

Flow Partitioning and Viscosity-Driven Dynamics in a Geothermal Multilayer Aquifer of the North German Basin

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Motivation

Changes in flow partitioning in multilayer aquifers due to temperature-dependent viscosity?

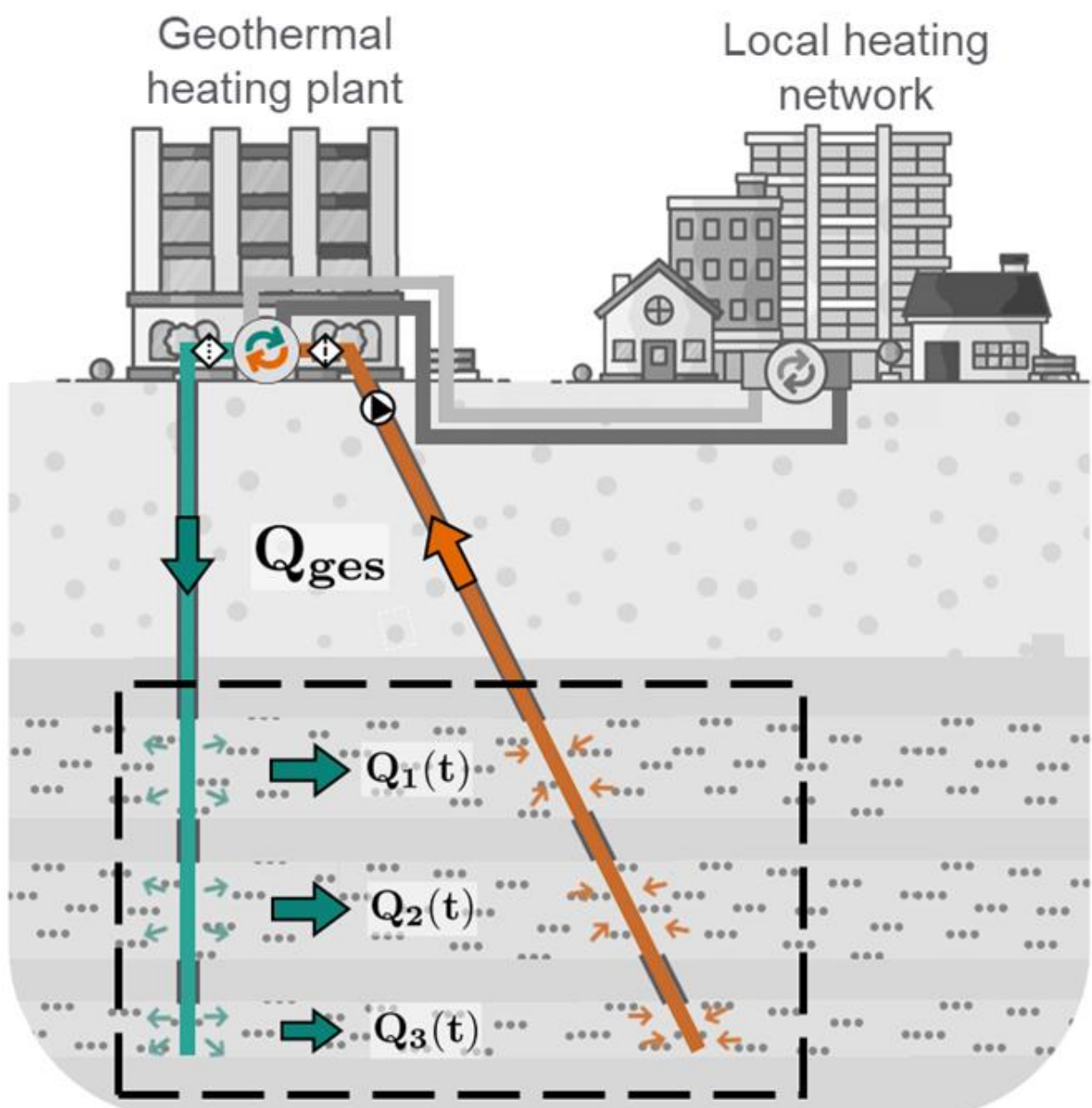


Figure 1. Conceptual sketch of a hydrothermal doublet in a multilayer aquifer.

