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Integrating near-field THMC processes into field-scale THC simulations for nuclear waste repository performance assessment

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1. Abstract

Performance assessment of geologic radioactive waste repositories can require three-dimensional simulation of highly nonlinear, thermo-hydrological-mechanical-chemical (THMC), multiphase flow and transport processes on large length scales (many kilometers) and over long timespans (tens to hundreds of thousands of years). The computational complexity involved poses challenges to efficient PA simulation, especially when taking a probabilistic approach. This work focuses on integrating the effects of a nearfield geomechanical process, buffer swelling, between fully-coupled THMC simulations (using TOUGH-FLAC) and THC simulations (using PFLOTRAN) to reduce dimensionality and improve computational efficiency. Simulations presented here use PFLOTRAN to model a single waste package in a shale host rock repository, where resaturation of a bentonite buffer causes the buffer to swell and exerts stress on a highly fractured disturbed rock zone (DRZ). Compressing these fractures results in reduced permeability, which could have implications for radionuclide transport and exchange with corrosive species in host rock groundwater that could accellerate waste package degradation.

2. Model Description

- Quarter-symmetry domain
- 24-PWR, 40 GWd/MTU, 100 years OoR waste package heat source
- DRZ physical properties match those of shale host rock
  - *Exception*: initial DRZ permeability is 2 orders of magnitude larger than host rock and can evolve over time
- Repository is 490 m below ground surface

