CO_2 Storage in Basalt Formations

An efficient method for field-scale reservoir simulation

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- Storage security
- Basalt as an alternative injection target
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Storage security

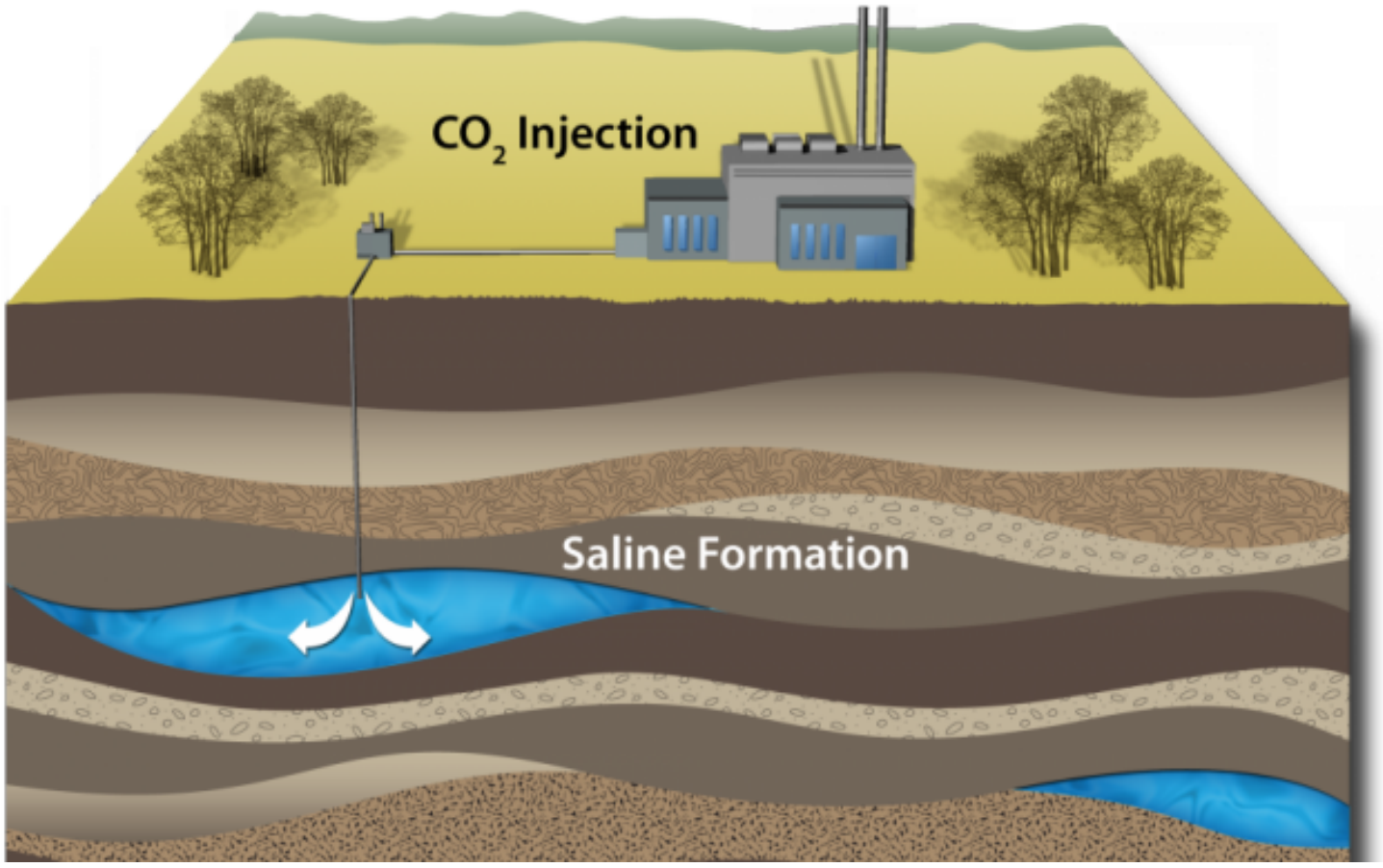

Figure 1: Schematic representation of a CCS project.

Storage security

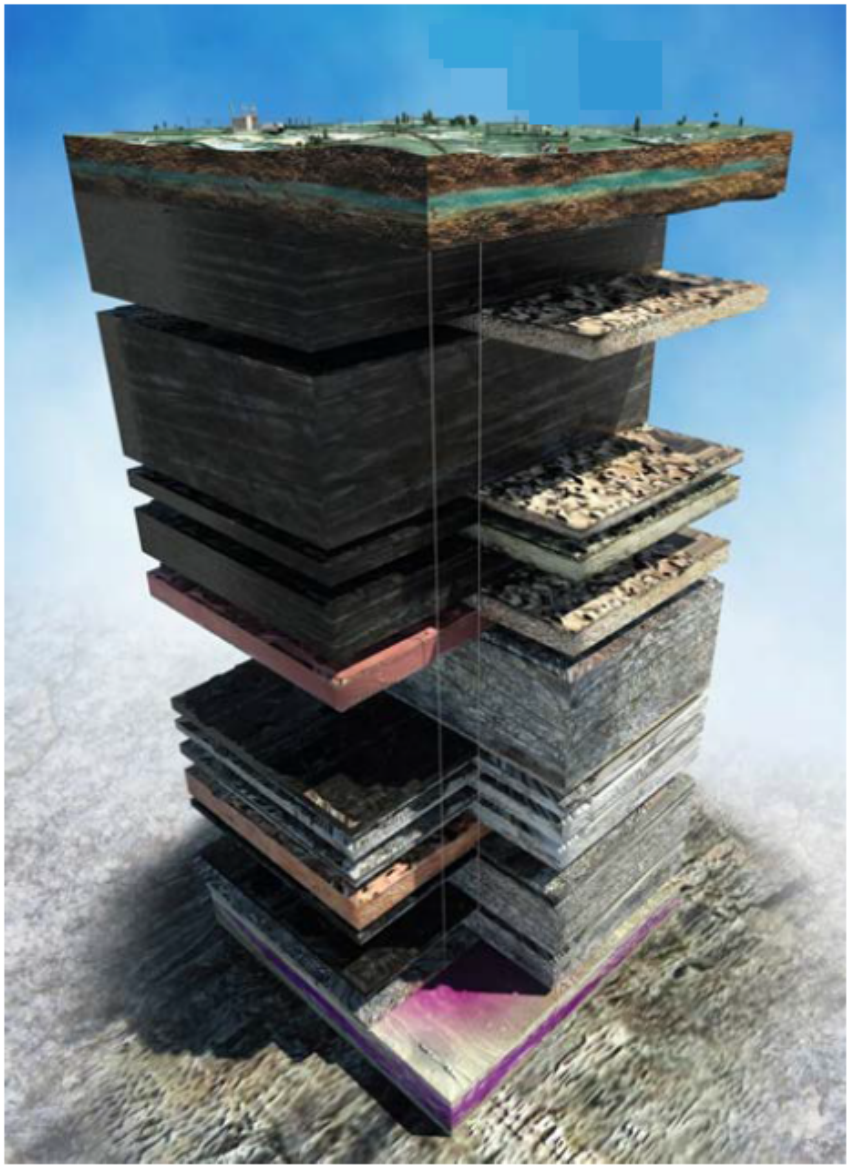

Figure 2: *Accurate* representation of a CCS project.

