GreenFire-LLNL Small Business Vouchers Pilot

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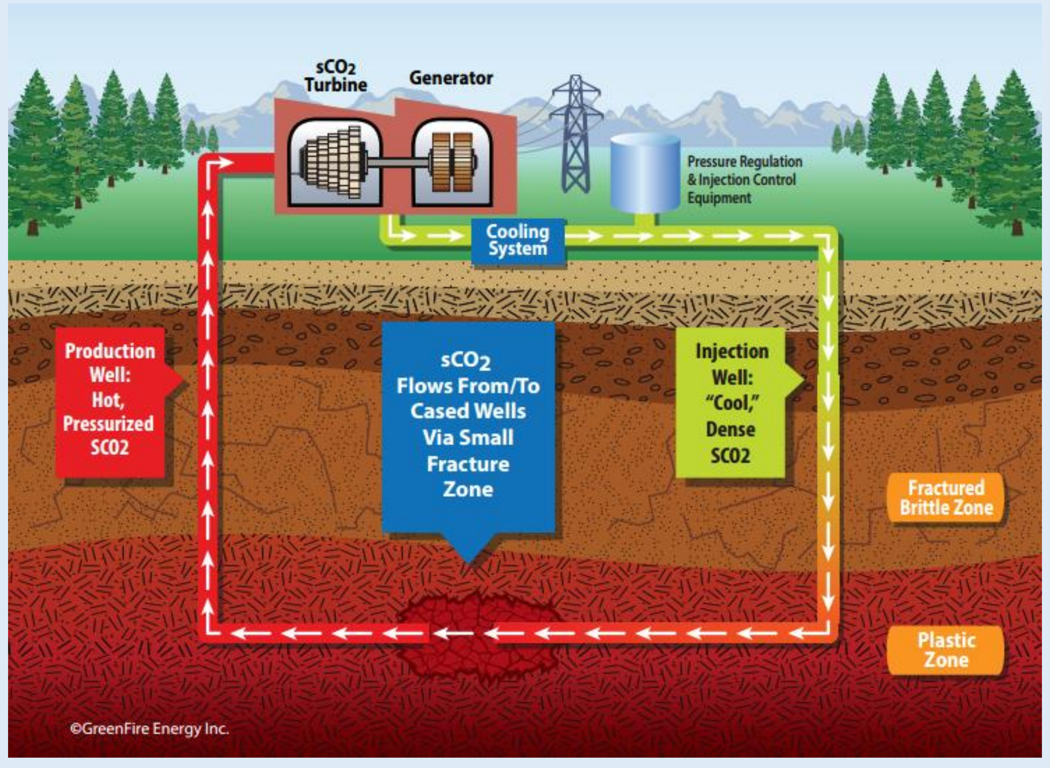
Introduction



Goal: Enable development of cost-effective geothermal power using supercritical CO_2 as the working fluid – the "ECO2G" system.

Problem Statement: investigate the possibility of creating and maintaining a relatively small fracture zone in very hot dry rock, bridging the gap between two cased well bottoms.

Evaluate

(1) the type of fracturing technique required,
(2) the extent of the fracture zone created,
(3) the rate of sustainable working fluid flow through the fracture zone and
(4) the expected behavior of the fracture zone over time.

At such great depths, what are the options for closing the flow loop?

Mechanical – perceived to be expensive
Energetic – Never been attempted before at this depth

Can energetic materials be used to bridge the gap between the two wells?
Will such a flow loop be sufficiently permeable?

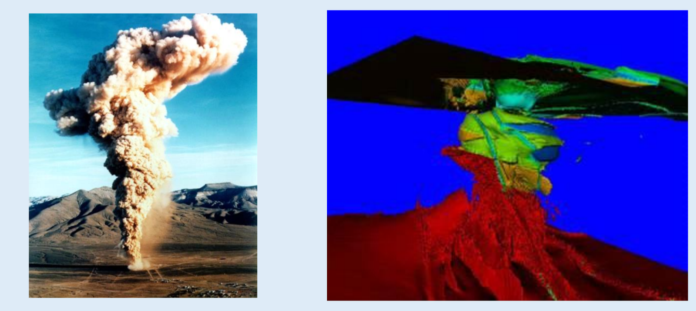
Methods

LLNL has developed a range of methods for predicting dynamic loading of rocks and soils.

