# Investigating the potential of using conductive or permeable proppant particles for hydraulic fracture characterization

Lindsey J. Heagy* & Douglas W. Oldenburg

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# Hydraulic Fracture Characterization

- How do we optimize:
  - Well spacing?
  - Stage spacing?
  - Cluster spacing?
  - Volume of proppant and fluid?
  - Pumping pressures?
  - …

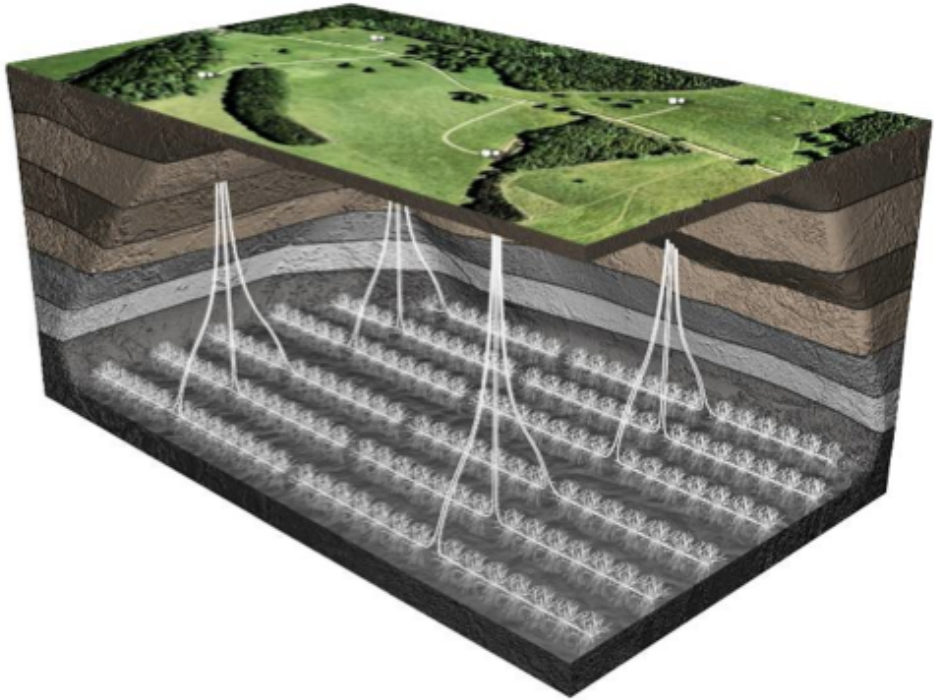

Figure courtesy of Encana

# Hydraulic Fracture Characterization

- Need to understand:
  - Fracture geometry
  - Properties of fractured rock
  - Production / Injection behavior
  - Proppant distribution

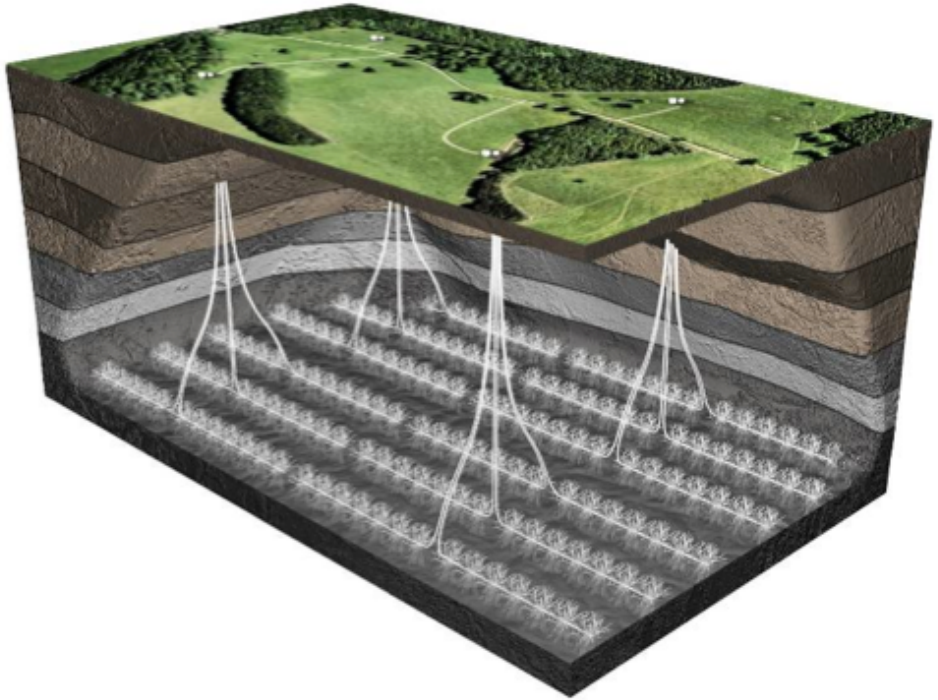

Figure courtesy of Encana

# Current Fracture Monitoring Technologies

- Microseismic
- Tiltmeters
- Pressure Transient Analysis
- Fiber Optics:
  - Distributed Acoustic Sensor
  - Distributed Temperature Sensor

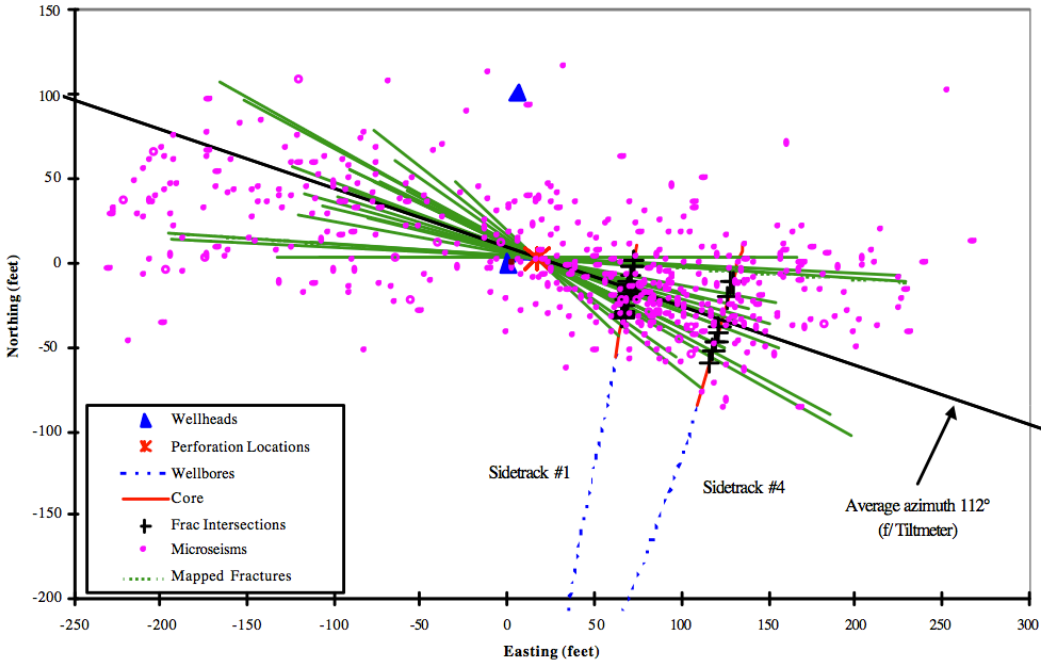


Figure: Cipolla and Wright, 2000

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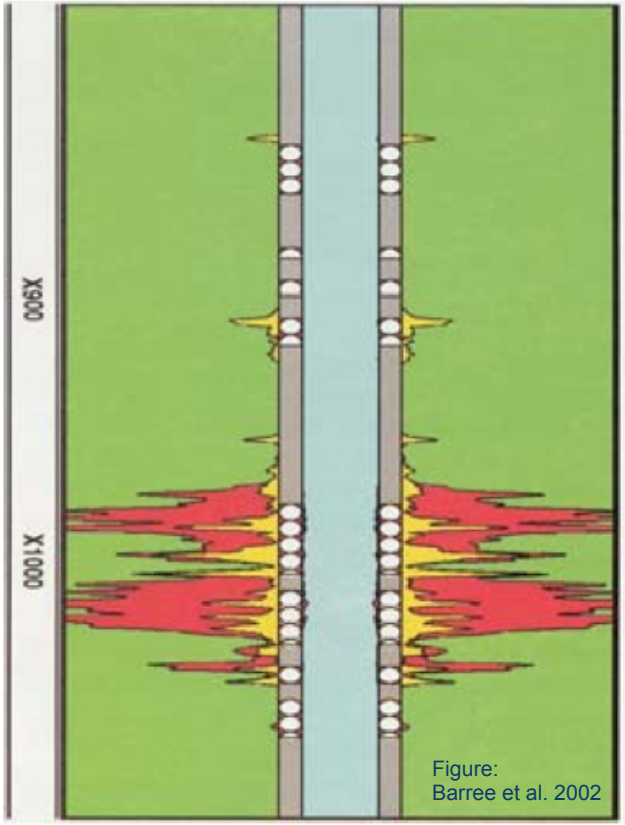


Figure:
Barree et al. 2002

- Logs:
  - Temperature
  - Production
  - Image
  - Caliper
- Tracers:
  - Radioactive
  - Chemical

# Current Fracture Monitoring Technologies

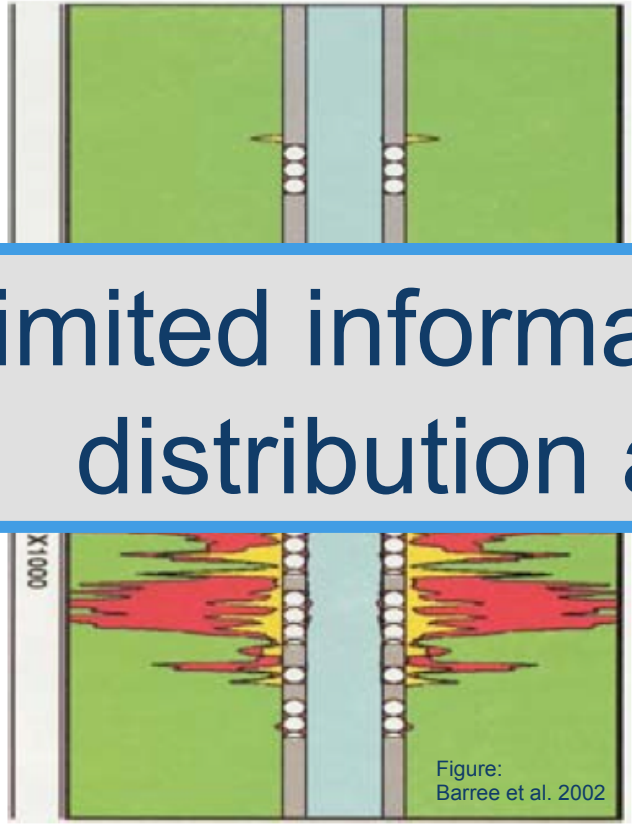


Figure:
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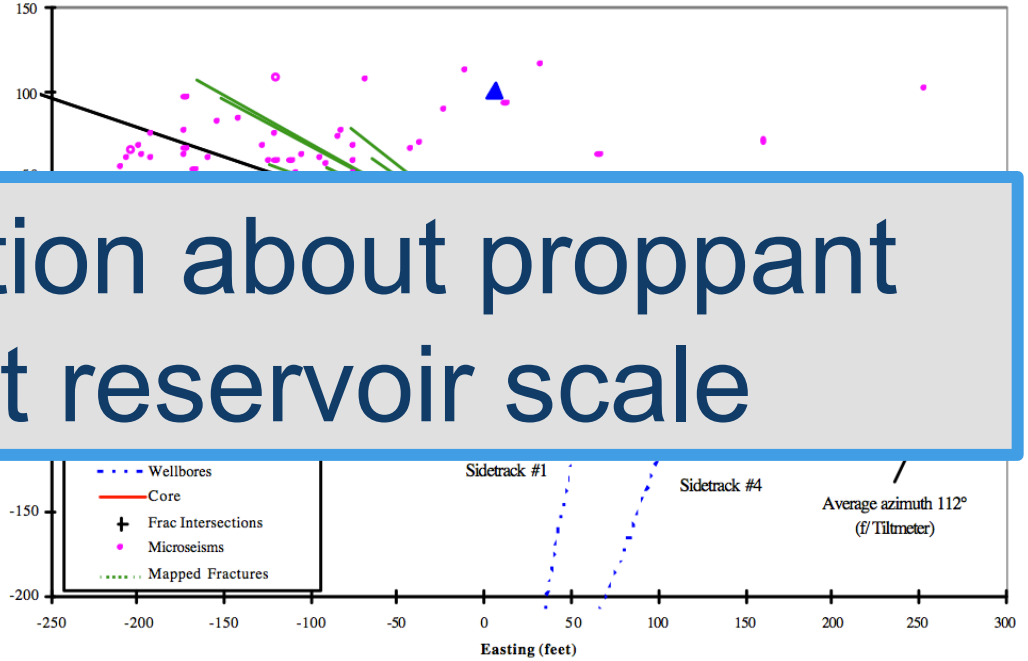


Figure: Cipolla and Wright, 2000

**Limited information about proppant distribution at reservoir scale**

# Objective

How do we map the propped region of a hydraulically fractured reservoir?