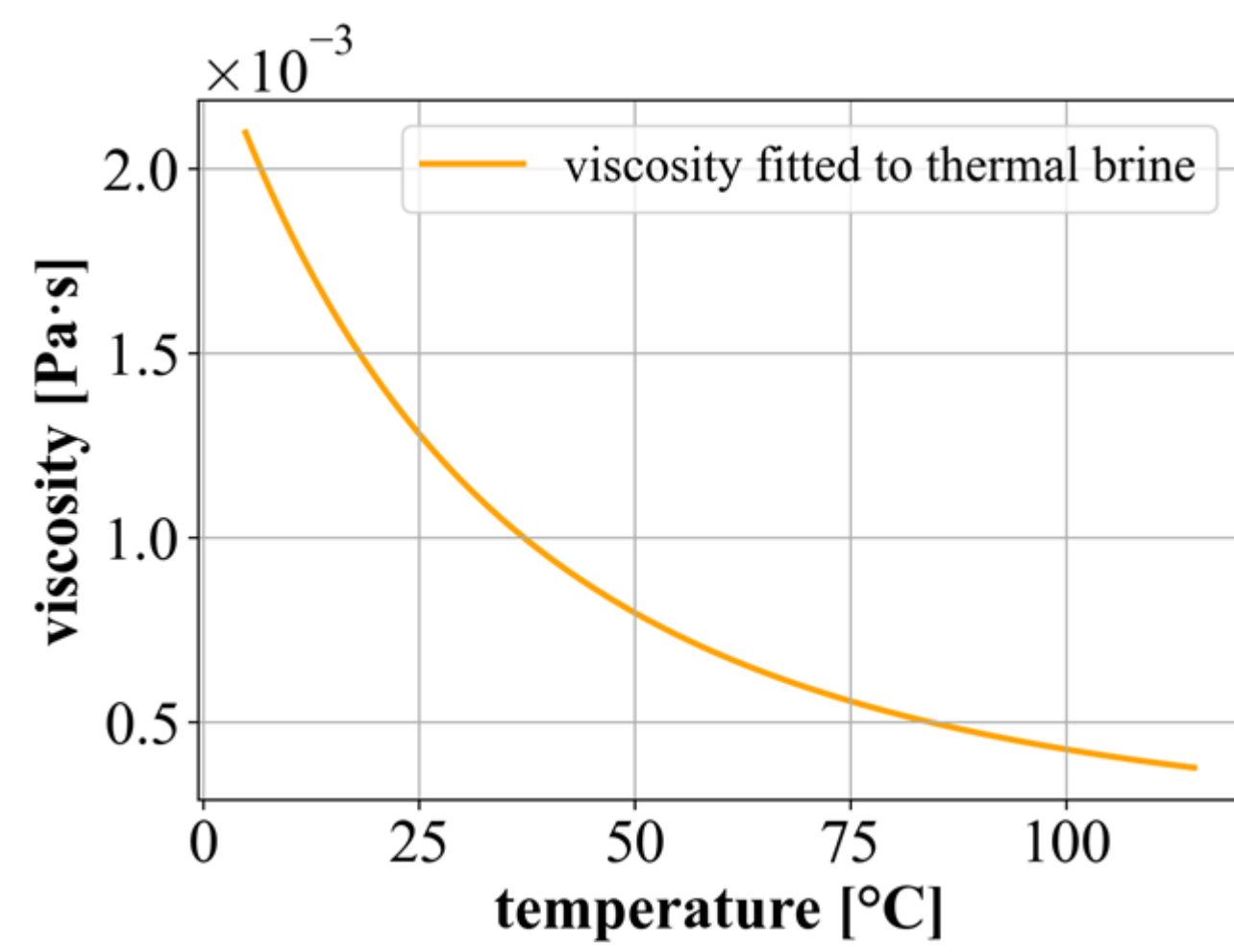


Figure 2. Temperature-dependent viscosity fitted to data for thermal brine (Mao and Duan, 2009).

