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Coupled Thermal-Mechanical-Hydrologic Processes Near a Deep Borehole and Potential Impacts on Hydrologic Testing

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Sandia National Laboratories

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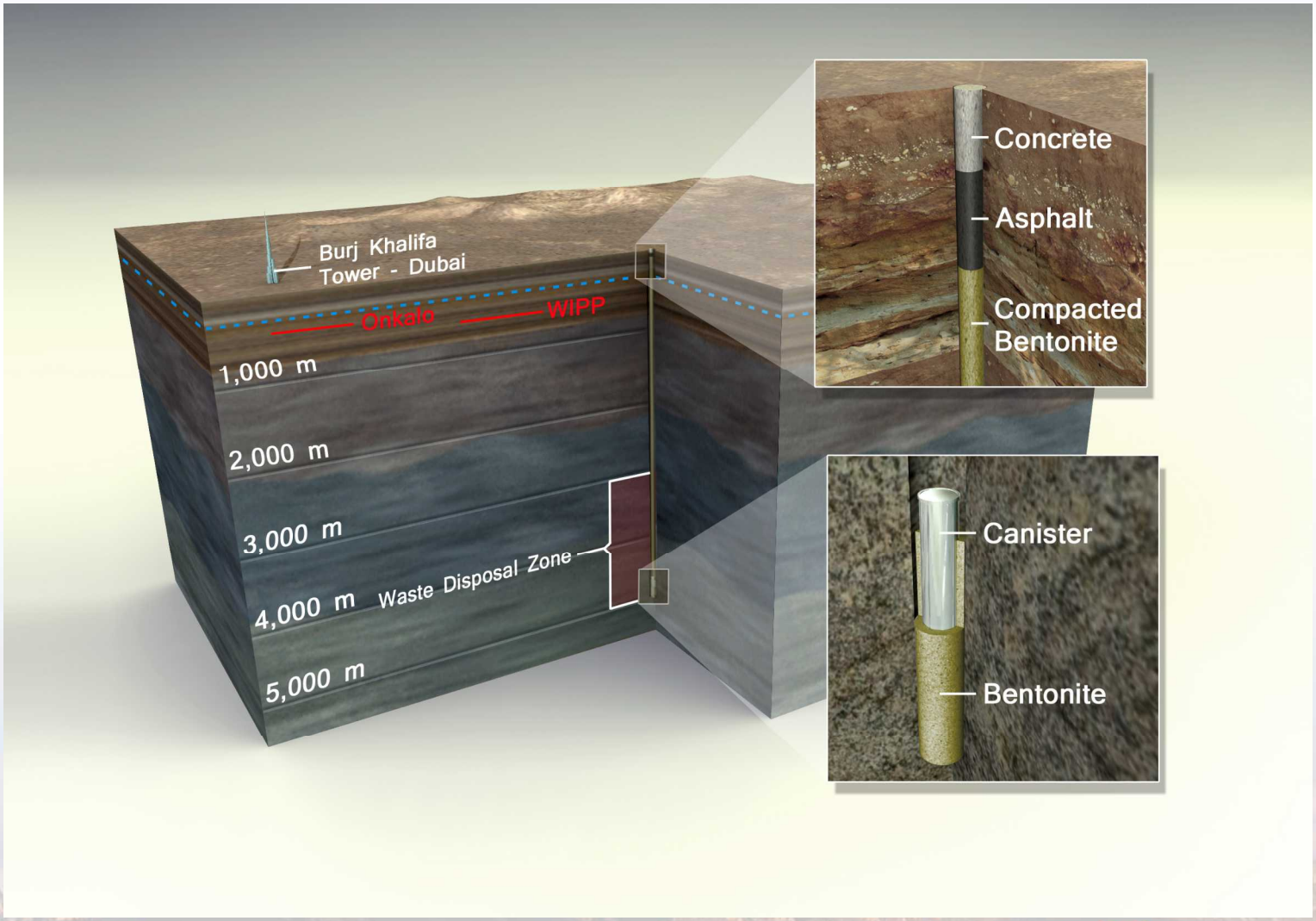
Outline

- Deep borehole disposal concept
- Mechanical modeling and stress relief near the borehole
- Thermal-mechanical modeling near the borehole
- Conclusions and implications for hydrogeological testing

