A NUMERICAL TOOL FOR THE DESIGN OF EGS BASED ON MODELING OF THM PROCESSES AND EXPLICIT REPRESENTATION OF FRACTURE NETWORKS

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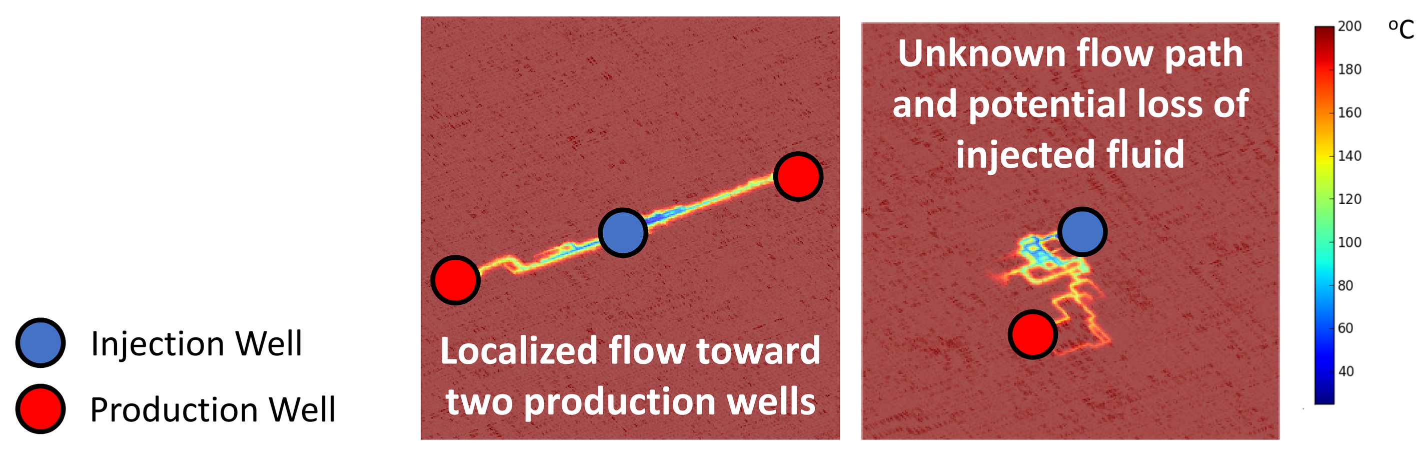
INTRODUCTION

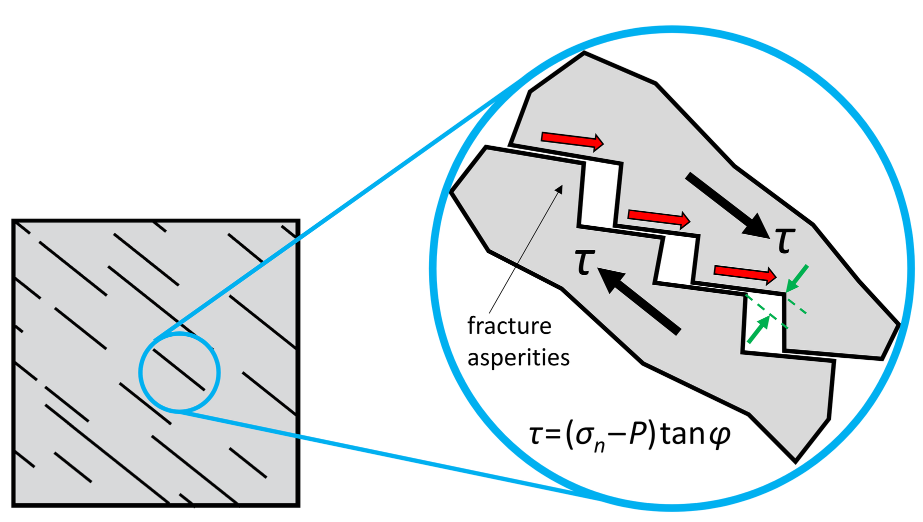
- Major challenges of Enhanced Geothermal Systems (EGS):
  - Relatively small injectivity (in-situ permeability).
  - Quick thermal drawdown.
  - Small heat recovery.
  - Uncertain and potentially limited lifetime of EGS wells.