Methodology

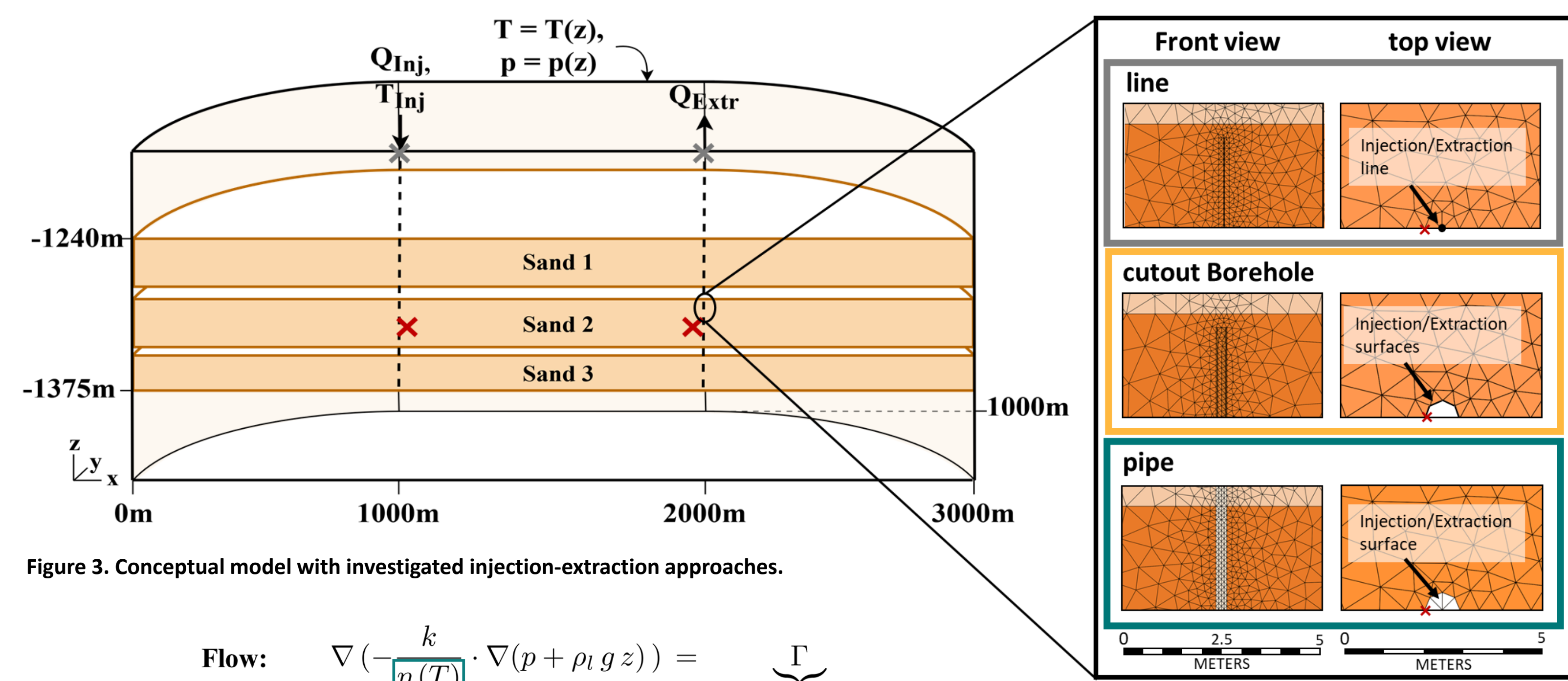


Figure 3. Conceptual model with investigated injection-extraction approaches.

$$\text{Flow: } \nabla \cdot \left(\frac{k}{\eta(T)} \cdot \nabla (p + \rho_l g z) \right) = \Gamma$$

flux divergence source / sink term

$$\text{Heat transport: } \underbrace{(\rho c_p)_{eff} \frac{\partial T}{\partial t}}_{\text{time derivative}} - \underbrace{\nabla \cdot (\lambda_{eff} \nabla T)}_{\text{conduction}} + \underbrace{\rho_l c_{p,l} q \cdot \nabla T}_{\text{advection}} = 0$$

- Numerical simulations were conducted with the open-source software OpenGeoSys (OGS).

