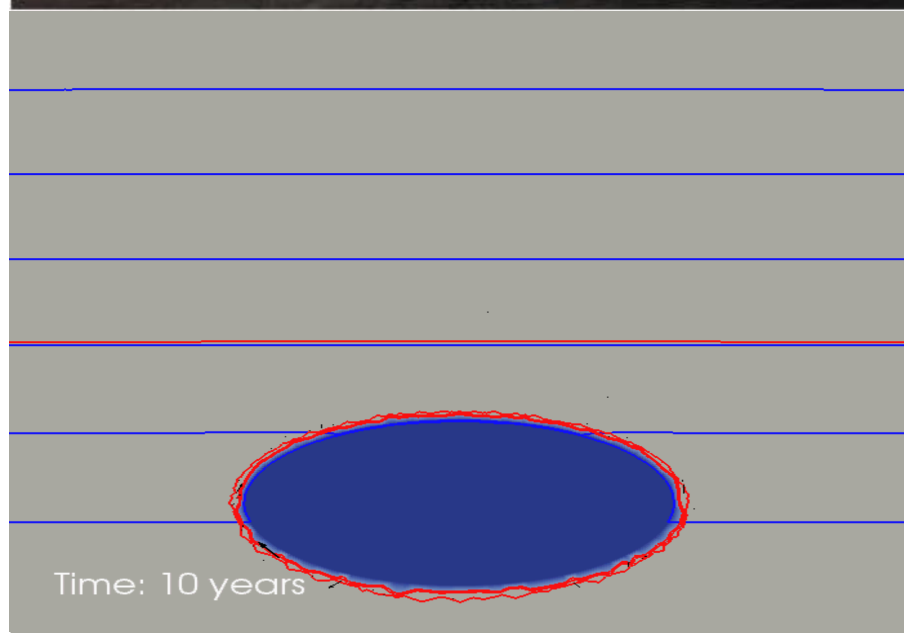
# Modeling the evolution of volcanic geothermal systems with CSMP++

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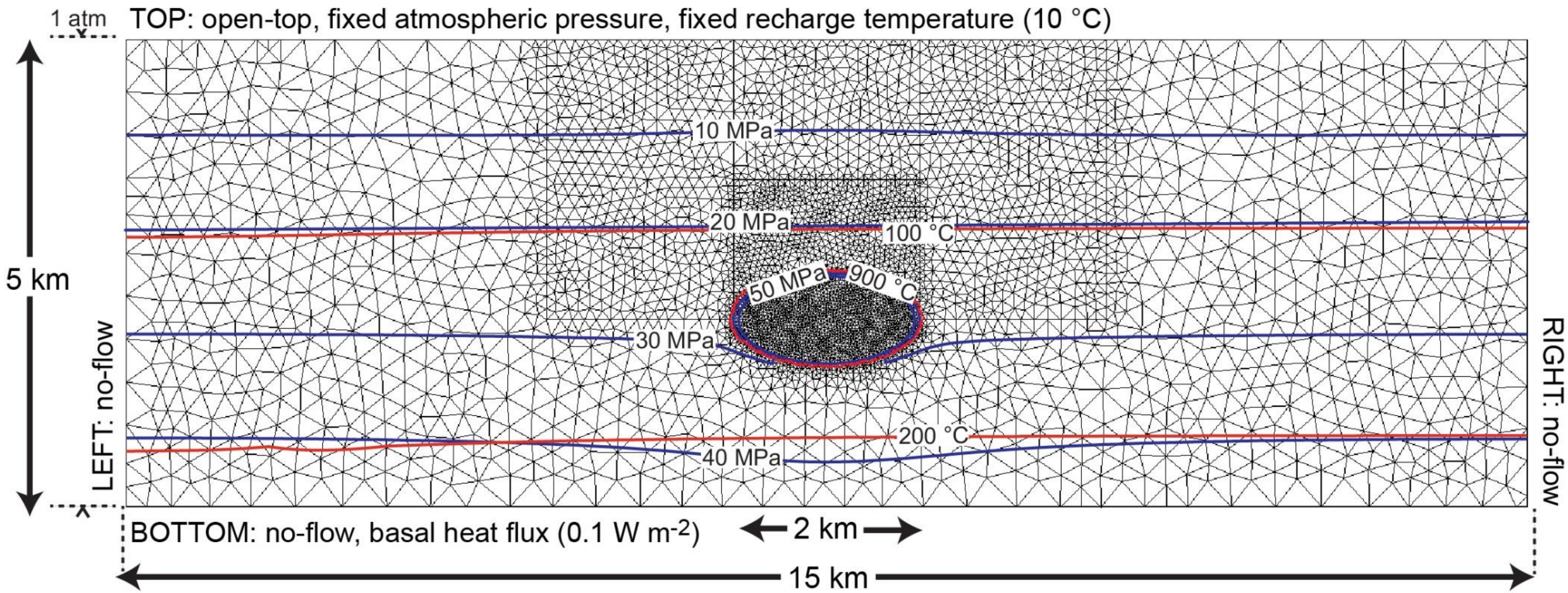
Special thanks to:
Thomas Driesner (ETH Zurich)
Philipp Weis (GFZ Potsdam)

# Outline:

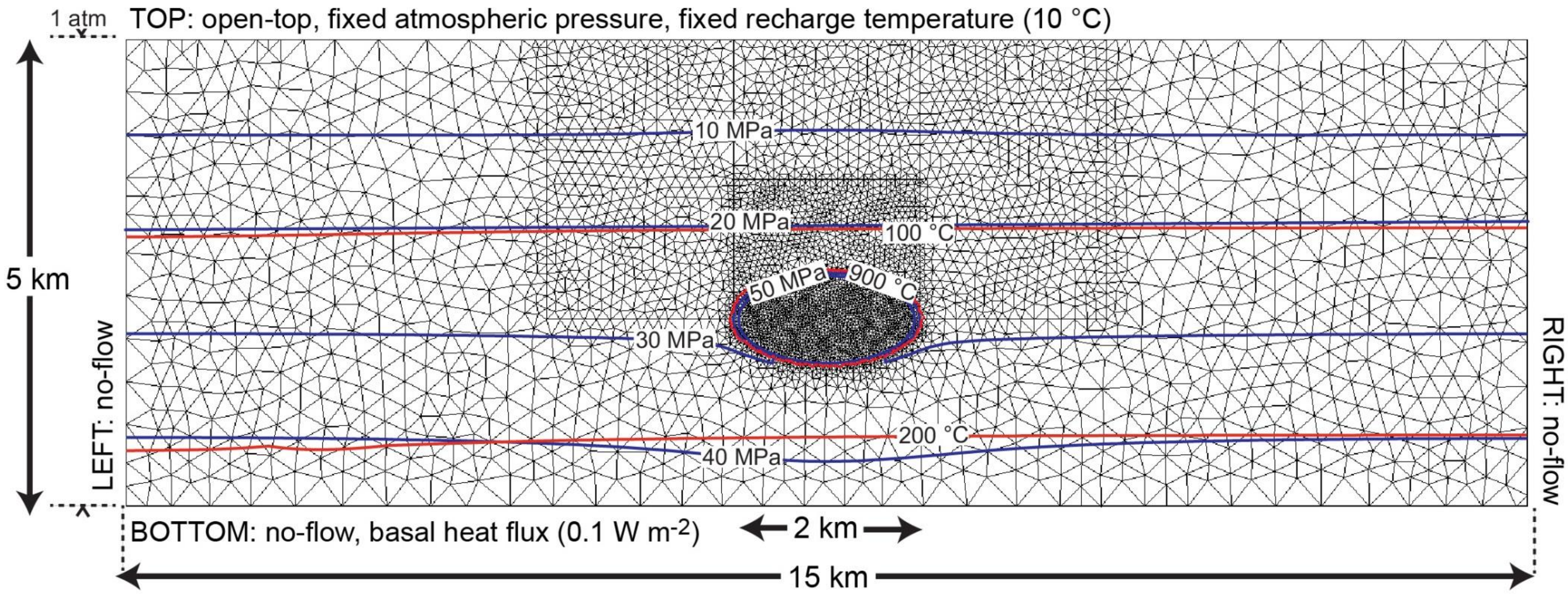
- Include a magmatic heat source in hydrologic models
- Simulate formation of supercritical geothermal resources
  – Published in *Nature Communications* (2015)
- Investigate how geology controls thermal structure
  – Published in *Geothermics* (2016)
- Compare meteoric- and seawater-recharged systems
  – Published in *Geophysical Research Letters* (2017)