Applications include defense and energy:

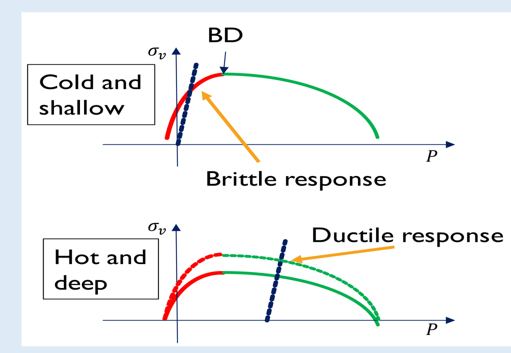
- Containment of underground explosions
- Effects on underground structures
- Stimulation of geological resources
  - Geothermal
  - Petroleum

Material models for hot granite have been calibrated against experimental data (Morris et al., 2017)

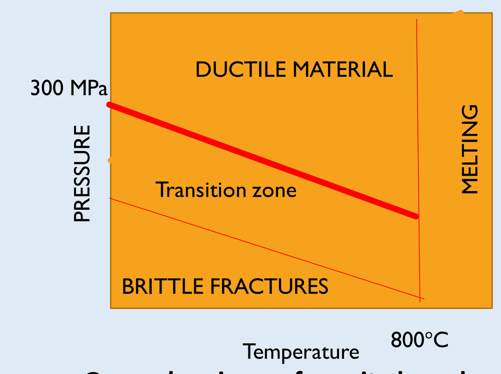


3D study of geological factors contributing to venting of Baneberry Test (10 kt at 270 m depth, 1970).

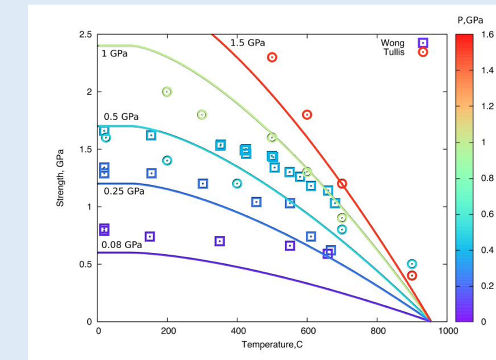
Weapon effects on underground structures (Heuze and Morris, 2007)



Hypothetical stress paths for cold and shallow versus hot and deep rock



General regimes of granite based upon pressure and temperature ranges

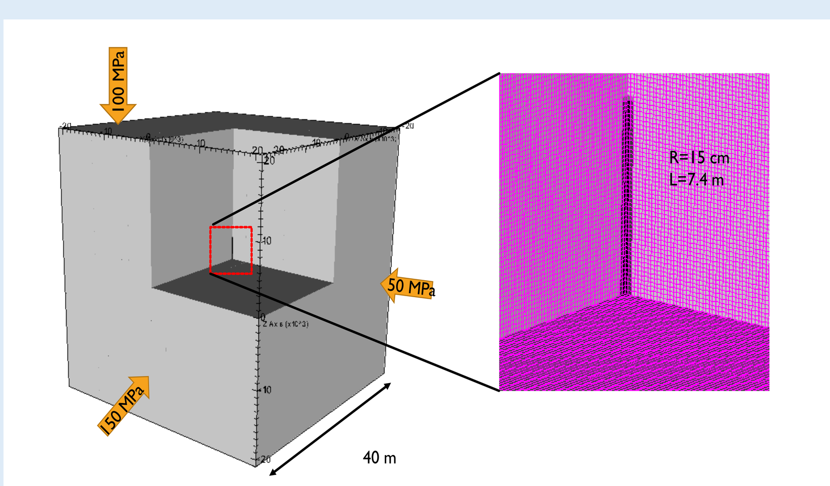


Example stress-strain response of model, exhibiting expected decrease in peak stress with increasing temperature