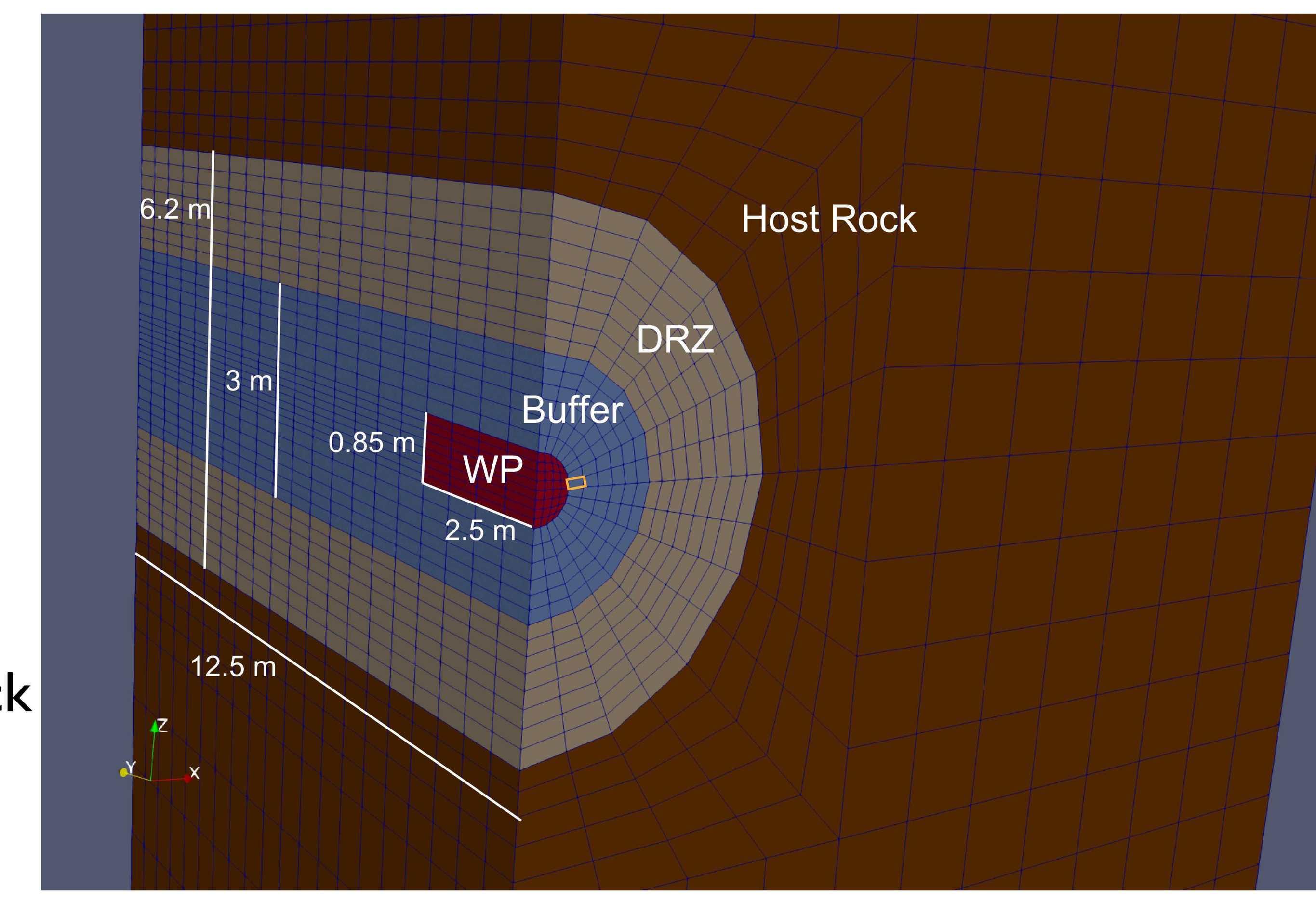

Figure 1. Nearfield, quarter-symmetry model which includes a waste package (WP), buffer, disturbed rock zone (DRZ), and host rock. Outlined cell (gold) corresponds to liquid saturation distributions in **Figure 5**.

3. DRZ Permeability Evolution

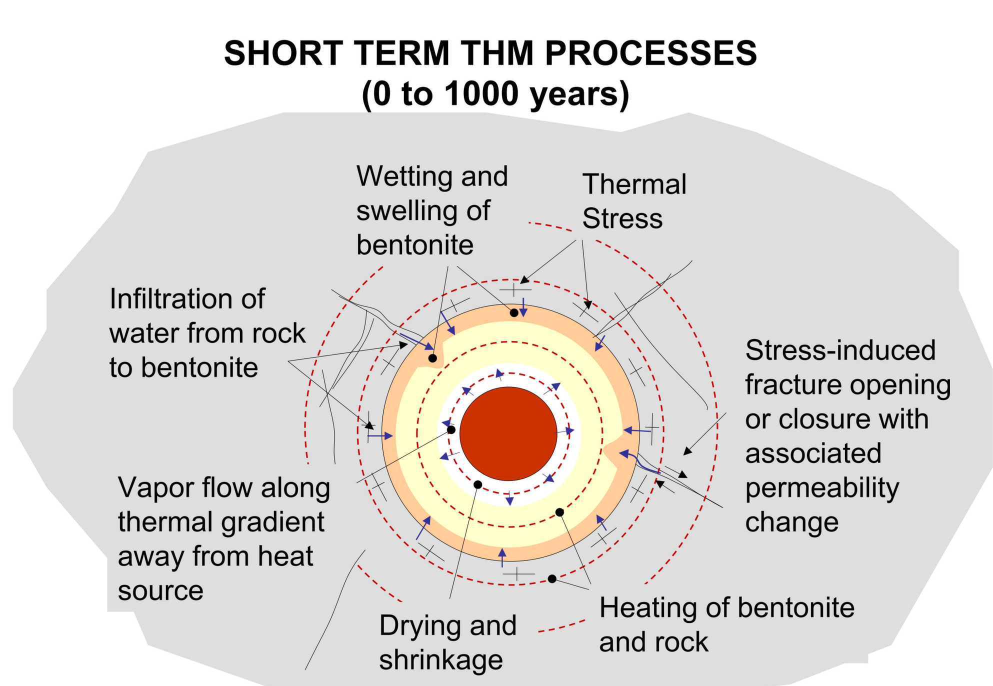

Figure 2. Adapted from Rutqvist et al., 2018

- Buffer swelling stress ($\Delta\sigma_s$) follows a linear swelling model as a function of water saturation (S_l) (Rutqvist et al., 2011):

$$\Delta\sigma_s = 3K\Delta S_l \beta_{sw}$$

where K is the bulk modulus (20MPa) and β_{sw} is the moisture swelling coefficient (0.238).