Deep Borehole Disposal Concept

- Disposal concept consists of drilling a borehole or array of boreholes into crystalline basement rock to about 5,000 m depth
- Approximately 400 waste canisters would be emplaced in the lower 2,000 m of the borehole
- Upper borehole would be sealed with compacted bentonite clay and cement
- Several factors suggest the disposal concept is viable and safe:
  - Crystalline basement rocks are common in many stable continental regions
  - Existing drilling technology permits dependable construction at reasonable cost
  - Low permeability and long residence time of high-salinity groundwater in deep continental crystalline basement at many locations suggests very limited interaction with shallow fresh groundwater resources
  - Geochemically reducing conditions at depth limit the solubility and enhance the sorption of many radionuclides in the waste
  - Density stratification of saline groundwater underlying fresh groundwater would oppose thermally induced groundwater convection

Deep Borehole Disposal Concept



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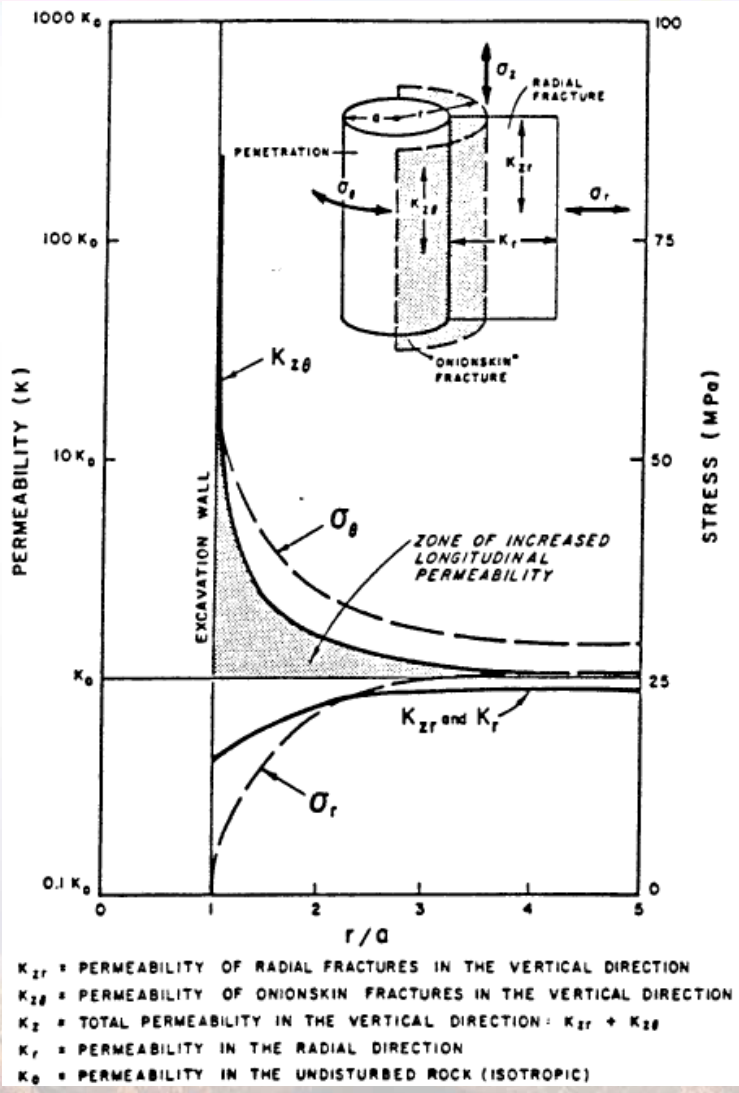
Disturbed Rock Zone and Coupled Processes Near the Borehole

- Although borehole seals can effectively prevent fluid flow in the borehole above the waste, enhanced rock permeability near the borehole may provide an axial pathway for fluid flow to bypass seals
- Similarly, enhanced axial permeability may cause assumptions of horizontal, radial flow to be violated in hydrologic packer tests
- Significant alteration of permeability for conditions of isotropic horizontal stress in homogeneous rock (from both plastic and elastic response) is limited to less than 1 borehole radius from the borehole wall, based on analytical solutions
- Stress relief for anisotropic horizontal stress in heterogeneous media is more complex in deep boreholes