# Model set-up



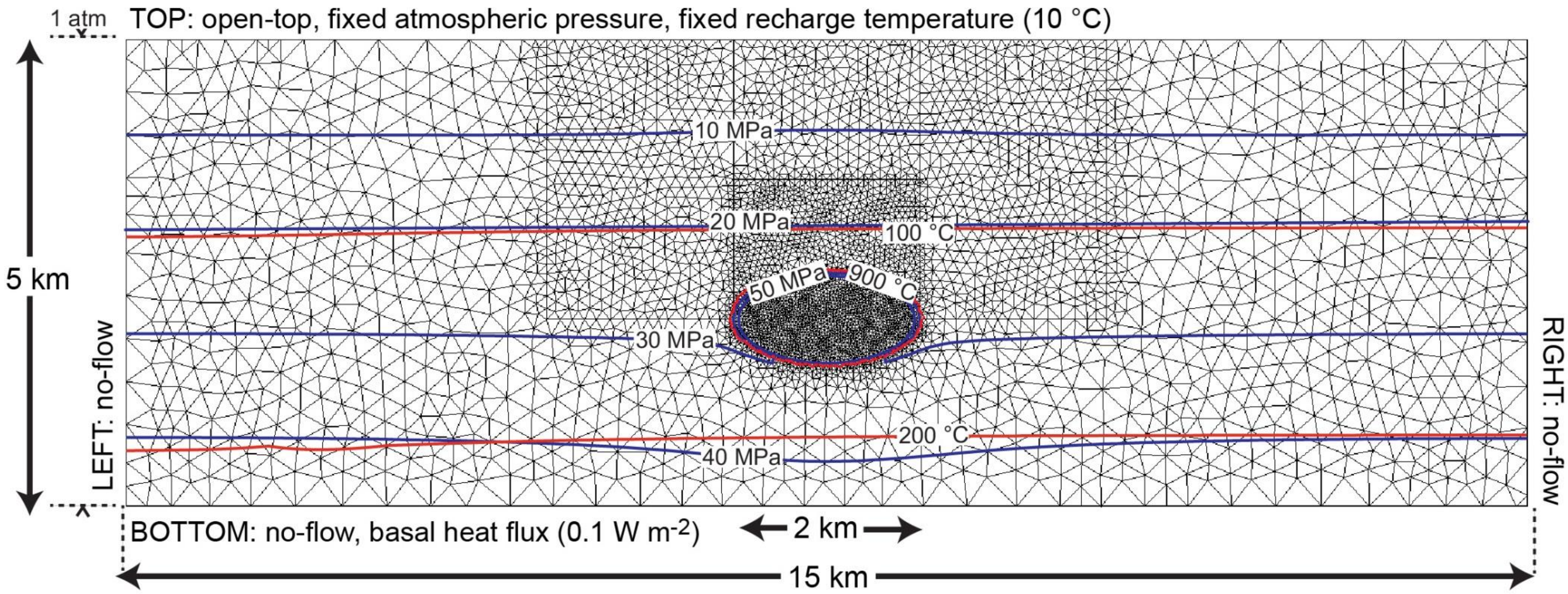

- Complex Systems Modeling Platform (CSMP++)
  - 2D porous media
  - Homogenous/isotropic permeability
  - Temperature-dependent permeability ($T_{BDT}$)

