Modelling the fluid and heat flows below the TVZ: the challenges of fluid properties

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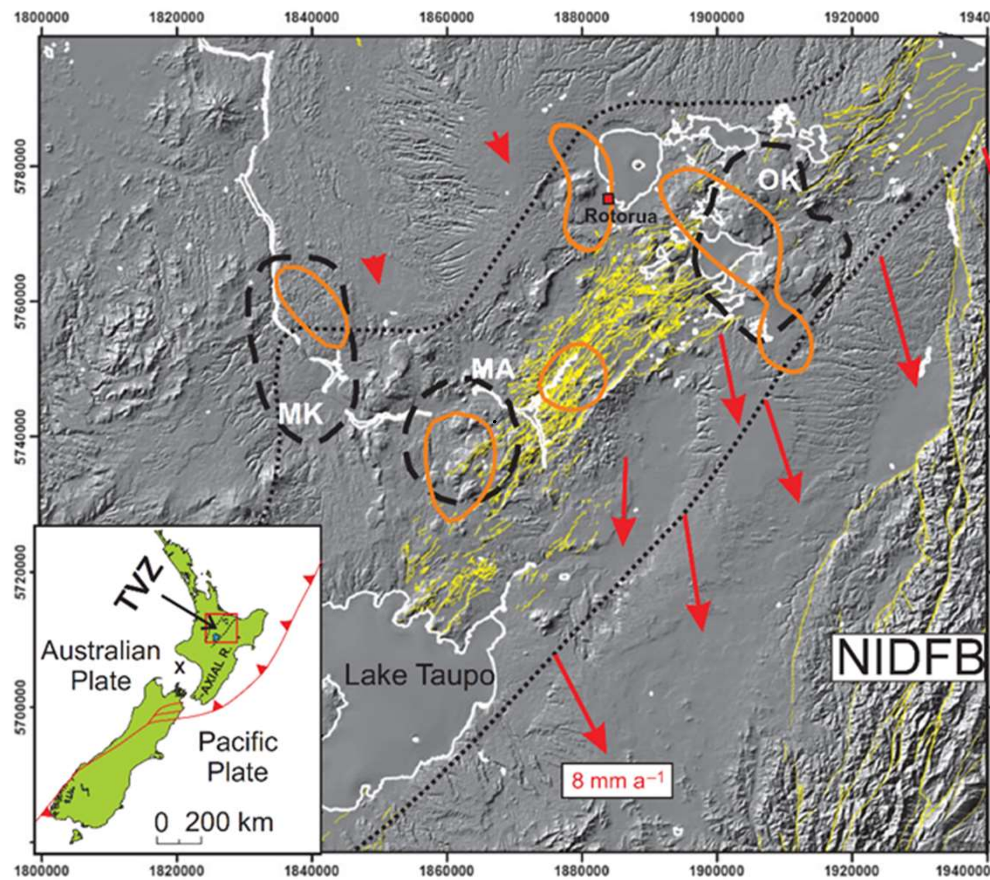
Taupo Volcanic Zone (TVZ)

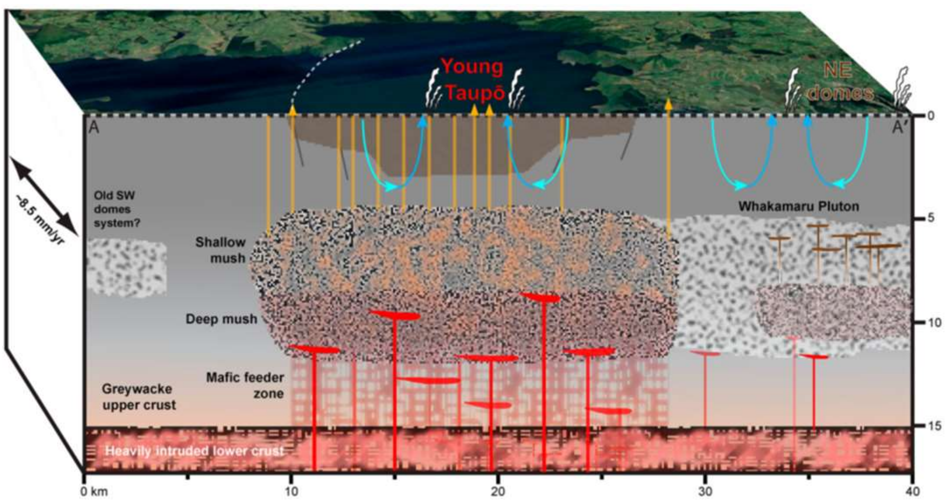
Regional-scale fluid and heat flow modelling with realistic deep heat source (~900ºC, 0.7 W/m^2)