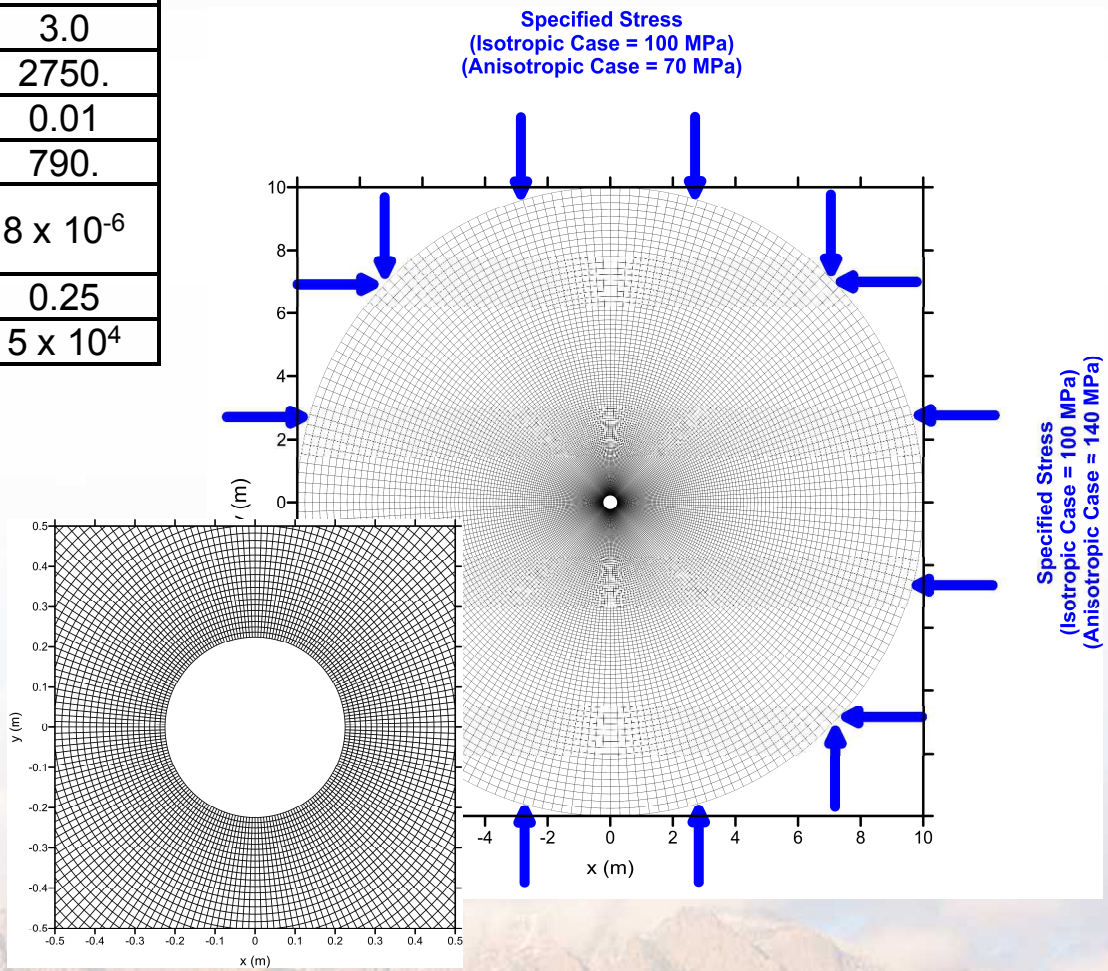


from Kelsall et al. (1982)

Thermal-Mechanical Numerical Modeling:

Parameter	Value
thermal conductivity (W/m ^{o}K)	3.0
density (kg/m^3)	2750.
porosity (-)	0.01
specific heat (J/kg ^{o}K)	790.
linear coefficient of thermal expansion (^{o}K^{-1})	8 x 10^{-6}
Poisson ratio (-)	0.25
elastic modulus (MPa)	5 x 10^4

- 2D model of linear elastic and thermo-elastic processes implemented with the FEHM code (Zyvoloski et al., 1995)
- Boundary and initial conditions consistent with a nominal depth of 4000 m
- Parameter values representative of granite