# Using Electromagnetics?

- Requirements:
  - Physical property contrast
  - Design a survey that generates a measurable response
  - Means of inverting and interpreting the data

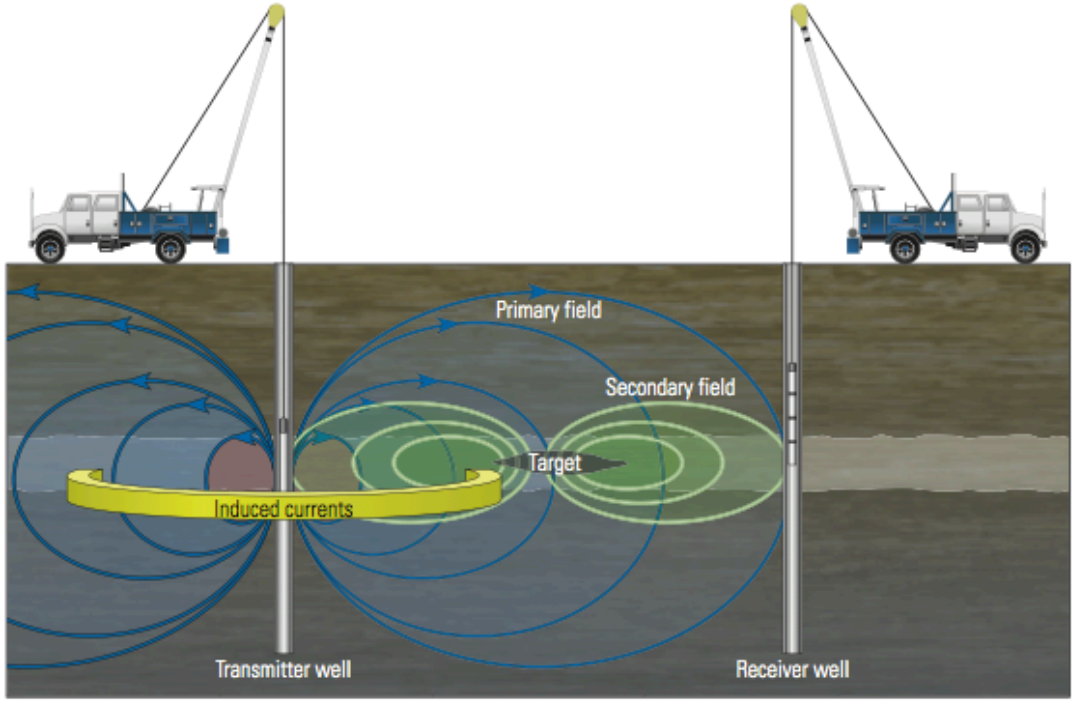


Figure courtesy of Schlumberger

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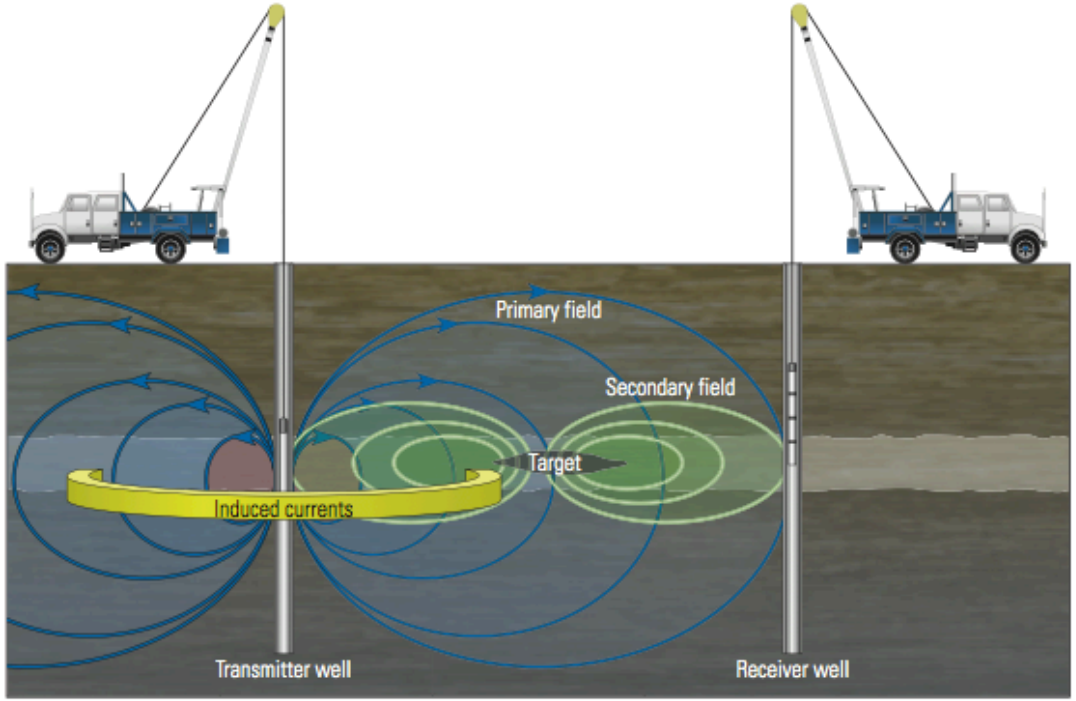



Figure courtesy of Schlumberger

# Idea: Create our own Geophysical Target

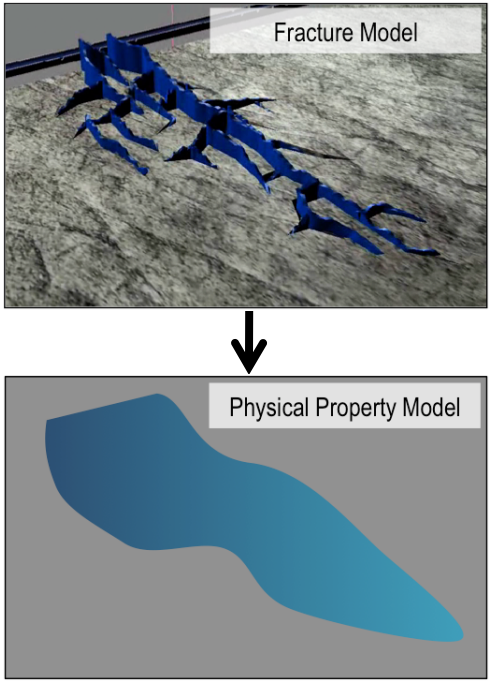
Use electrically conductive or magnetic proppant

↓

Physical property contrast

↓

Image the contrast using EM



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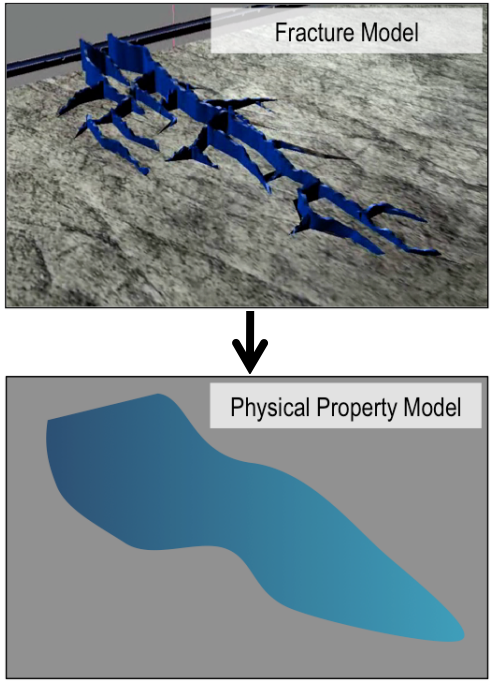
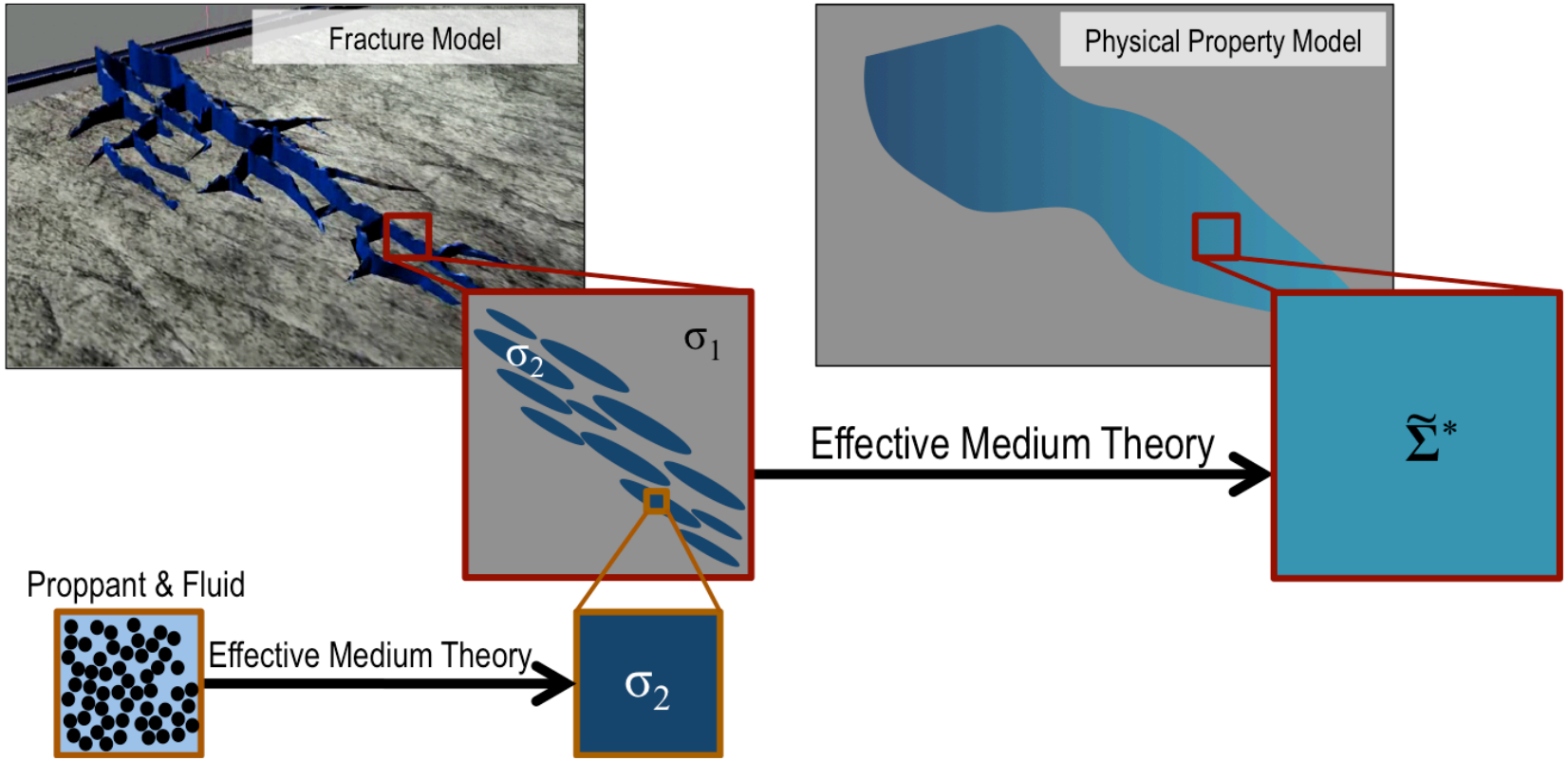