- Permeability in the DRZ is related to buffer swelling stress by an exponential fracture closure model (Chen et al., 2015):

$$k = k_0 e^{-3c_f \Delta\sigma_s}$$

where c_f is the DRZ fracture compressibility (0.18)

4. Results

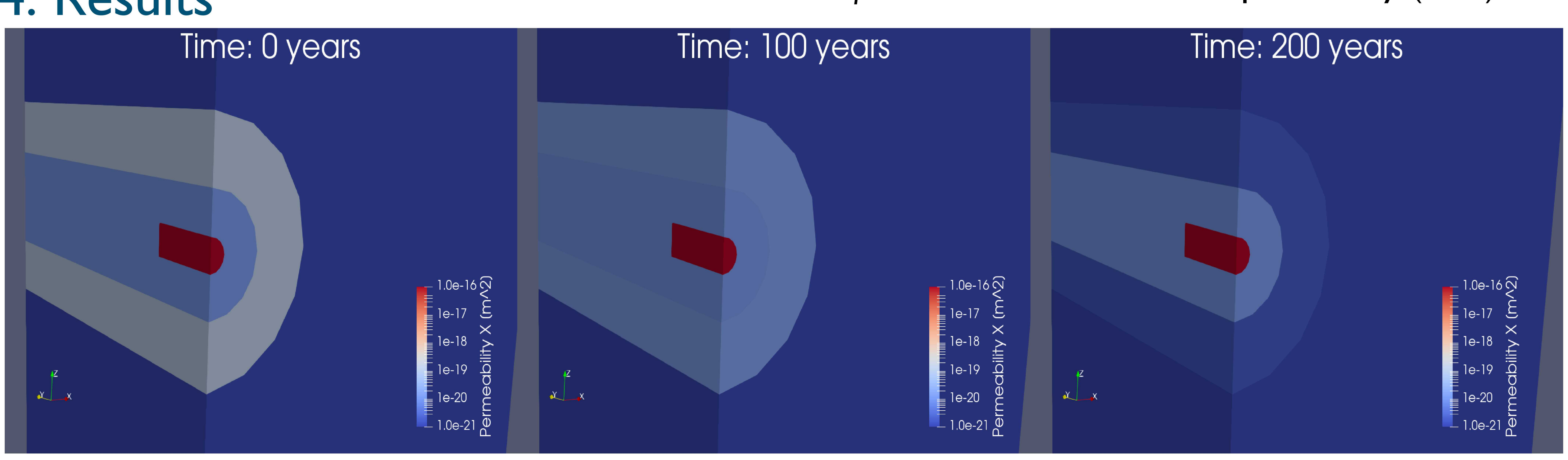

Figure 3. Example of permeability evolution in the DRZ region for simulations where buffer swelling stress causes DRZ permeability reduction.

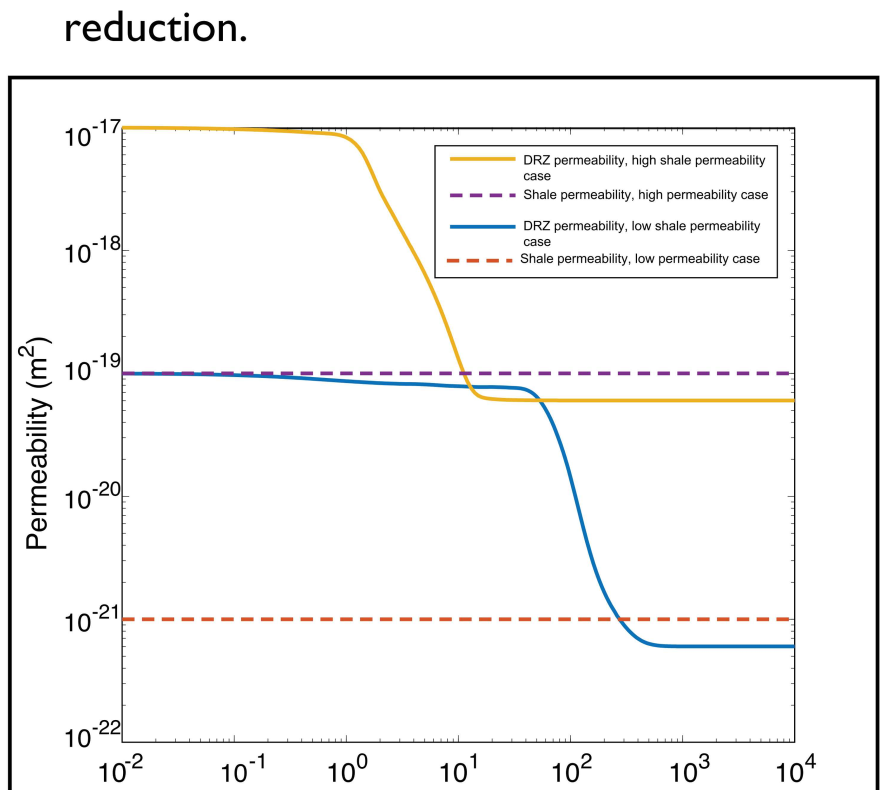

Figure 4. Permeability vs. time in the DRZ for a low-permeability shale host rock and a high-permeability shale host rock. Flat lines indicate shale permeability for each case.