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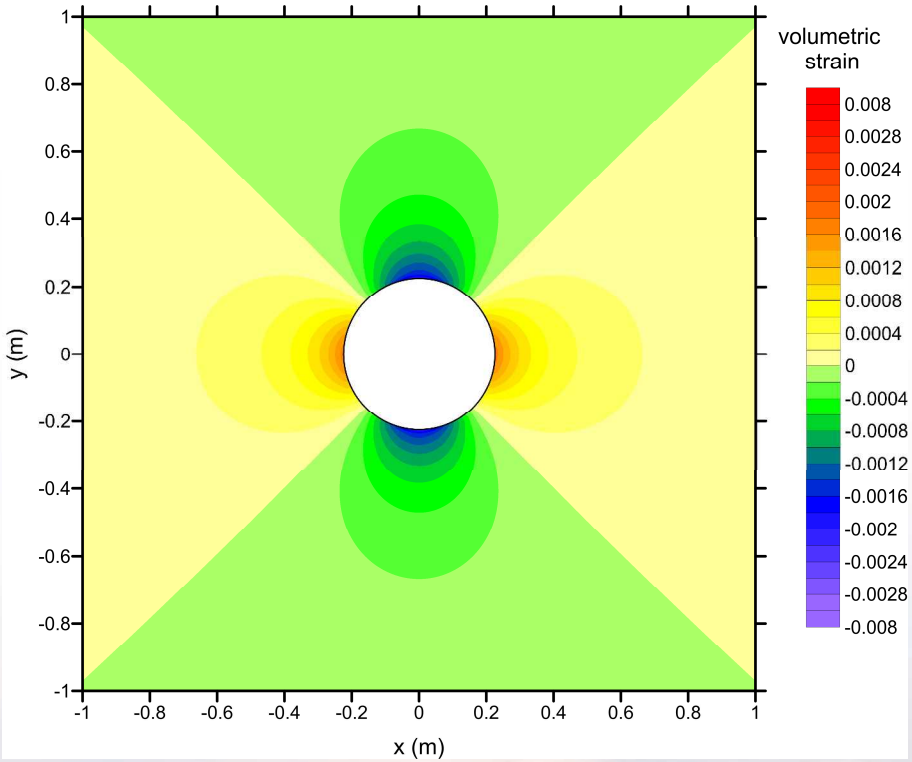
Mechanical Modeling:

- For differential horizontal stress, the host rock is placed in compression in the direction of maximum horizontal stress and in extension in the direction of minimum horizontal stress
- Concentration of stress at the borehole walls in the direction of minimum horizontal stress can result in borehole breakouts (not explicitly analyzed here)
- Permeability will be increased by extensional strain and decreased by compression
- Permeability changes are a function of strain, fracture porosity, and fracture orientation – sensitivity is amplified by the cubic relationship between permeability and fracture aperture

