Modeling Supercritical Systems With Tough2: Preliminary Results Using The EOS1sc Equation Of State Module *

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Summary

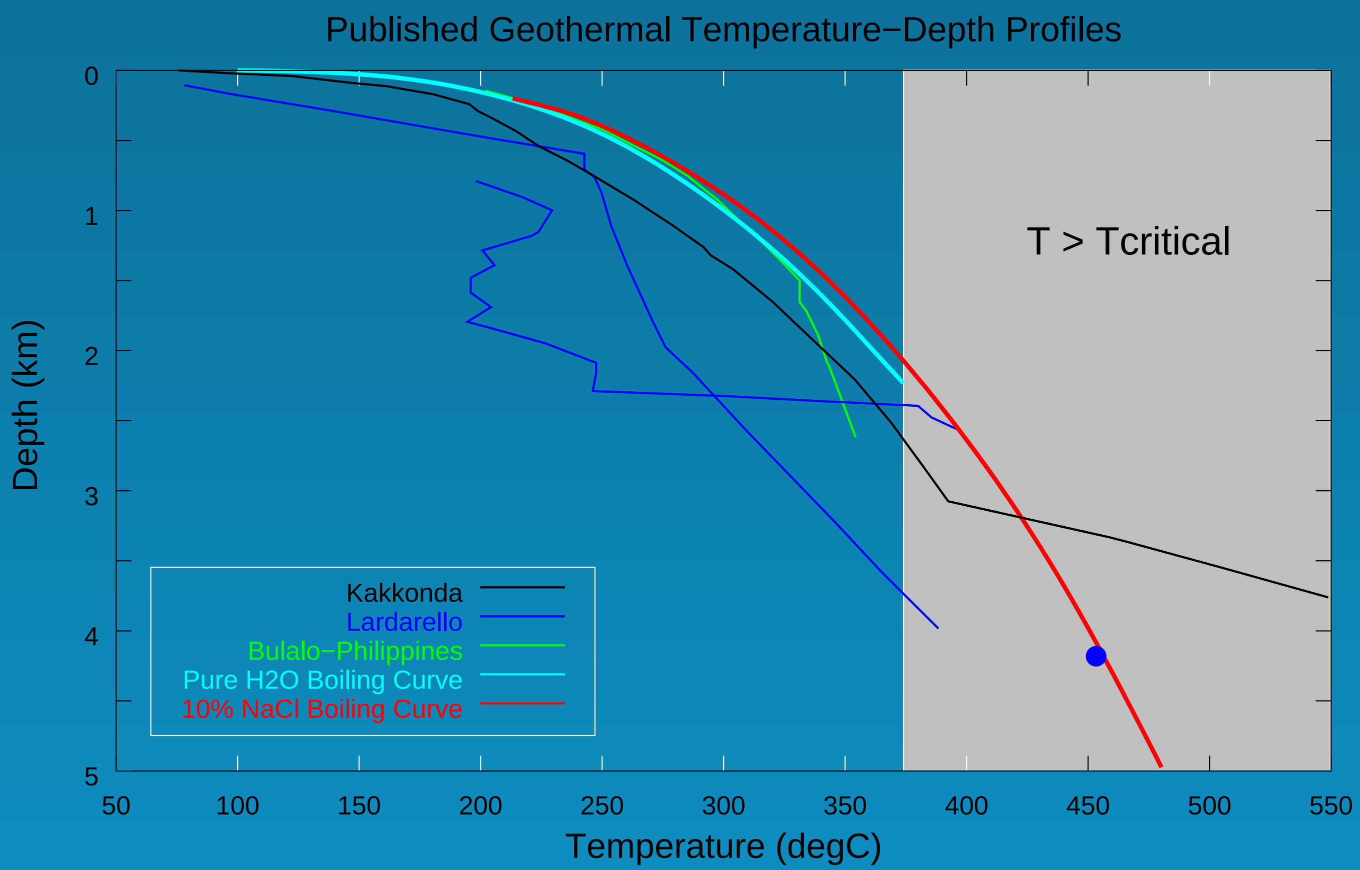
- Announcing the development of a plug-in EOS module for *TOUGH2* that handles supercritical conditions for pure H_2O
- Designated "EOS1sc" reflecting is origins as a combination of the EOS1 module [Pruess *et al.*(1999)] and an existing supercritical numerical equation of state for water [Johnson and Norton(1991)]
- Still in "alpha" testing stage (first truly successful runs less than a month ago)
- Intended to bridge the gap between natural state and geothermal reservoir models

Introduction

- Why supercritical?
  - ⋆ deep drilling magmatic geothermal systems encounters these conditions
  - ⋆ models of non-magmatic systems often encounter these conditions during iteration along bottom boundary, e.g. the Basin and Range [Wisian(2000)]
- Why Tough2?
  - ⋆ flexible (irregular) gridding
  - ⋆ variety of choices for matrix solution
  - ⋆ other capabilities needed for history matching, reactive transport modeling, etc.

