A 3D model for chimney formation in sedimentary basins

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Introduction

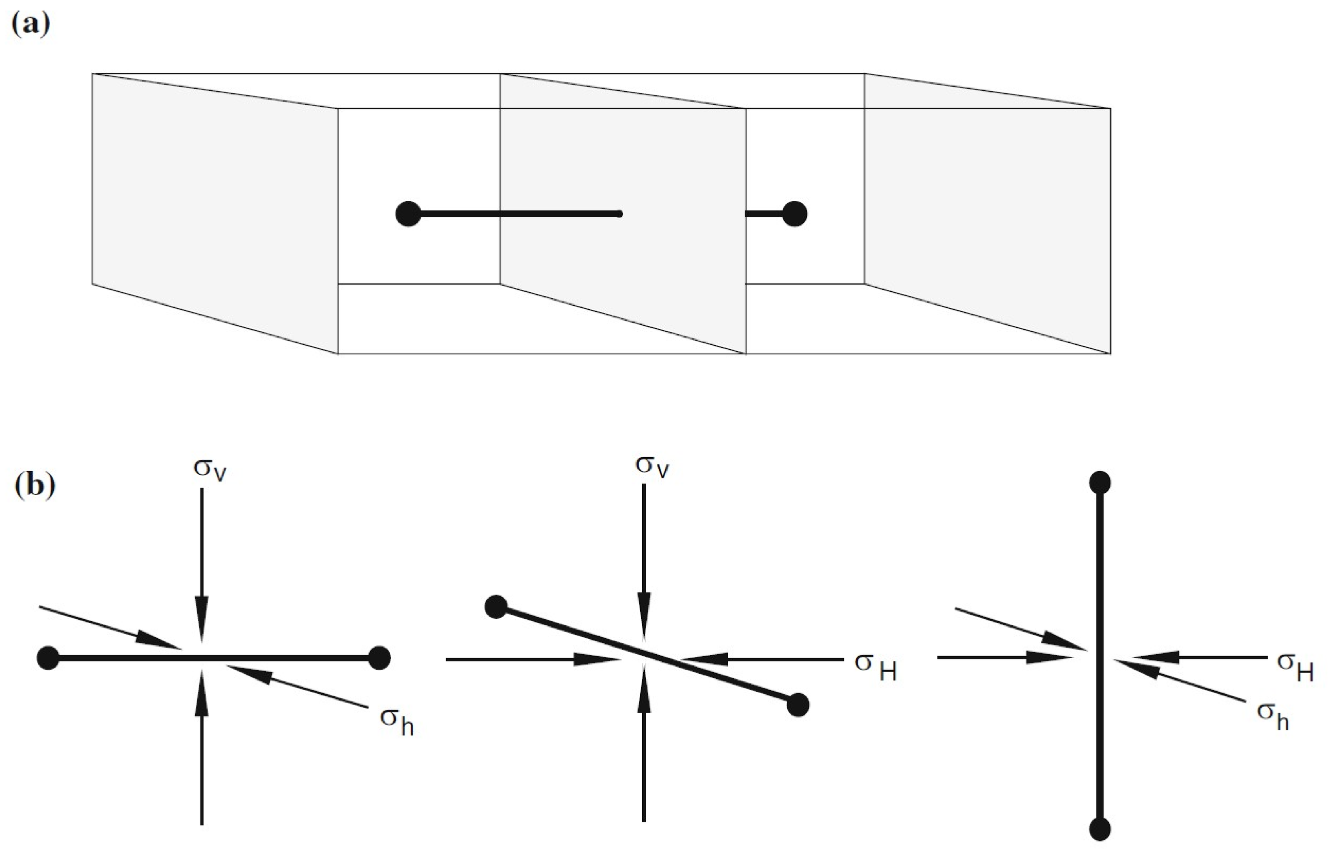
We present a 3D model for chimney formations in tight rocks in sedimentary basins. This is an adaption of a model for hydraulic fracturing in an anisotropic stress field by fluid injection (fracking). The model assumes that a chimney formation is triggered and sourced by overpressure build-up in permeable units, such as reservoirs or aquifers.

The model

The model produces pipe-like structures and chimneys as accumulations of branches that reach the surface. The degree of random rock strength controls how pipe-like the chimneys become. Chimney formation stops when the rate of fluid leakage through the chimneys surpasses the production of excess fluid by the overpressure-building process.