Homogeneous Elastic Modulus,
2:1 Anisotropic Horizontal Stress



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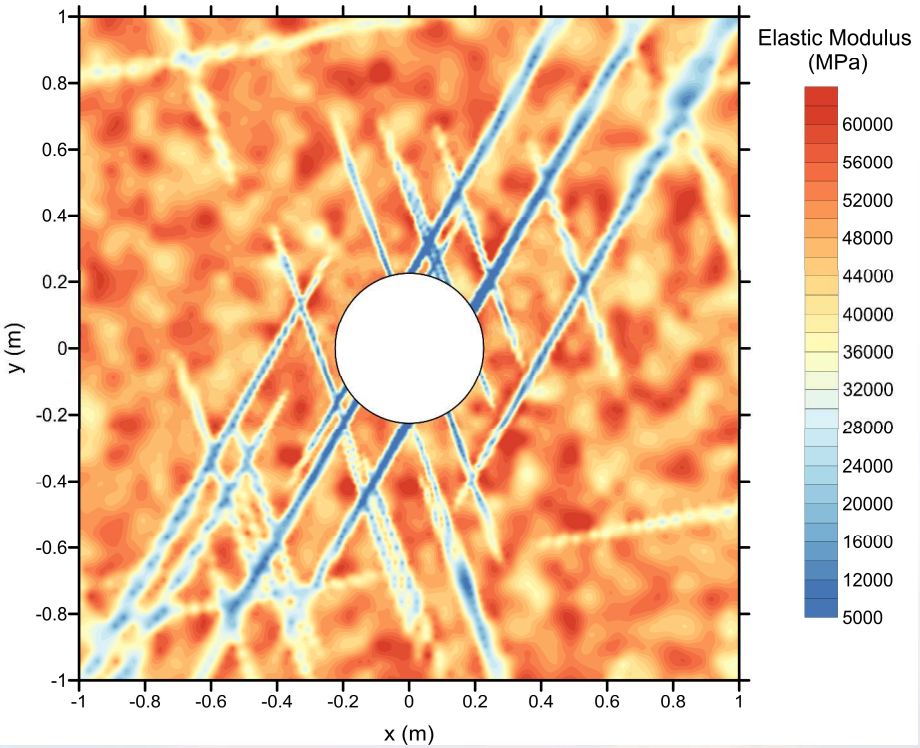
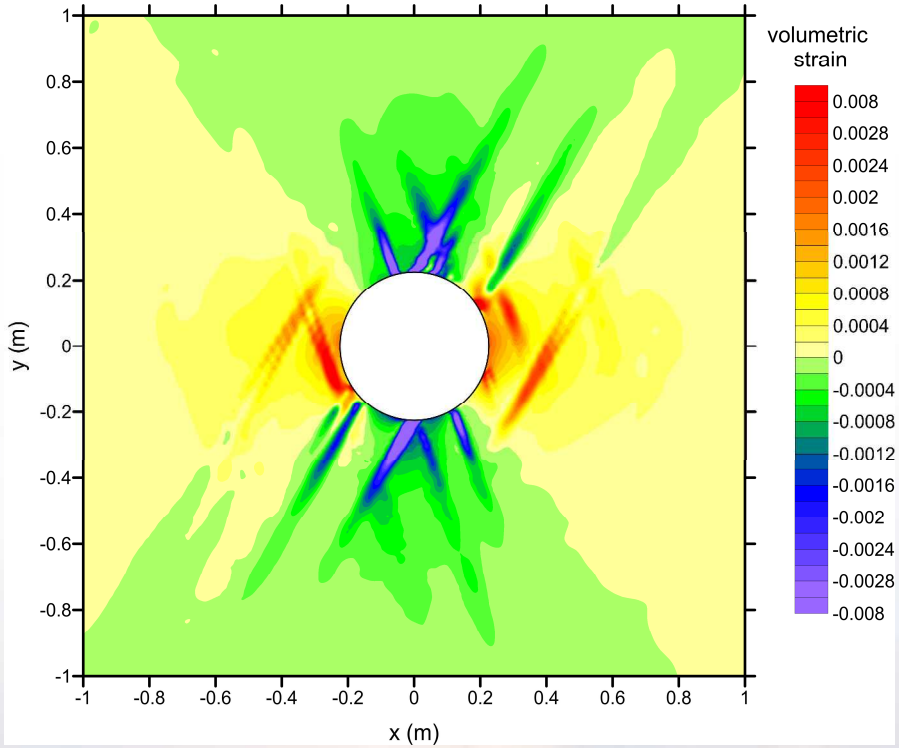
Mechanical Modeling:

Sequential Gaussian and Discrete Fracture Simulation of Heterogeneous Elastic Modulus