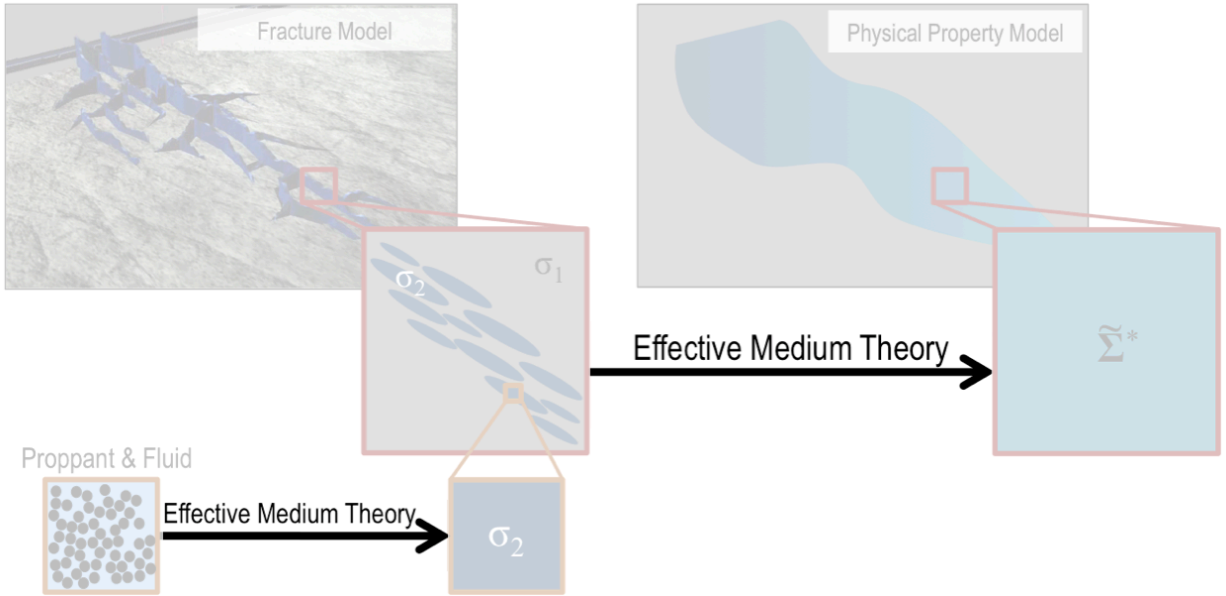

What does a doped hydraulic fracture look like as a geophysical target?

# Overview


Fracture Model
Physical Property Model
$\sigma_1$
$\sigma_2$
Effective Medium Theory
$\tilde{\Sigma}^*$
Proppant & Fluid
Effective Medium Theory
$\sigma_2$

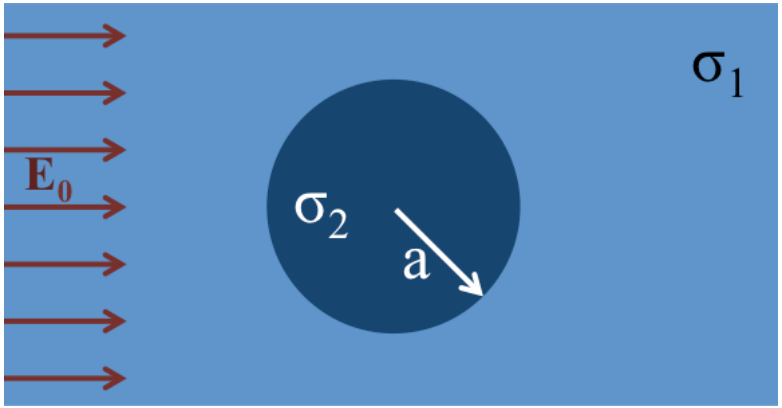
# Effective Medium Theory

Goal: Assign an effective property that captures the macroscopic response of a material whose properties vary on the microscopic scale



# Single Inclusion Solutions

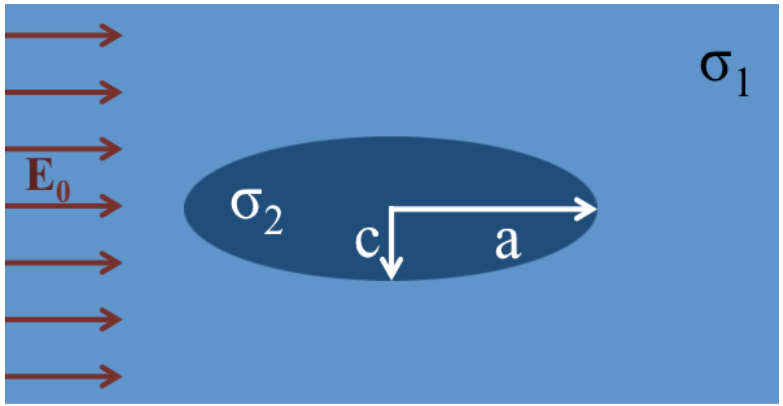
## Inside the Sphere:




$$\mathbf{E} = \mathrm{R}^{(2,1)}\mathbf{E}_0$$

$$\mathrm{R}^{(2,1)} = \left[1 + \frac{1}{3}\frac{\sigma_2 - \sigma_1}{\sigma_1}\right]^{-1}$$

## Inside the Ellipsoid:

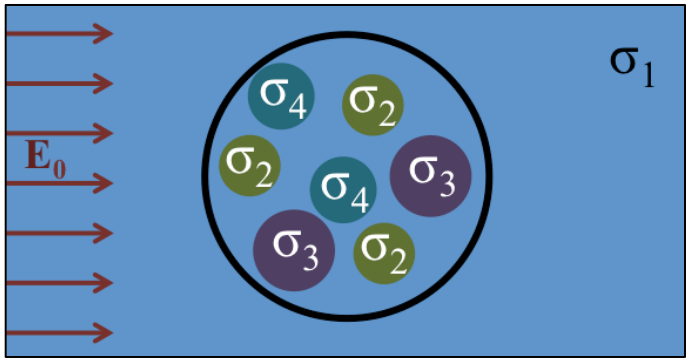



$$\mathbf{E} = \widetilde{\mathbf{R}}^{(2,1)}\mathbf{E}_0$$

$$\widetilde{\mathbf{R}}^{(2,1)} = \left[\widetilde{\mathbf{I}} + \widetilde{\mathbf{A}}_2\frac{\sigma_2 - \sigma_1}{\sigma_1}\right]^{-1}$$

# Maxwell Approximation

## Spherical Inclusions




$$\sum_{j=1}^{N} \phi_j(\sigma^* - \sigma_j)\mathrm{R}^{(j,1)} = 0$$

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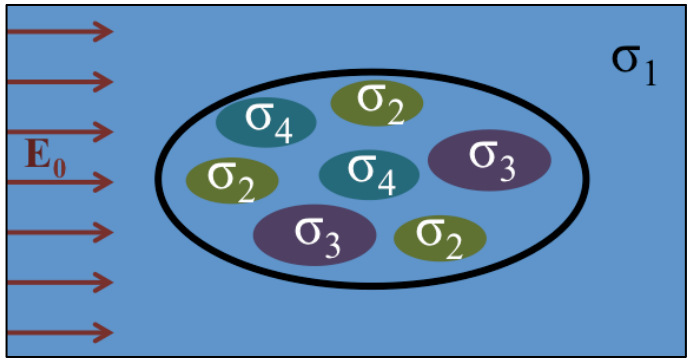
## Ellipsoidal Inclusions

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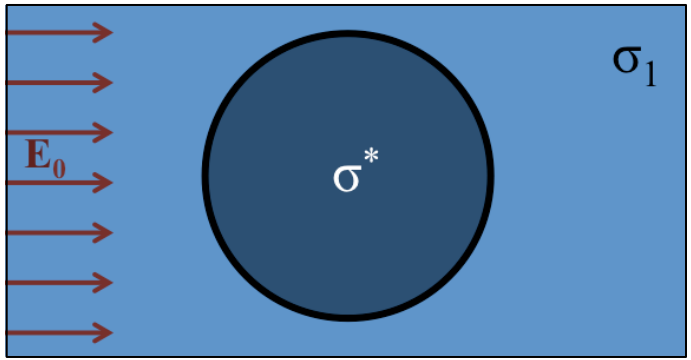


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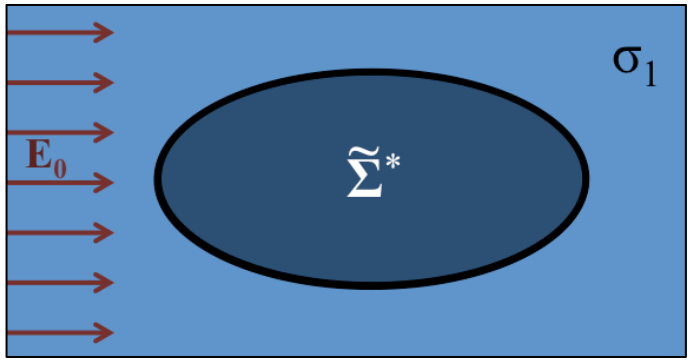


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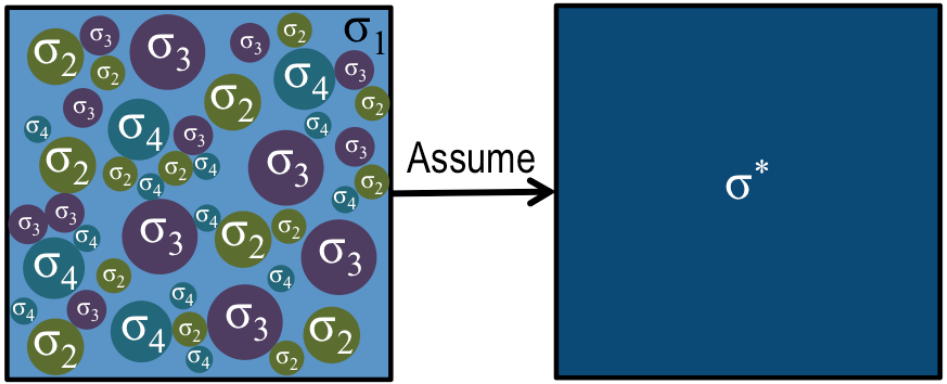
# Self Consistent Approximation