2D models of reservoir (length scale 2 km by 2 km) showing temperature after 10 years of production.

NUMERICAL MODELING: AN IMPORTANT TOOL FOR SOLVING EGS CHALLENGES

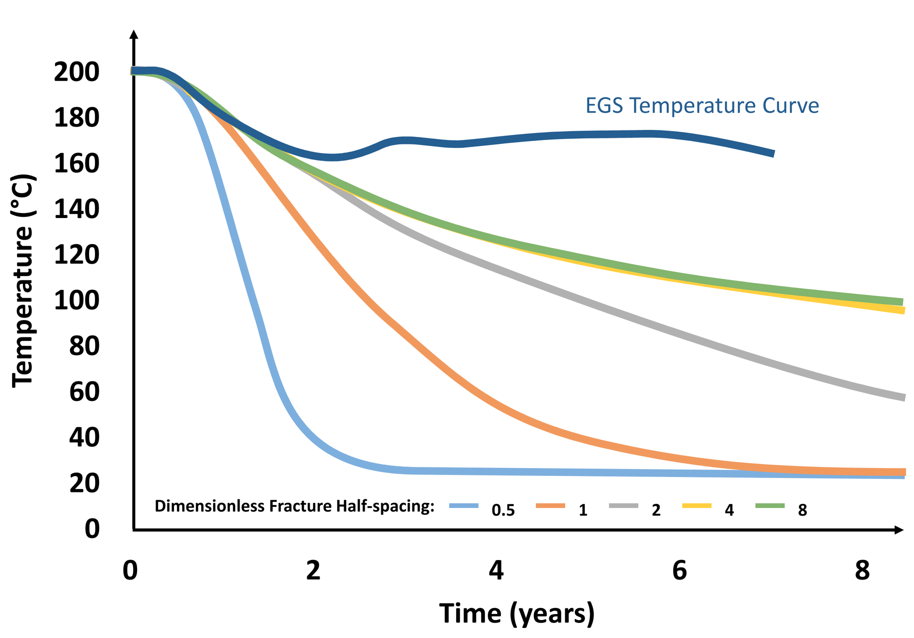
- Critical features required for numerical modeling of EGS:
  - Explicit representation of the discrete fracture network.
  - The fracture opening as a function of effective stress changes and deformation.
  - Shear deformation of fractures.
  - The relation between fracture deformation and conductivity.
  - Channeling and thermoelastic effects.



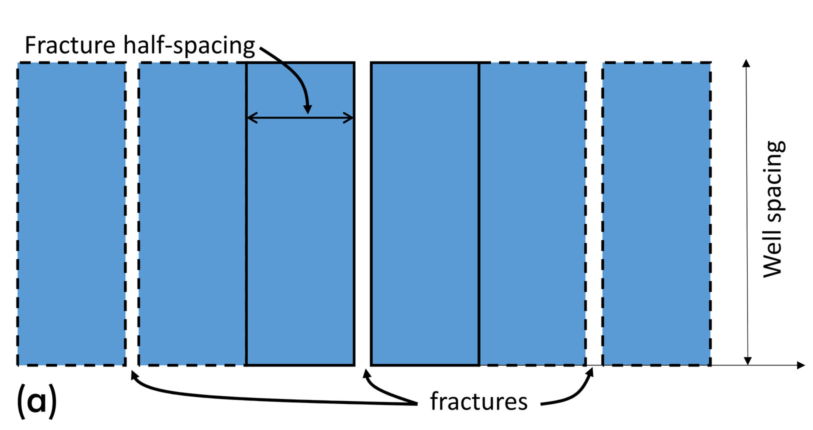
Mechanism for irreversible fracture opening (dilatational opening).