Results

Influence of temperature-dependent viscosity

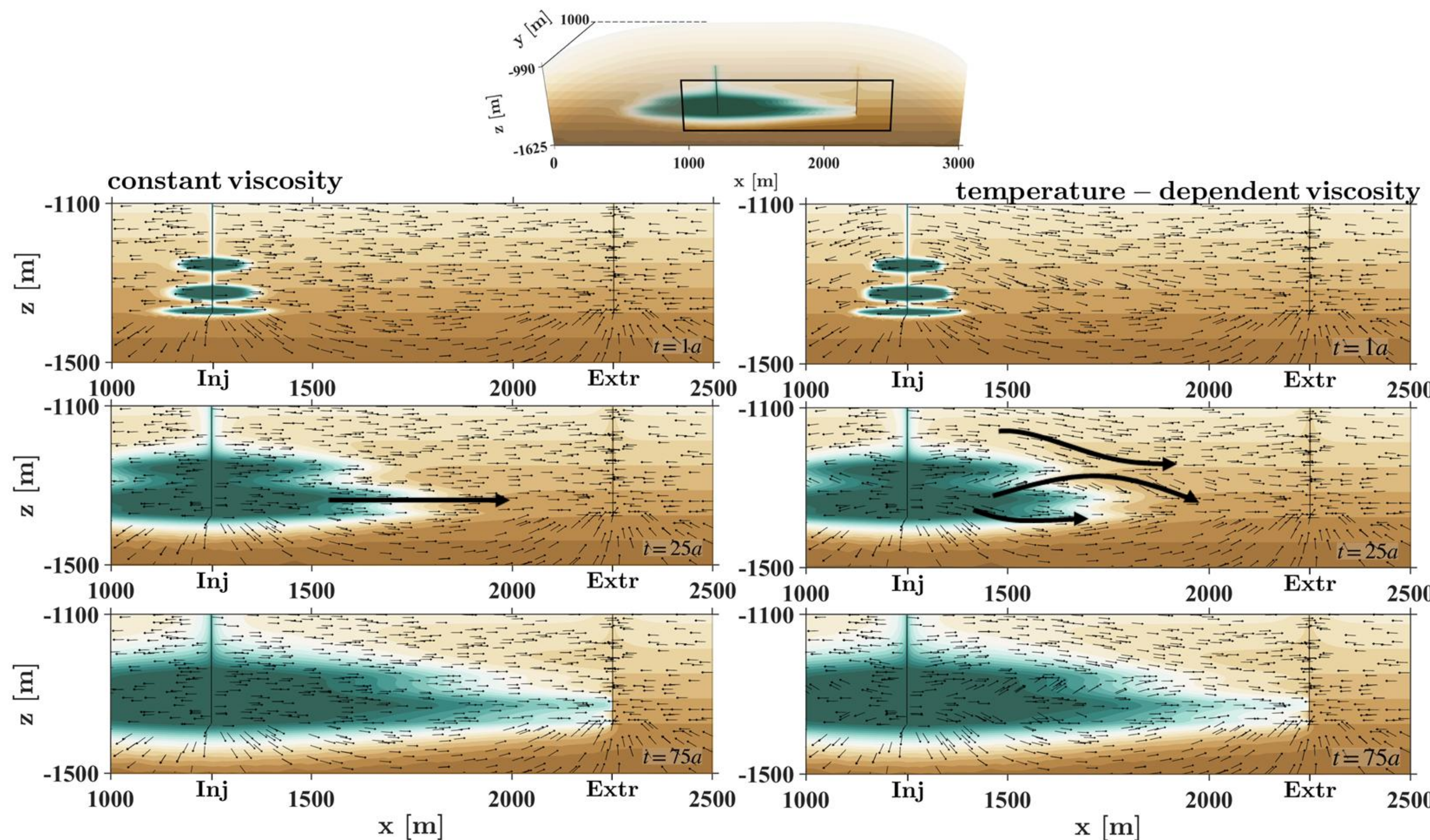


Figure 4. Temporal evolution of the flow field in the pipe model comparing constant and temperature-dependent viscosity, shown for the front view.