How does the heat get from ~15 km deep to near-surface at 100-300ºC ?

What do super-critical geothermal resources look like ?



Super-critical geothermal resources



Barker et al., NZJGG, 2020.

Shallow magma 'mush' or a magma intrusion is likely to underlie super-critical resources in the TVZ

Temperatures of ~900ºC possible at < 5 km depth

Vigorous shallow convection and boiling is challenging to model

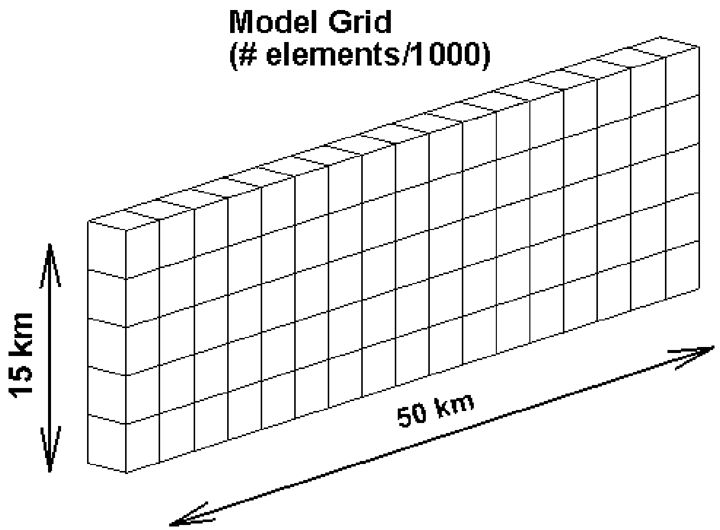
Fluid and heat flow modelling for geothermal

TGNS is an in-house fluid and heat transport research code

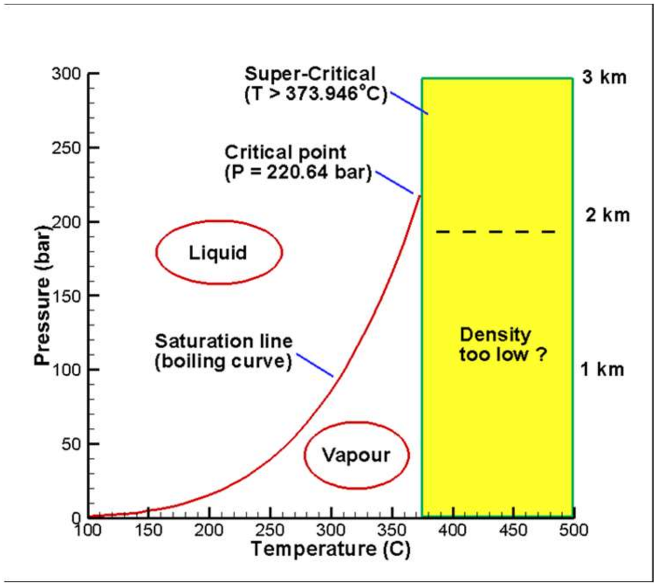
Similar 'fully implicit' algorithm to Tough2 but with extended thermodynamics