Heterogeneous Elastic Modulus with Fractures, 2:1 Anisotropic Horizontal Stress



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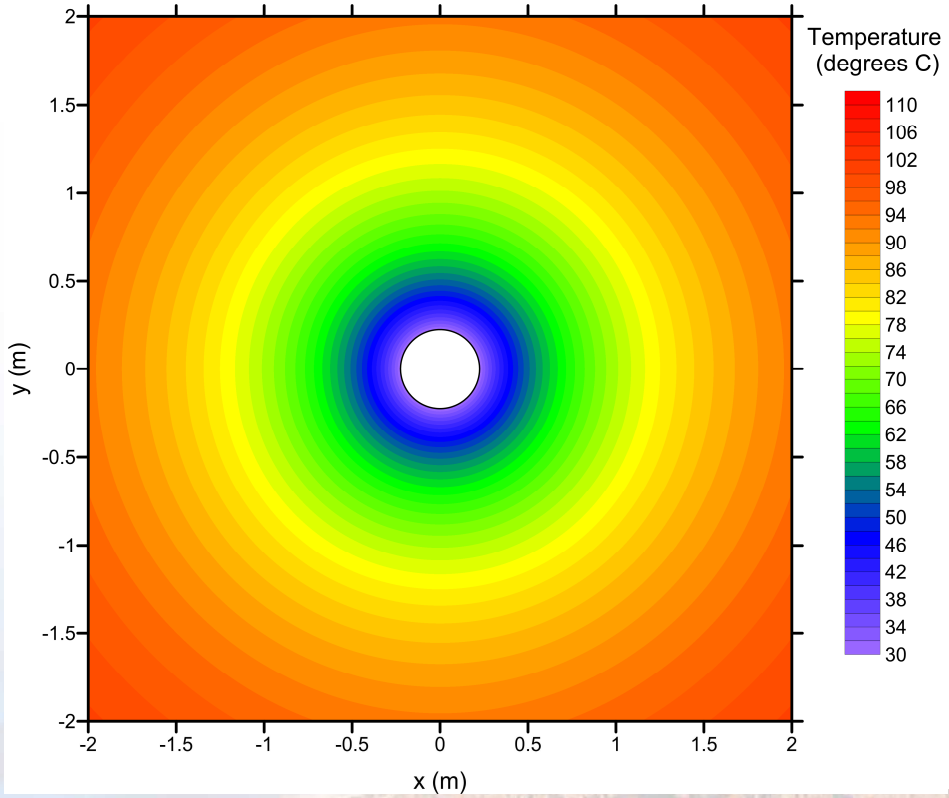
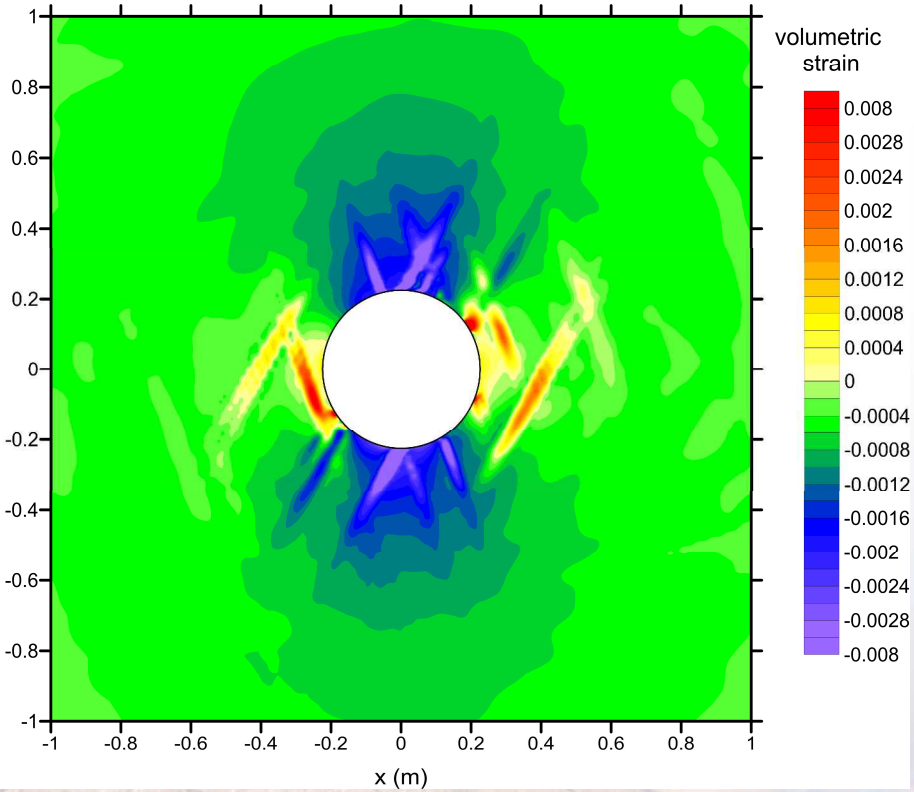
Thermal-Mechanical Modeling:

Heterogeneous Elastic Modulus with Fractures,
Homogeneous Thermal Conductivity,
2:1 Anisotropic Horizontal Stress ,
30 days of Fluid Circulation at 30 ºC



Heterogeneous Elastic Modulus with Fractures,
Homogeneous Thermal Conductivity,
2:1 Anisotropic Horizontal Stress ,
30 days of Fluid Circulation at 30 ºC



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Conclusions and Implications for Hydrogeological Testing

- Stress relief and thermo-elastic response may have a significant impact on permeability in the disturbed rock zone near a deep borehole under anisotropic horizontal stress, particularly for rocks with low fracture porosity
- Zones of increased permeability are oriented parallel to the borehole, enhancing flow in the axial direction during packer tests
- Fracture zones with lower elastic modulus than the intact rock tend to concentrate volumetric strain, resulting in areas with increased (or decreased) permeability that extend farther into the host rock and a complex pattern of changes in permeability
- The bulk permeability derived from pump tests may be an overestimate because of axial flow and cooling of the rock near the borehole
- Flow dimensionality derived from the pump tests may be lower than undisturbed host rock due to the pattern of stress relief
- Extensional strain of the rock may alter noble gas isotopic compositions through release of intergranular gas (e.g., ^{4}He)?