Storage security

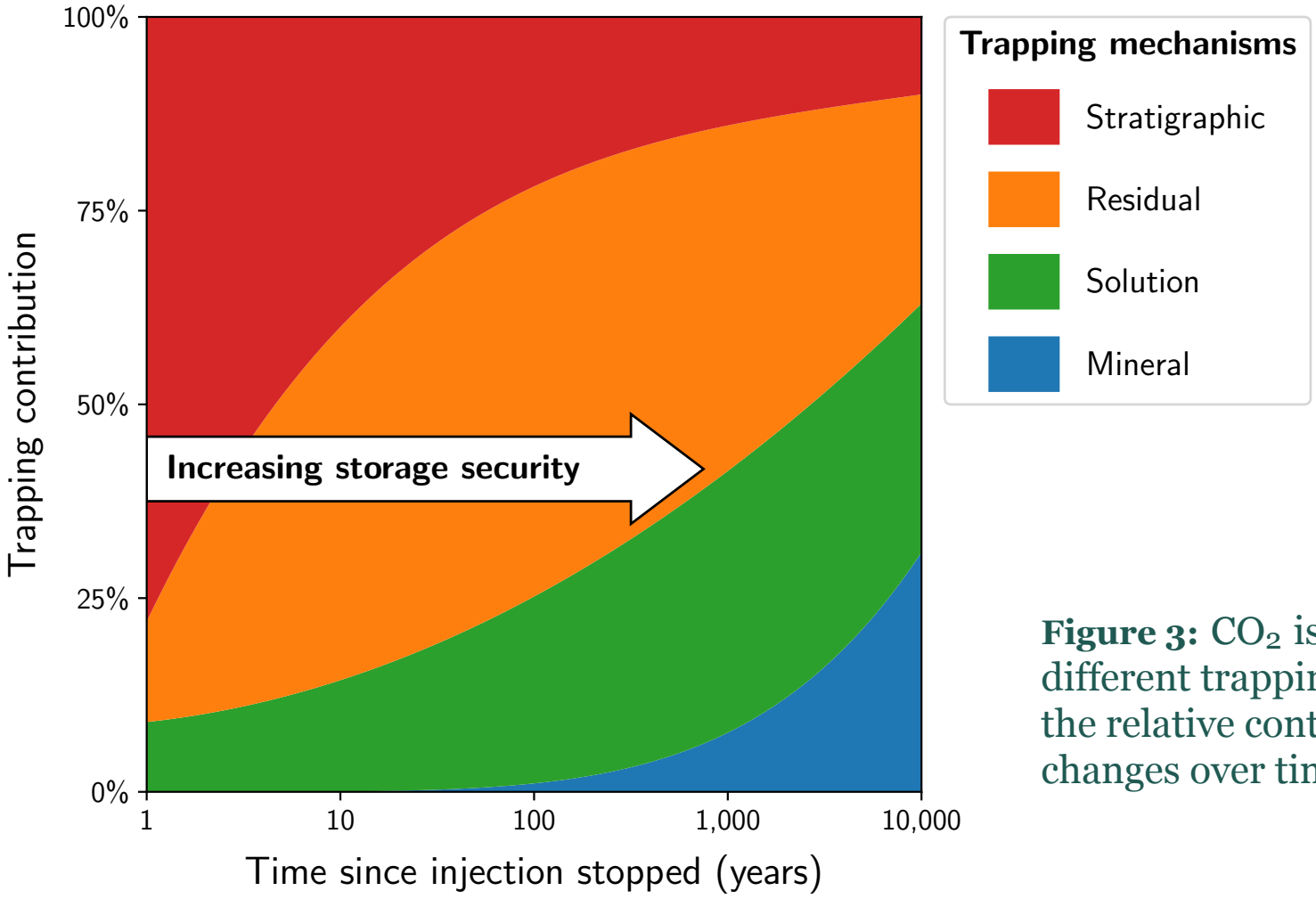

Figure 3: CO_2 is secured by different trapping mechanisms, the relative contribution of each changes over time.

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Basalt as an alternative injection target

Figure 4: Basalt outcrop on the Isle of Staffa, Scotland.

Basalt as an alternative injection target

- Layered sequence of solidified lava flows.
- Porous, permeable flow tops can provide storage capacity.

- Potential for rapid mineral trapping due to Ca, Mg and Fe(II)-rich mineralogy.
- Pilot-scale injections show compelling evidence of mineral trapping on short time scales.

Figure 5: Scoria from flow tops: porous and permeable.

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Relevance for BP: CCS and the energy transition

- Basalt can provide **alternative CO_2 storage capacity** when sedimentary formations are **absent or costly to develop.**
- Possible examples include: India, Iceland and the NW-U.S.A.

- Stability and security of mineral trapping may **improve prospects for building and maintaining social license** for CCS deployment.

- Mineral trapping on short time scales may **significantly reduce the risks and costs** associated with **postinjection monitoring and verification.**

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Open questions before large-scale implementation

- How will chemical reactions alter the formation?
  - Porosity
  - Permeability
  - Formation integrity
- Can we control where and when chemical reactions take place?

- Can a full-scale project expect mineralization on political time scales?
- To what extent do the 'chemical details' matter?
  - Exact mineralogy
  - Formation water composition

- **We need a flexible, efficient modeling tool.**

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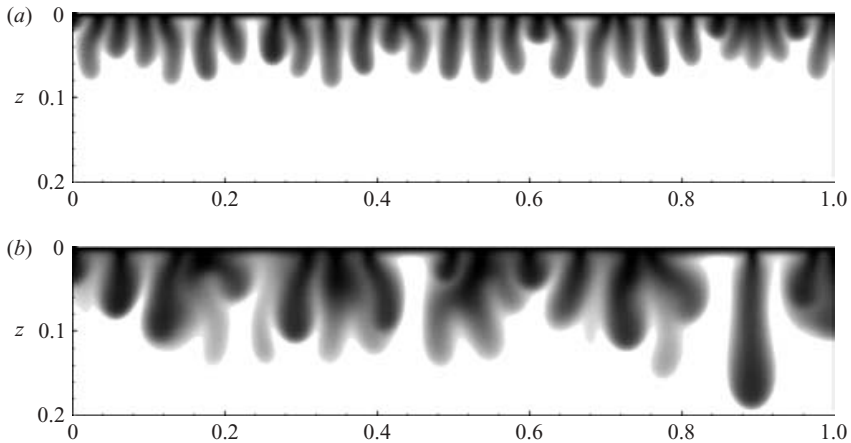
Development of an efficient numerical simulation method

Modeling of CO_2 injection in reactive rocks is a complex problem:

- Flow of two phases, with CO_2 dissolving into formation water.
- An arbitrarily large number of chemical reactions.
- A rock formation that changes over time.

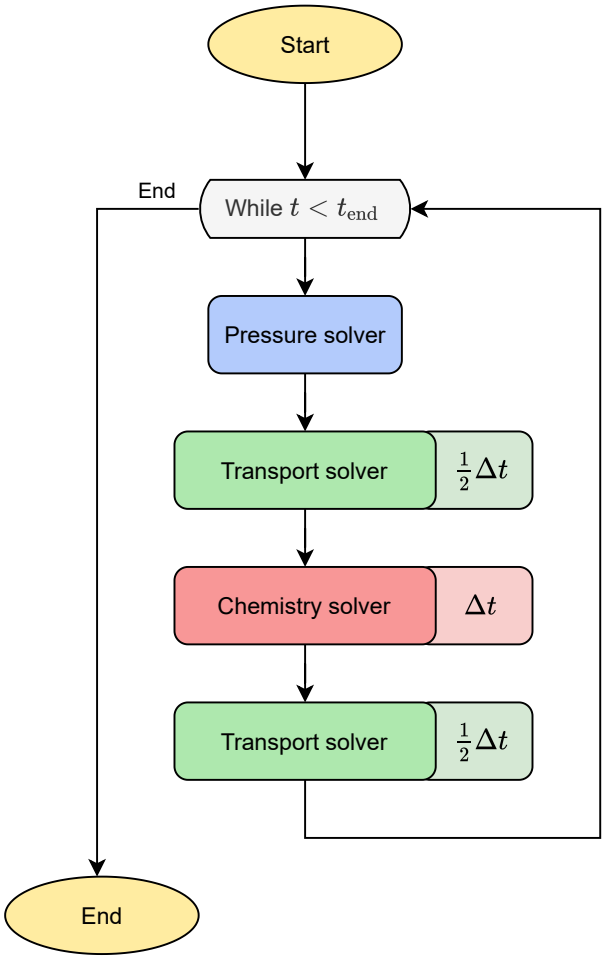


$$CO_2 + H_2O \rightarrow CO_3^{2-} + 2\,H^+$$

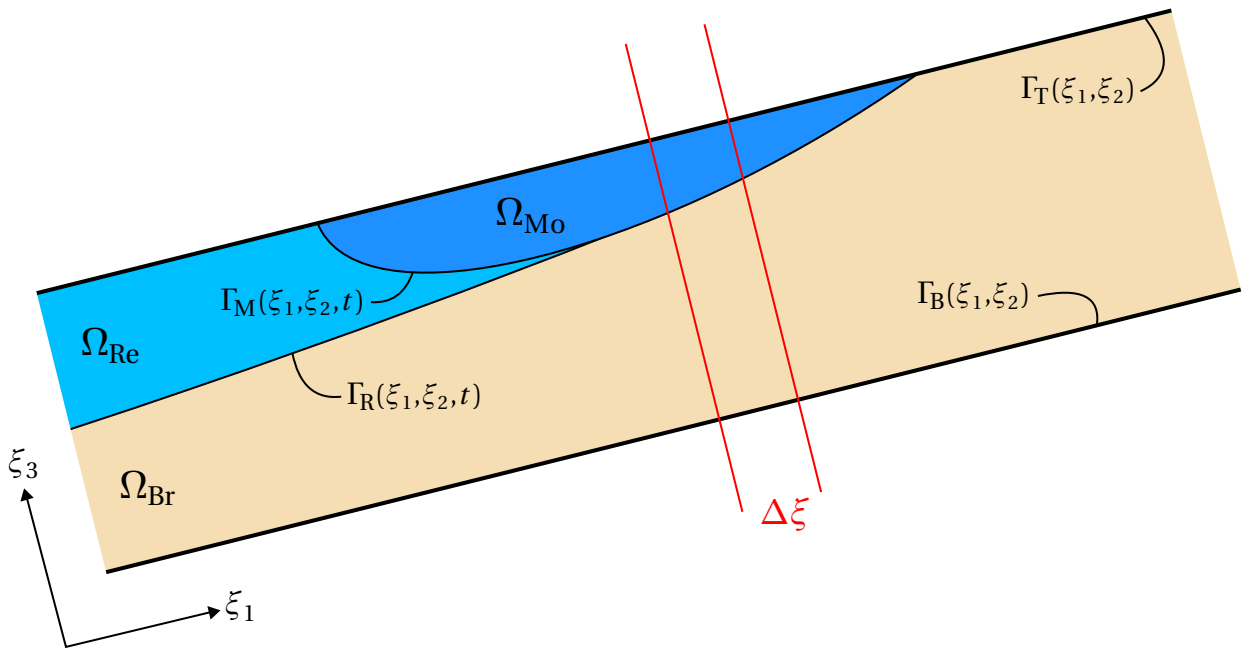
$$Fe_2SiO_4 + 4\,H^+ \rightarrow 2\,Fe^{2+} + H_4SiO_4$$

$$Fe^{2+} + CO_3^{2-} \rightarrow FeCO_3$$

Development of an efficient numerical simulation method



- An efficient fluid flow model of CO_2 injection in saline aquifers.
- A highly customizable gechemistry solver.
- Combined in an operator splitting algorithm.