CONTINUUM VERSUS DISCRETE ELEMENT MODELS

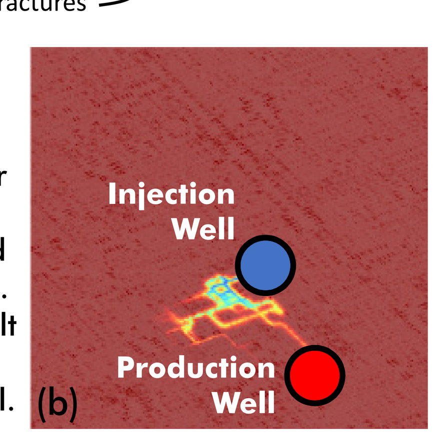
- Flow in EGS reservoirs is usually localized along discrete fractures and cannot be predicted by the continuum models or analytical solutions based on simplified geometry (e.g., parallel flow model).
- The percolated fracture area is a function of complexity of the Discrete Fracture Network (DFN) and its interaction with potential hydraulic fractures. The percolated fracture area and distribution of flow between and within the fractures will determine the temperature-time curve.



Typical parallel flow (Gringarten solution) results showing temperature-time curves for four flow channels and different fracture spacing compared to an actual, complex EGS temperature curve (dark blue).

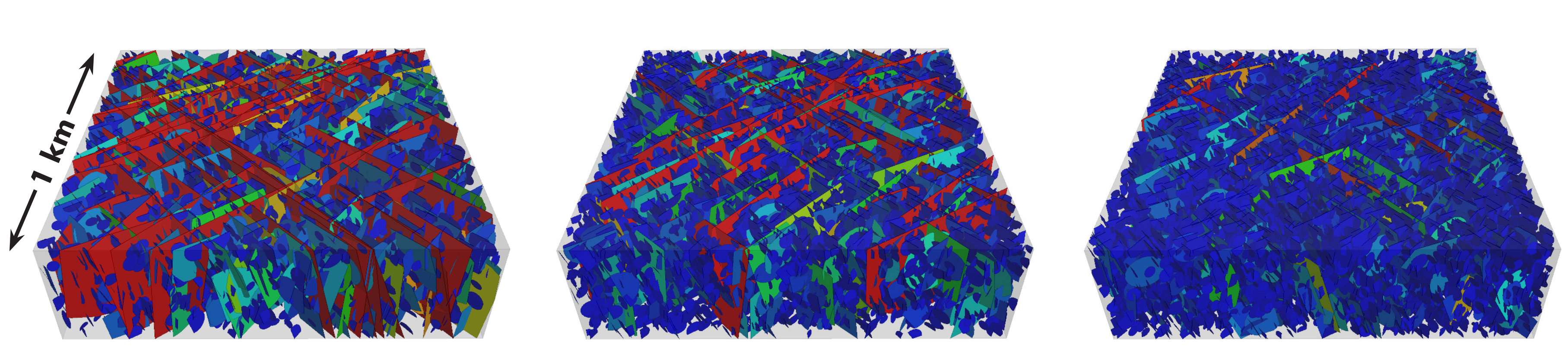


Mathematical model based on Parallel Flow / Gringarten Solution (a) assumes simple geometry with known number of equally spaced fractures, equal distribution of flow, and simplified boundary condition. In reality, heterogeneities result in a complex flow path (b) as shown in this numerical model.