# Model set-up



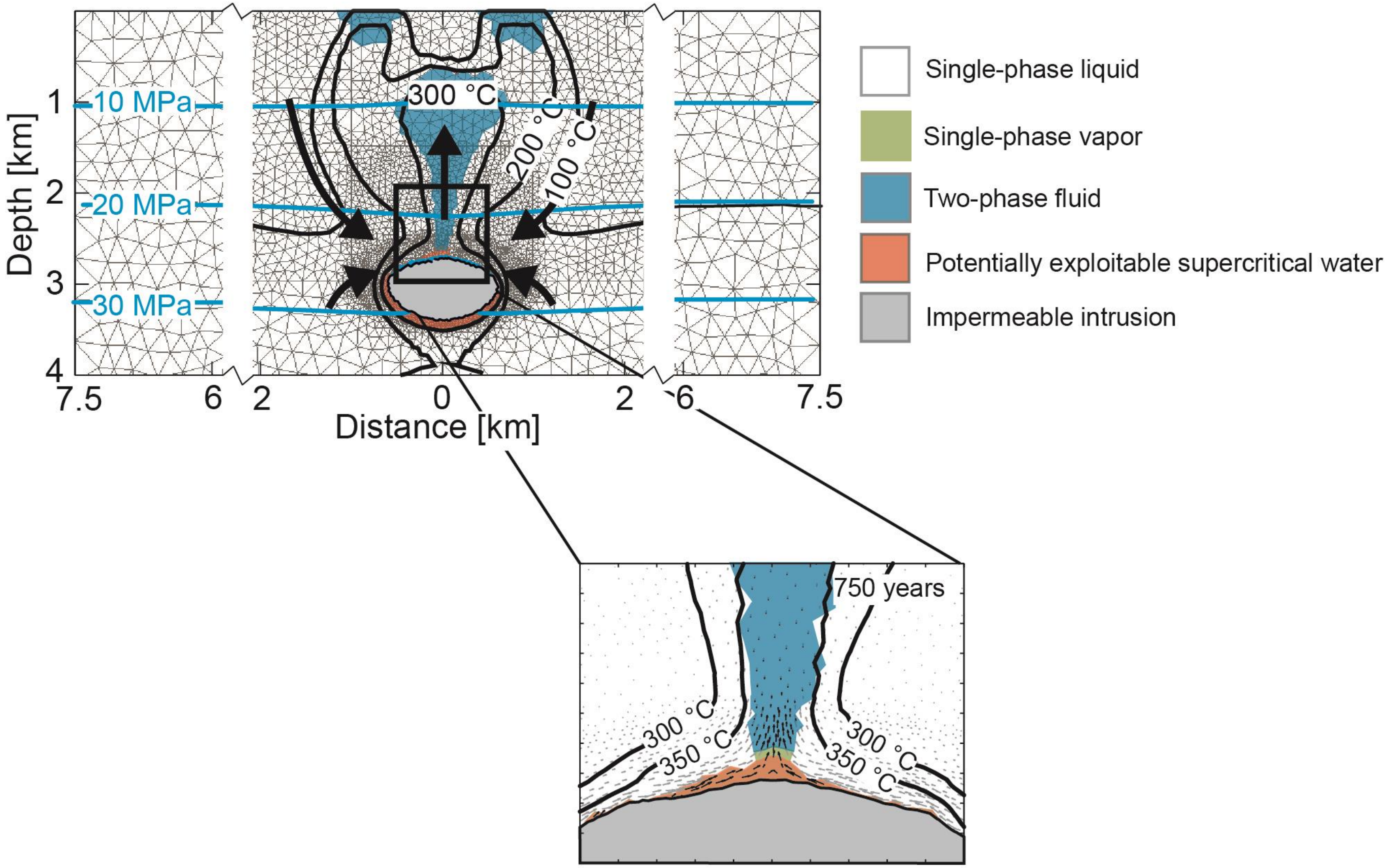

- Governing equations
  - Two-phase Darcy's law
  - Mass conservation
  - Energy conservation (enthalpy-based)