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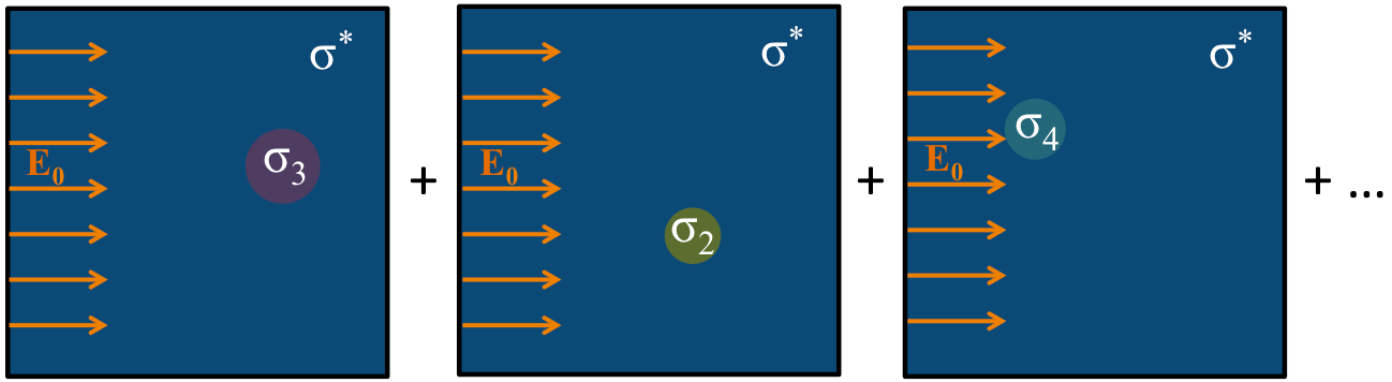


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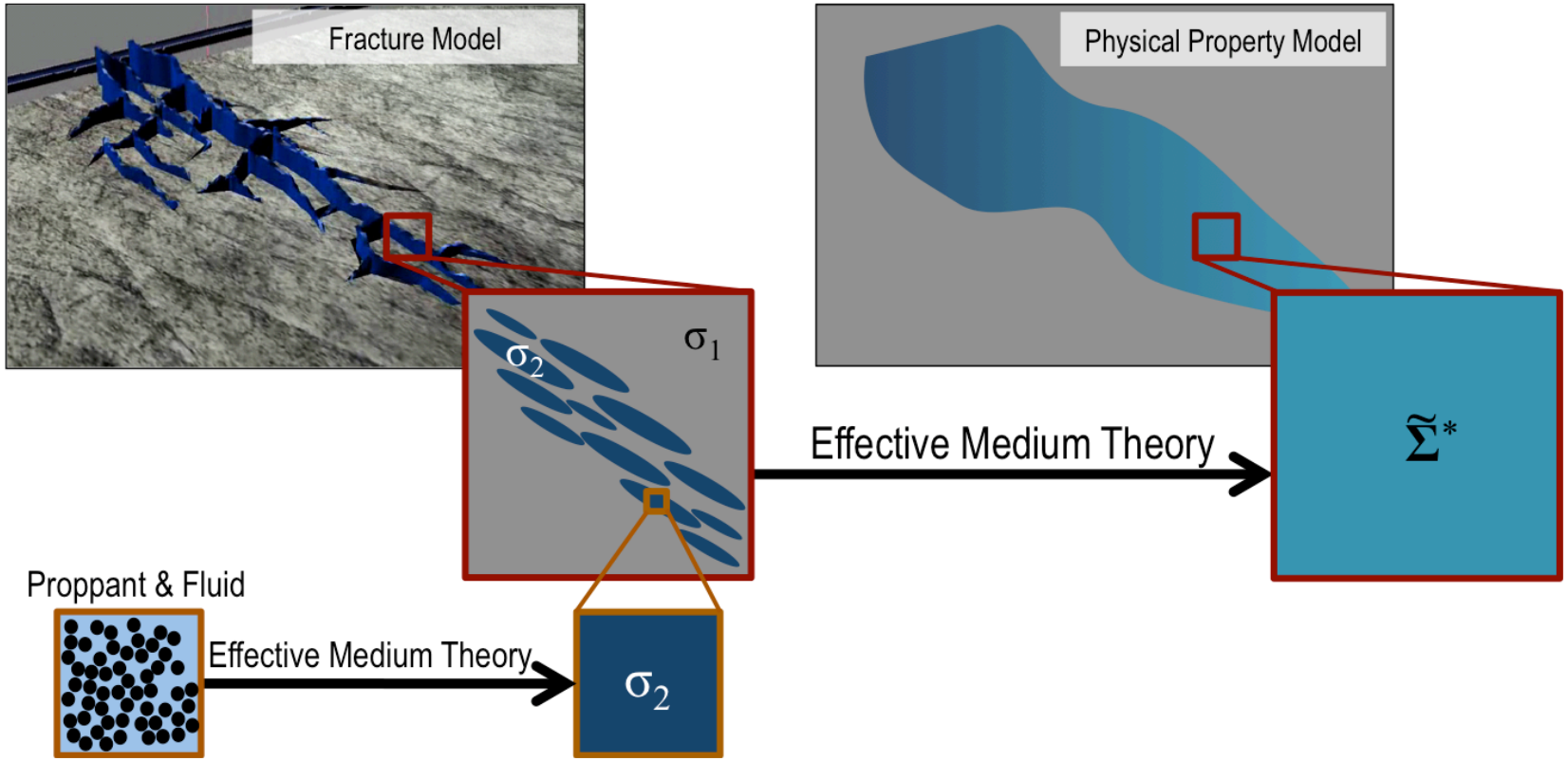
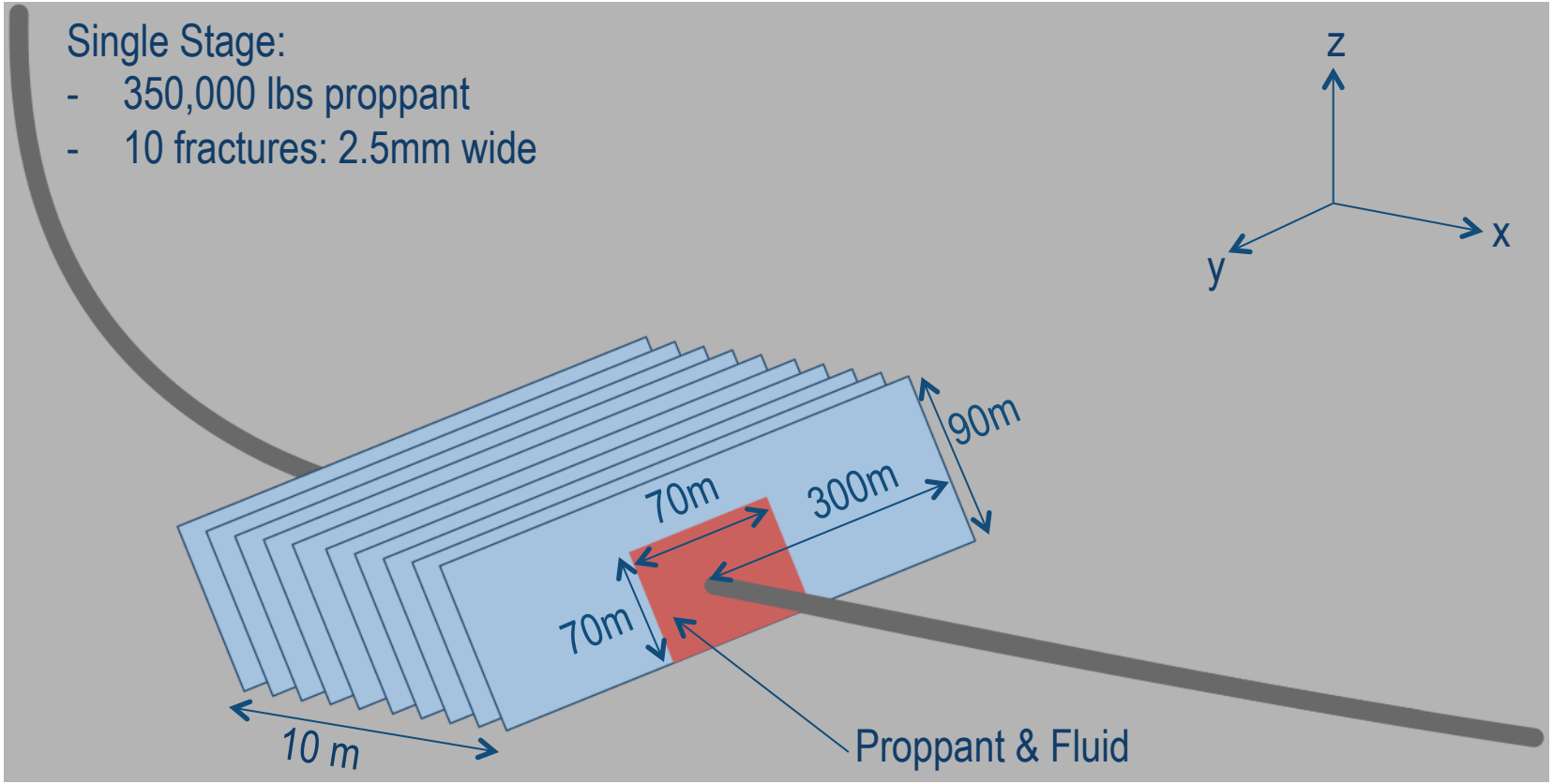
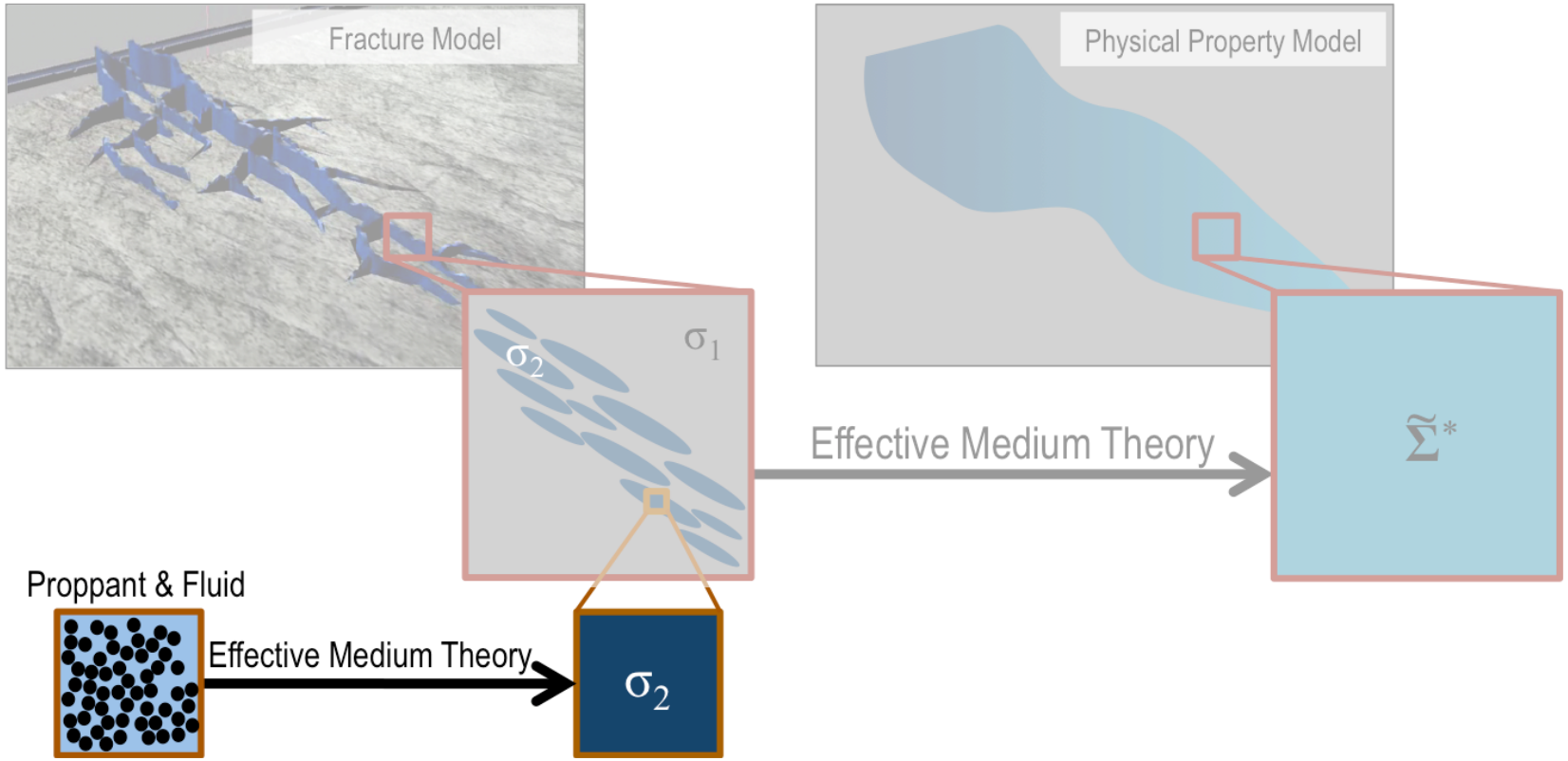
# Implementation