Deep Geothermal Systems

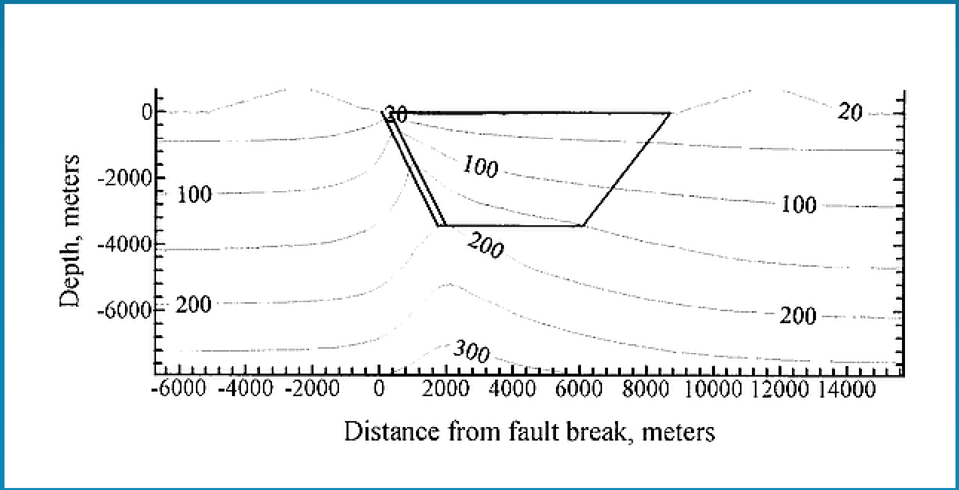
Super-critical fluid conditions occur deep in most magmatic systems



after [Muraoka *et al.*(2000)]

Extensional Geothermal Systems

Fluid conditions approach critical at the base of current models, model depth limited by capabilities of the reservoir simulator.



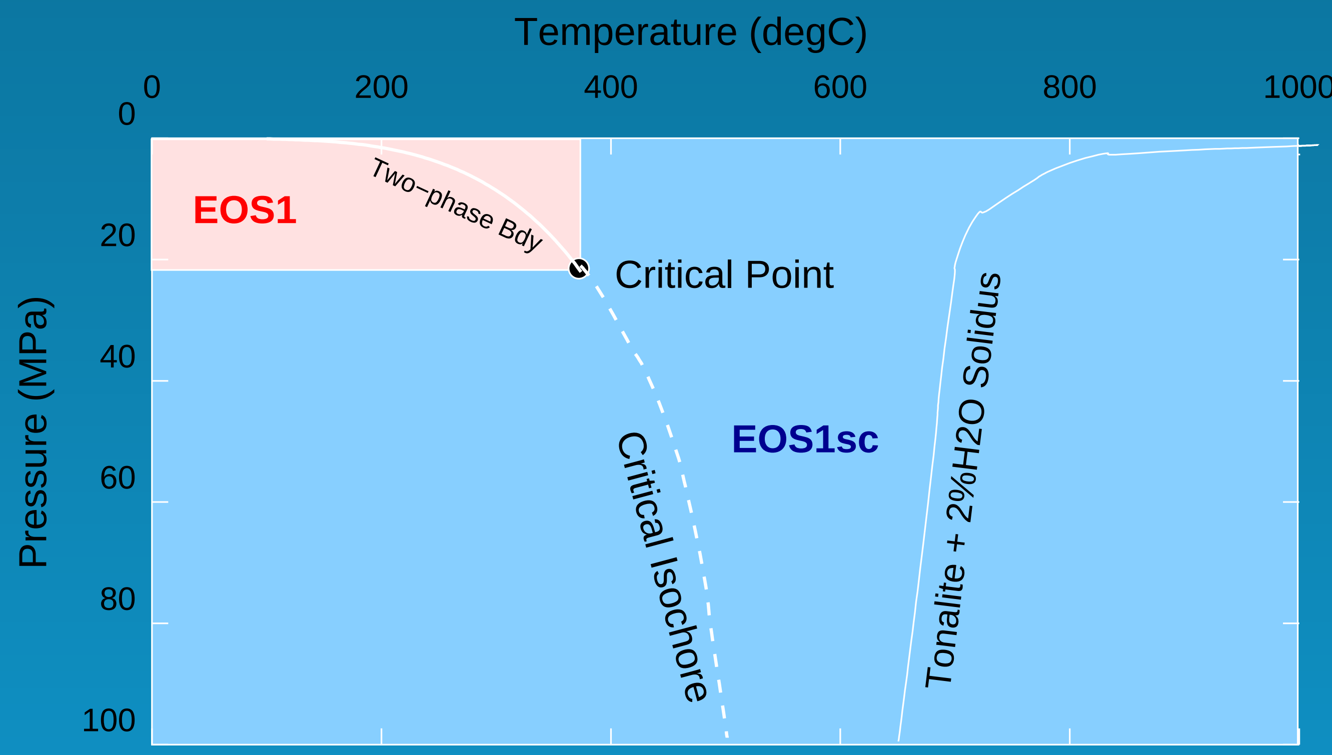
after [Wisian(2000)]