# Model set-up



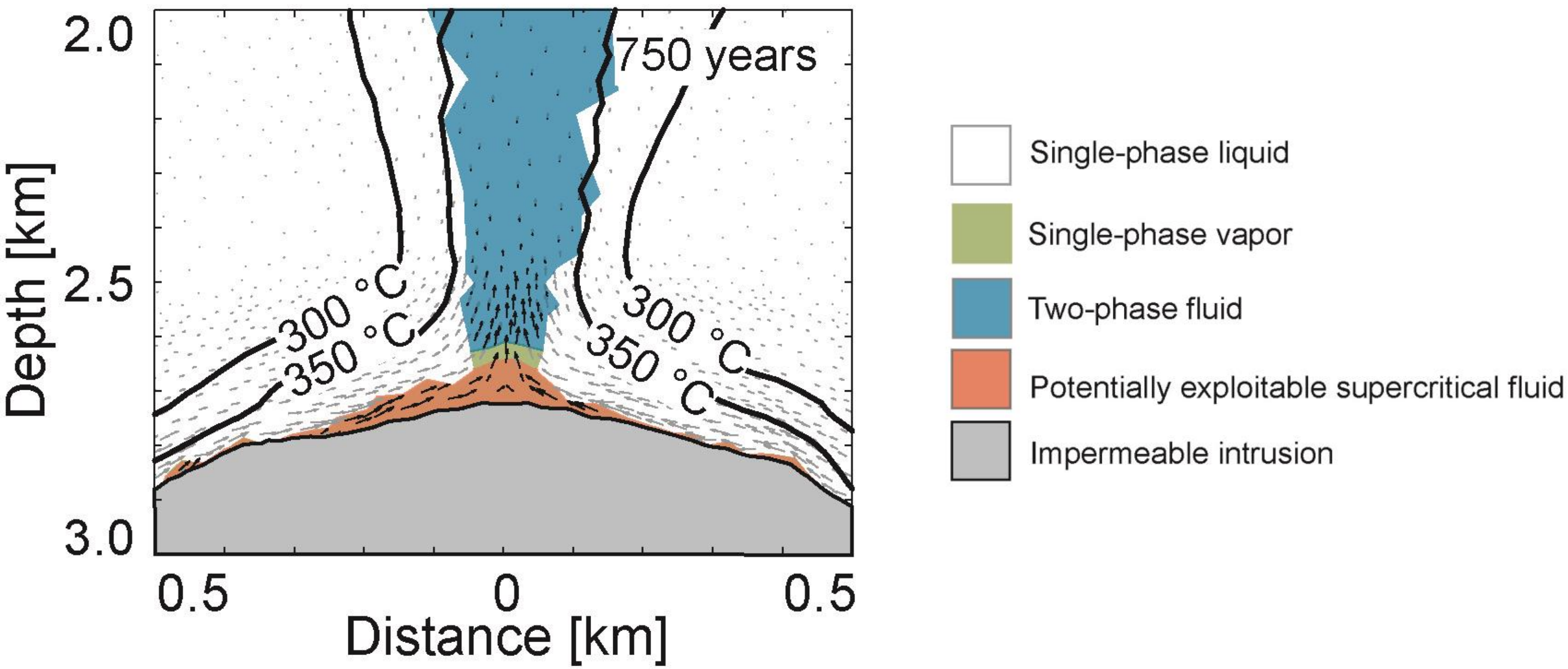

- Control Volume-Finite Element Numerical Scheme

# Example results - high permeability




Scott et al., 2015, *Nature Communications*

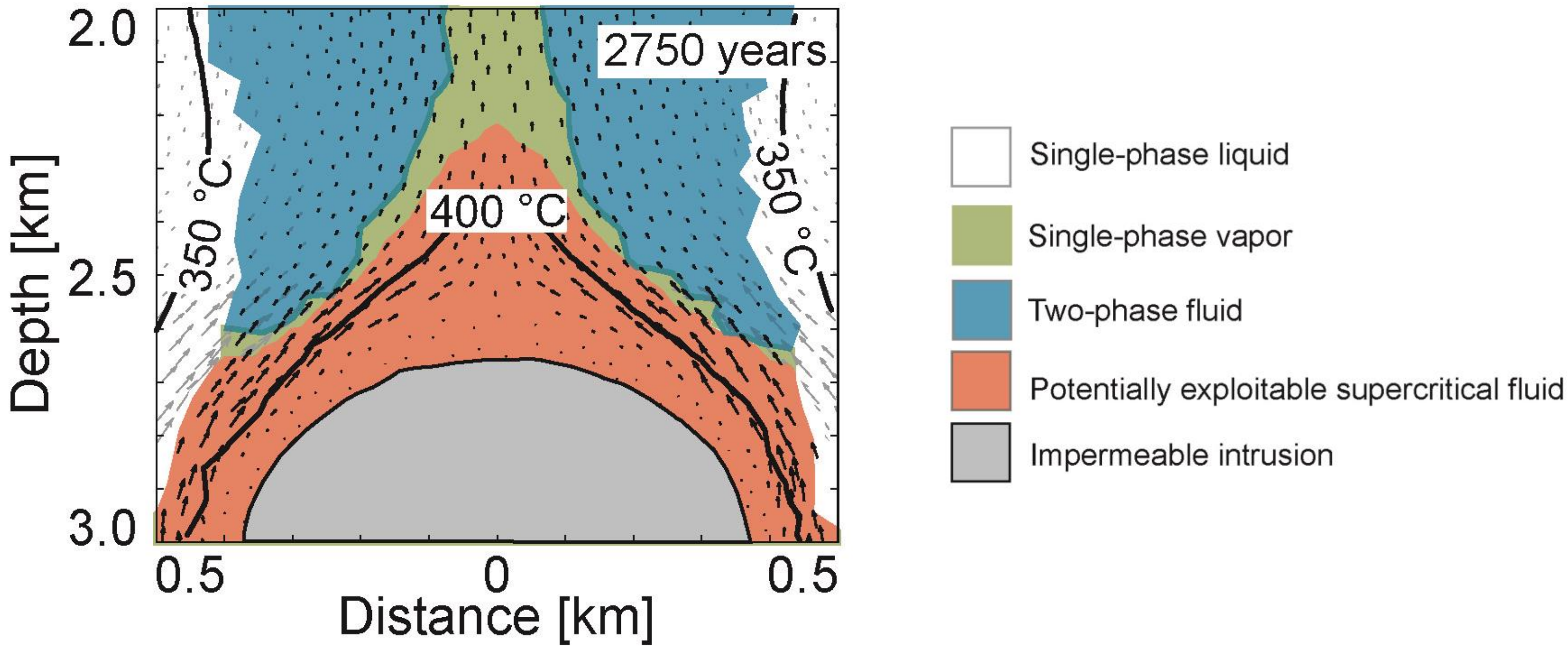
# High permeability, $T_{BDT}$ = 450 ºC




- 'Potentially exploitable supercritical resources' defined as:
  - $T$ > 373.9 ºC, $h$ > 2.086 MJ/kg, $k > 10^{-16}$ m$^2$

Scott et al., 2015, *Nature Communications*

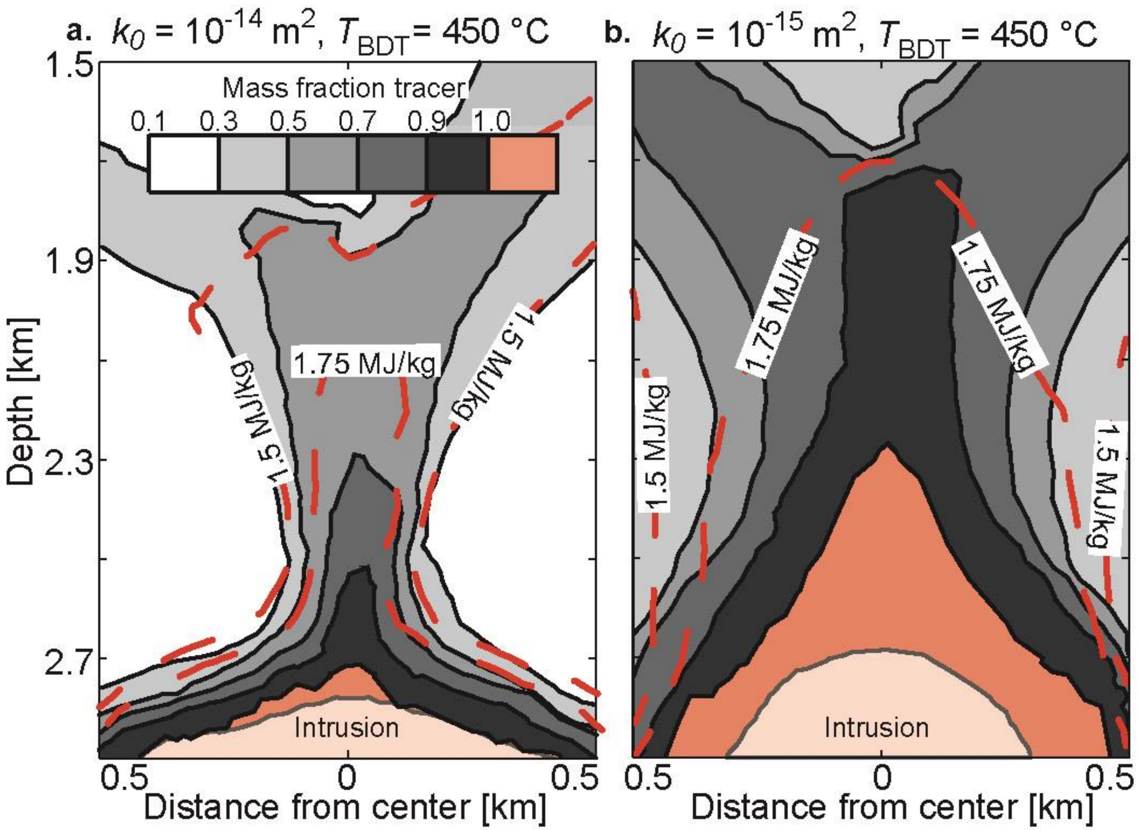
# Intermediate permeability, $T_{BDT}$ = 450 ºC




- Supercritical resources much larger in spatial extent and show hotter temperatures