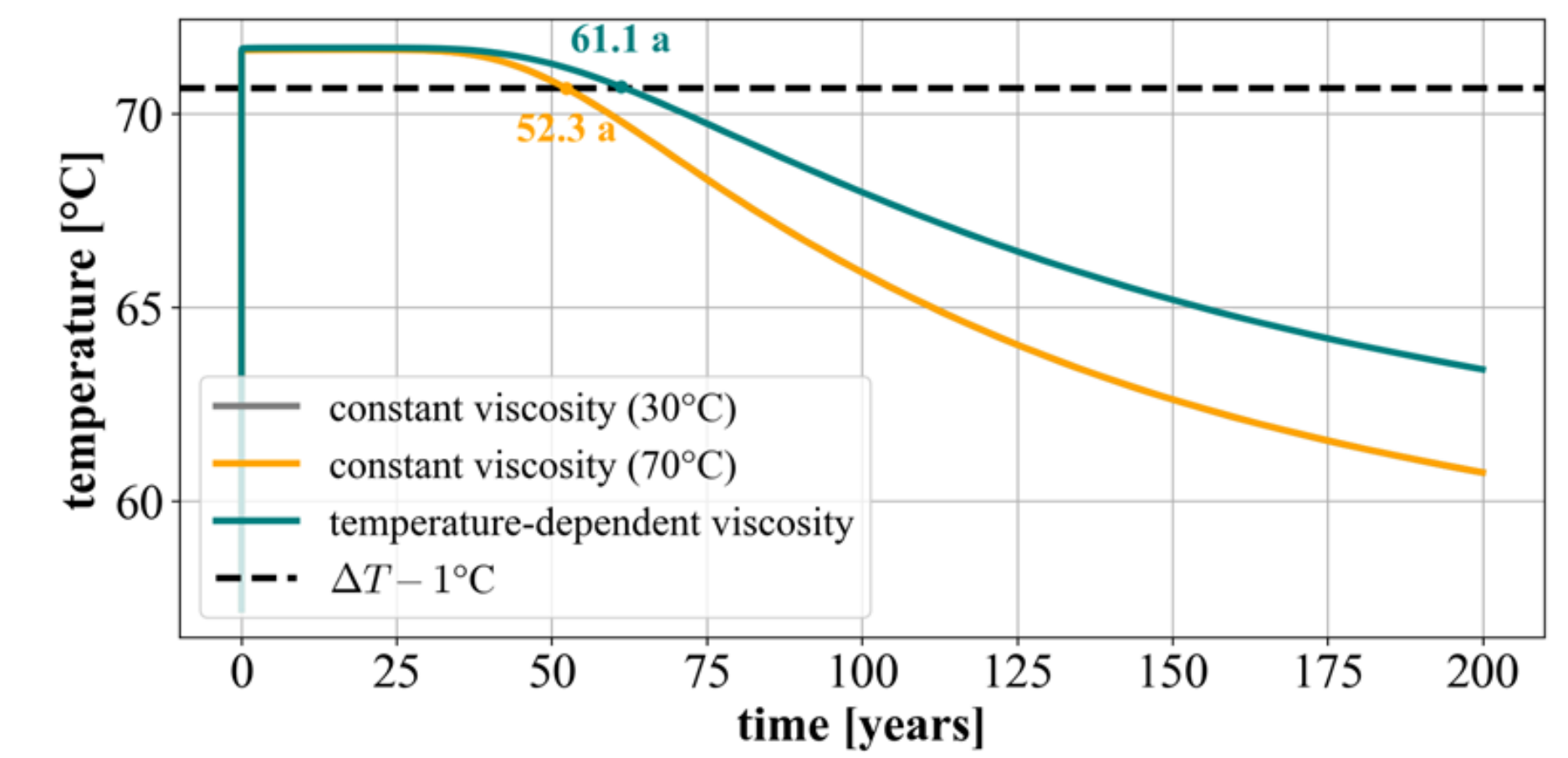


Figure 5. Comparison of production temperature over time in the pipe model using constant and temperature-dependent viscosity.

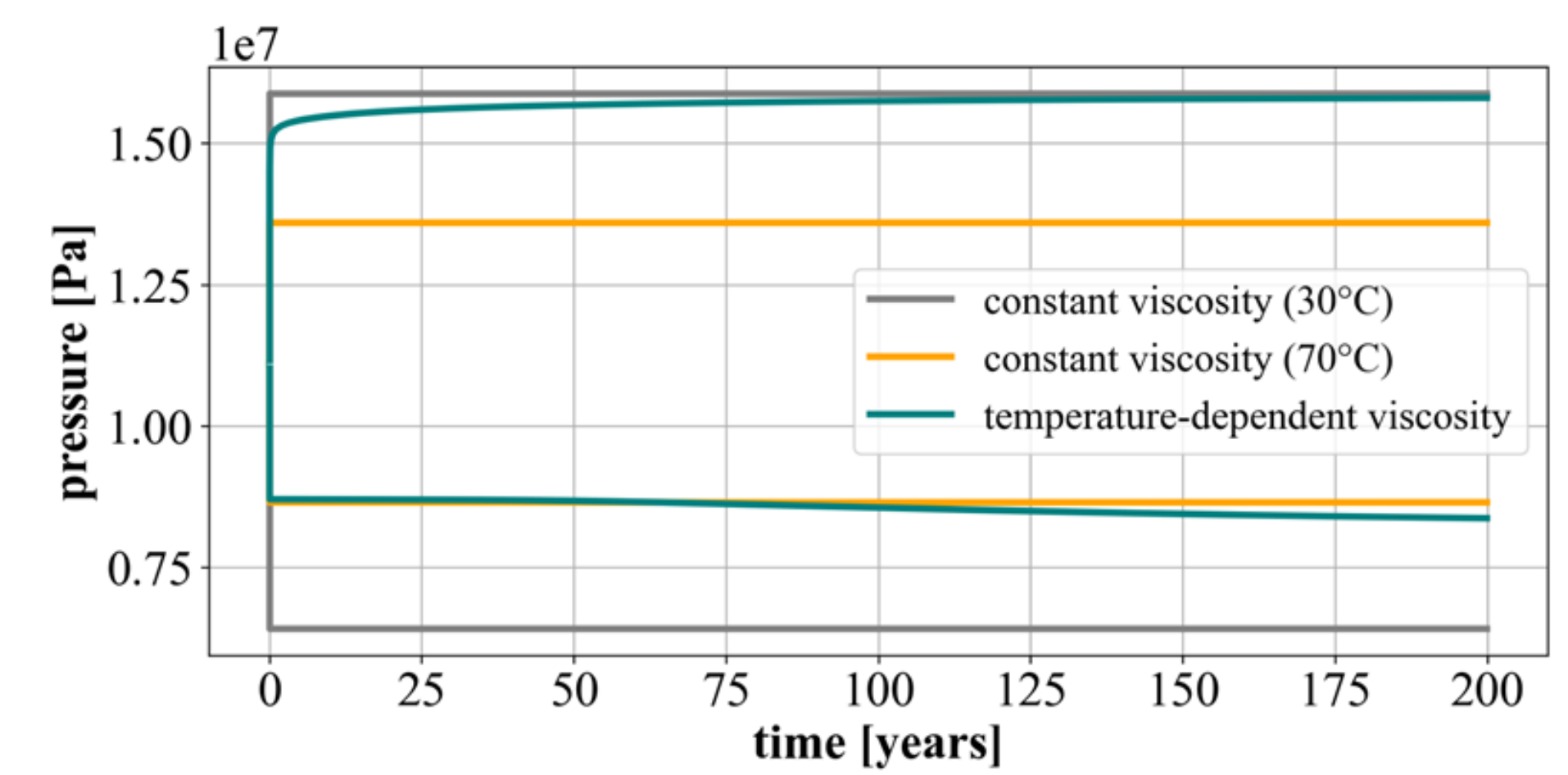


Figure 6. Pressure development over time using constant and temperature-dependent viscosity at position B in the pipe model.