# Effective Conductivity of Fractured Rock Volume



# Effective Conductivity of Proppant & Fluid



# Effective Conductivity of Proppant & Fluid

- Conductive proppant & fluid
- Self-Consistent Method
  - Spherical Inclusions

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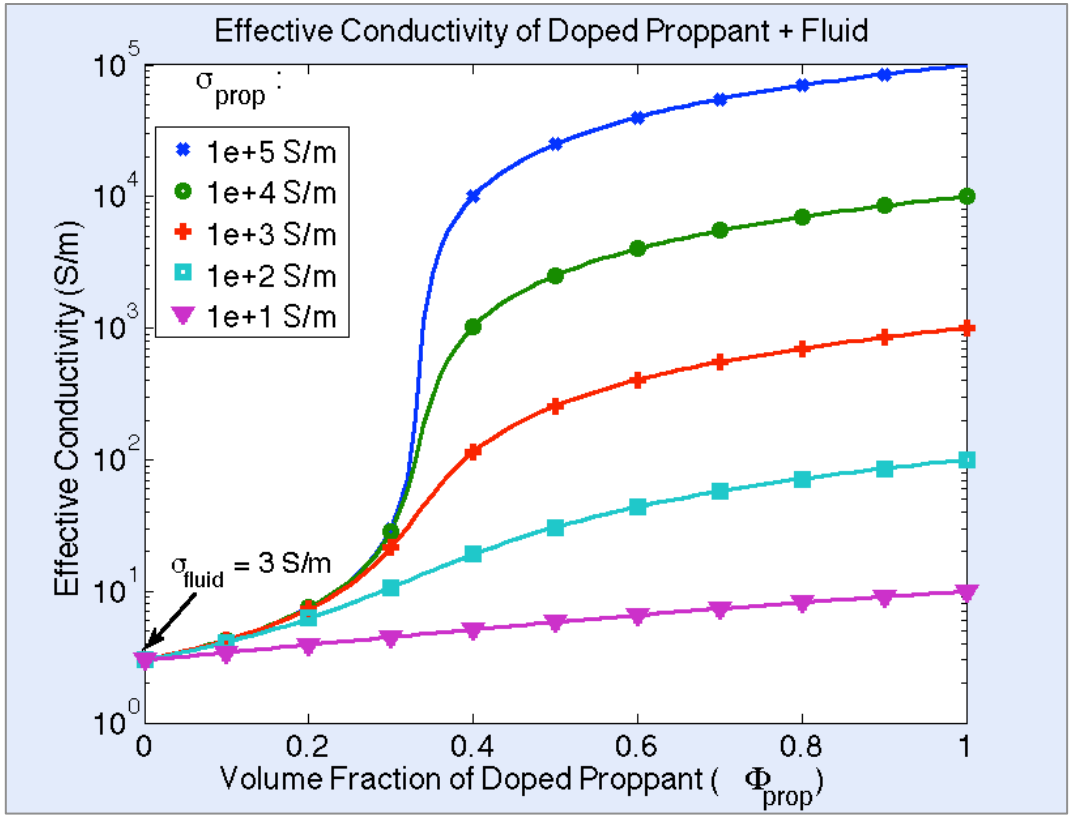

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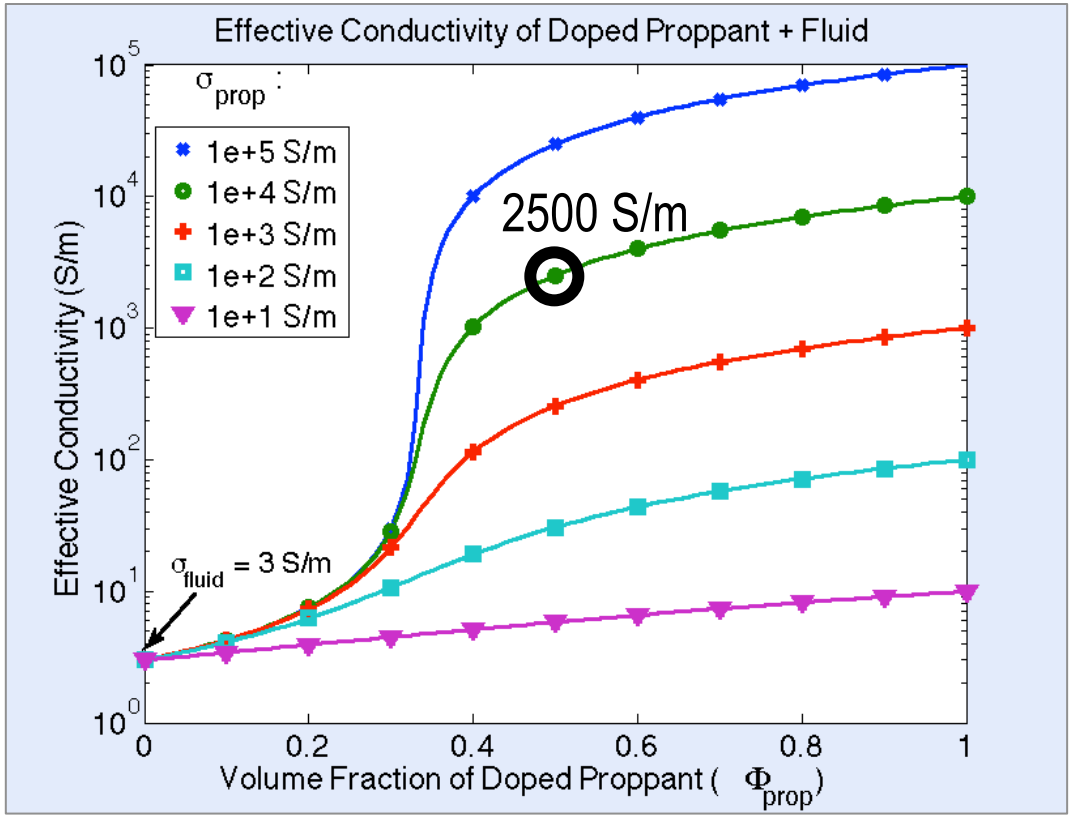

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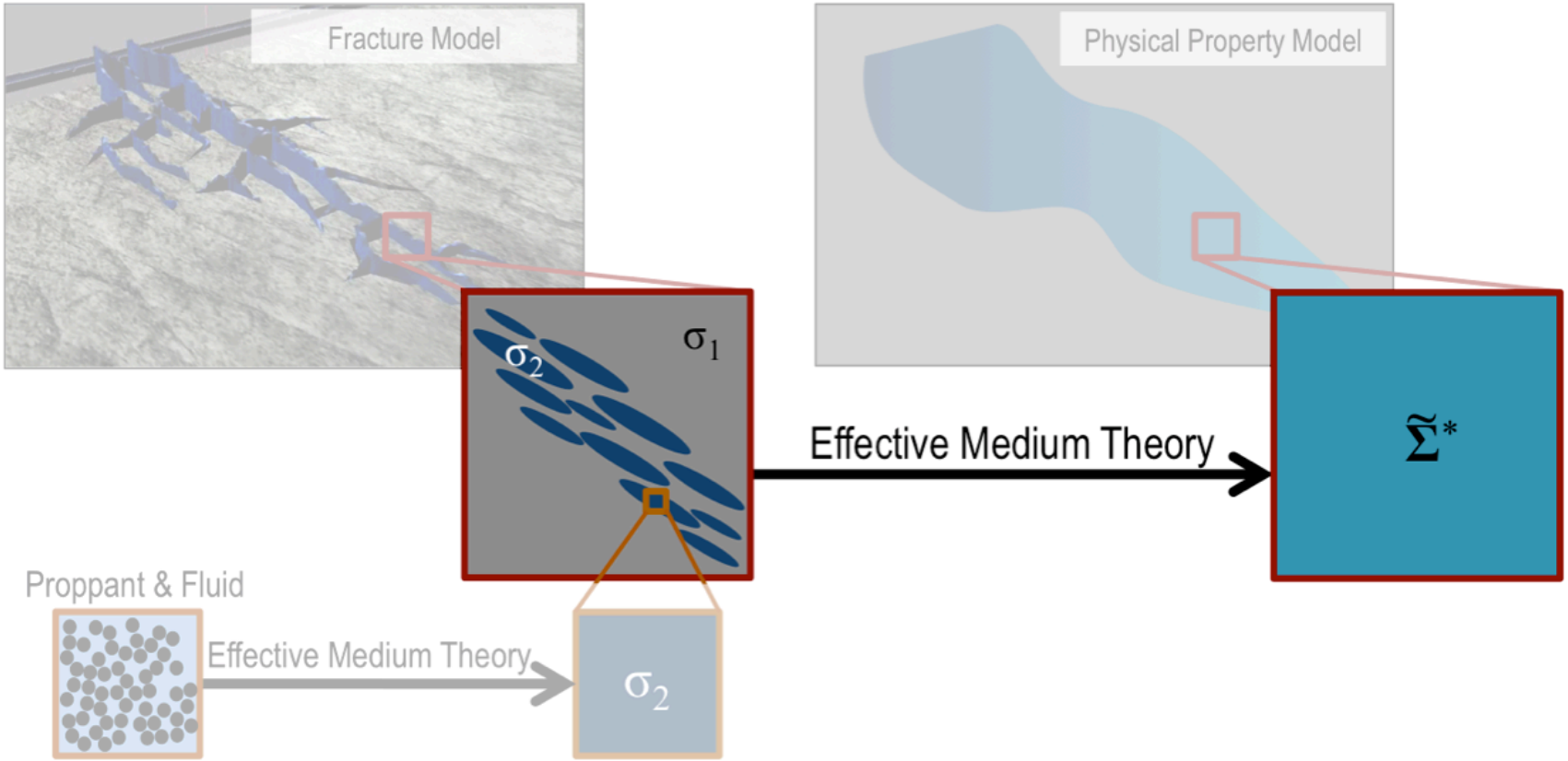