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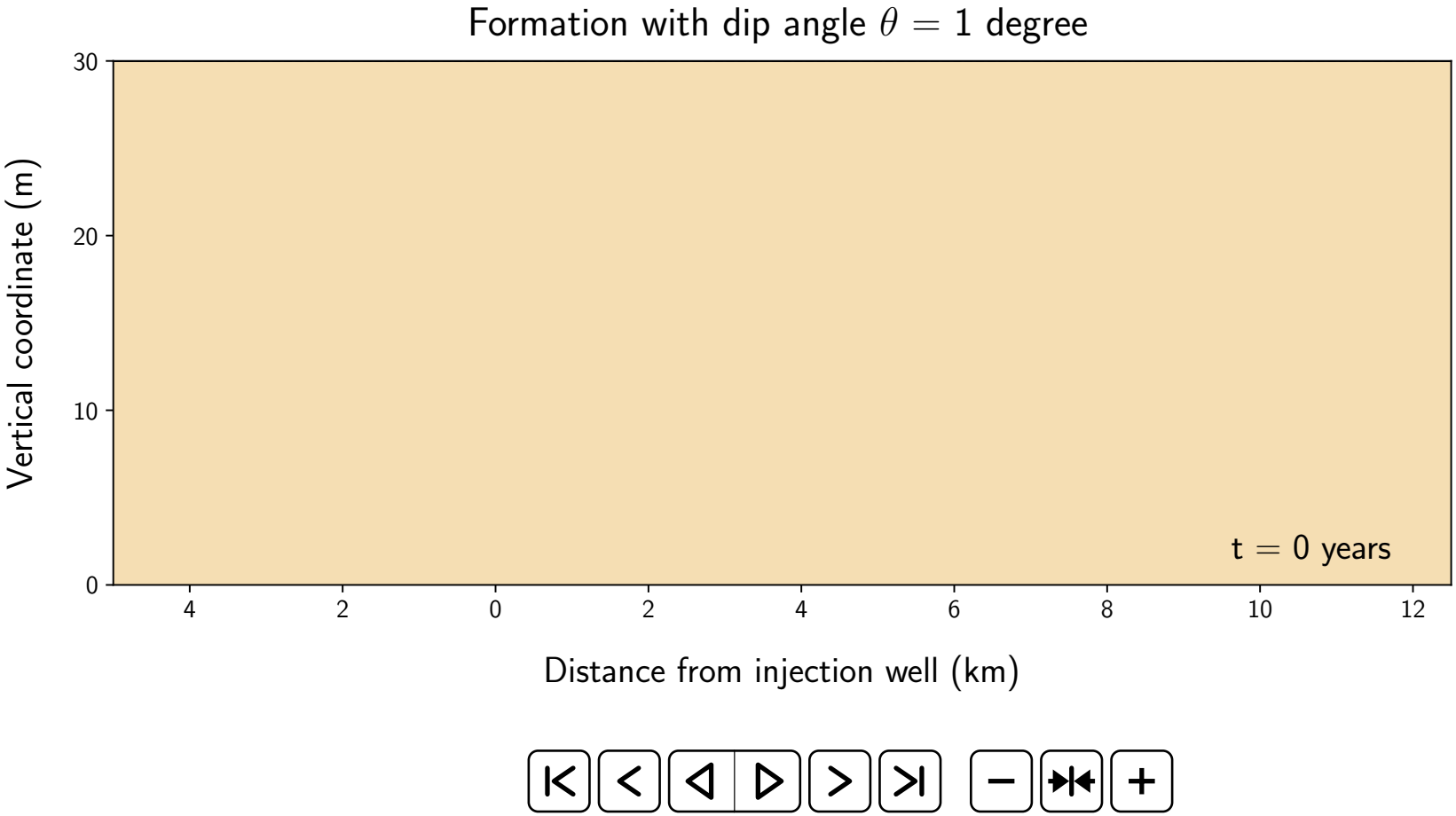
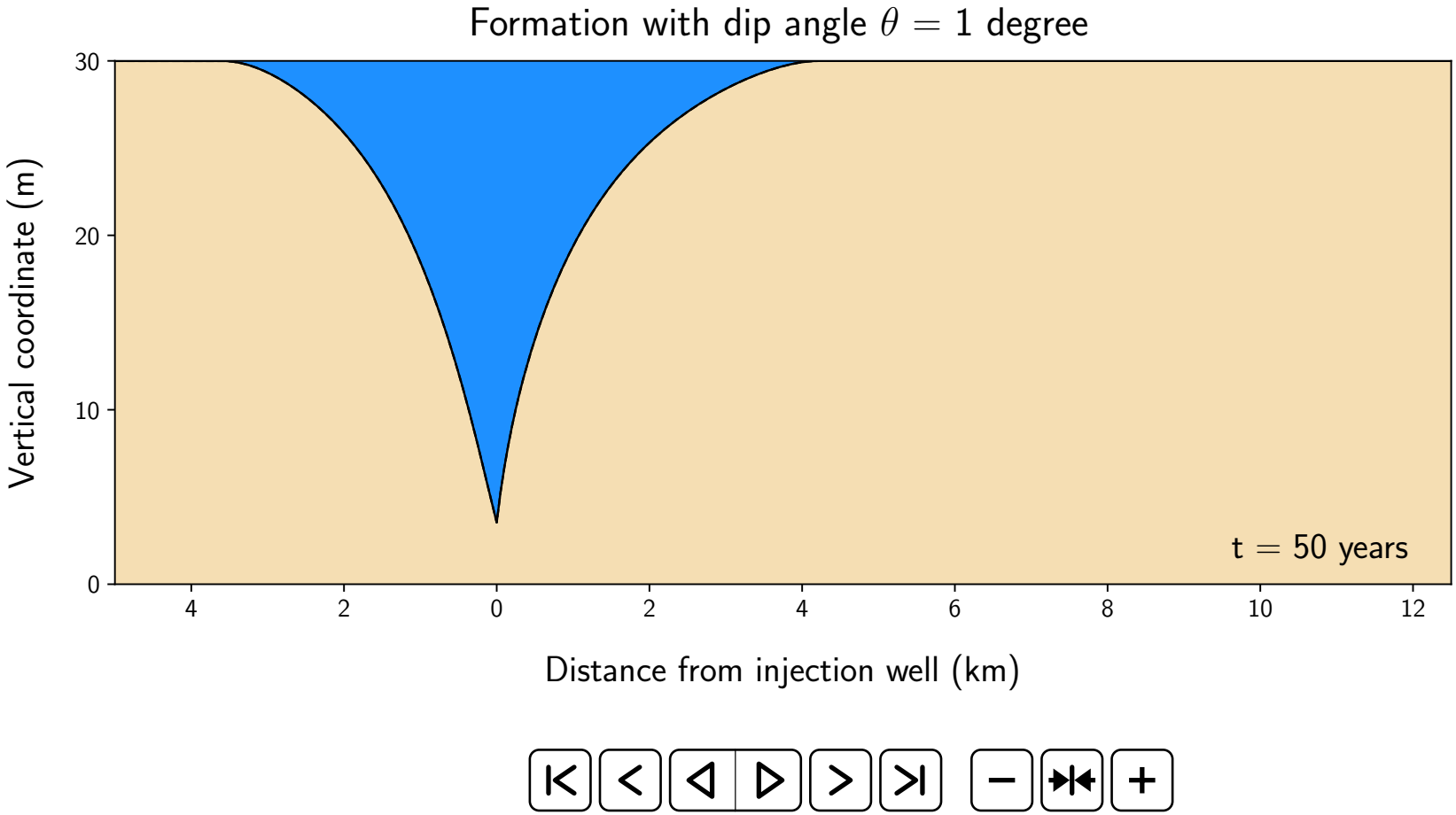
CO_2 injection into a non-reactive rock type