Solves the equations describing how water and heat move together in the Earth's crust

Uses IAPWS-95 and can handle pressures and 'magmatic' temperatures at base of crust



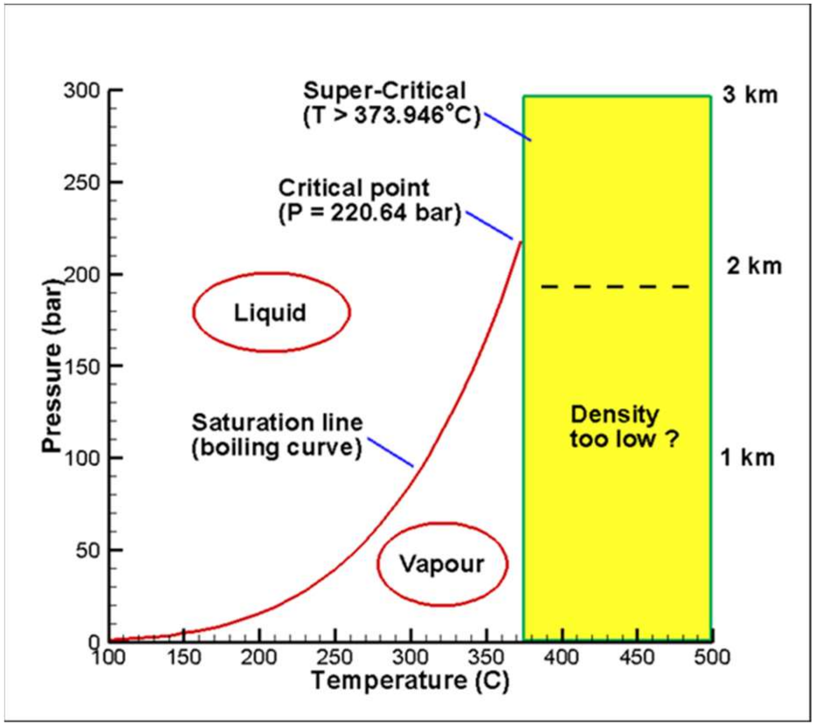
Properties of (liquid) water

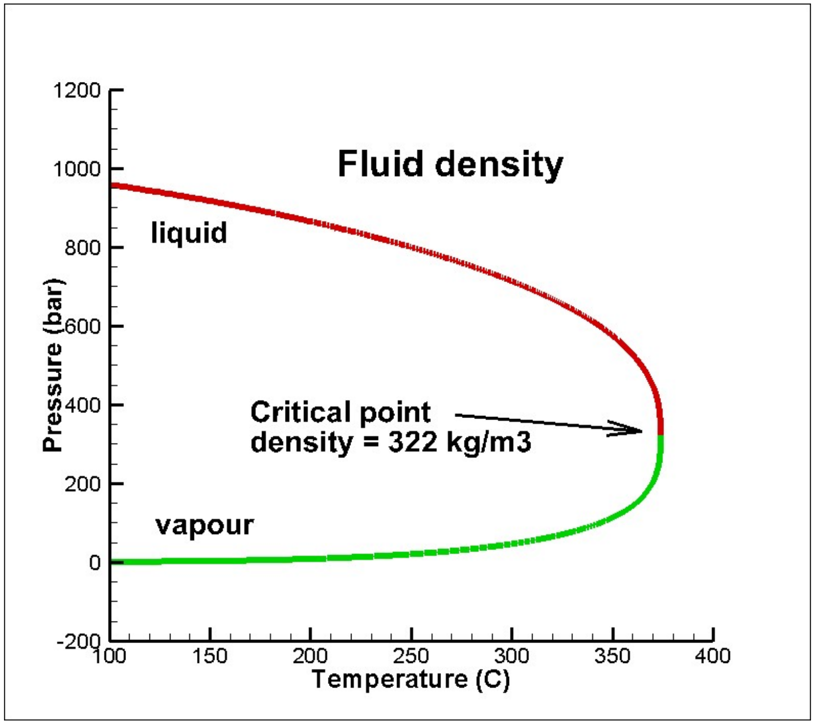


	Atmospheric conditions 1 bar, 20ºC	‘Normal’ geothermal 100 bar, 300ºC	Super-Crit. geothermal 300 bar, 380ºC	Base of crust (15km) 1000 bar, 900ºC