EXPLICIT REPRESENTATION OF FRACTURE NETWORKS

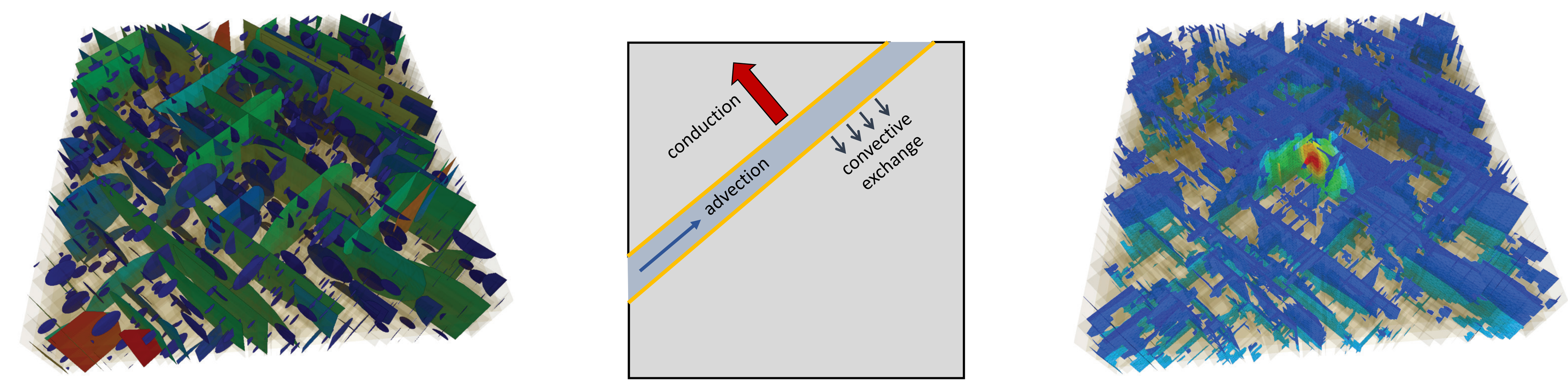
- Three-dimensional DFN can be built deterministically or stochastically based on field observation and statistical characterization of fractures.
- DFN in the model can include hundreds to thousands of fractures, with multiple fracture sets and variable fracture orientations, fracture sizes, shapes, and apertures.



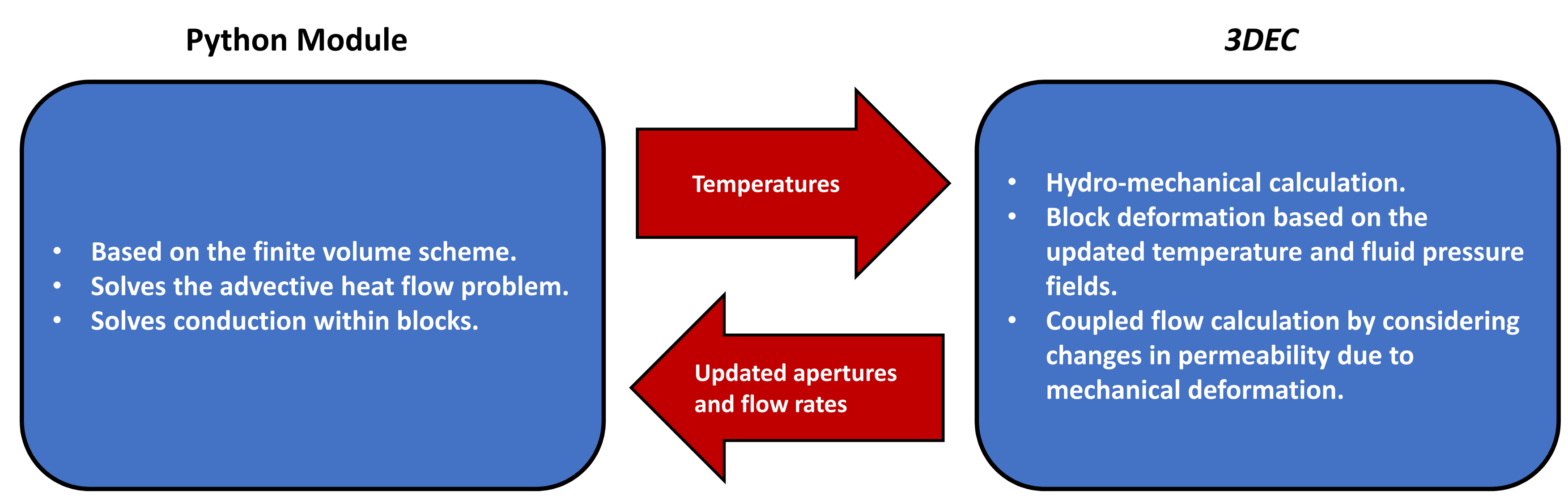
DFNs, colored by joint area, created stochastically assuming power law for fracture size distribution with different exponents (α).