CO_2 injection into a non-reactive rock type



CO_2 injection into a non-reactive rock type

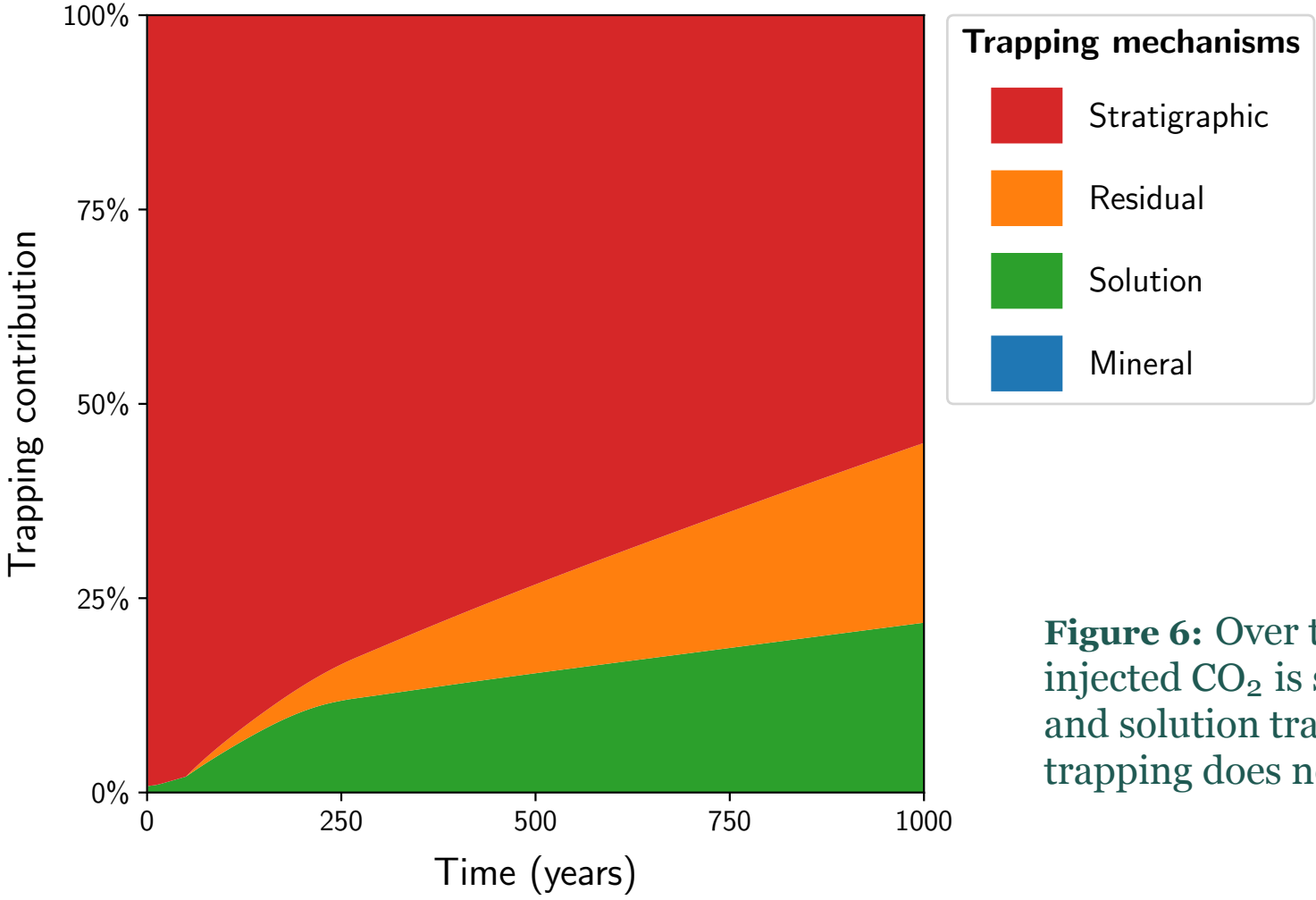
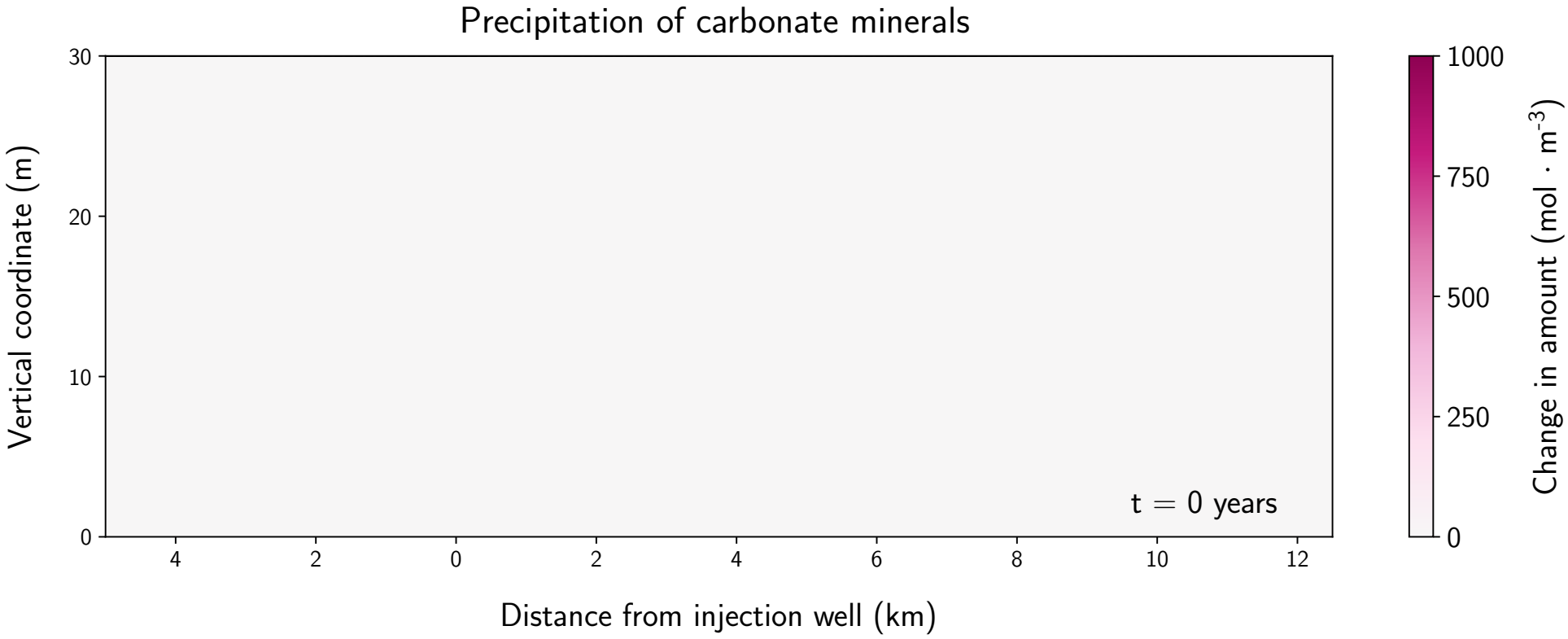
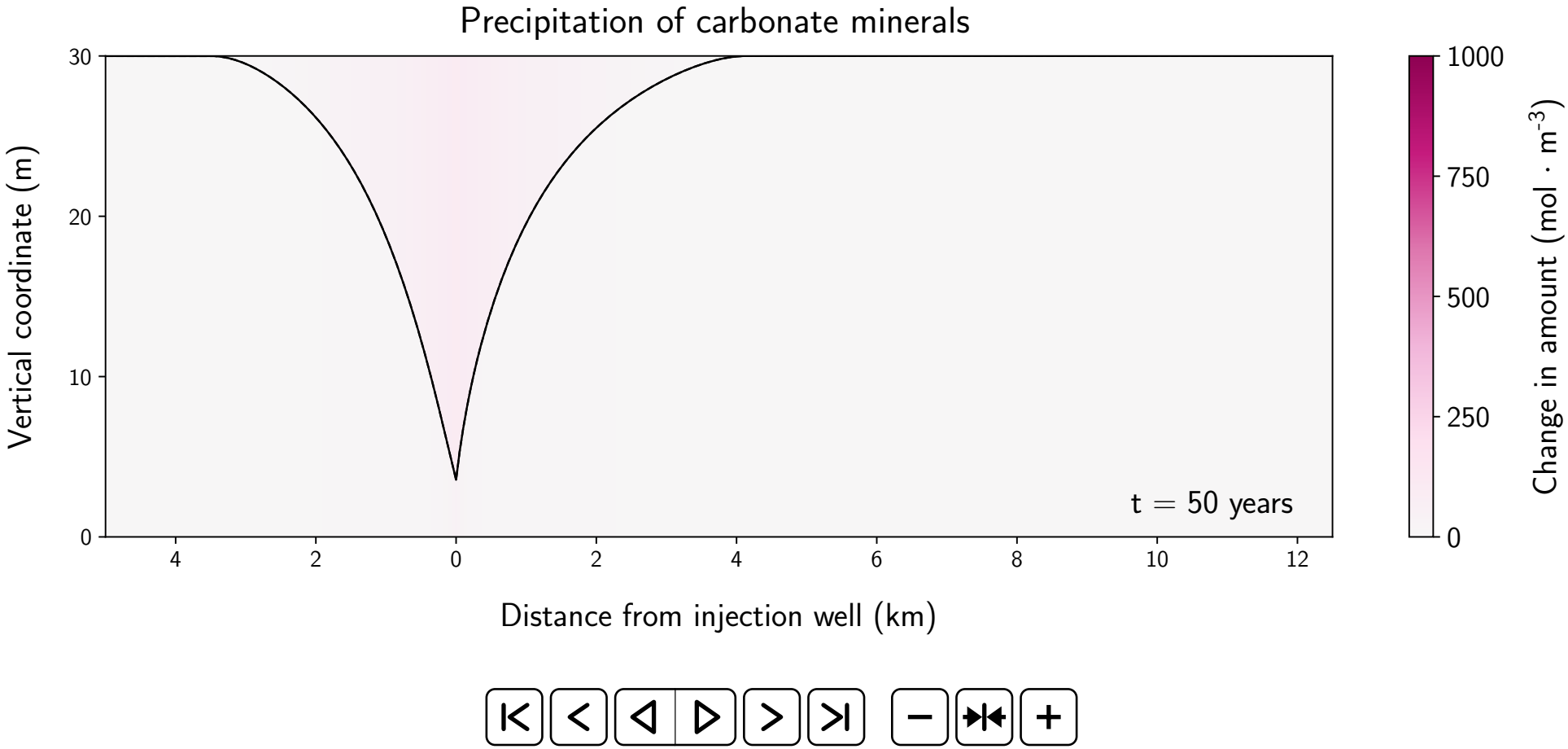


Figure 6: Over time, more of the injected CO_2 is secured by residual and solution trapping. Mineral trapping does not occur.

