Boundary conditions and the roots of geothermal systems

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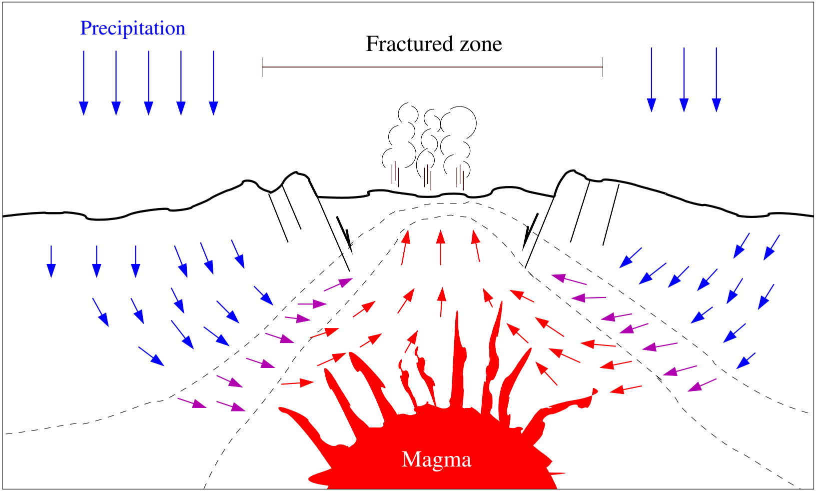
Boundary condition

- Lateral boundary conditions. “Easy”.
  - Fixed temperature gradient at the boundary.
  - Fixed hydrostatic pressure.
- Boundary condition in the top layer.
  - Interaction of precipitation and cold ground water to the geothermal system.
  - Fixed temperature and pressure.
- The boundary condition of the bottom.
  - Interaction with the heat sources of the system.
  - The driving mechanism of the geothermal activity.

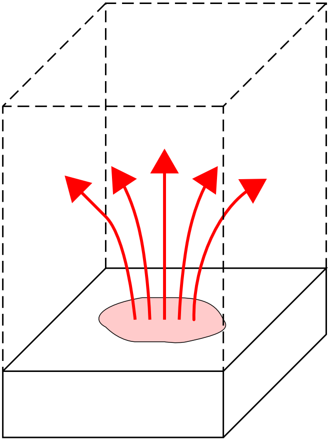
Geothermal system



The bottom of the model

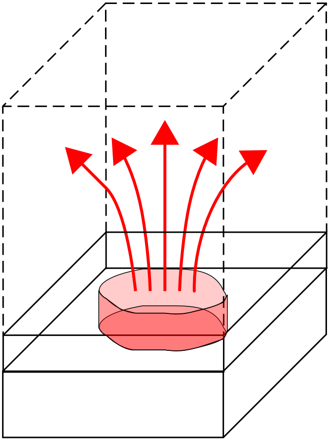
- Depth of the models is limited
  - Knowledge on the roots of the geothermal systems is limited.
  - Most numerical codes cannot handle superheated fluid.
- Boundary conditions describe the roots of the system.
  - Temperature and mass introduced into the bottom layers.
  - Fixed temperature and fixed pressure in the bottom layer. Flow from the bottom into the system.
- Where are the heat sources?
  - How is the heat transfer from magma to fluid?
  - Where does it occur?

Dealing with the bottom – Constant pressure



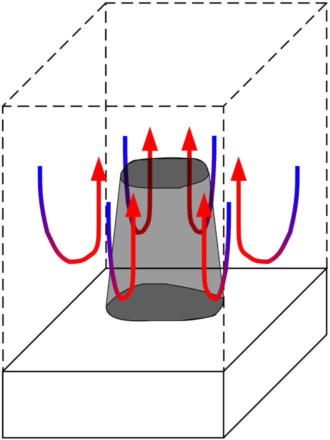
- Constant pressure and temperature in bottom layer.
- Permeable areas in the bottom layer – Potential difference drives the flow.
- Optimistic approach – drawdown due to production increases inflow.
- All heat exchange between intrusions and water takes place below the model.