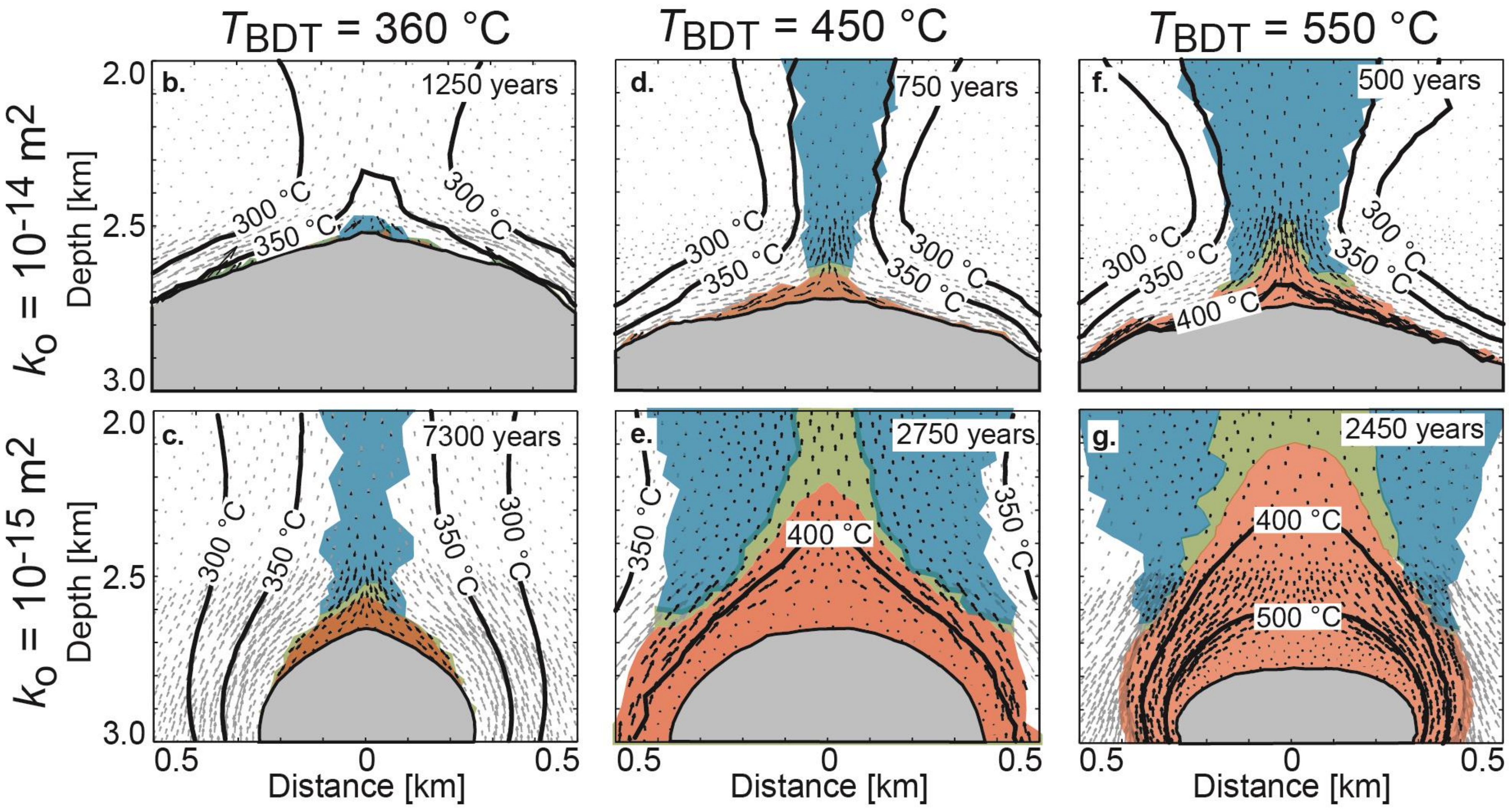
Scott et al., 2015, *Nature Communications*

# Permeability controls fluid mixing




Conventional geothermal resources result from mixing of ascending supercritical and cooler circulating waters

Scott et al., 2015, *Nature Communications*

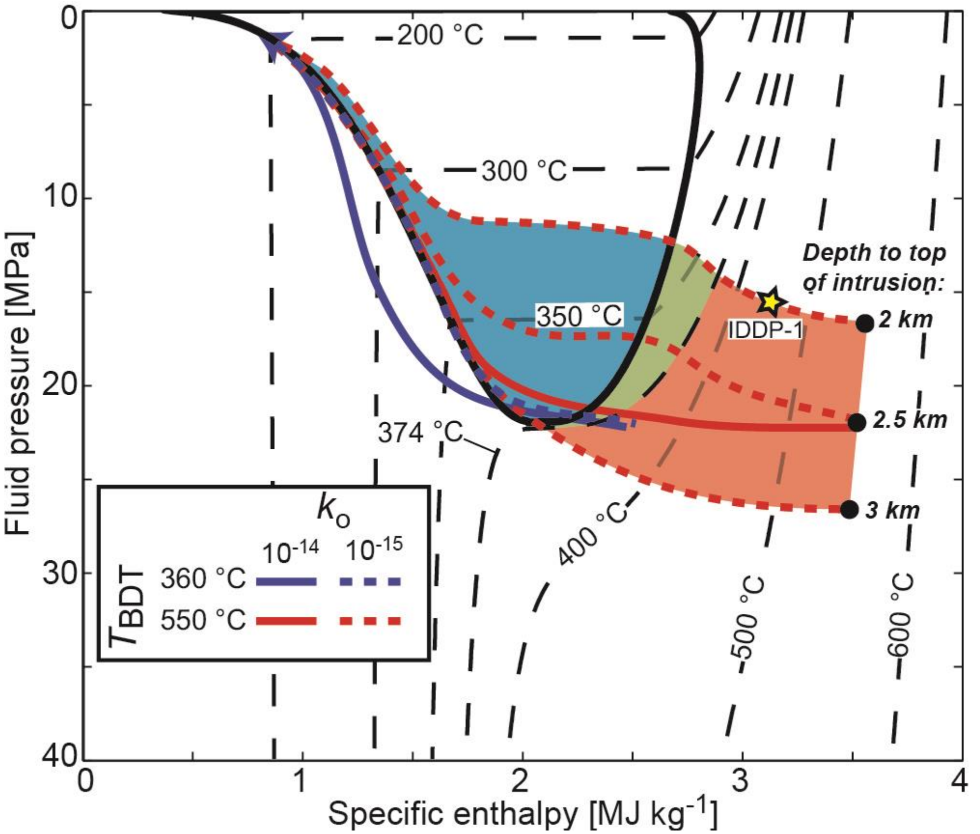



Scott et al., 2015, *Nature Communications*

# Conclusions: Meteoric water systems

Larger, hotter supercritical zones ($T$ > 374 ºC, $h$ > 2.083 MJ kg$^{-1}$) favoured by:

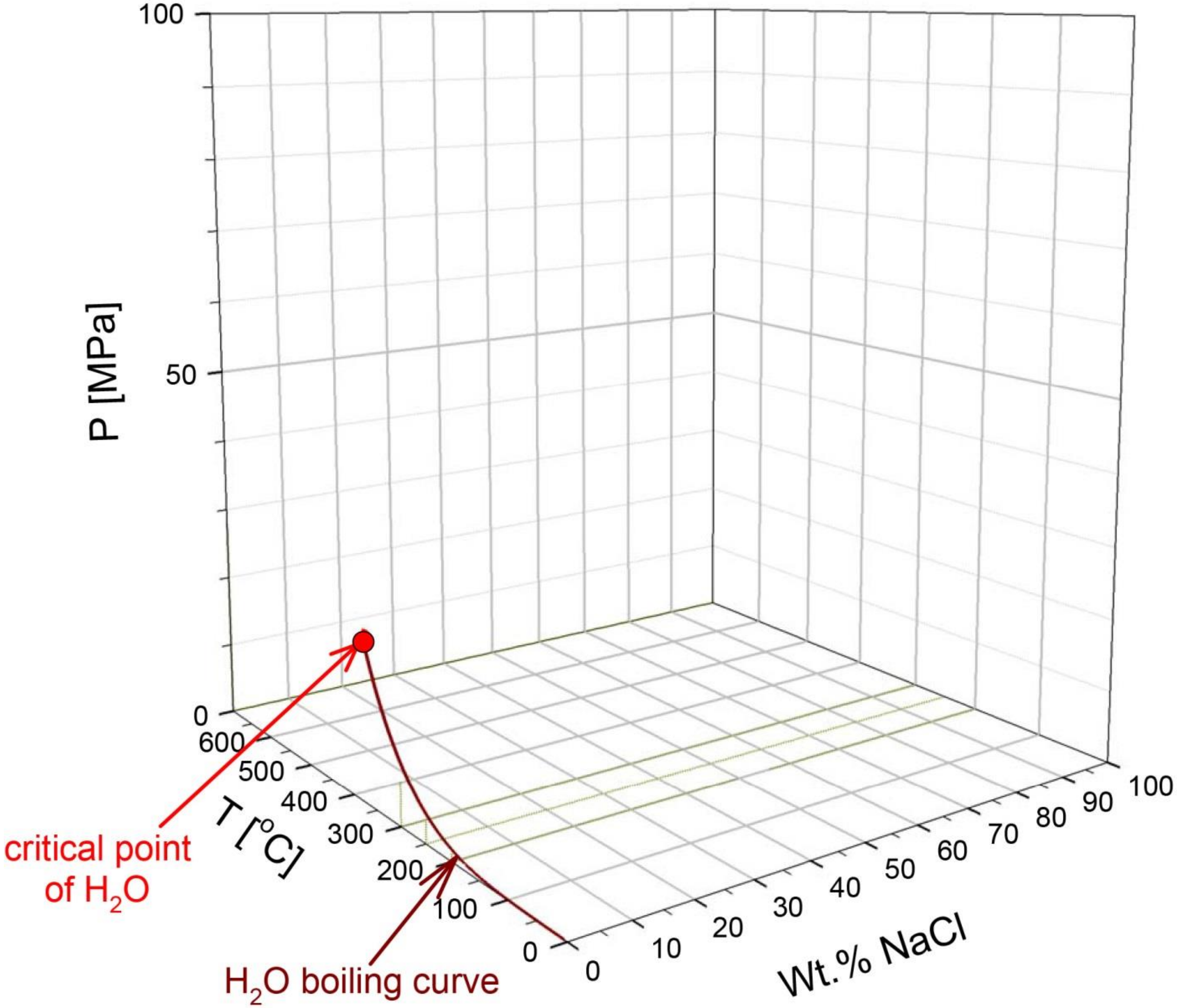
- Permeability near $10^{-15}$ m$^2$
- *High* $T_{BDT}$ (>400 ºC)
- Shallow intrusion depth (2-3 km)




- **IDDP-1**: Measured reservoir conditions match predicted values assuming appropriate values for the geologic controls

Scott et al., 2015, *Nature Communications*

# The system $H_2O$-NaCl




Driesner & Heinrich, *GCA*, 2007

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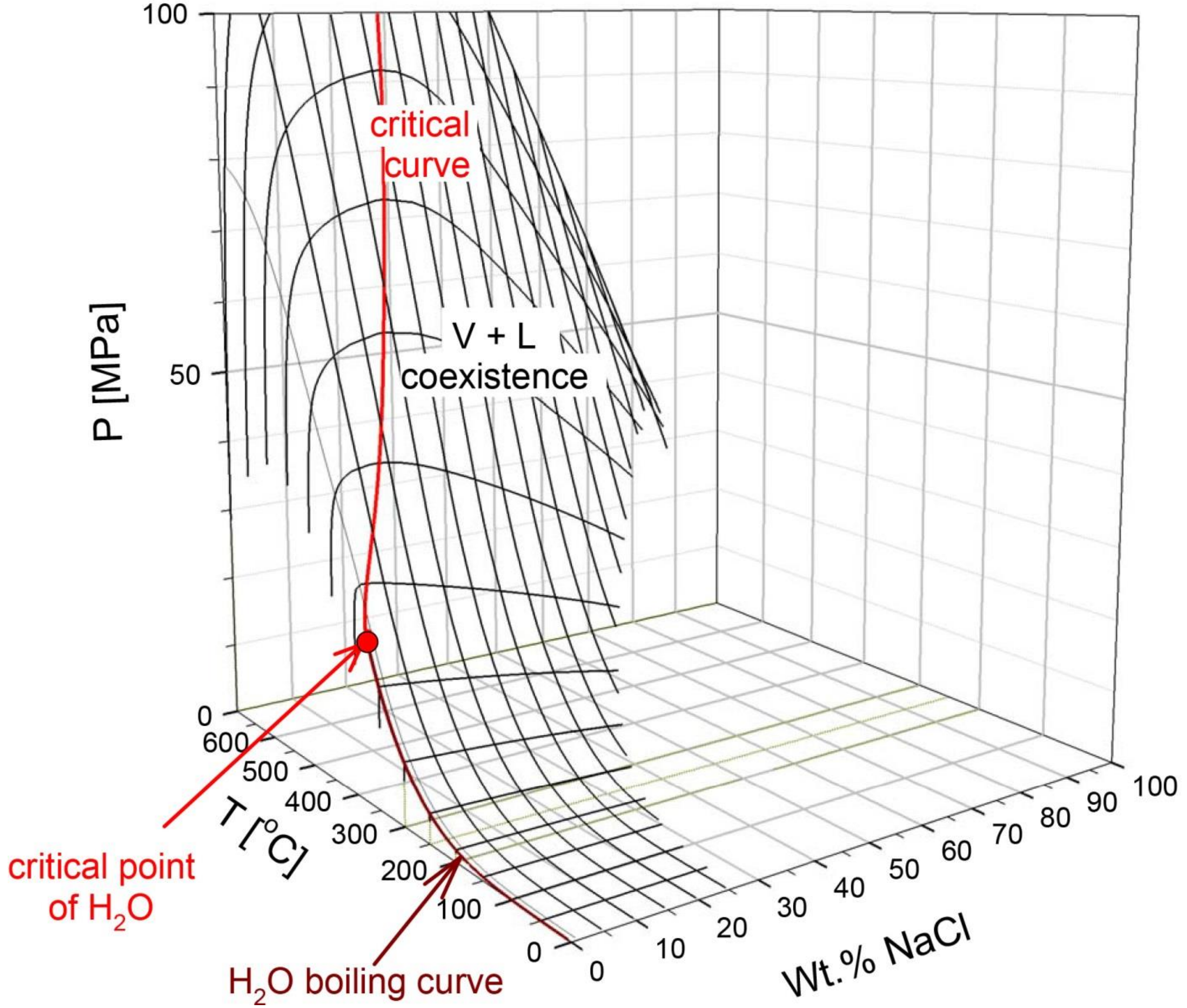