Motivation

- Want to model the *entire* geothermal system
  - ⋆ ensures consistent treatment of problem, e.g. boundaries based on geologic criteria, rather than on program limitations
- Where is this important?
  - ⋆ Mature geothermal fields
    - ∗ evaluating sustainability, planning and evaluating field enhancements (e.g. artificial recharge)
  - ⋆ Exotic targets, e.g. proposed supercritical target, Iceland [Fridleifsson and Albertsson(2000)]
  - ⋆ Exploration/Resource Evaluation: increased confidence/accuracy derived from ability to model entire system [Parini and Riedel(2000)]

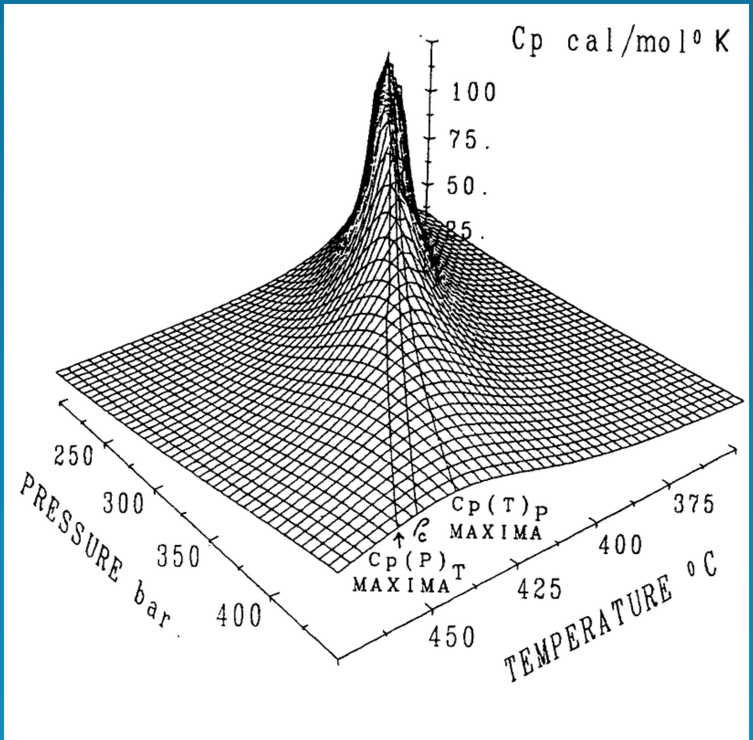
Extended Range using EOS1sc

- using EOS1sc, the validity range of Tough2 is greatly expanded to well beyond typical magmatic conditions