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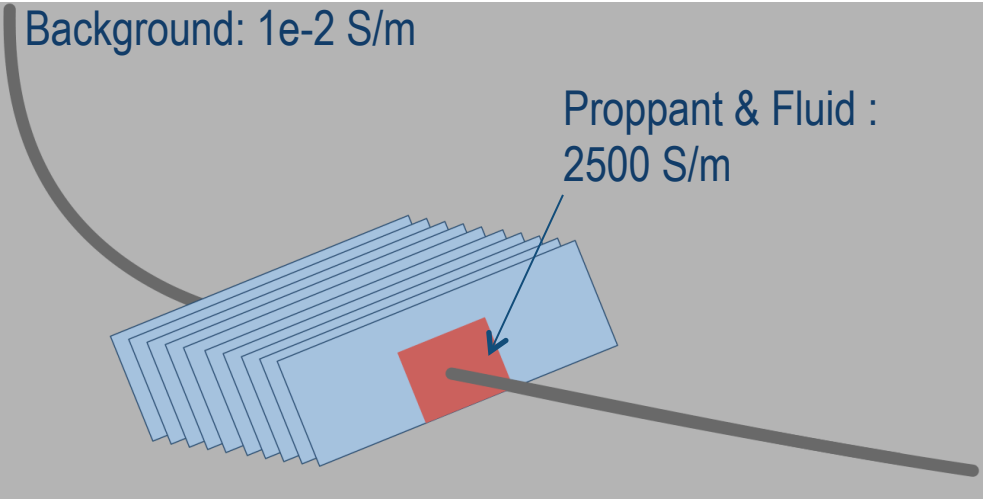
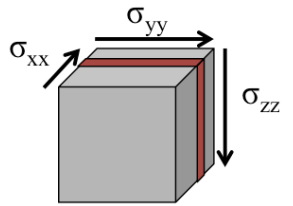
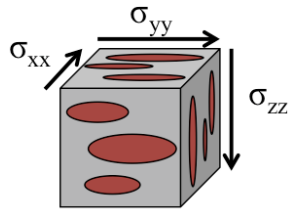



- Conductive Cracks
- Self Consistent Method
  - Inclusion Shape?
    - Ellipsoids
    - Spheroids
  - Form?
    - Strong
    - Weak

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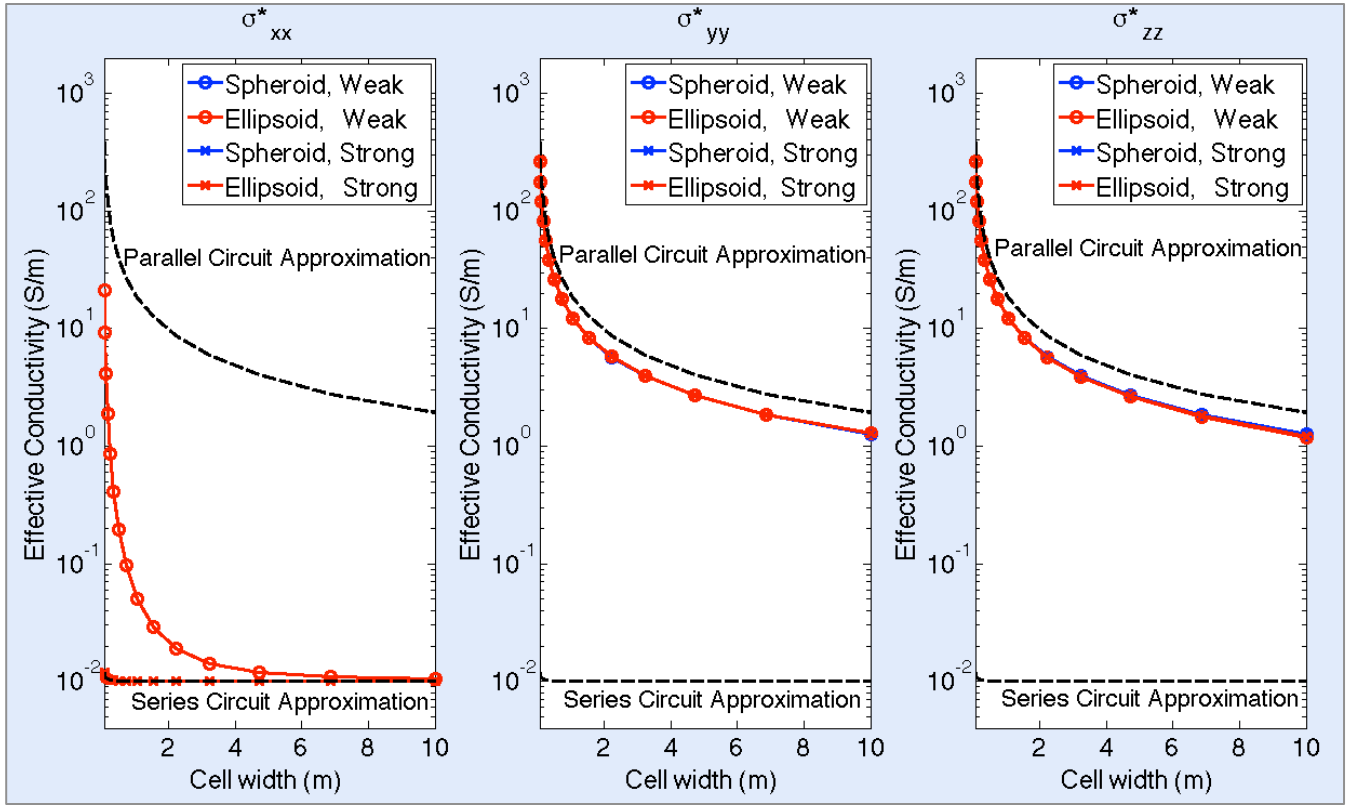


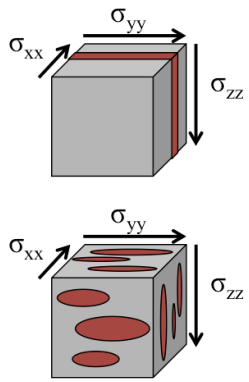

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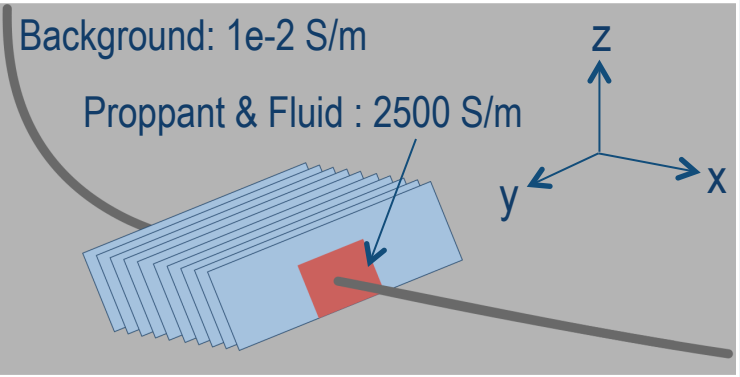
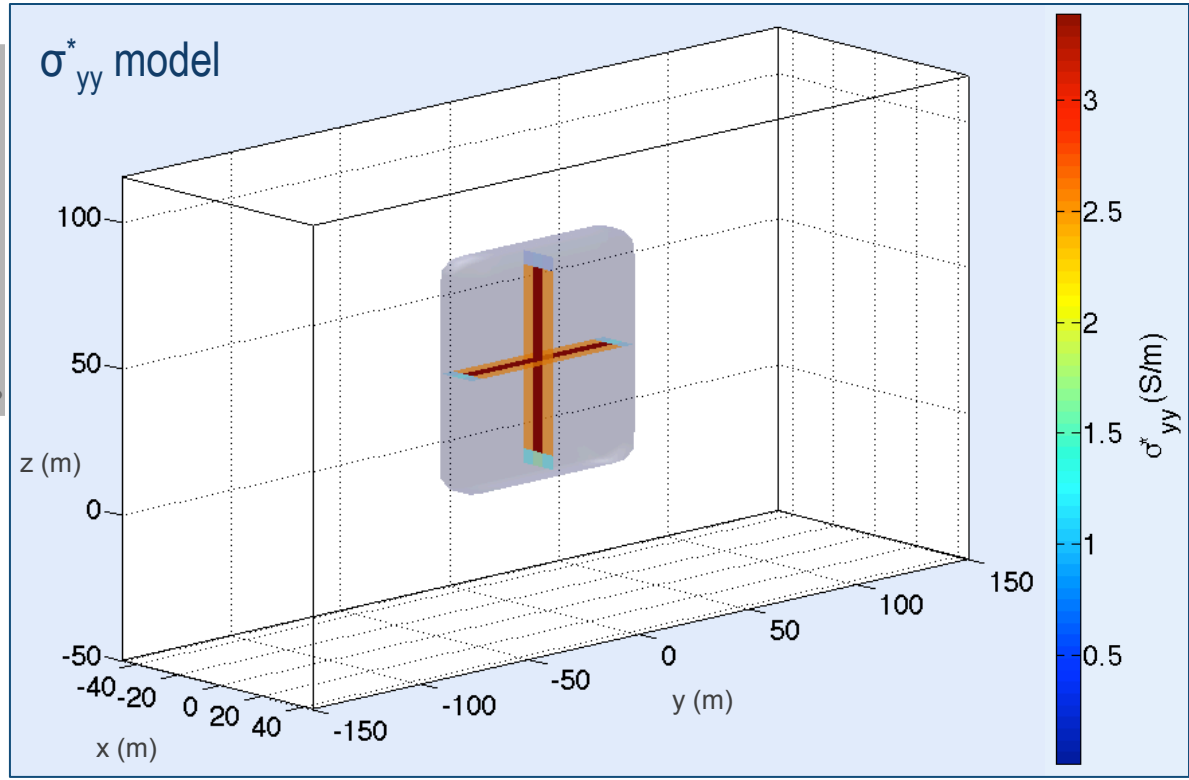
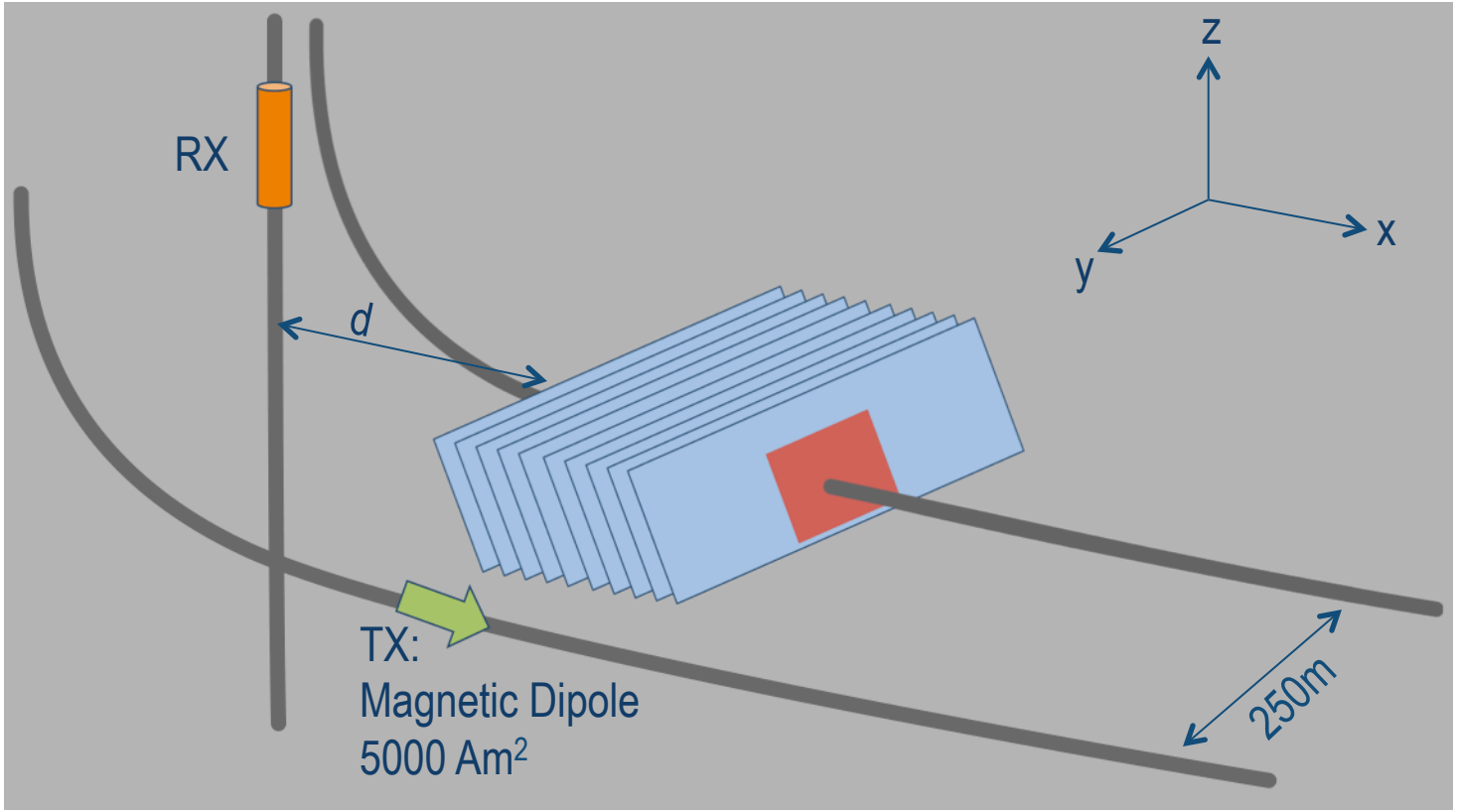