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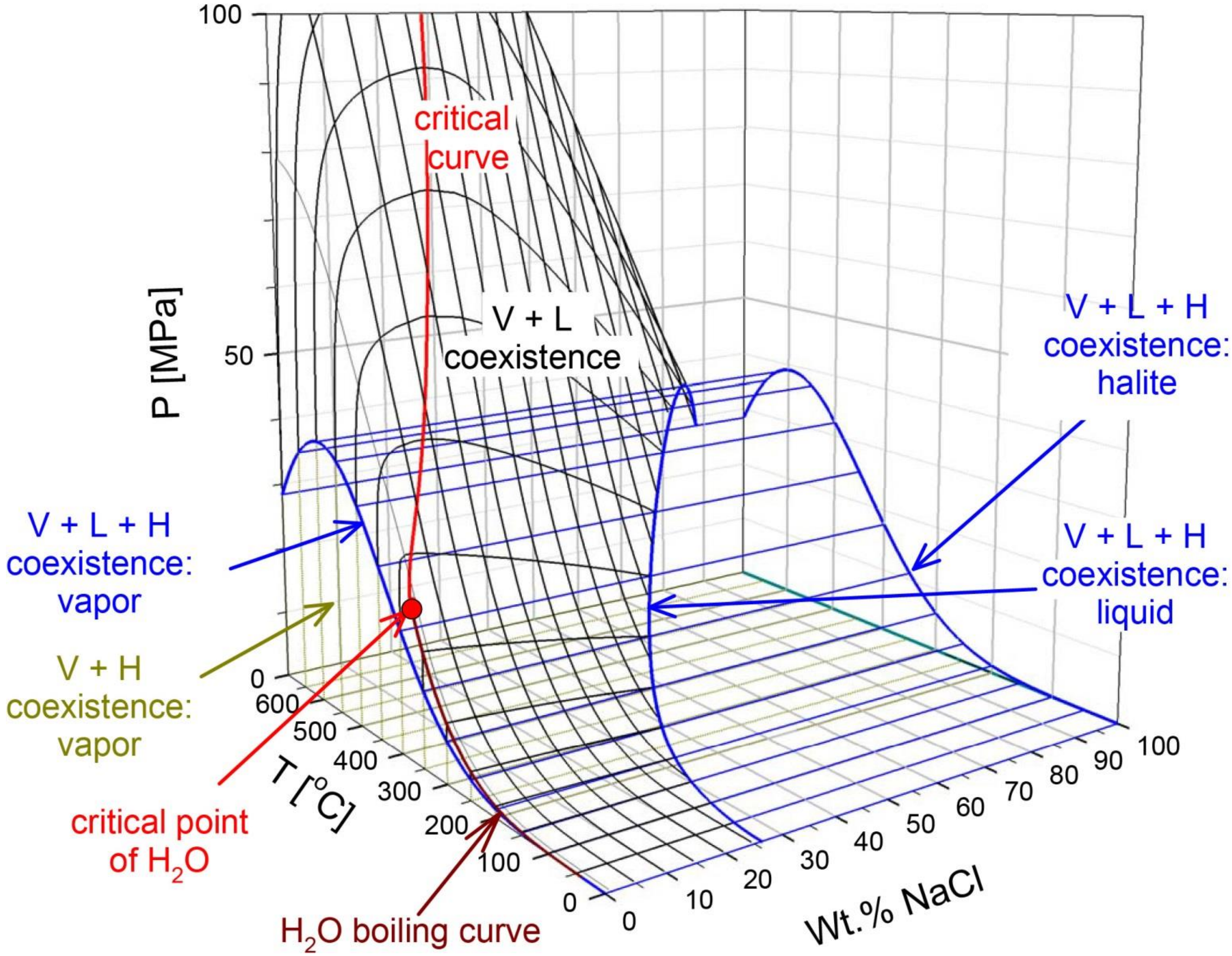
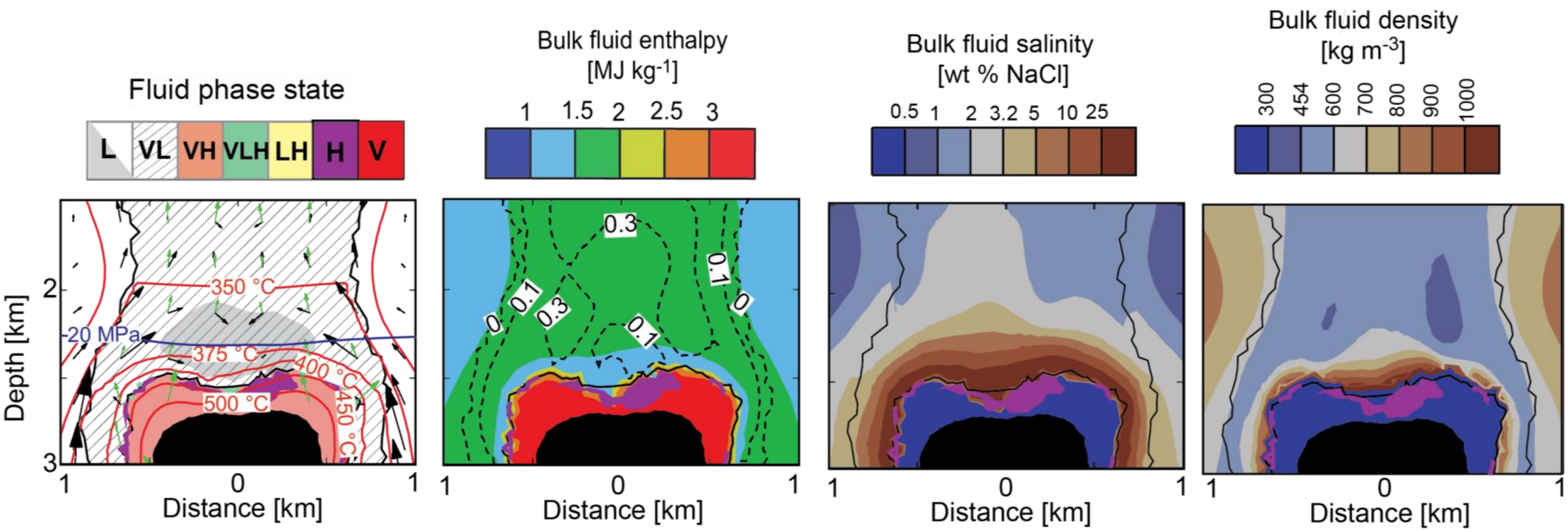