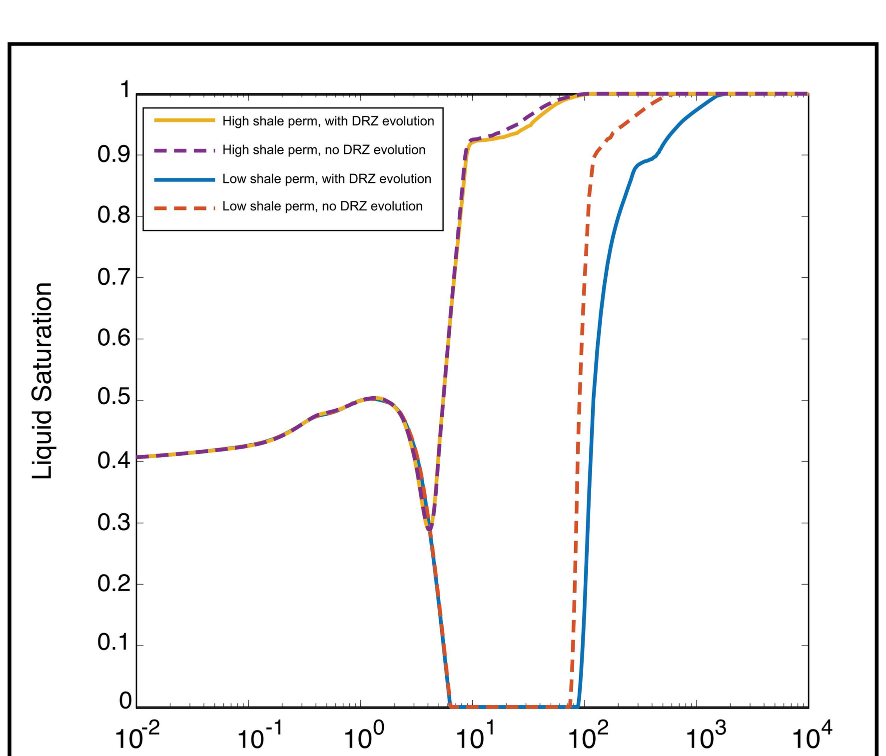

Figure 5. Saturation at the waste-package - buffer interface for a low-permeability shale host rock and a high-permeability shale host rock.

5. Discussion

- At early time, the evolution of liquid saturation at the waste package interface is predominantly controlled by buffer permeability and thermal loading due to the waste package heat source, resulting in similar liquid saturation profiles regardless of DRZ and host rock permeabilities.

- The buffer resaturates completely at earlier time for a higher host rock/DRZ permeability combination regardless of whether DRZ permeability changes over time. In the high shale host rock permeability scenario, reduction of DRZ permeability with buffer swelling plays a ***minimal role*** in determining resaturation behavior.

- Lower shale host rock permeability requires longer time to completely resaturate the buffer. Furthermore, DRZ permeability evolution plays a much more important role in controlling the resaturation process for a lower-permeability host rock.

- In this example, buffer resaturation took about ***5x longer*** when considering permeability changes in the DRZ for a very low permeability shale host rock.

6. Conclusions

Permeability evolution in the DRZ can play a significant role in controling flow of liquid water to a waste package under conditions where the host rock and DRZ have relatively low permeabilities in comparison to the buffer material. This not only can affect the transport of corrosive aqueous species to the waste package surface, but it can also control how radionuclides are transported to the far-field in the event of waste package breach.

Future work will refine both the buffer swelling model and the model of DRZ permeability evolution as a function of fracture compression by comparing results to nearfield TOUGH-FLAC simulations. These models will then be incorporated into larger PA-scale simulations to study the resulting effects on far-field radionuclide transport.

7. References

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8. Acknowledgements

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