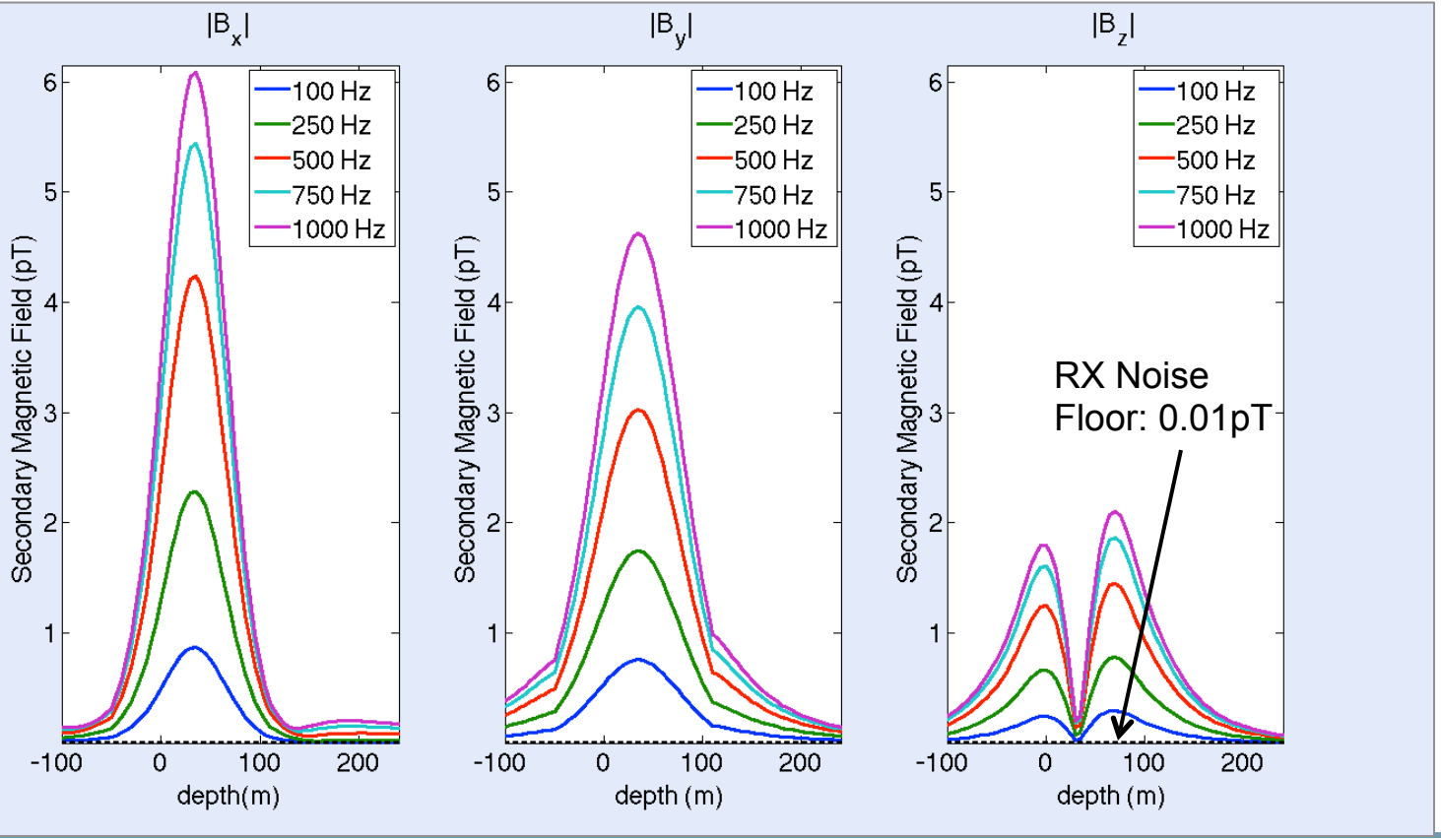

- 5x5x5 m cells
- Spheroidal inclusions
  - $\sigma^*_{yy} = \sigma^*_{zz}$
  - $\sigma^*_{xx} = 0.01 S/m$



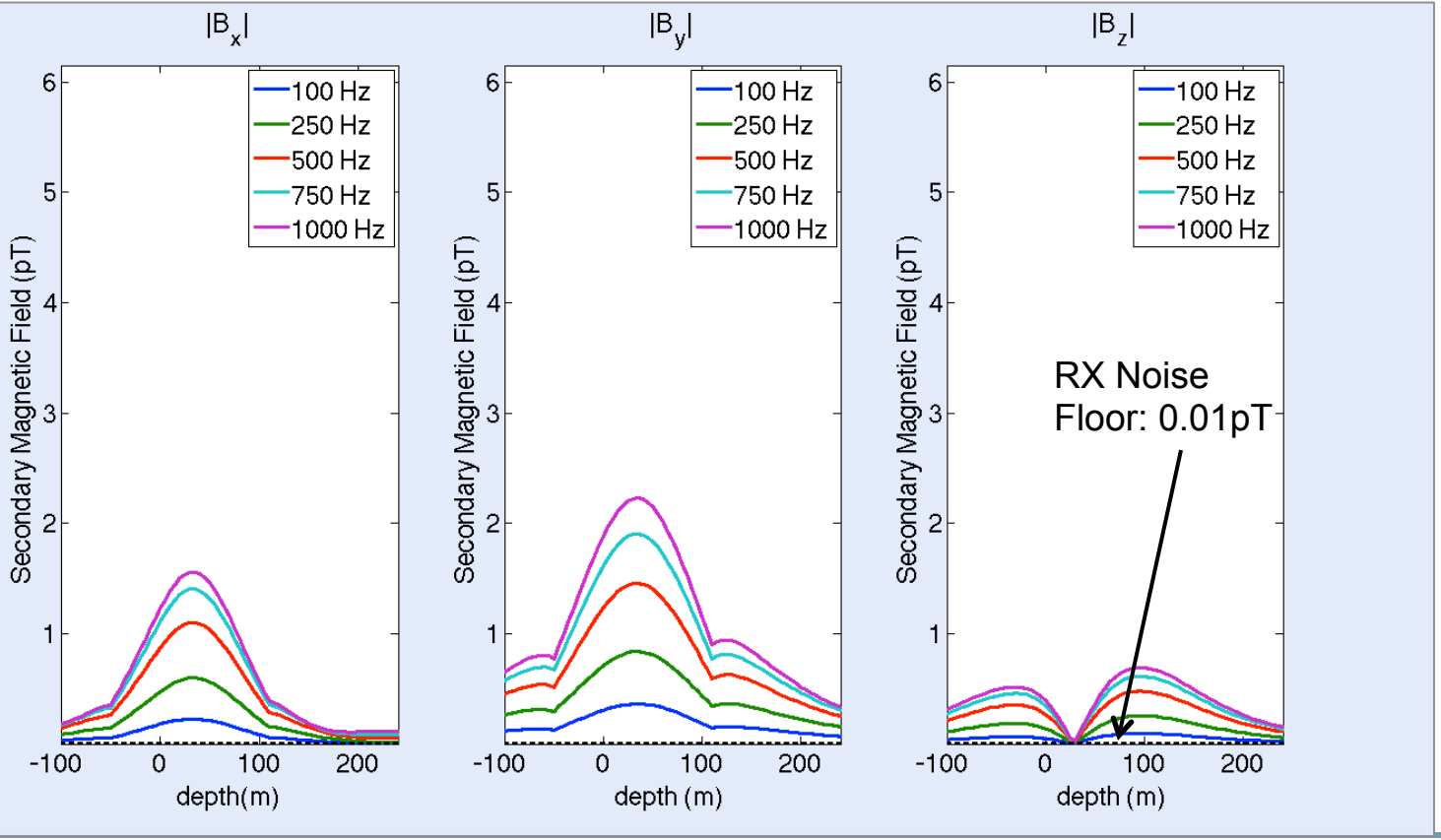
# Signal Analysis



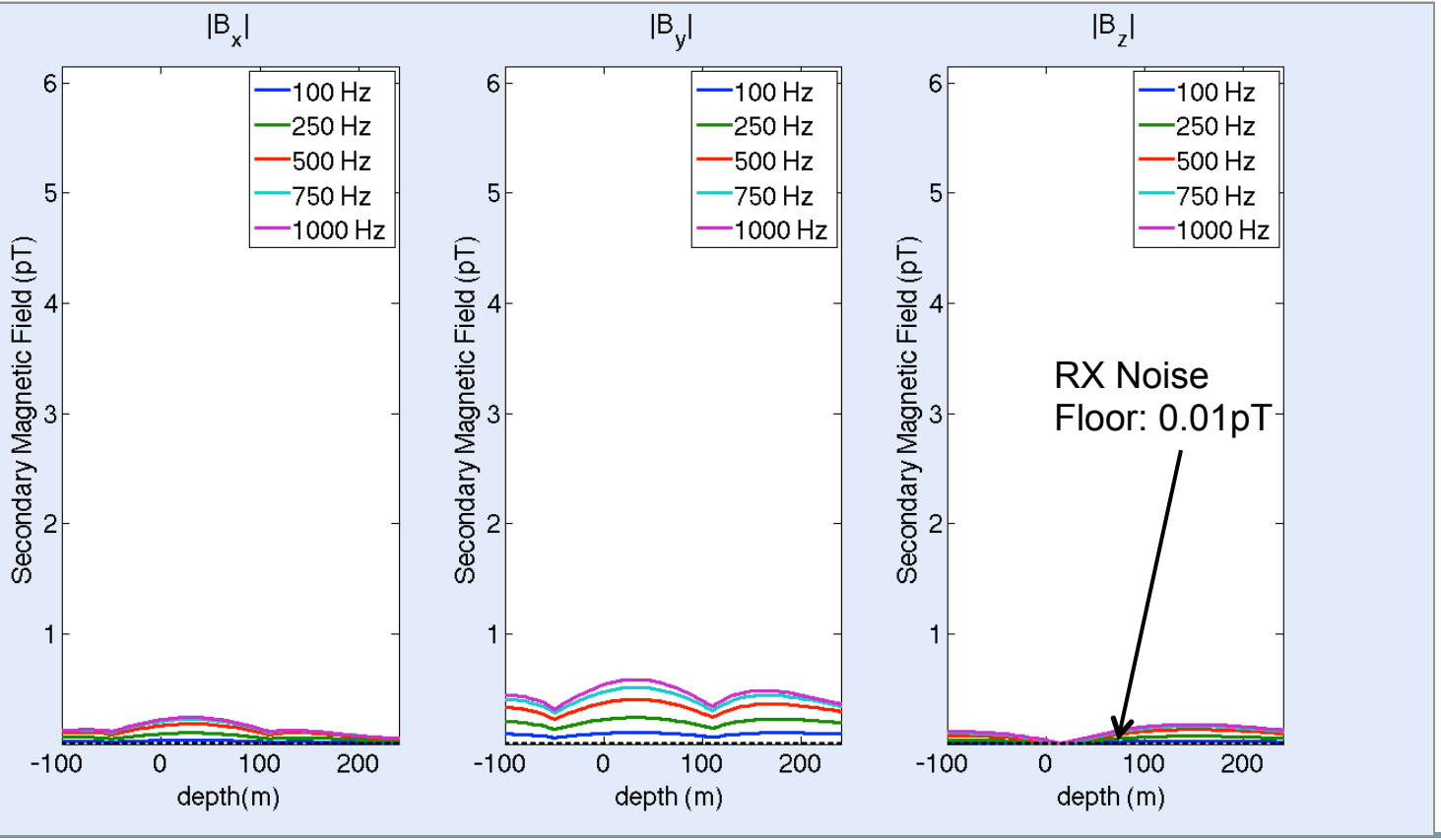
# Signal Analysis: Secondary Magnetic Field d = 50m