THERMO-HYDRO-MECHANICAL NUMERICAL TOOL

- Three-dimensional software tool, based on the discrete element method, implemented in *3DEC*.
- The main components are discrete fracture simulation, complex thermal calculations, and a discrete mechanical model with matrix (i.e., rock) and fracture fluid flow to provide a completely coupled THM solution.
- For Phase 1, which is focused on proof of concept, the proposed steps will be implemented using the Python scripting language coupled to *3DEC*.



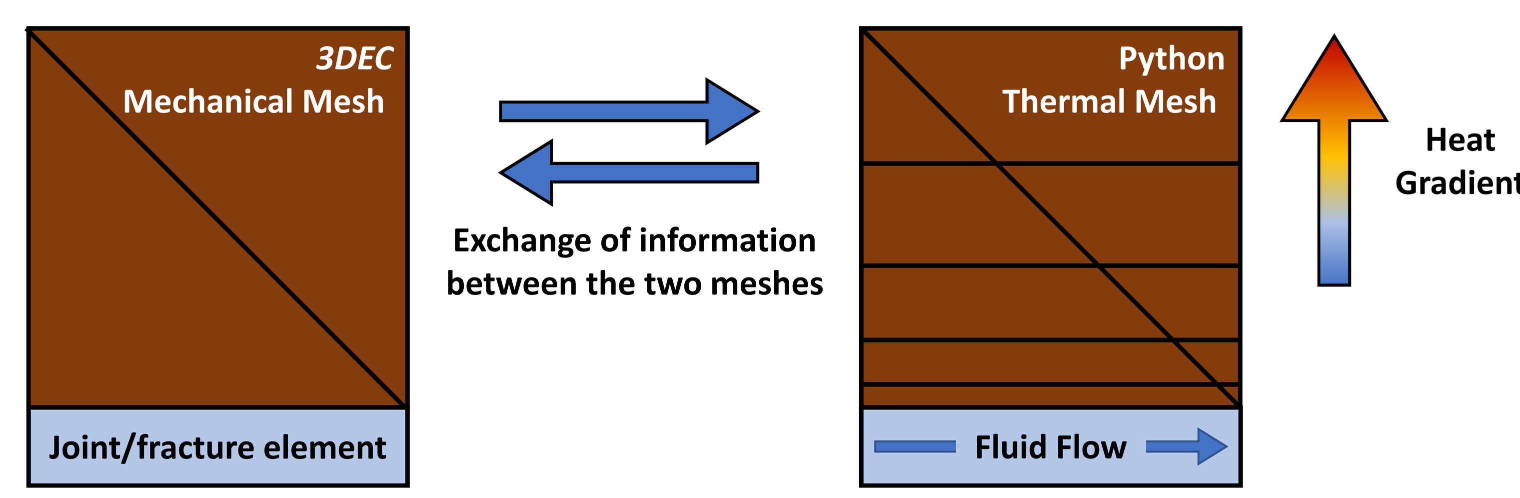
1. Explicit representation of DFNs, faults, and hydraulic fractures.
2. Thermal module computes conduction within rock, fracture fluid advection, and convective exchange along fluid/fracture surfaces.
3. Models are fully coupled for Thermal (T), Hydraulic (H), and Mechanical (M) processes.