The grid

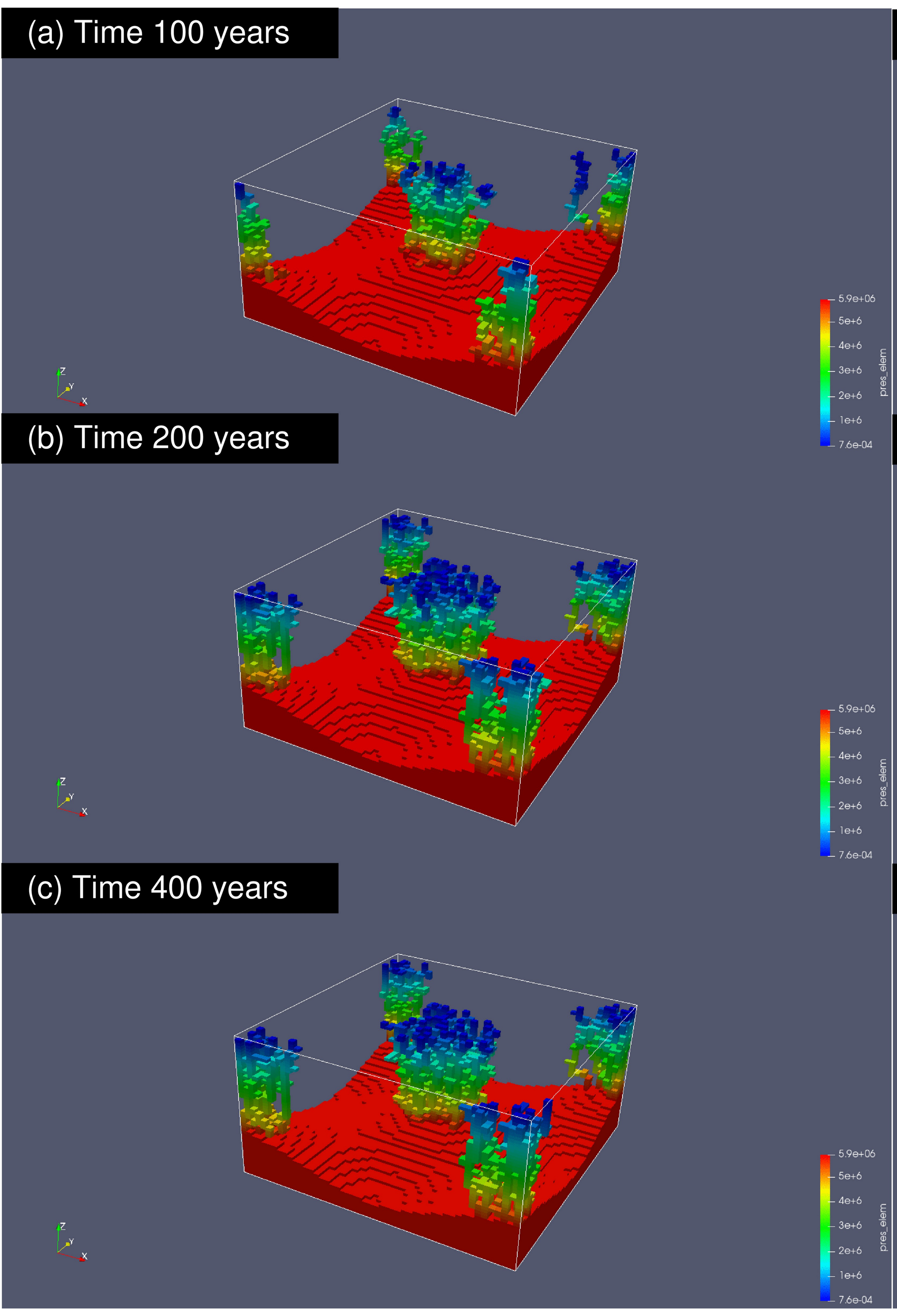
The simulation grid is regular, and all nearest neighbour cells are connected by transmissibilities, also called bonds. The grid is aligned with the anisotropic stress field, where the bonds are orthogonal to two principal stress directions. An intact bond breaks when the fluid pressure exceeds the least compressive stress and a random bond strength.