CO_2 injection into reactive basalt



CO_2 injection into reactive basalt



CO_2 injection into reactive basalt

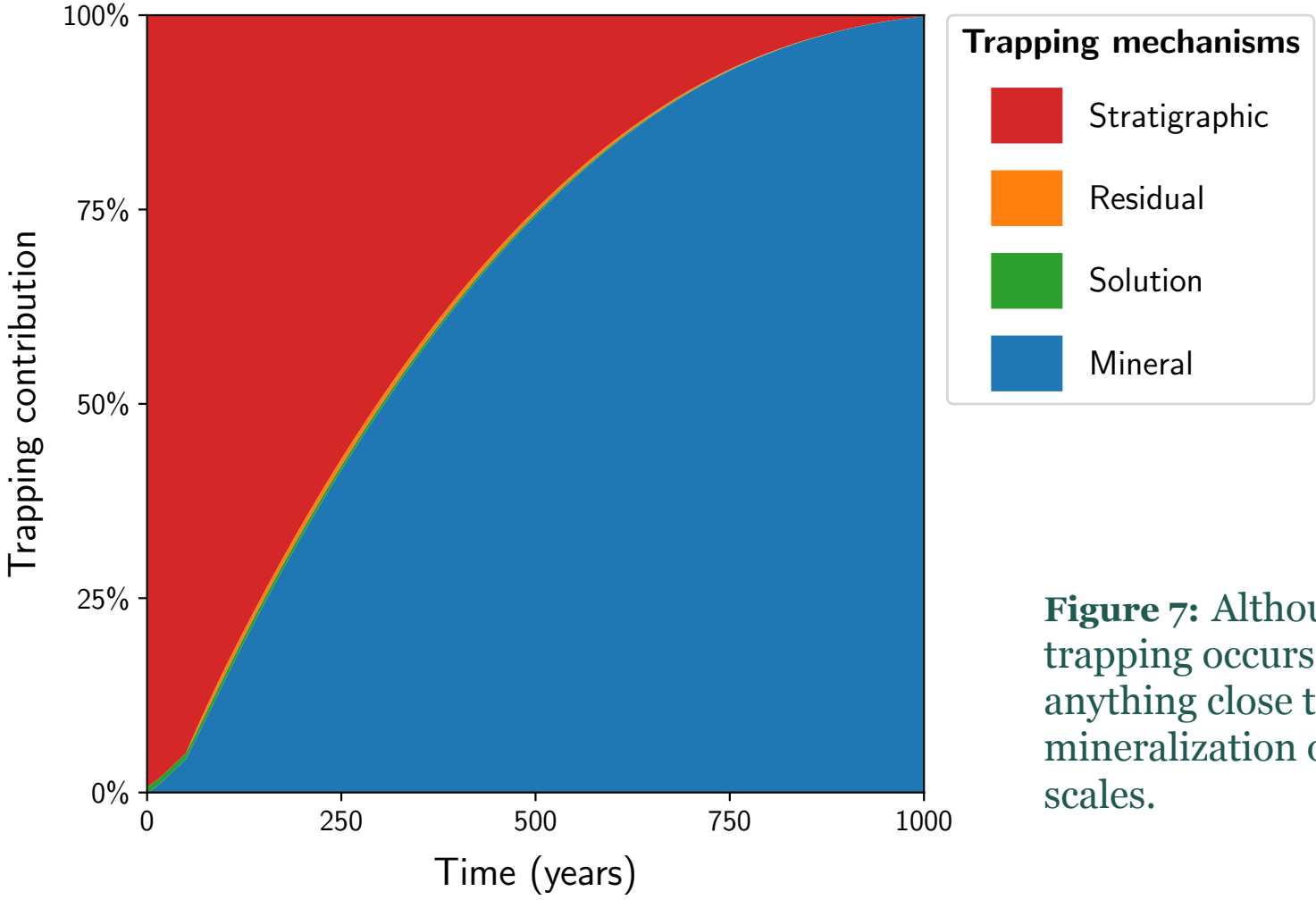


Figure 7: Although mineral trapping occurs, we do not observe anything close to full mineralization on political time scales.

CO_2 injection into reactive basalt

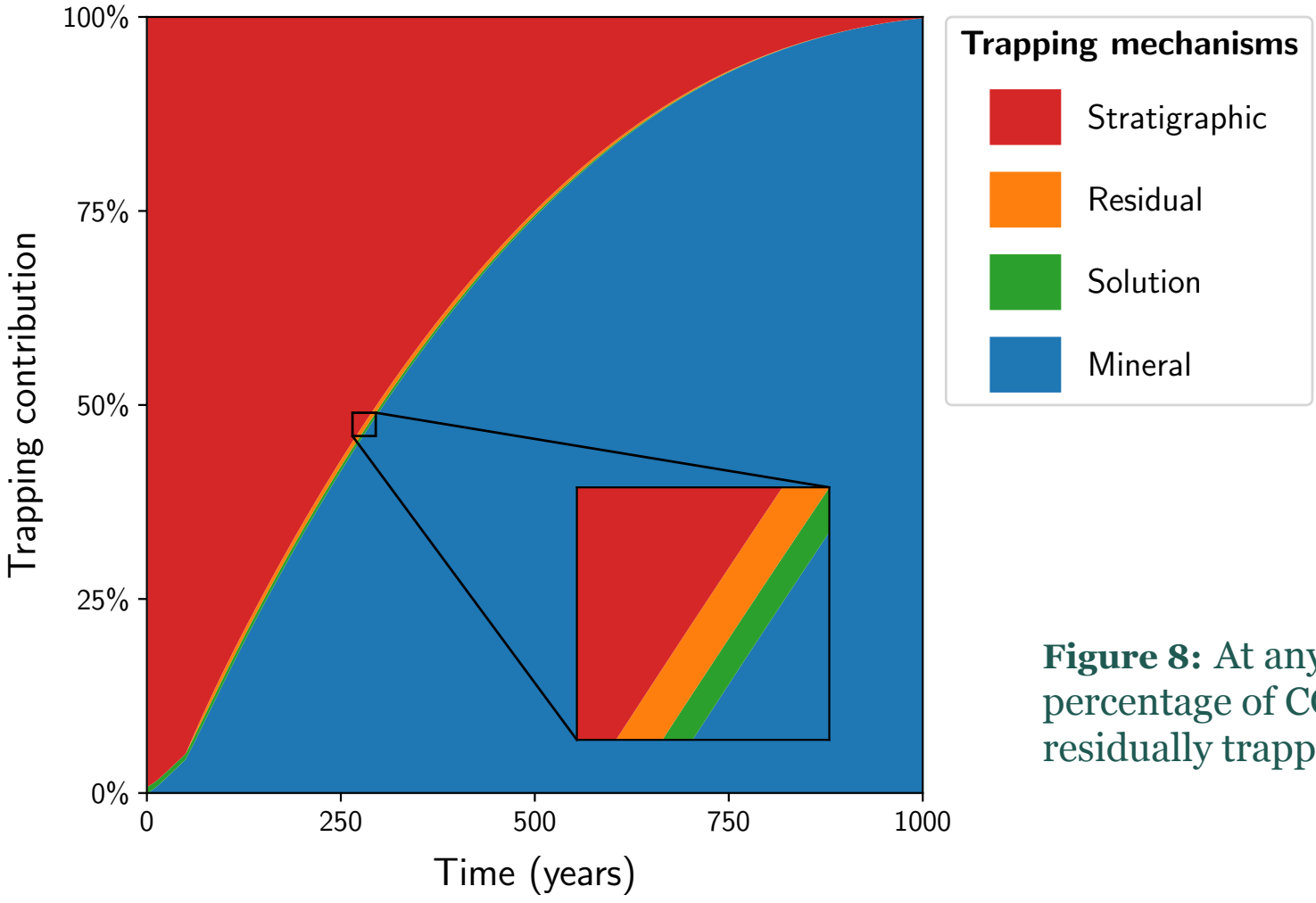


Figure 8: At any time, only a small percentage of CO_2 is dissolved or residually trapped.

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Putting the model's efficiency to use