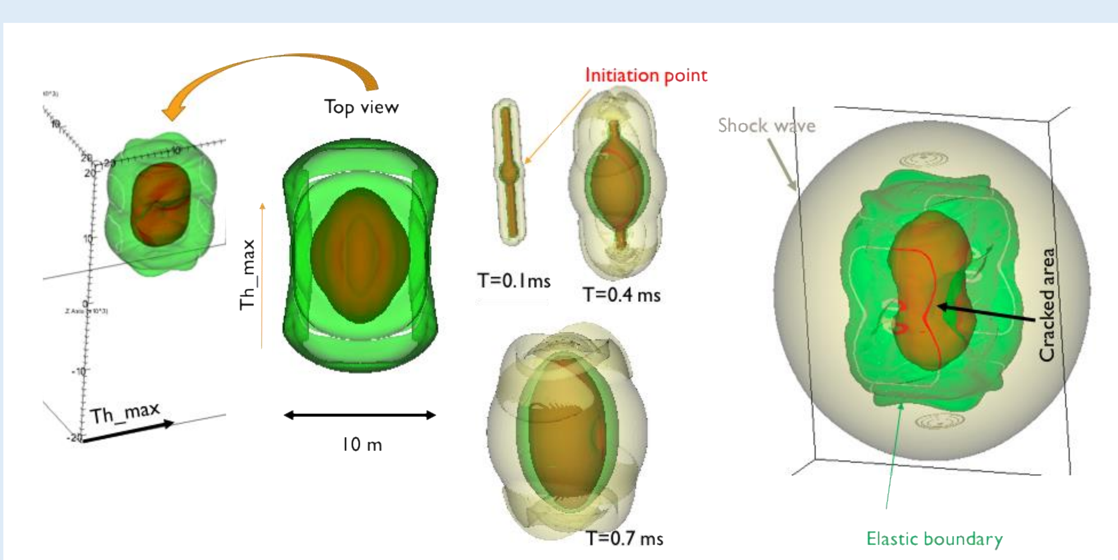
Results of Dynamic Stimulation Models

First series of stimulation scenarios using the calibrated "hot granite" material model considered:

- Single well
- Influence of stress and temperature



Geometry and stress conditions for a single, 850 kg TNT charge.



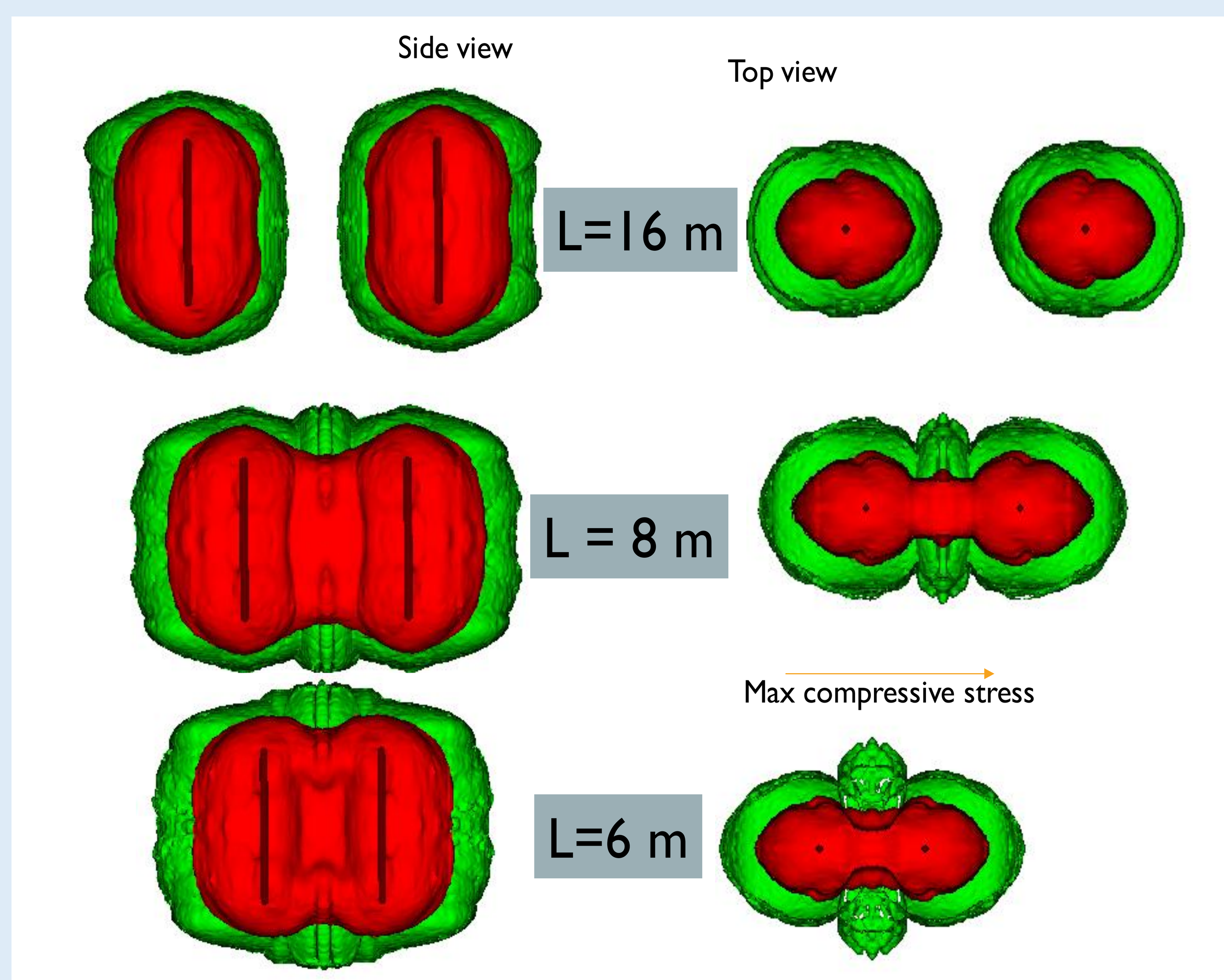
First series of models consider a single 750 kg. Brittle failure zone indicated with red dotted lines and ductile with green solid lines.