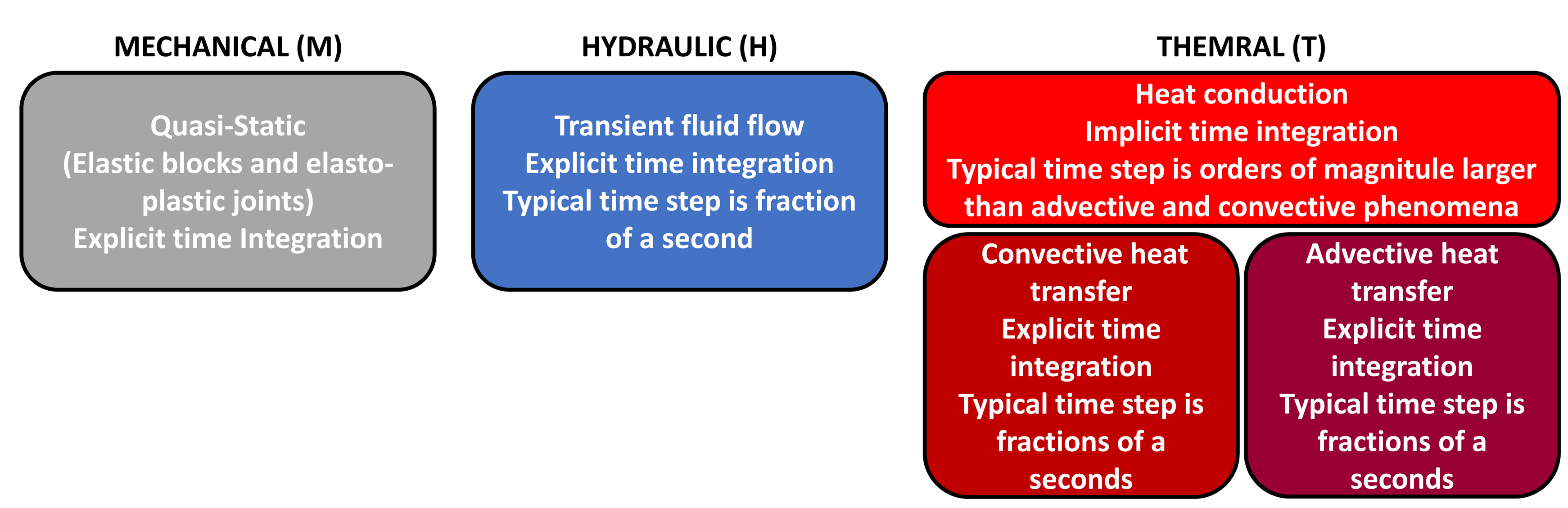
The thermal module will be developed for Phase 1 using the Python scripting language to calculate temperatures in fractured reservoirs and will be coupled with *3DEC* for hydraulic and mechanical calculations.

MAJOR CHALLENGES

- Optimized block discretization for heat conduction to better capture the thermal gradients perpendicular to the faces of discrete elements (*3DEC* blocks) in contact with percolating fluid (i.e., better boundary layer mesh).
- Exploiting both implicit and explicit time integration techniques for solution of physical phenomena with significantly different time scales (seconds to years).



For heat conduction solution using a finite volume module, *3DEC* blocks will be discretized into a mesh that is finer near the fracture and becomes more coarse with increased distance.



THM processes have vastly different time scales which must be reconciled.

FUTURE WORK FOR PHASE II

- Given the size of reservoirs, complexity of DFN, and duration of heat extraction in EGS reservoirs, numerical modeling is computationally intensive and time consuming.
- From a technical perspective, Phase II will focus on optimization steps to make solution computationally more efficient. These include:
  - Developing an implicit time-integration scheme for efficient simulation of transient flow problem.
  - Integration of the developed THM model in *3DEC* source code.
  - Adding coupling of the existing model with chemical processes.
  - Potential possibility of exploiting parallel processing techniques.

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