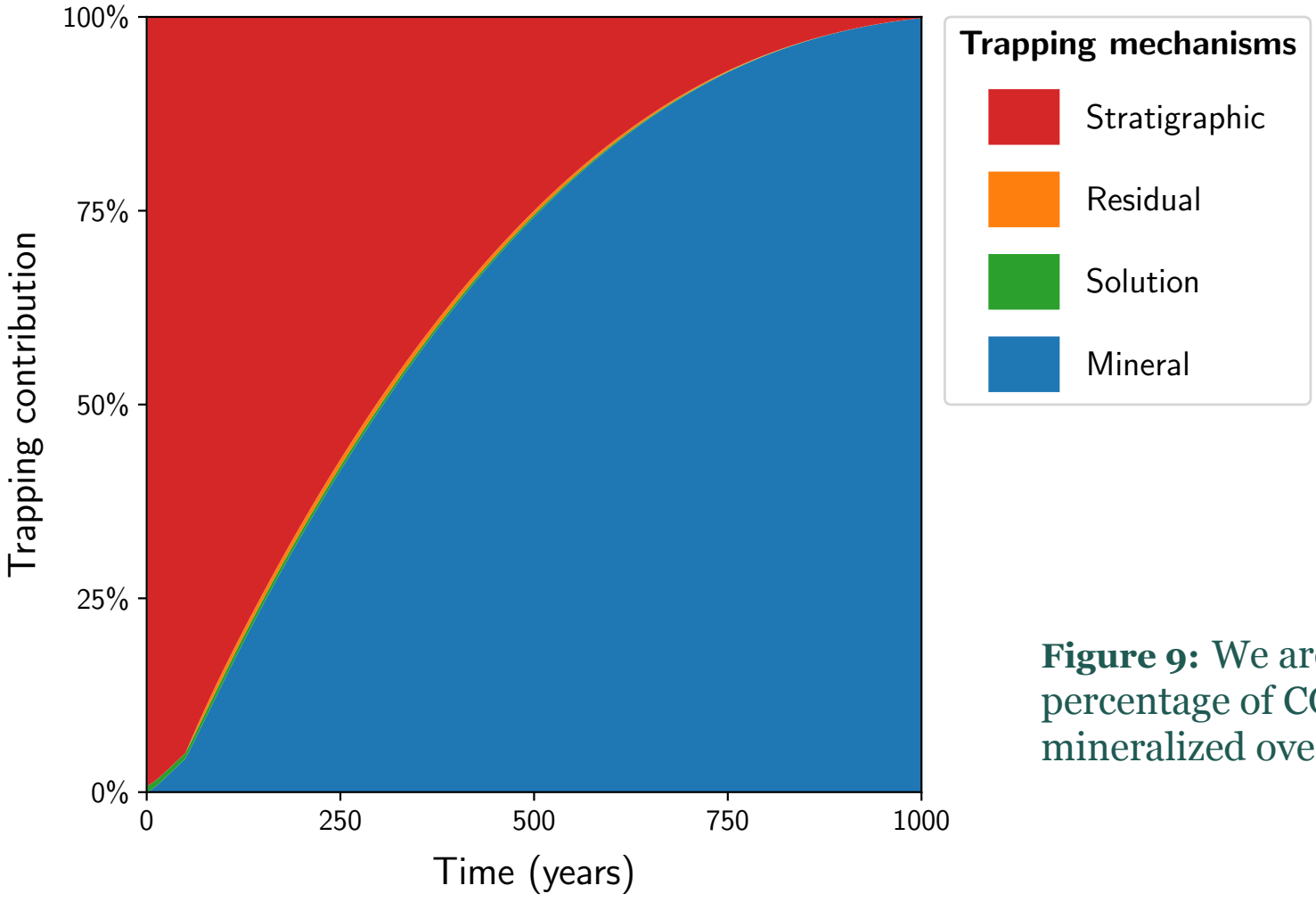


Figure 9: We are interested in the percentage of CO_2 that has mineralized over time.

Putting the model's efficiency to use

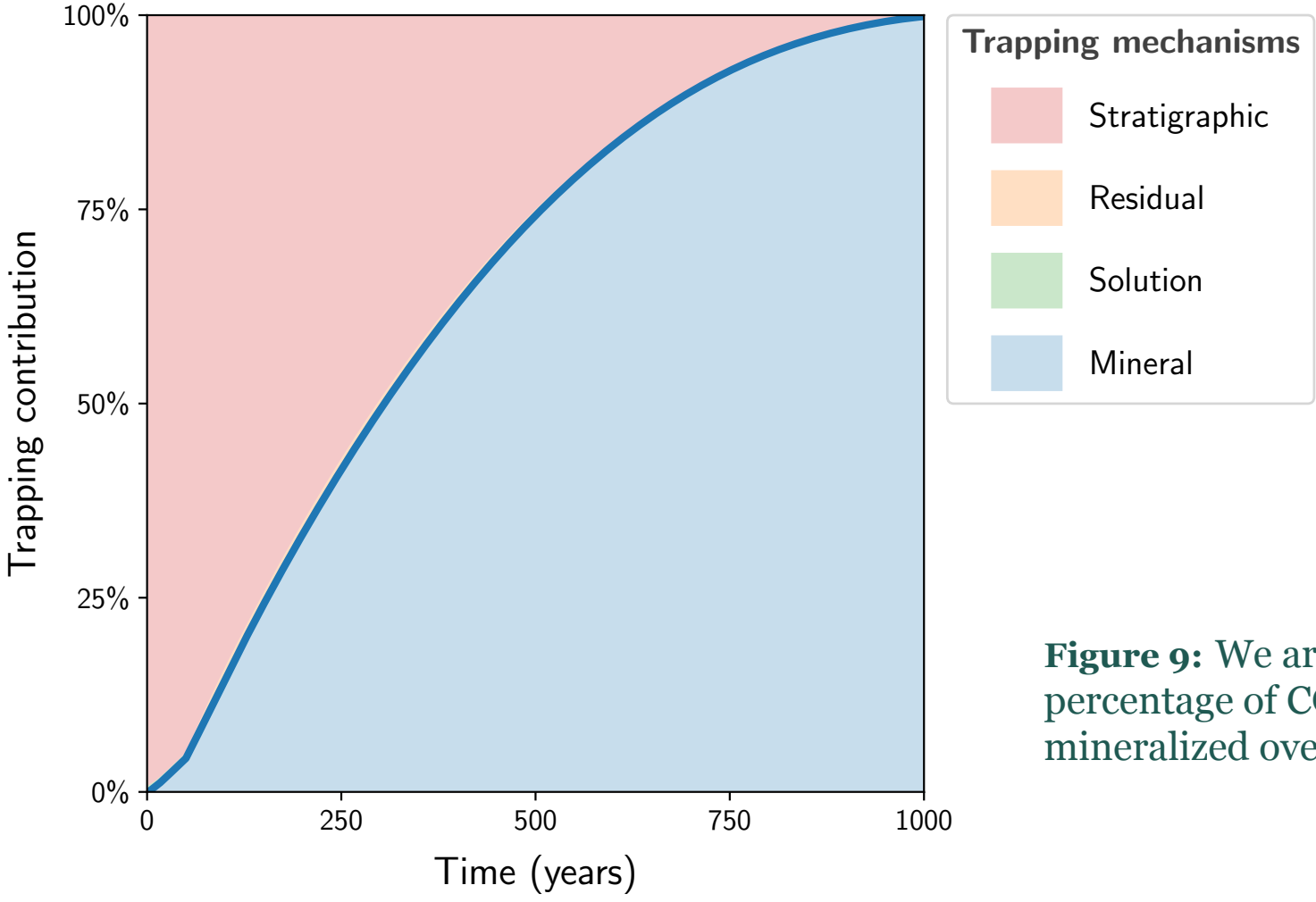


Figure 9: We are interested in the percentage of CO_2 that has mineralized over time.

Putting the model's efficiency to use

- Investigate how mineralization time depends on reservoir properties:
  - Dip angle
  - Permeability
  - Initial porosity

- Identify a range of possible values for real systems.
- Analyze simulation results for many different combinations of values.

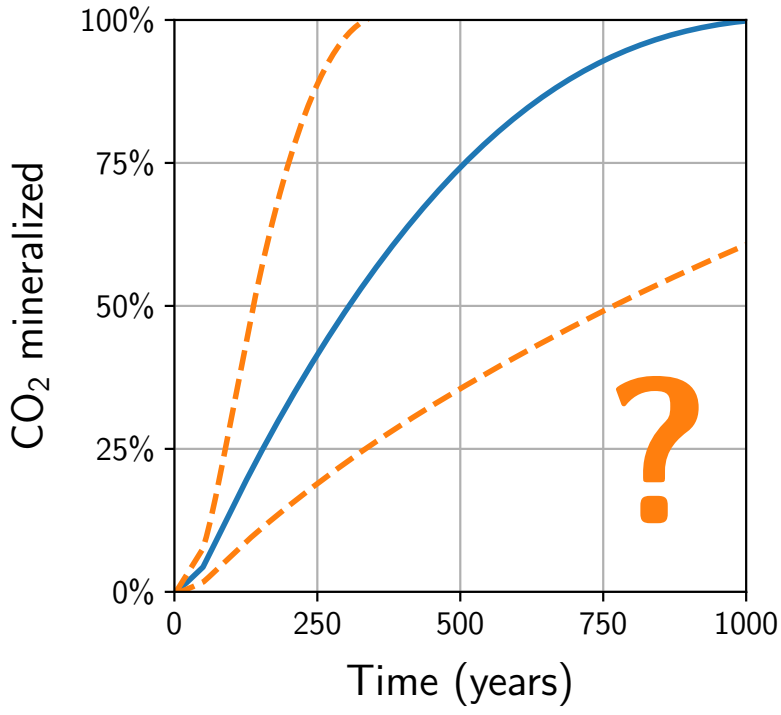
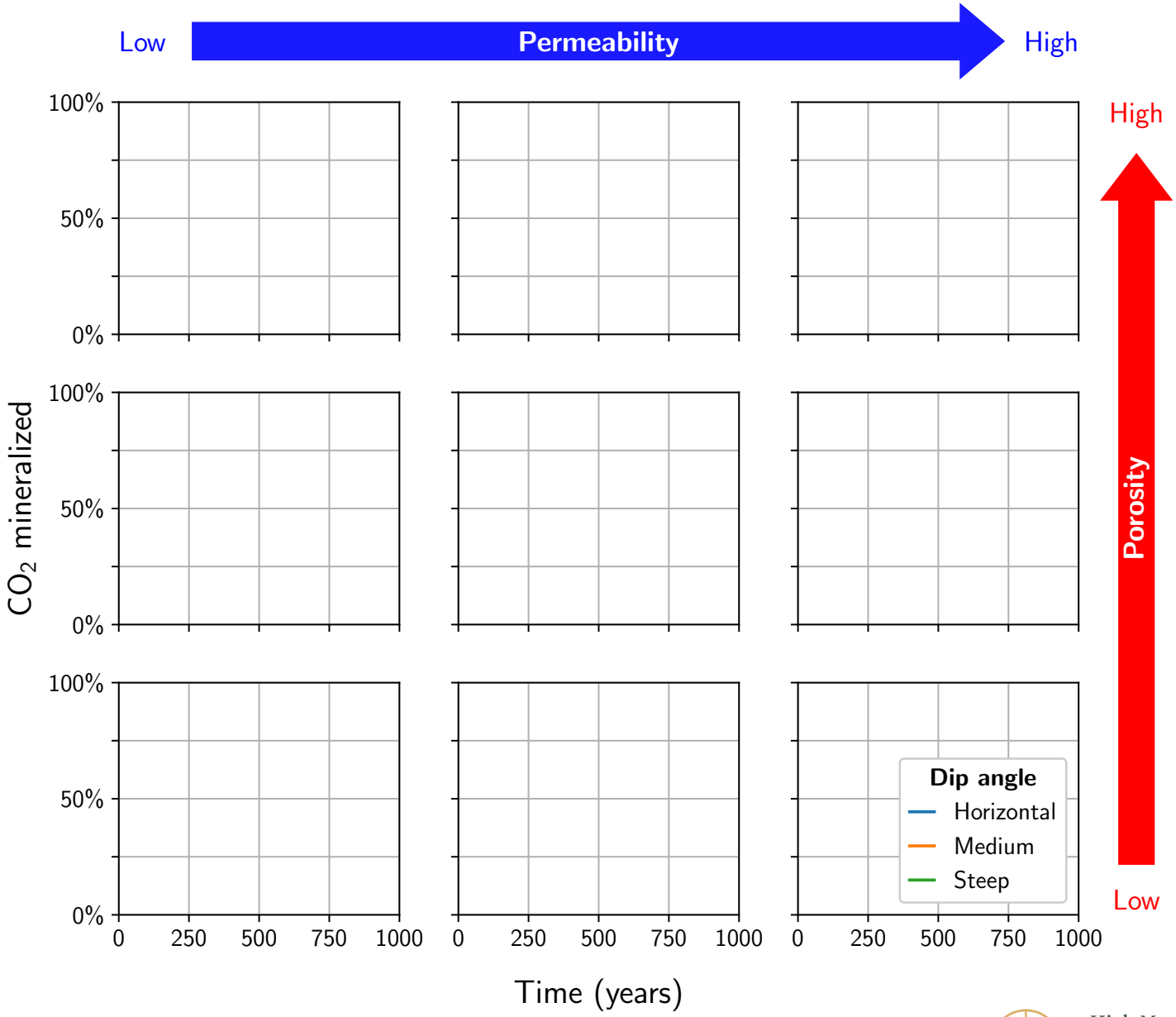