# Signal Analysis: Secondary Magnetic Field d = 100m



# Signal Analysis: Secondary Magnetic Field d = 200m



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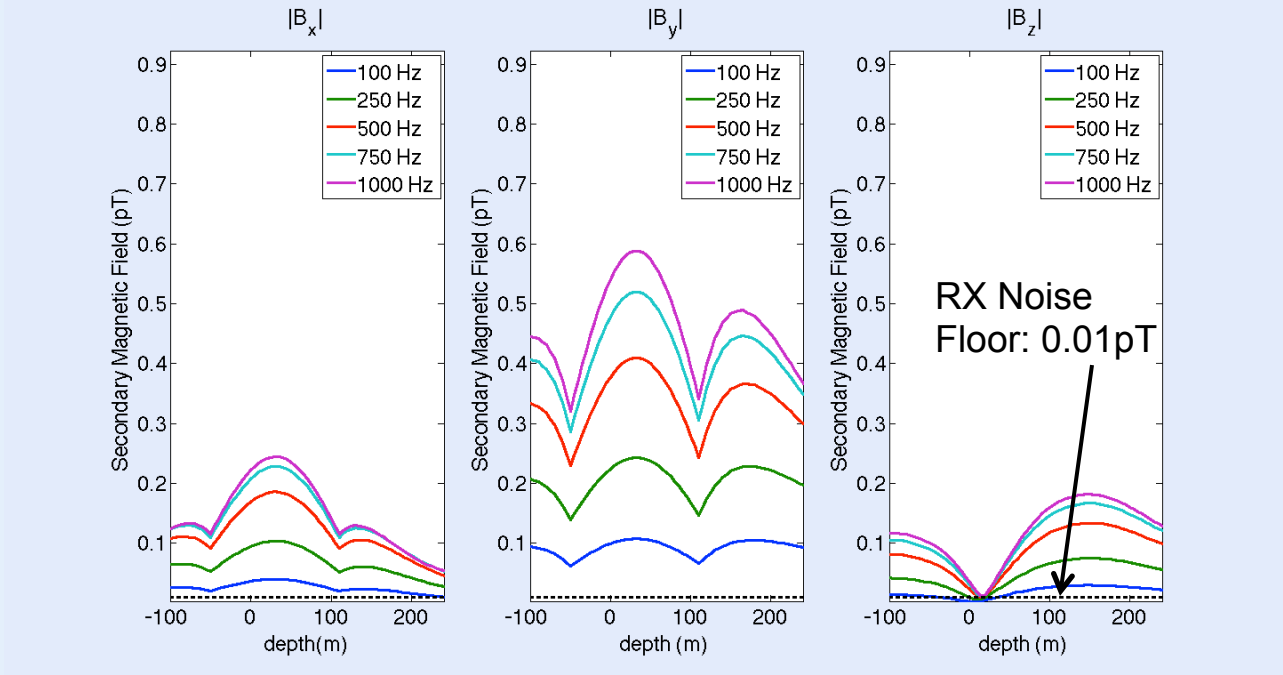
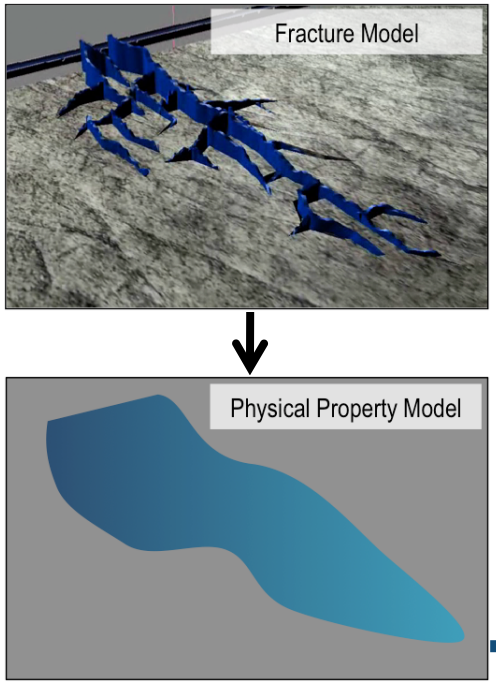


# Conclusions




- Using effective medium theory:
  - Fracture model → physical property model
  - Self Consistent Method – strong form
    - Characterizing shape of fractures exactly: not as essential
- Can detect a response
- Next:

Forward Model & Survey Design → Field Survey → Inversion & Data Interpretation

# Acknowledgements


- Thanks to Michael Wilt, Jiuping Chen, Nestor Cuevas and Ping Zhang with the Schlumberger EMI Technology Center for their help and support on this project

# Thank you!

Questions?

# References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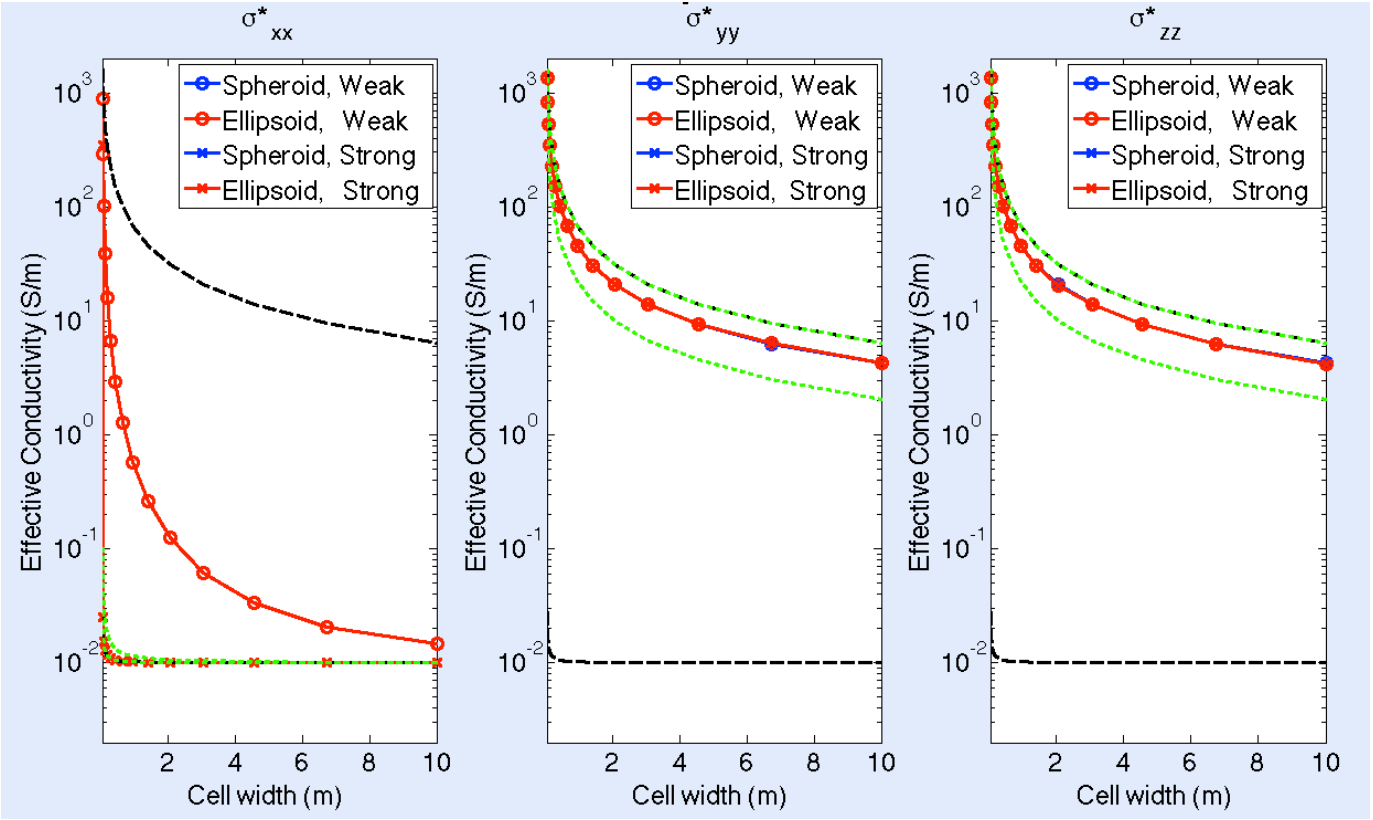
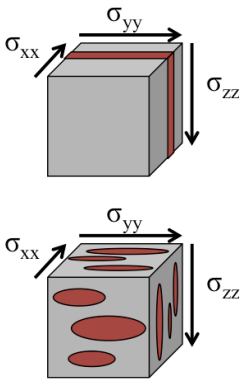
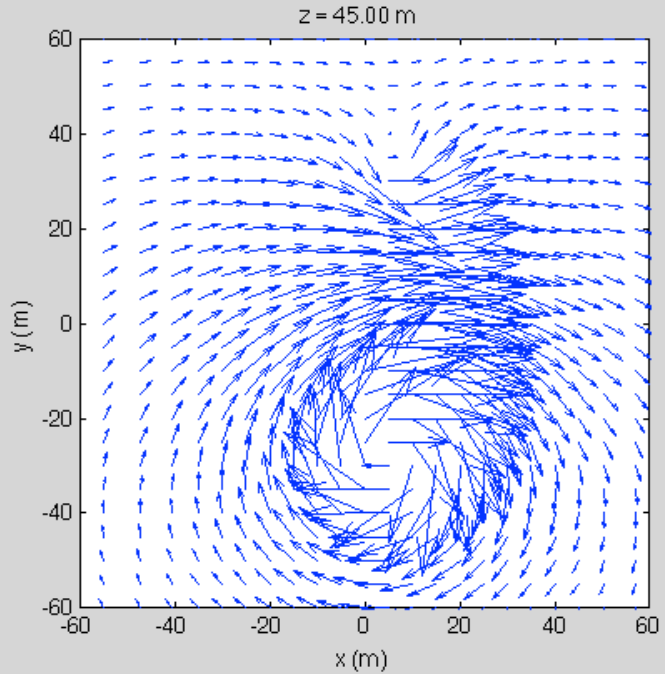
# Effective Conductivity of Fractured Rock Volume



# Signal Analysis: Secondary Magnetic Field

Real




Imaginary