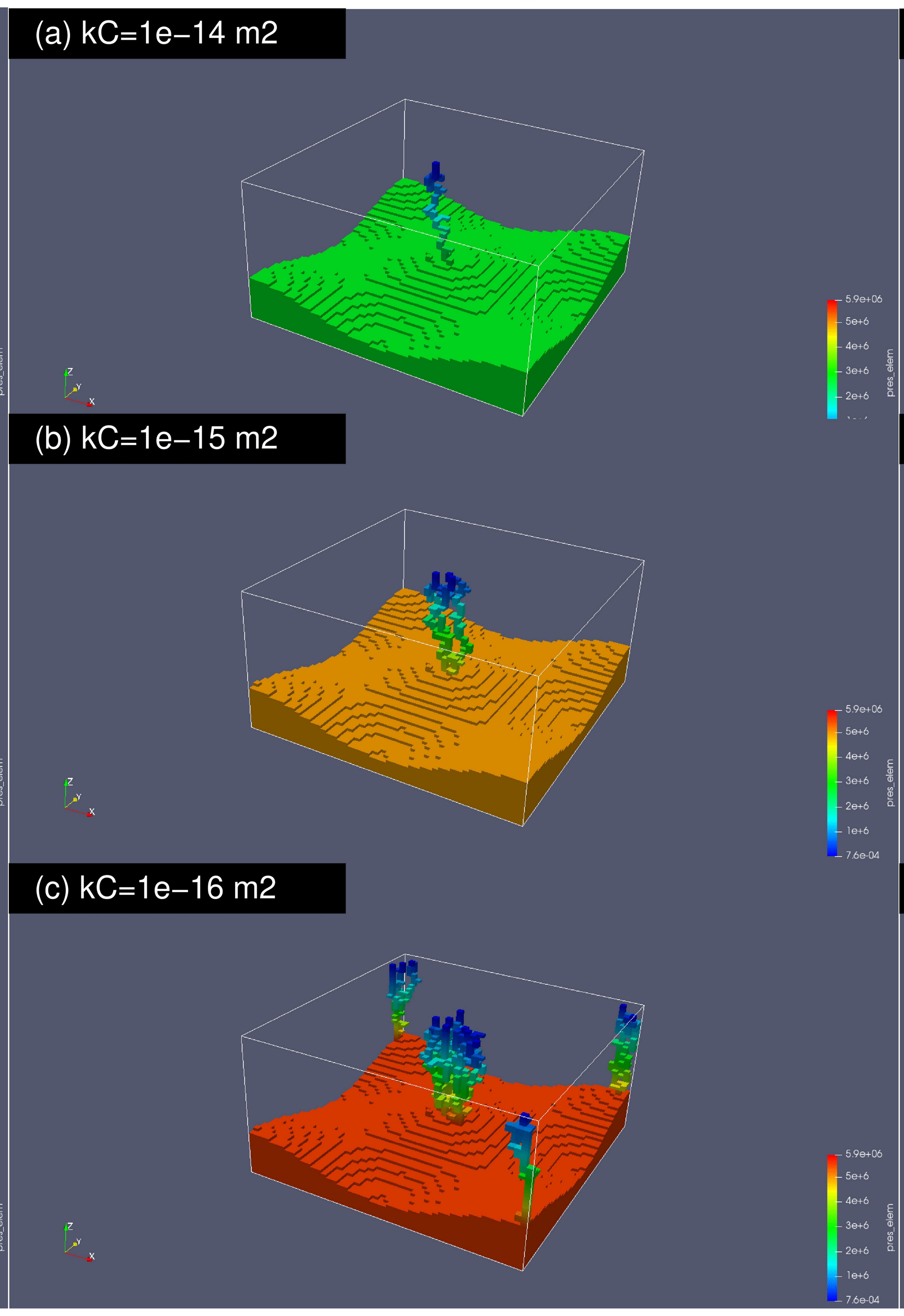
Chimney formation

Chimney formation starts when the overpressure exceeds the least compressive stress and a random rock strength. This model produces chimneys that develop as branches of fractured cells emanating from the base of the cap rock. A chimney accumulates fracture branches, thus growing in width over time. Chimney growth ends when fluid leakage through the fracture branches keeps pace with the production of excess fluid, the process that is responsible for the pressure build-up.

