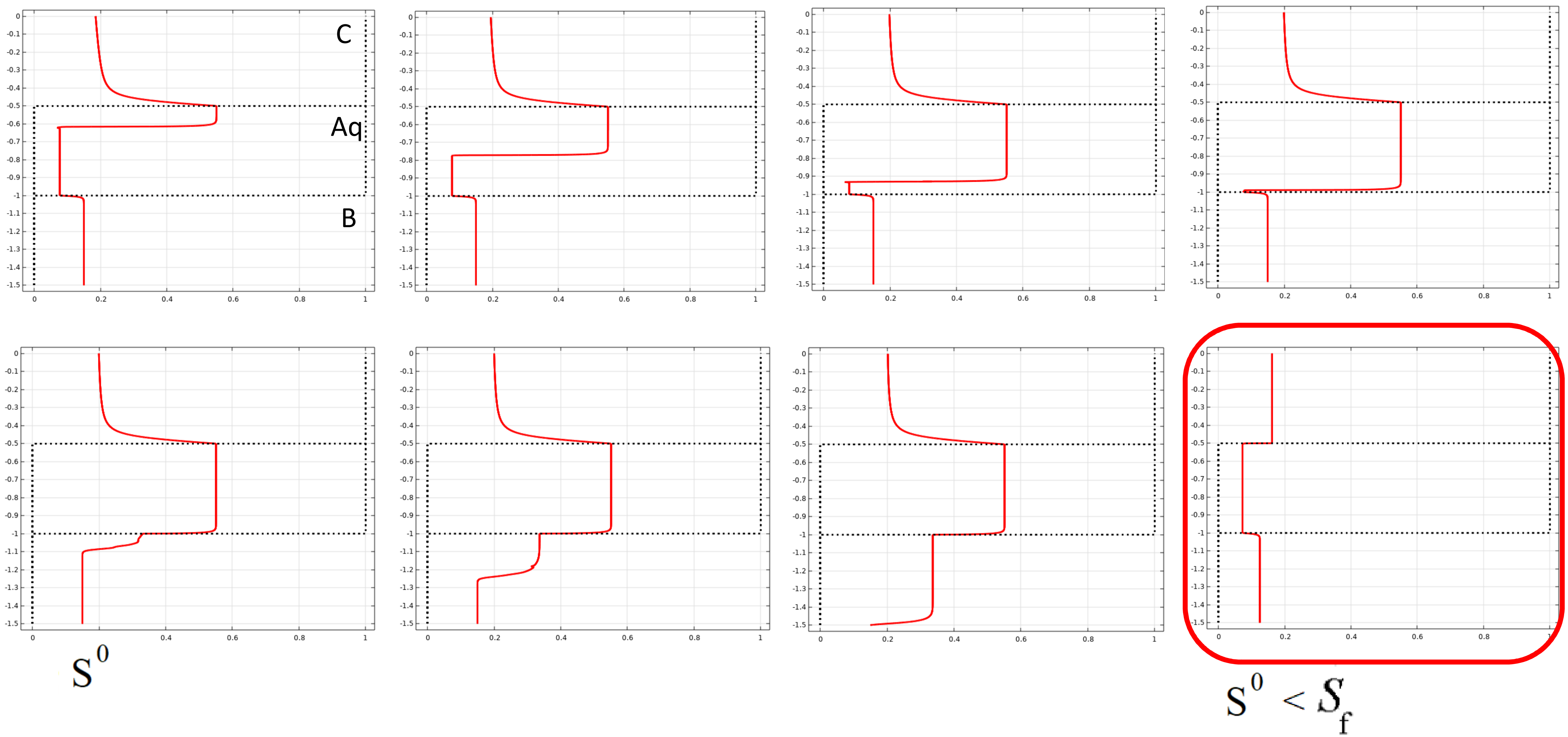
$$K_{Cover} < K_{Bot} < K_{Aq}$$

Demonstration of numerical simulation

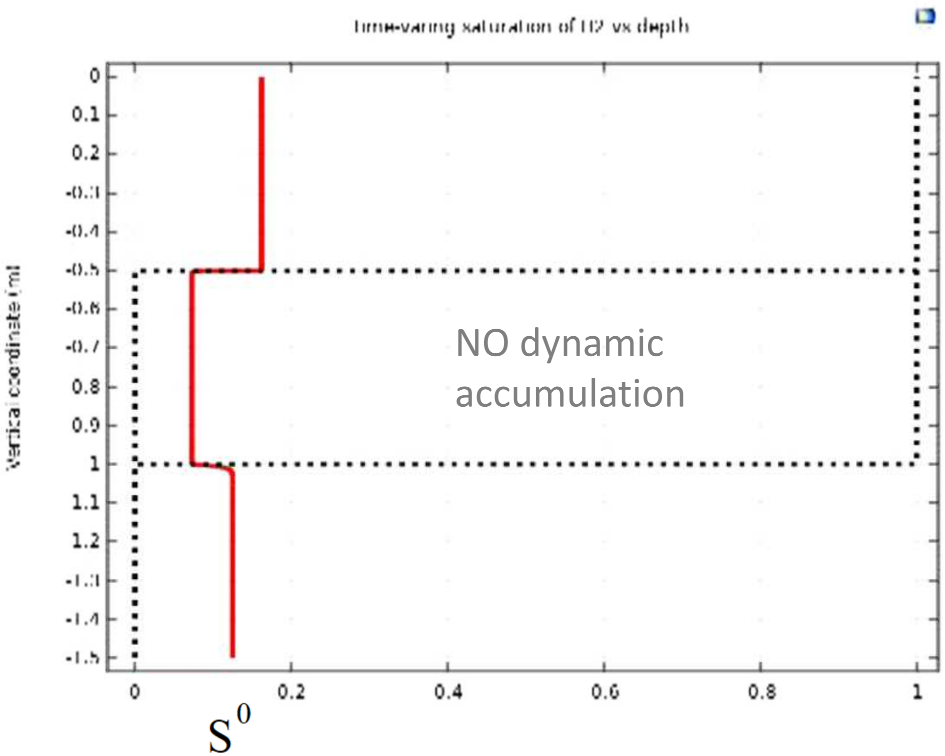


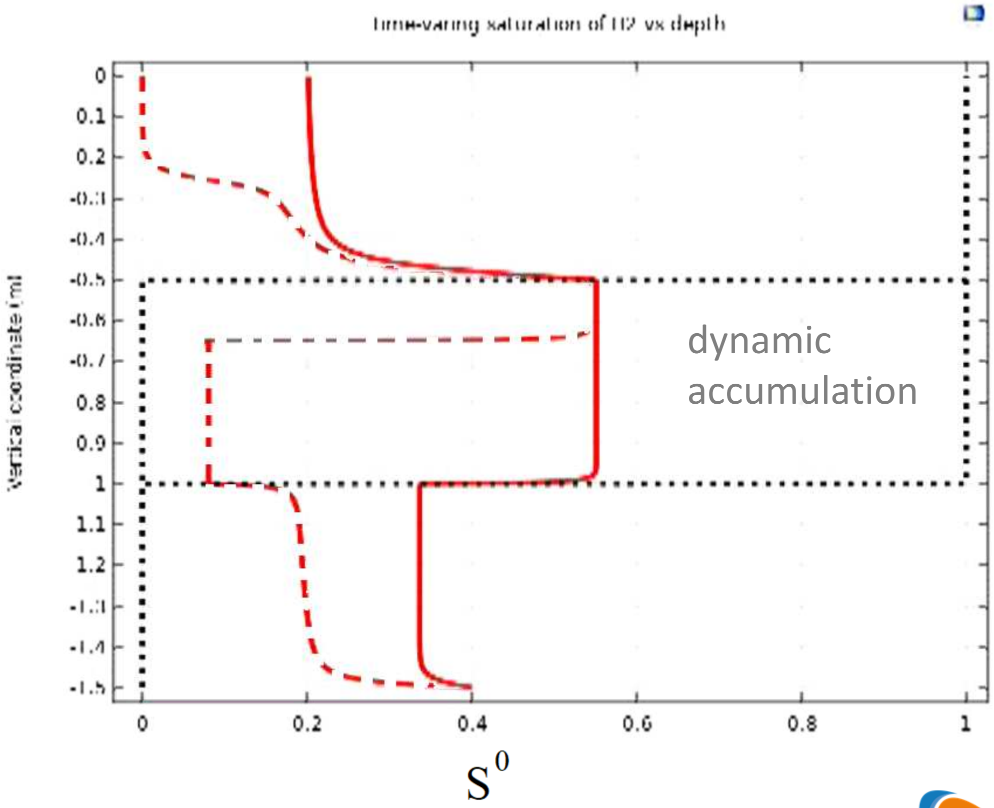
S^0

Demonstration of numerical simulation

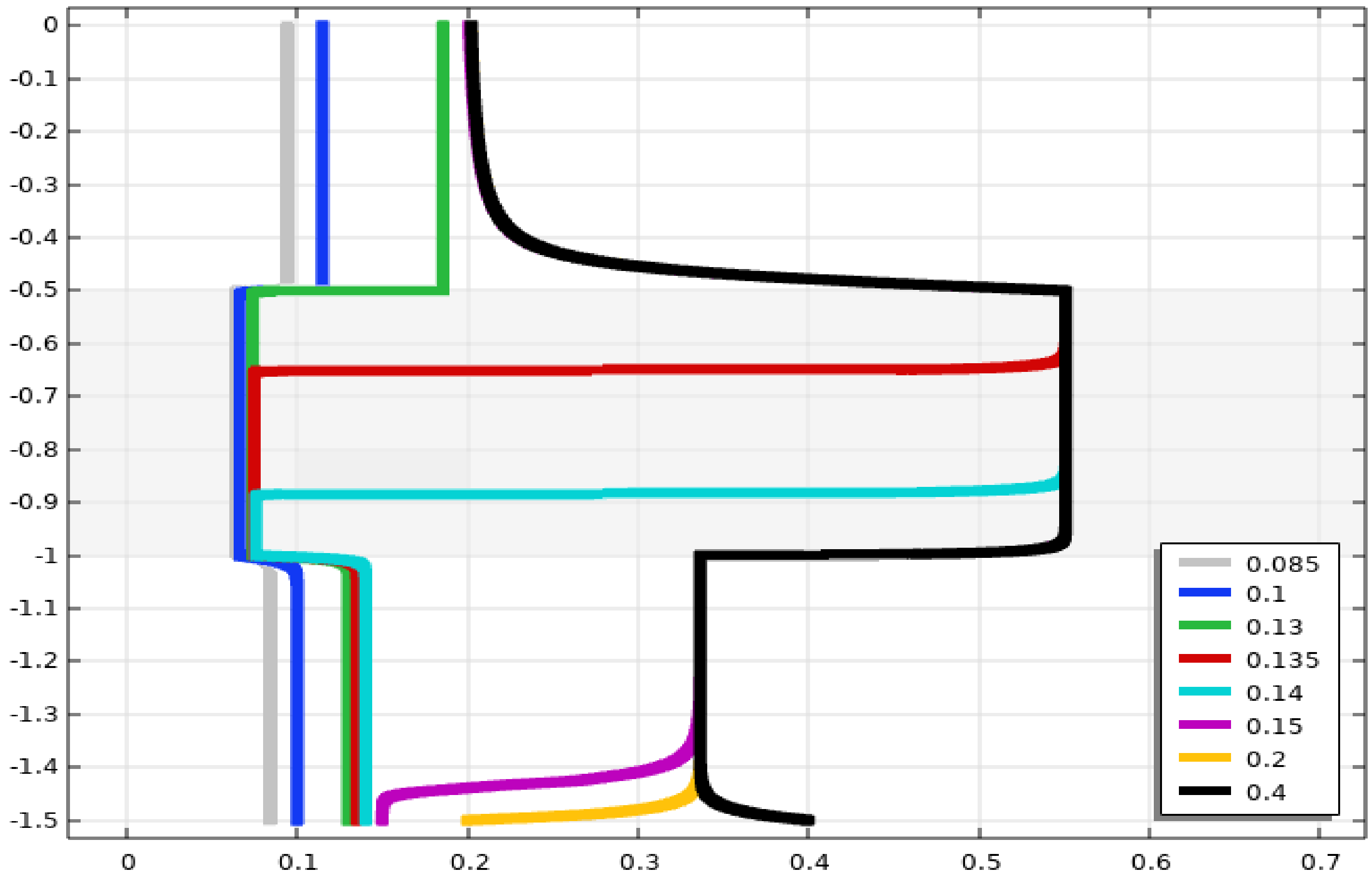


Stabilisation in time of H2 saturation for 2 cases of S°





Variation of initial saturation of H2



Conclusions

We have shown that the formation of hydrogen accumulation is possible, it occurs inside the aquifer during the phase of the return movement of the hydrogen wave reflected from the low permeable covering layer.

We have shown that hydrogen accumulations may not be formed if its forward flow exceeds the intensity of the backward wave.
We have found a hydrodynamic criterion for the formation of hydrogen deposits.

We have shown that at long times the solution of this system under the aquifer does not depend on the initial conditions and tends to the same state of a two-phase mixture with the same saturation of H_2, the value of which is determined only by the effective permeability of the rocks and the phase permeabilities of hydrogen and water.