A second series of stimulation scenarios addressed the interaction of two charges in neighboring wells:

- Spacing was varied from 6 m to 16 m
- Stress state:

$$\sigma_{zz} = 100 \text{ MPa}$$
$$\sigma_{xx} = 120 \text{ MPa}$$
$$\sigma_{yy} = 80 \text{ MPa}$$

- Temperature of 400 C



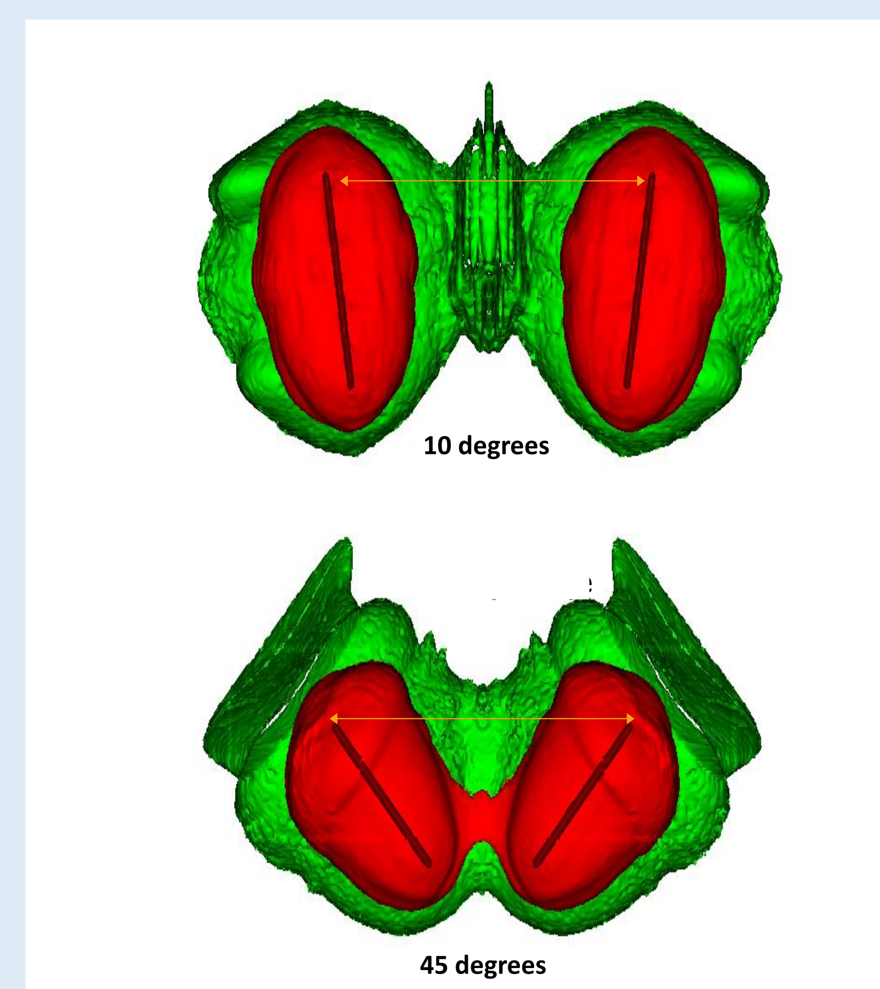
Final state for two parallel charges of 850 kg TNT with varied spacing. Red indicates brittle and green ductile, respectively.