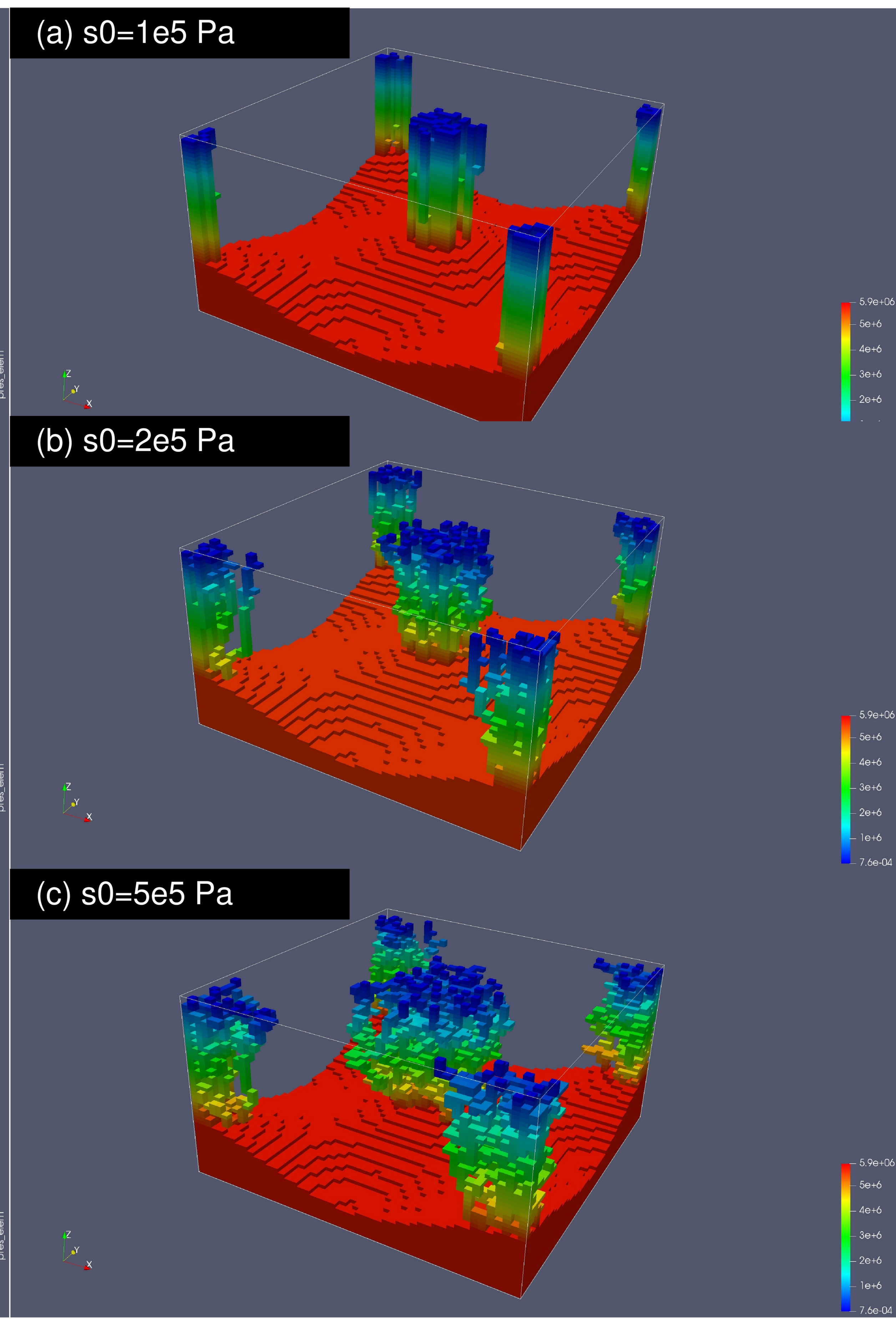
(a) A bond (or a transmissibility) is a hydraulic connection between two nearest neighbour cells. **(b)** The bonds are oriented orthogonally to the directions of the principal stress.



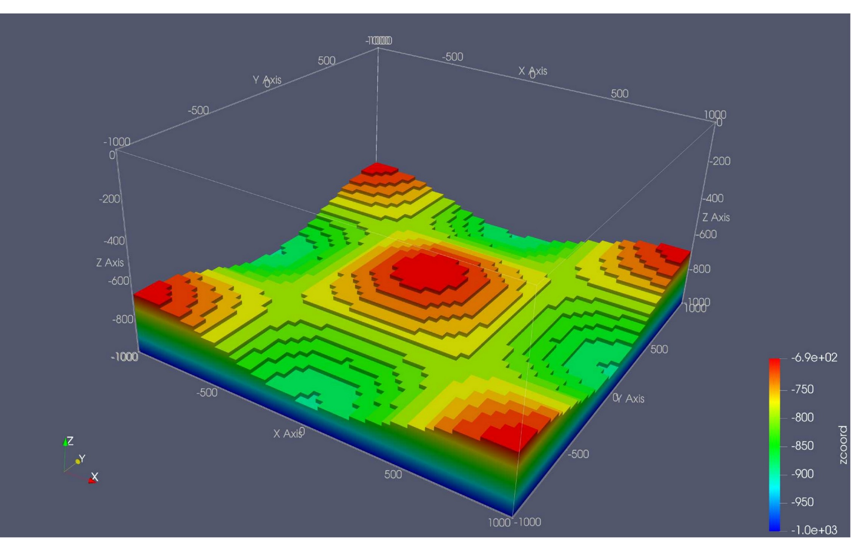
Chimney development through time: (a) at 100 years, (b) at 200 years and (c) at 400 years, where the time span is $t0$ = 400 years. The colours show the overpressure in Pa.