- Assuming constant viscosity leads to a steady flow field and causes thermal breakthrough (-1°C) to be reached approximately 14% earlier than in the case of temperature-dependent viscosity.
- Including temperature-dependent viscosity is essential in hydrothermal doublet simulations to capture reinjection-driven cooling effects and the associated transient flow redistribution.

Comparing injection/extraction approaches

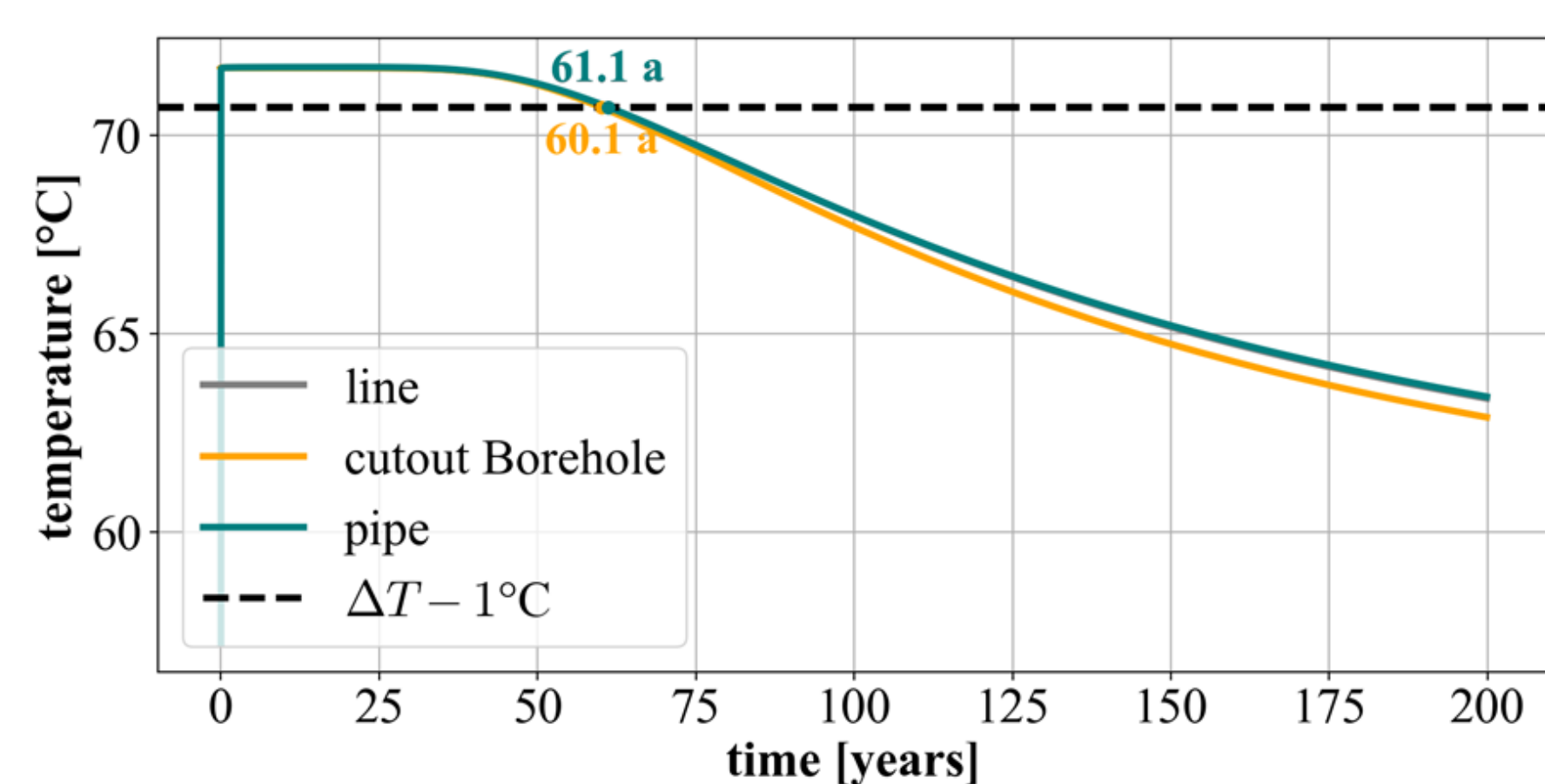


Figure 7. Comparison of production temperature over time across the different modelling approaches.