The final series of model considered the influence of inclination upon well-to-well interactions

- Stress state:

$$\sigma_{zz} = 100 \text{ MPa}$$
$$\sigma_{xx} = 120 \text{ MPa}$$
$$\sigma_{yy} = 80 \text{ MPa}$$

- Temperature of 400 C
- HE tops separated by 16 m



Final state for two parallel charges of 850 kg TNT with well inclination. Red indicates brittle and green ductile, respectively.

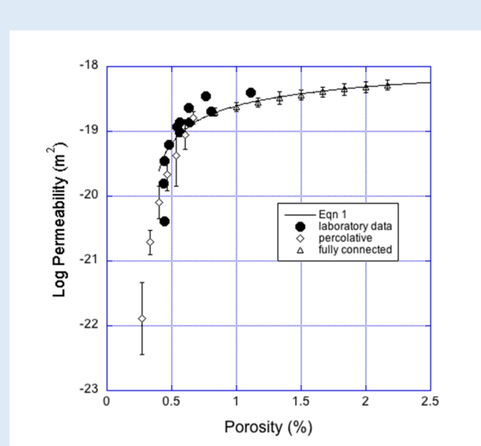
Summary and Conclusions

Parametric studies using a calibrated material model for hot granite demonstrated that:

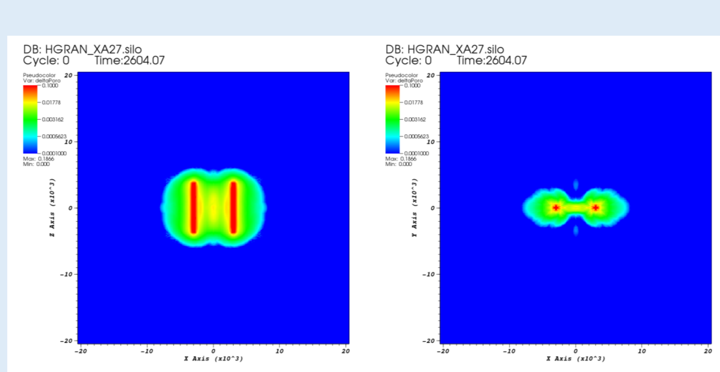
- Brittle fracturing is possible even at high pressure and temperature
- Wellbores separated by 10 m or less are likely to be connected by a brittle-fractured zone
- It is preferred to have the wells within 6 m separation for some portion of their length

A mapping from porosity to permeability was developed using data from the literature:

$$k = 5 \times 10^{-19} ln(\phi_{\%} + 0.65) \text{m}^2$$



Permeability evolution as modeled by Zhu and Wong (1997, 1999) is shown with open symbols. Solid symbols represent laboratory data for Westerly granite (Brace et al., 1968). Our fit is shown by the solid line.



Permeability field (µDarcy) and change in porosity field (volume fraction) on y and z planes with HE cylinders placed 6 m apart

Stimulated permeability increase is several orders of magnitude:

- We observe a region between the wells with ~0.2 μDarcy
- This is unlikely to be sufficient permeability to sustain suitable flow

In reality deformation will likely localize into a number of individual cracks:

- This process is very sensitive to the heterogeneity and any preexisting flaws
- In this instance the flow rate will be much higher

We conclude that the successful connection of the two wells will likely require one of two scenarios:

1) higher initial permeability of the formation, or
2) localization of the rock deformation upon individual fractures

→ Both mechanisms are sensitive to the geological setting

References

Heuze, F. E., Morris, J. P., 2007, "Insights into ground shock in jointed rocks and the response of structures there-in," International Journal of Rock Mechanics and Mining Sciences, Volume: 44 (5) 647-676.

Morris. J. P., Vorobiev, O. Y., Ryerson, F. J., 2017, "Application of energetic stimulation at high temperature and pressure for deep geothermal reservoirs," 51st US Rock Mechanics / Geomechanics Symposium held in San Francisco, California, USA, 25-28 June 2017, ARMA 17-371.

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Prepared by LLNL under Contract DE-AC52-07NA27344.
LLNL-POST-740726