Critical Fluid Properties

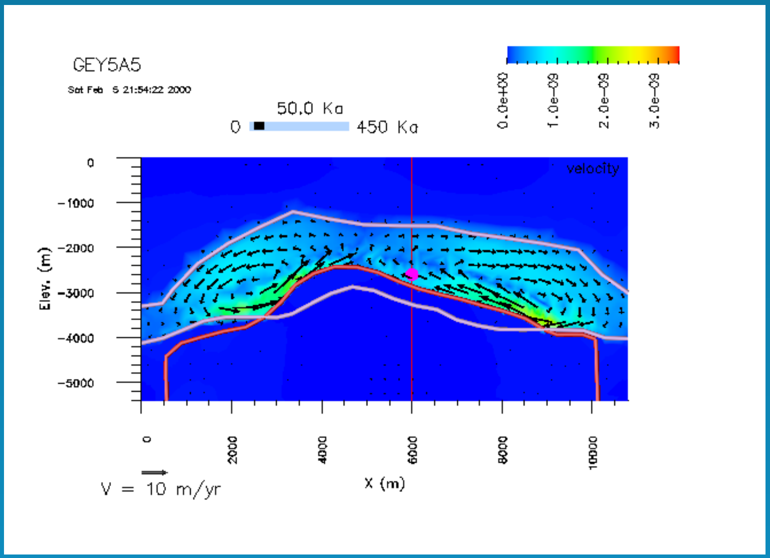
- Fluid flow and transport properties reach strong extrema at the critical point. Isobaric heat capacity (C_p) approaches $+\infty$:



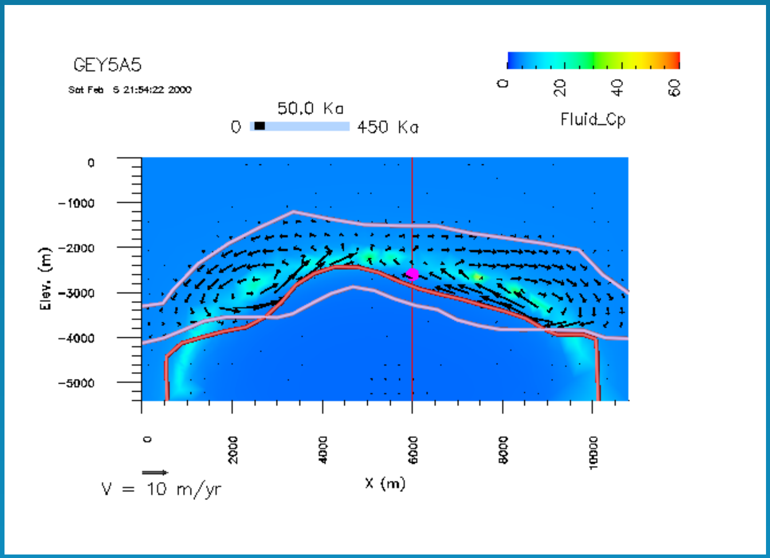
after [Johnson and Norton(1991)].

Geysers Supercritical Models

- Hydrothermal flow models that accurately treat critical fluid properties tend to show strong control by these on the deep system, e.g. Geysers liquid-dominated stage models [Brikowski(2001)]