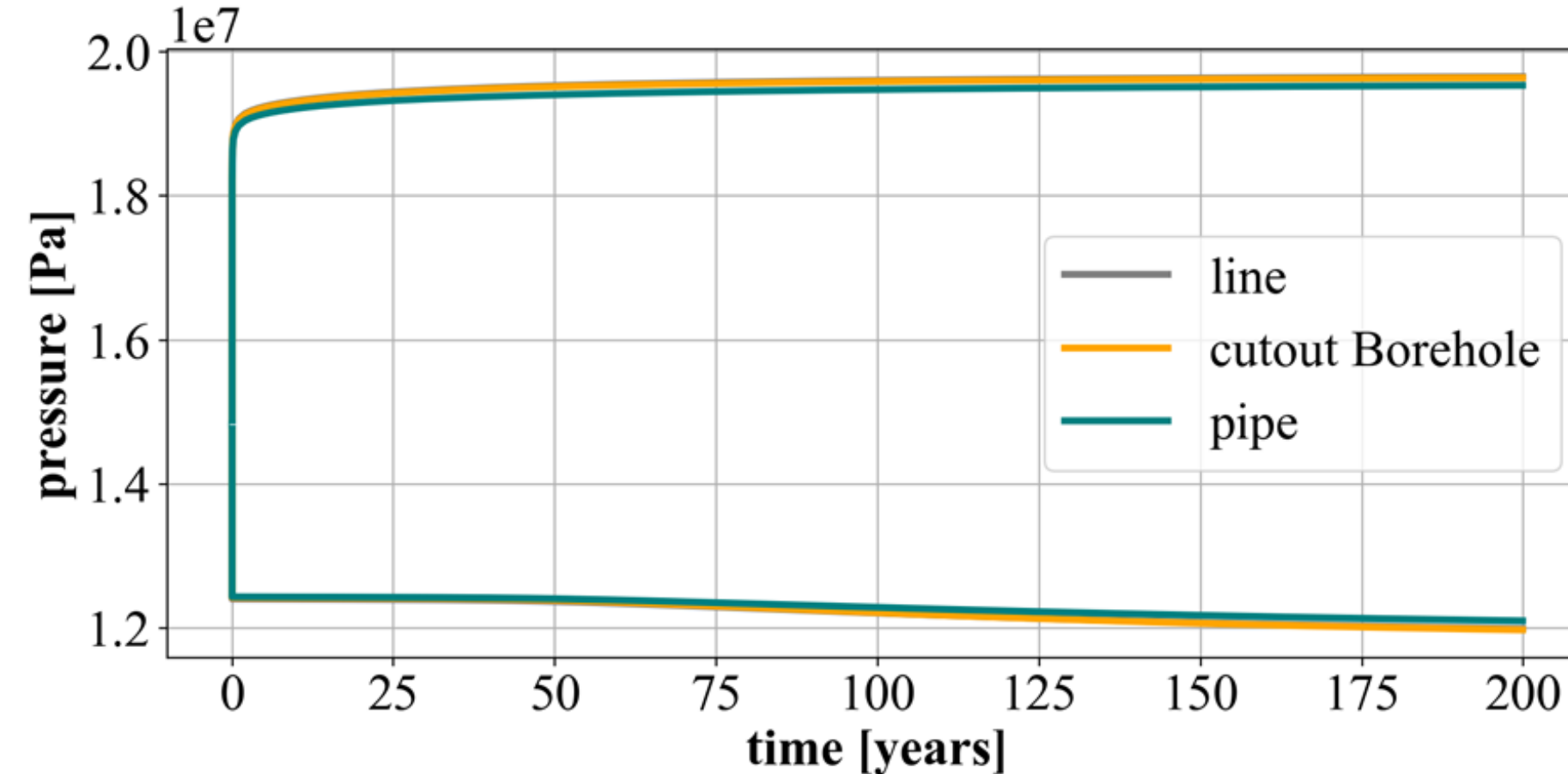


Figure 8. Pressure development over time using different model approaches at position A.

- The partitioned, imposed flow (line, cutout borehole) was distributed according to transmissibility.
- forced-flow partitioning across the homogenous sandstone layers closely reproduces the free-flow case.
- The simulated pressure evolution is similar across the model setups.
- Line and cutout borehole approach offers favorable balance between computational cost and predictive fidelity.