Density	998 kgm^{-3}	715	534	198
Enthalpy	84 $kJkg^{-1}$	1343	1838	4056
Dyn. viscosity	1×10^{-3} Pa.s	9×10^{-5}	6×10^{-5}	5×10^{-5}

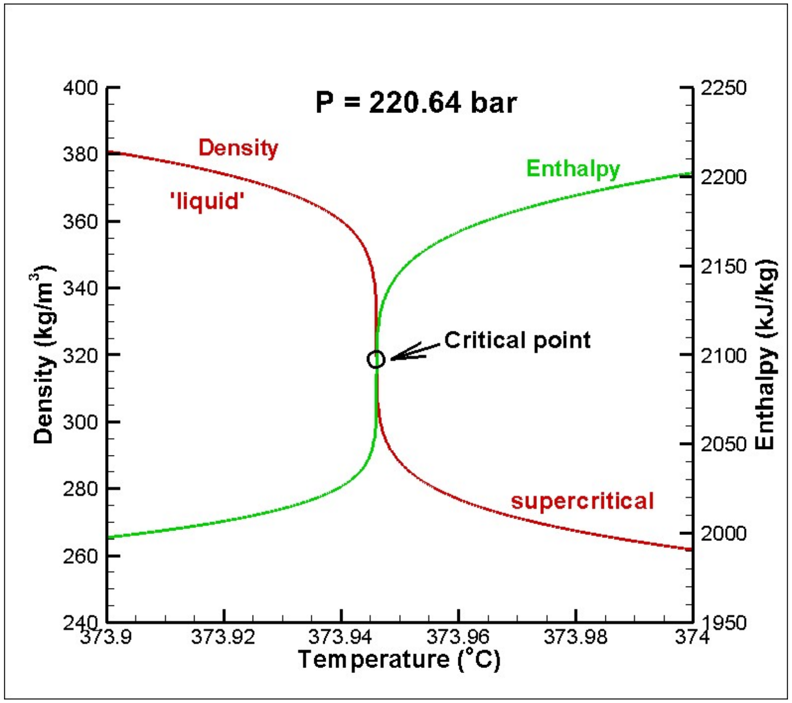
Differences between hot and cold fluid properties make for challenging modelling

Saturation line and liquid/vapour phase properties





Phase properties near the critical point



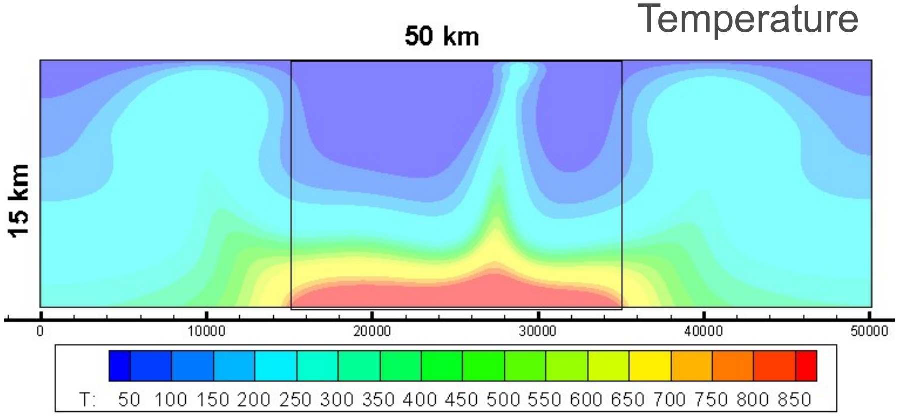
Sub-critical: single- and two-phase fluids behave ‘normally’