Dealing with the bottom – Constant inflow



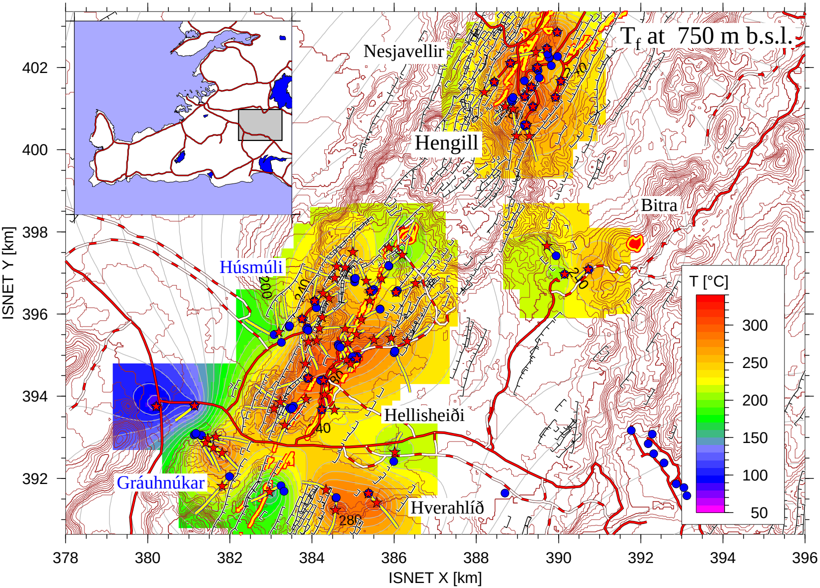
- Constant pressure and temperature in the bottom layer.
- Heat and mass introduced to the second deepest layer.
- Conservative approach – inflow independent of drawdown.
- Heat exchange takes place partly in the second deepest layer.

Heat sources at shallower depths



- Constant pressure and temperature in bottom layer with low permeability.
- The heat sources is located in the model.
- All heat exchange takes place within the model.
- Limited or no mass flow from below.

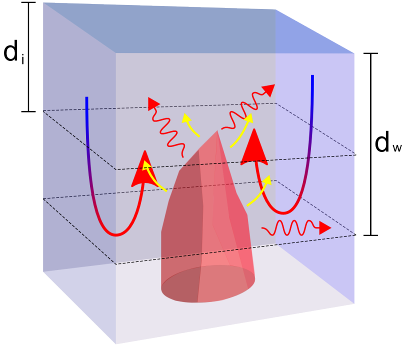
An example – Formation temperature in Hengill



An example – Formation temperature in Hengill

- Sharp temperature anomalies. Local maxima in formation temperature and colder regions in between.
- This might indicate local heat sources at shallower depths.
- The Hengill area is an active volcano – Geothermal activity very dynamic.
- The reservoir is regularly loaded with heat by formation of new dykes.

Coupling to the heat source



Heat source: Cooling/solidifying intrusion in the crust.

- Heat transferred by conduction and magmatic gases.
- Depths (d_i and d_w) needed to be estimated.
- Origin and movement of the water.
- Model depth range (d_m):
  - Const. pressure bottom: $d_m < d_i$
  - Const. inflow bottom: $d_m > d_i$, $d_m \approx d_w$
- Impermeable bottom ($d_m \geq d_w$)

Conclusions

- Lateral and top boundary conditions are relatively easy to postulate.
- The depth range of numerical geothermal models is limited and bottom boundary conditions are used to avoid modeling the roots of the system.
- Depth range of the water circulation and the depth of the hot bodies interacting to the circulating water are not fully known.
- Better understanding on the magma to water heat transfer and codes that can handle supercritical conditions are essential for comprehensive geothermal modeling.