Computational Cost

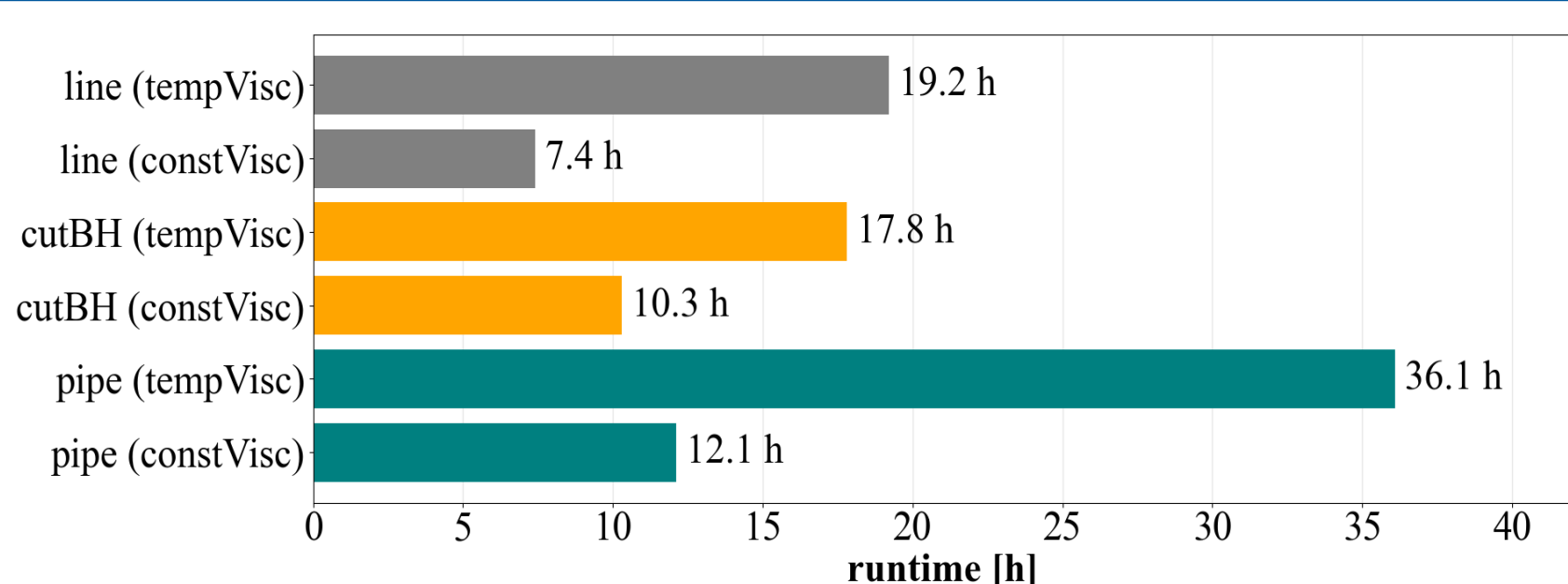


Figure 9. Computational cost of the investigated modelling approaches for a 200-year simulation period.

Future Goals

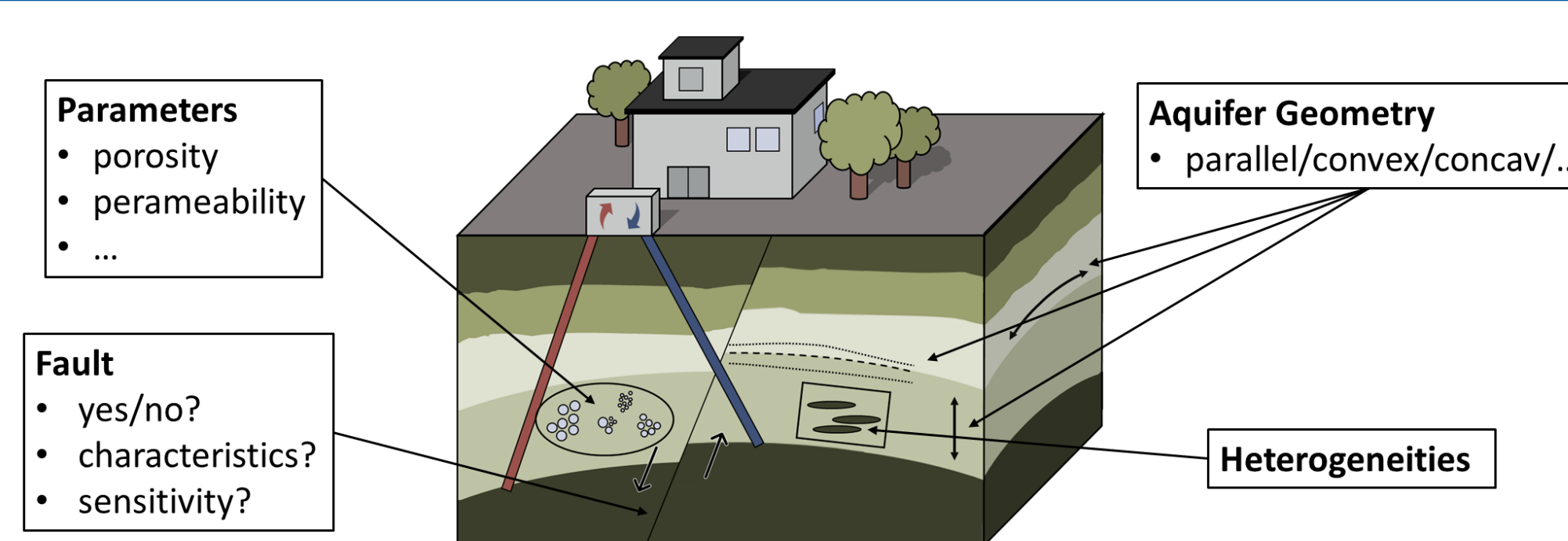


Figure 10. Uncertainty analysis to extend the model towards uncertainty-aware simulations.

References

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