How chimney structures depend on the closed-fracture permeability. (a) kC = 1 · 10−14 m2. (b) kC = 1 · 10−15 m2. (c) kC = 1 · 10−16 m2.



How the chimney branches depend on rock strength: (a) $s0$ = 0.1 MPa, (b) $s0$ = 0.2 MPa and (c) $s0$ = 0.5 MPa.



Parameter	Value	Units
Number of time steps	25	–
Number of nodes x- and y-dir	50	–
Number of nodes z-dir	1	–
Length x- and y-directions (l)	2000	m
Thickness (h)	1000	m
System compressibility (α_D)	4e−10	Pa^{-1}
Viscosity (μ)	0.001	Pa s
Reservoir permeability (k_R)	1e−12	m^2
Open-chimney permeability (k_O)	1e−12	m^2
Closed-chimney permeability (k_C)	1e−17	m^2
Damage porosity (ϕ_D)	0.15	–
Factor f_h	0.7	–
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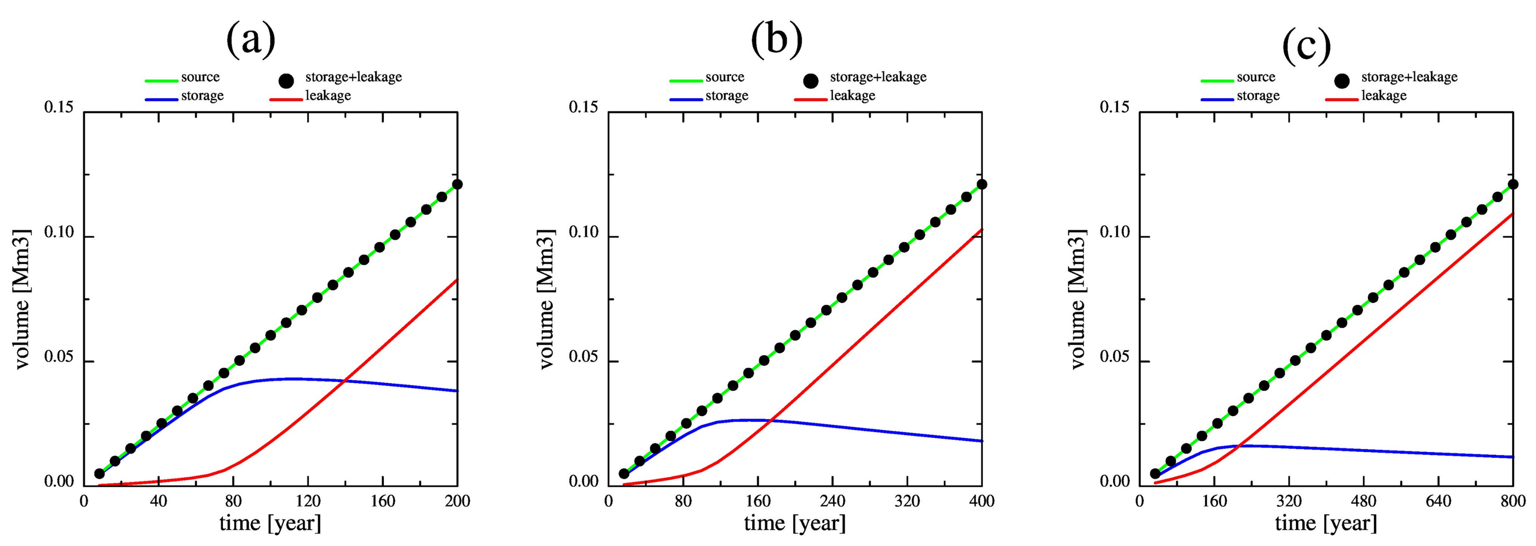
Max bond strength (s_0)	1e+07	Pa

The computational domain: The seafloor is the top of the box. The top reservoir follows a sin-shaped surface that oscillates between 700 m and 900 m depth; the base of the reservoir is at 1000 m.



Volume balance of the reservoir and chimney in the figure to the left over time spans of (a) 200 years, (b) 400 years and (c) 800 years.

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Further reading: **(1)** Wangen, M., A 3D model for chimney formation in sedimentary basins, Computers & Geosciences, vol. 137, 2020, pp 1-10. https://doi.org/10.1016/j.cageo.2020.104429. **(2)** Wangen, M., 2018, 3D model of hydraulic fracturing and microseismicity in anisotropic stress fields, GGGG, https://doi.org/10.1007/s40948-018-0096-4