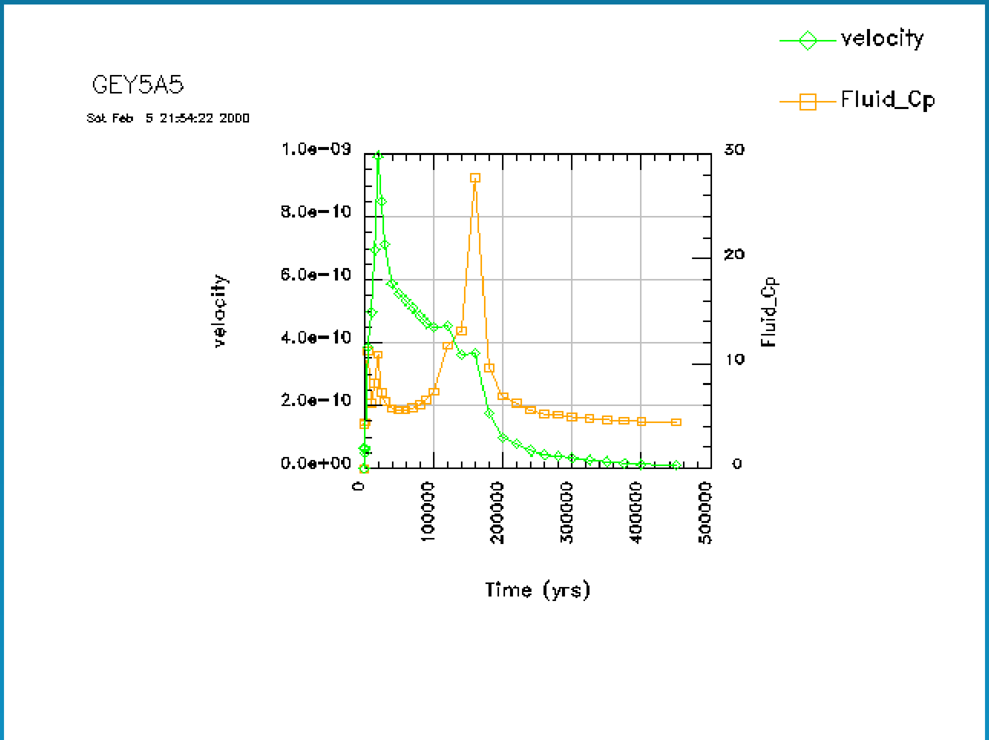
Fluid Velocity



Fluid Cp

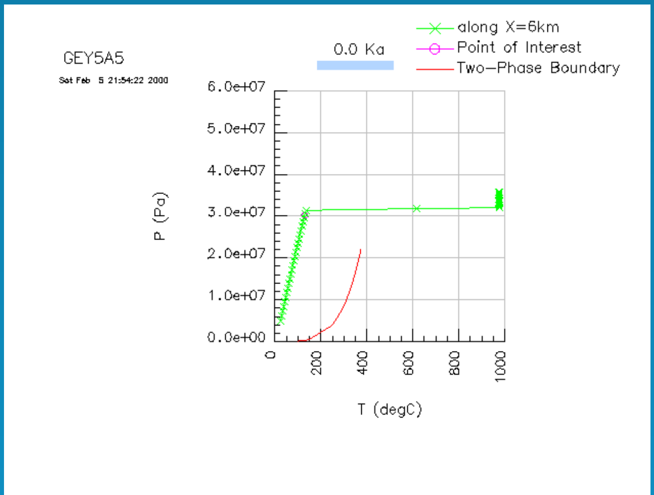
Influence of Critical Phenomena at The Geysers

- Zone of critical conditions “drives” the pre-boiling flow system at The Geysers



Toward a More Realistic Model of The Geysers

- single-phase (liquid) models of The Geysers successfully reproduce observed δ^{18}O alteration [Brikowski(2001), Brikowski(2000)]
- but P-T distribution somewhat contrived to avoid two-phase boundary