Figure 10: Do reservoir properties have a large impact on mineralization time?

Impact of reservoir properties



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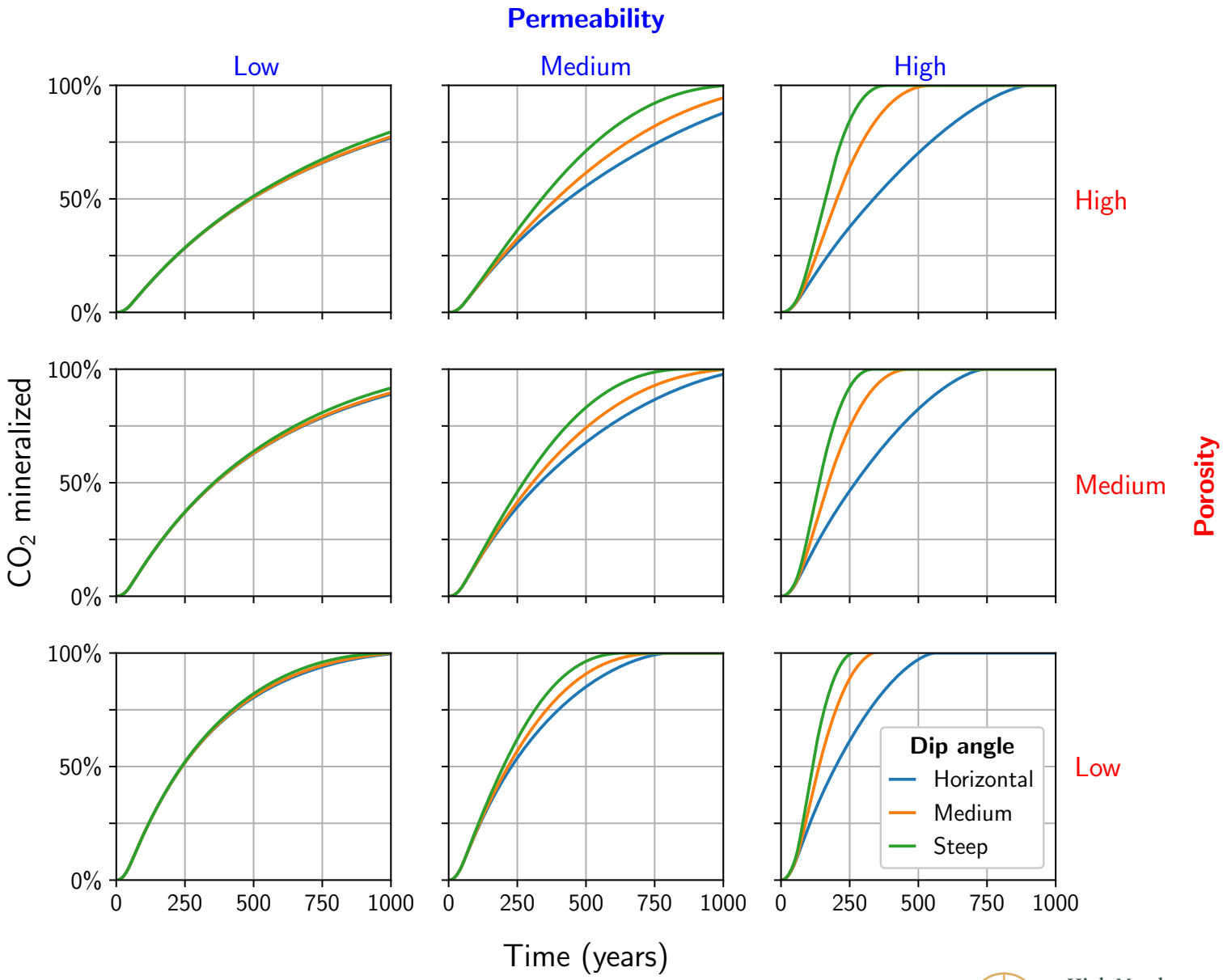
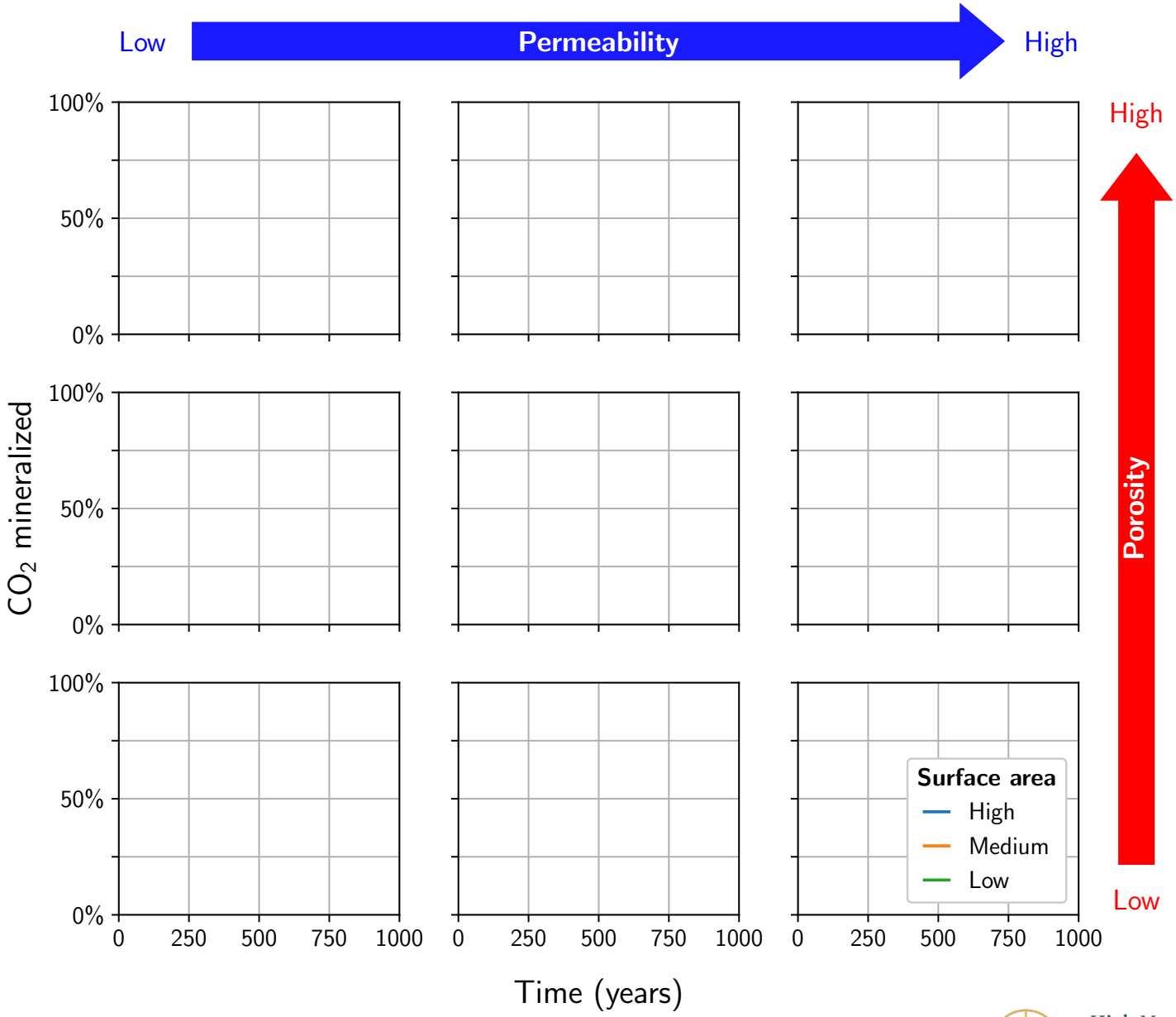


What if chemical reactions were much faster?