Driesner & Heinrich, *GCA*, 2007

# **Shallow intrusion** - Initial salinity 3.2 wt %, $k_o = 10^{-15}$ m$^2$, $T_{BDT}$ = 550 ºC




Systems develop deep hypersaline brines underlain by halite-filled pore space

Scott et al., 2017, *Geophysical Research Letters*

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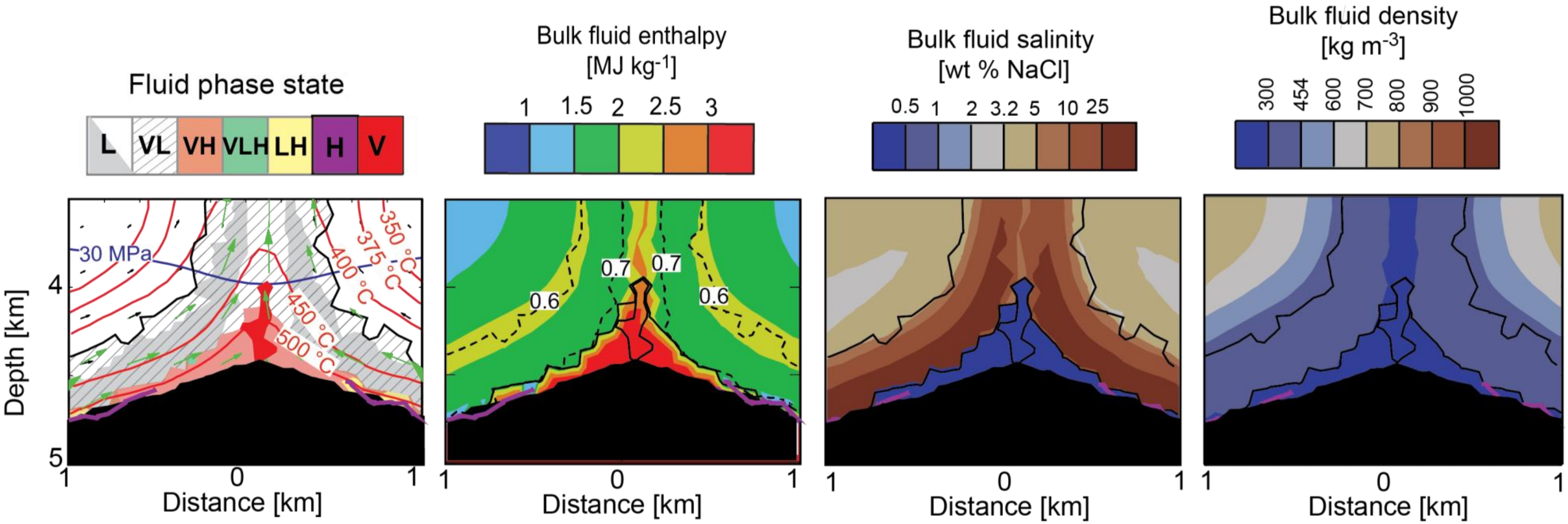
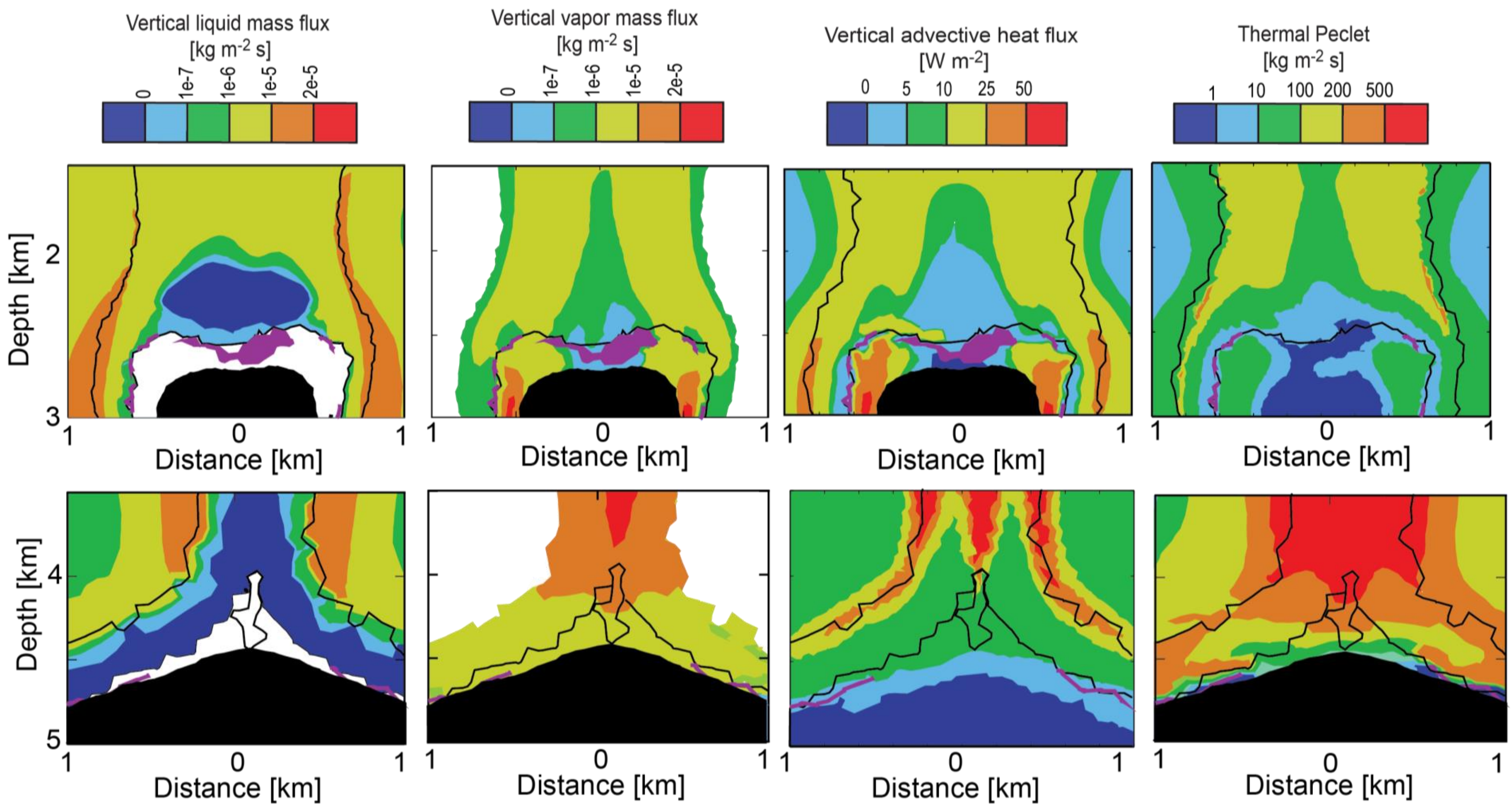



Halite-undersaturated vapor above center of intrusion

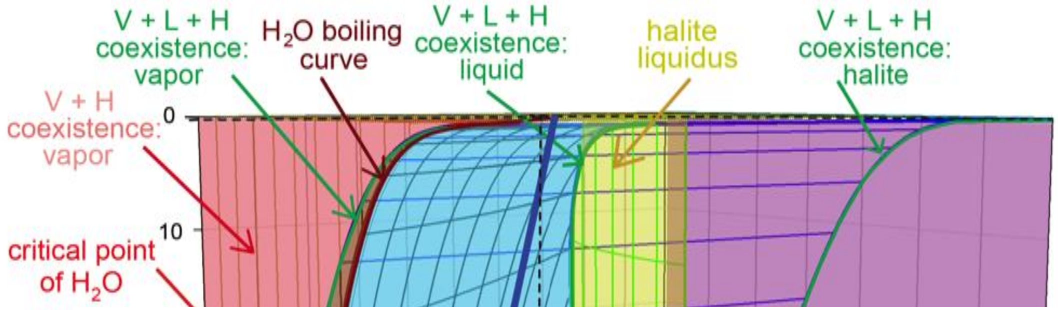
Scott et al., 2017, *Geophysical Research Letters*

# Shallow (2-3 km) depth boiling zones with descending hypersaline brines underlain by halite-filled pore space insulate shallow intrusions




Deep condensation zones maximize vapor mass fluxes and overall heat transfer

# Intrusion depth controls phase separation style




# Thanks for listening!