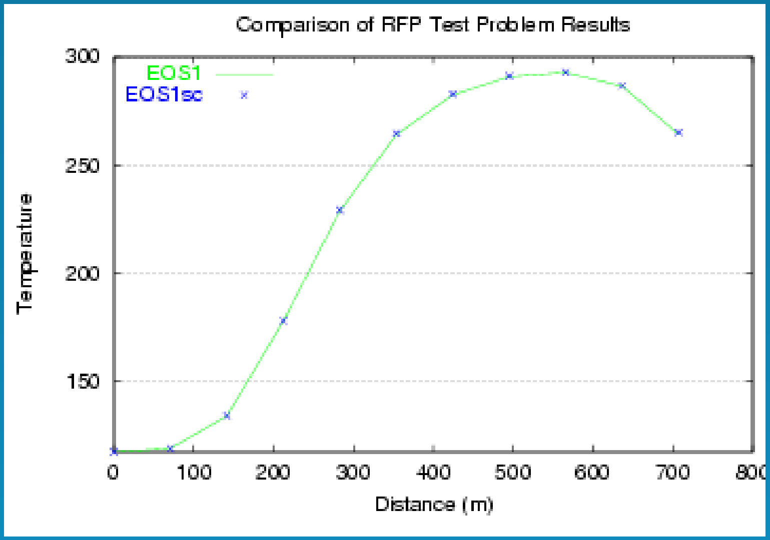


Supercritical EOS For Tough2

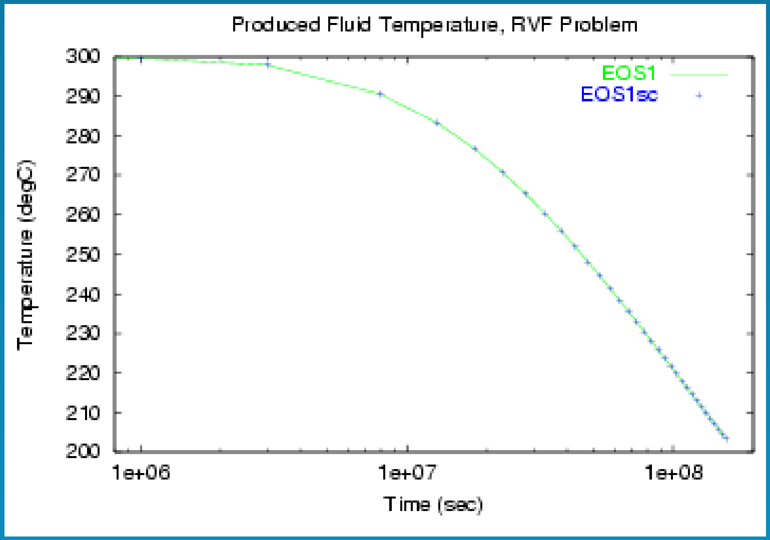
- utilize the numerical equation of state from the liquid-dominated stage models above (MARIAH, [Brikowski(1995)])
- that package is H2O92, freely available as part of the SUPCRT release [Johnson *et al.*(1992)]
- treats pure H_2O, uses Taylor's series approximations to physically-based equation in vicinity of the critical point [Levelt-Sengers *et al.*(1983)]
- sacrifices efficiency for extreme accuracy in the critical region
- design of *TOUGH2* forces assumption of artificial extension of 2-phase boundary. Chosen here as the critical isochore of density.

Subcritical Results

- comparison of *TOUGH2* test problem results using EOS1 and *EOS1sc* show excellent match; however *EOS1sc* run times are 5-50 times longer.



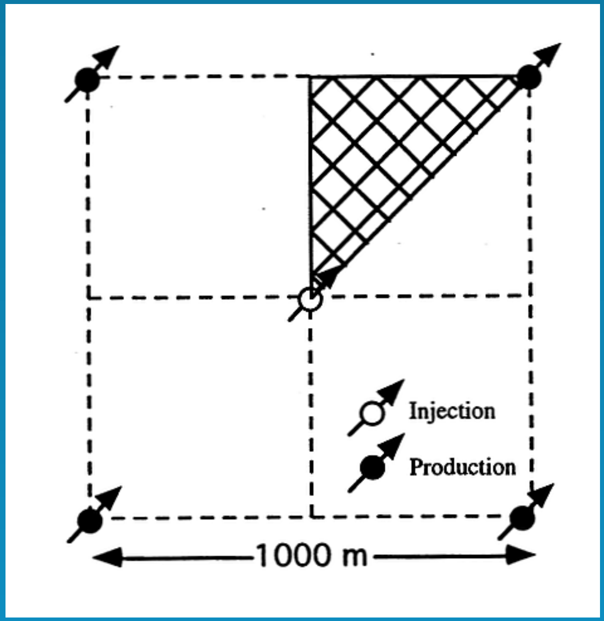
Geothermal 5-Spot



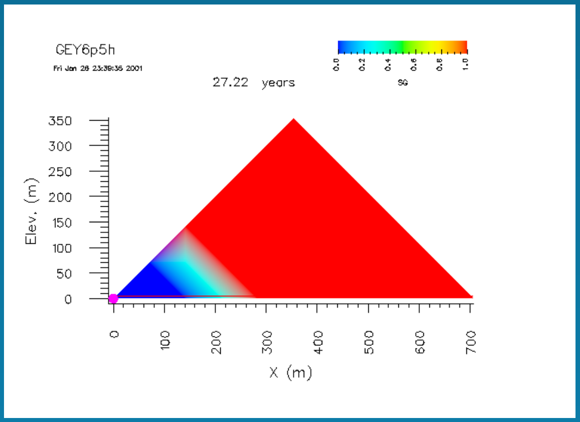
Fracture Heat Sweep

RFP Test of EOS1sc

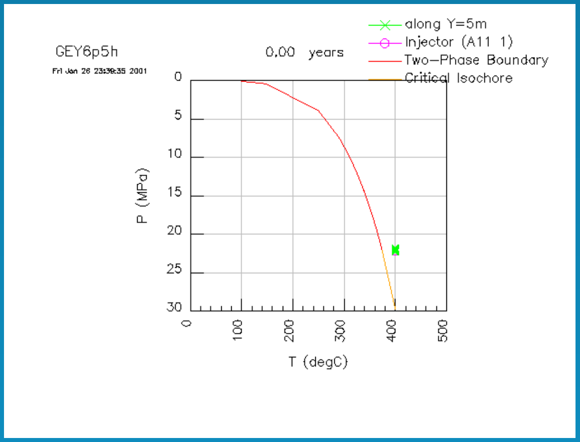
- Tough2 sample problem RFP (geothermal 5-spot well problem) revised to have supercritical initial conditions. Similar to P-T conditions at bottom of well WD-1a, Kakkonda, Japan.