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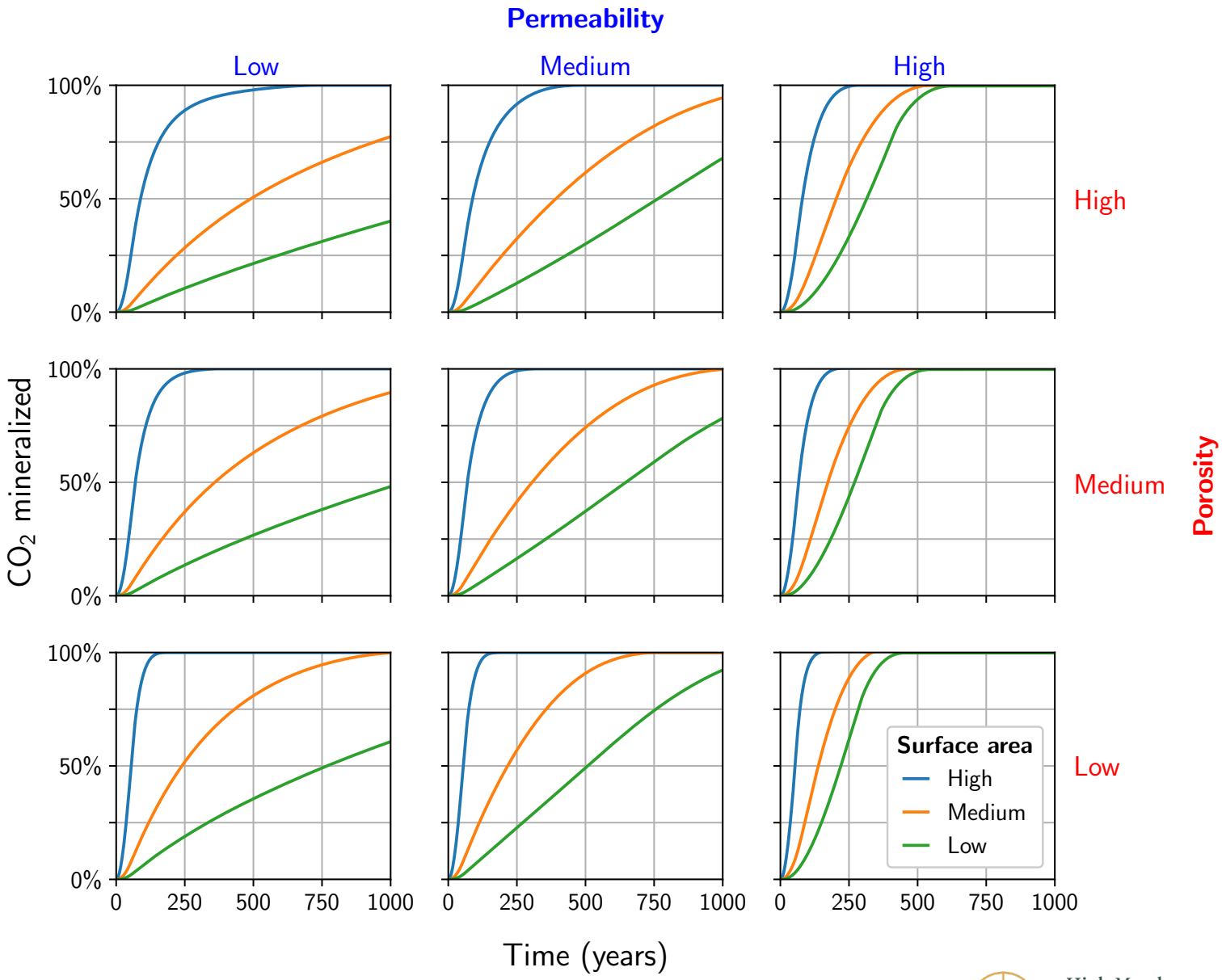
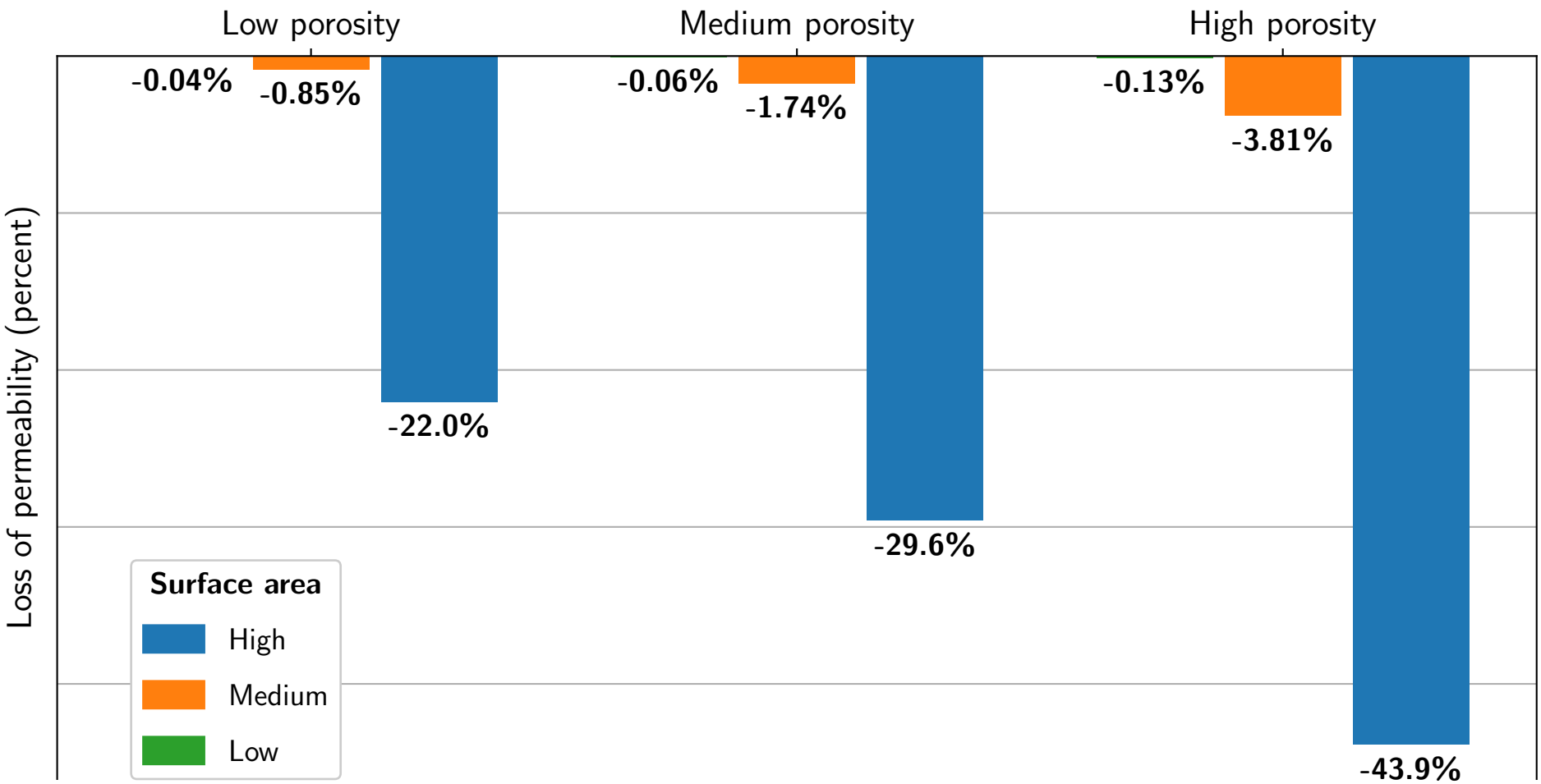


Estimated loss of permeability

- Mineral reactions can alter the **porosity** of the formation, which will in turn affect **permeability.**
- This may result in an unacceptable **decrease in injectivity.**

- There is not yet a generally accepted **porosity-permeability relationship** for basalt.
- To get a **first estimate**, assume that basalt behaves like sedimentary formations and use a commonly used **relationship for sandstones.**

Estimated loss of permeability



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Conclusions

- Basalt formations may provide **alternative storage capacity** to supplement that of conventional reservoirs.

- Consistent with previous research, CO_2 injection in basalt was observed to result in **significant mineral trapping** due to the reactivity of the rock.

- However, our results indicate that an **increased scale of injection** may result in mineralization times that are **orders of magnitude longer** than those observed in small-scale pilot injections.

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