Near-critical point: two-phase fluids very different from ‘normal’ and steep gradients difficult to deal with numerically

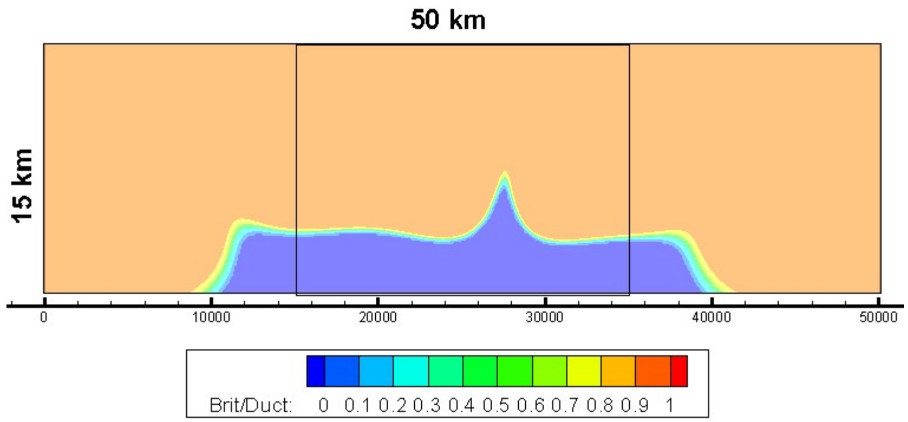
Better high-temperature phase changing algorithm remains elusive

Examples of model results

Temperature



Brittle-Ductile transition (BDT)

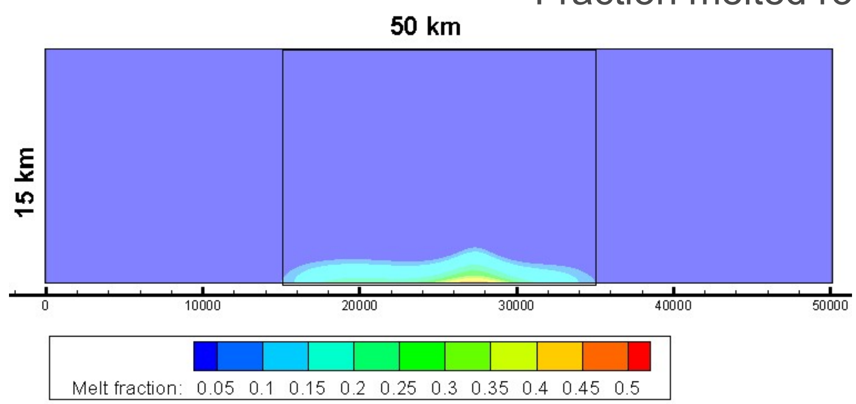


No boiling at surface and the ‘geothermal systems’ are too cool

B-D transition is too deep

Too much melted rock

Fraction melted rock



Conclusions: IAPWS-95 formulation

IAPWS-95 formulation uses density and temperature as independent variables
Pressure is more ‘intuitive’ than density. Requires finding pressure corresponding to density and temperature (iterative, expensive and prone to convergence problems)

Water properties must be ‘mathematically’ smooth and continuous functions of pressure (density) and temperature
IAPWS-95 has largely fixed the smoothness problems in earlier formulations, except (possibly) on the saturation line near critical point

Conclusions: modelling/algorithms

High-temperature boiling (say > 330ºC) is difficult to achieve
This occurs above *any* magma/mush body and so it is important to know how to handle it…

In the near-super-critical point region the gradients of thermal properties of water with respect to P & T are large and cause spurious results and lack of convergence
Maybe avoid implicit solution methods ??