RFP Test Results



Injected front of cold water progresses steadily from left to right toward producing well. Two phase boundary encountered between the two wells



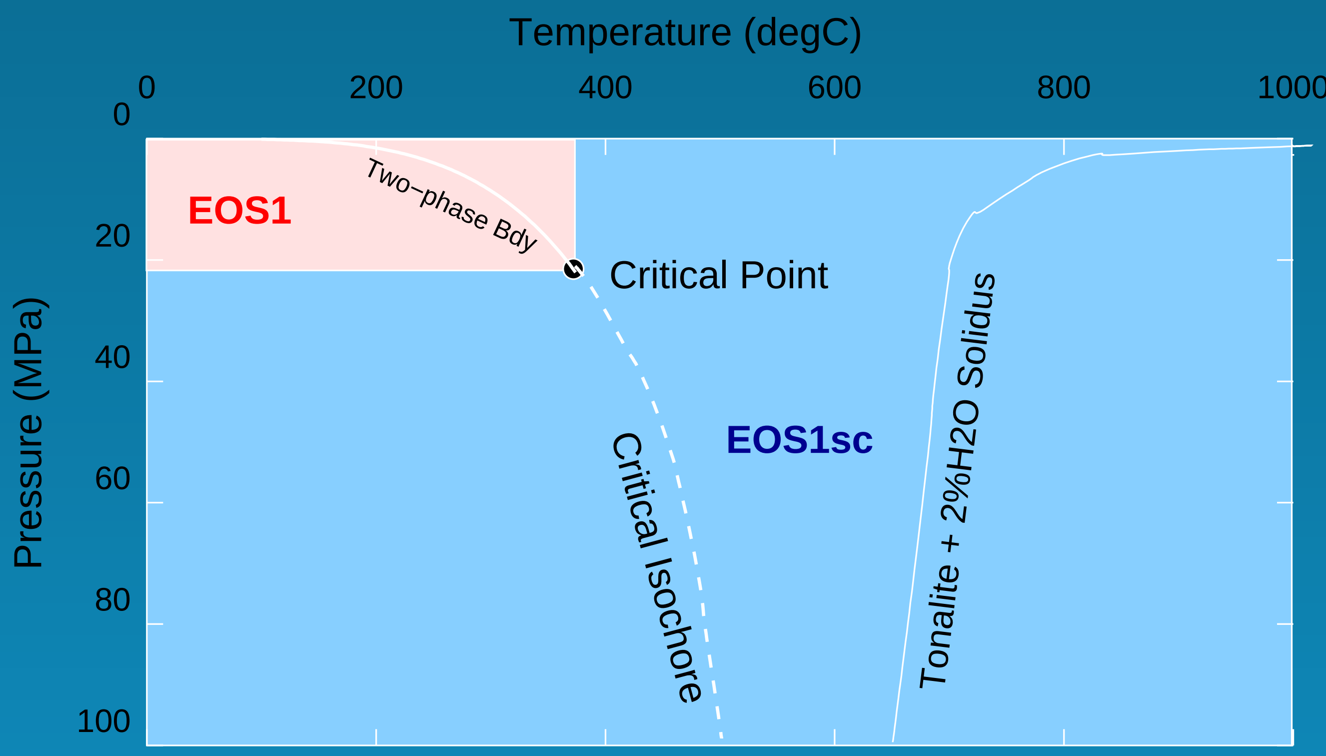
P-T conditions sweep across critical point between the two wells

Summary

- Super-critical EOS module ($EOS1sc$) has been developed
  - ⋆ currently works under low-velocity conditions (difficult convergence otherwise)
  - ⋆ these difficulties not surprising owing to fluid property extrema near critical point
  - ⋆ work will continue to optimize convergence using $EOS1sc$

- $EOS1sc$ allows continuous spectrum of modeling scales
  - ⋆ allows model scoping in magmatic systems (large-area natural state models to directly set boundary and initial conditions for smaller area reservoir models)
  - ⋆ provides for consistency between large and small-scale models

Extended Range using EOS1sc



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