# EMSP Project: Effects of Fluid Distribution on Measured Geophysical Properties for Partially Saturated, Shallow Subsurface Conditions

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**P.I., EMSP Project 70108**

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# Outline

- EMSP Project to Improve Seismic Imaging of Fluids
  --Lab Ultrasonic Measurements
  --X-ray CT Imaging of Lab Samples
  --Rock Physics Theories

- Combining Different Geophysical Data Sets

- Field Experiment Recommendations

# EMSP Project #70108

- **Lab Ultrasonic Measurements**

  **--New apparatus to collect P, S velocity data**

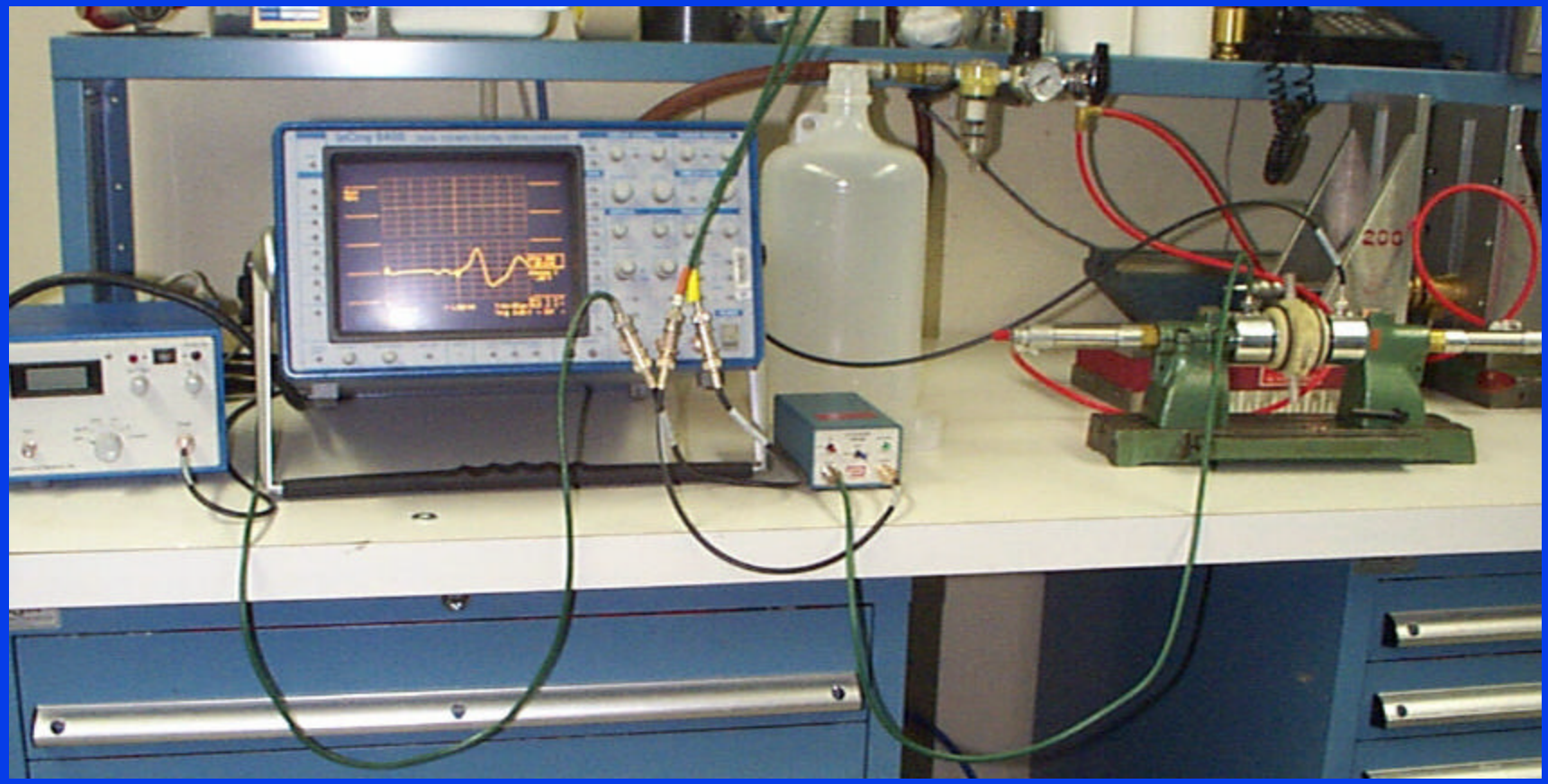
- **X-ray CT Imaging of Lab Samples**

  **--Know the fluid, clay content and distribution**

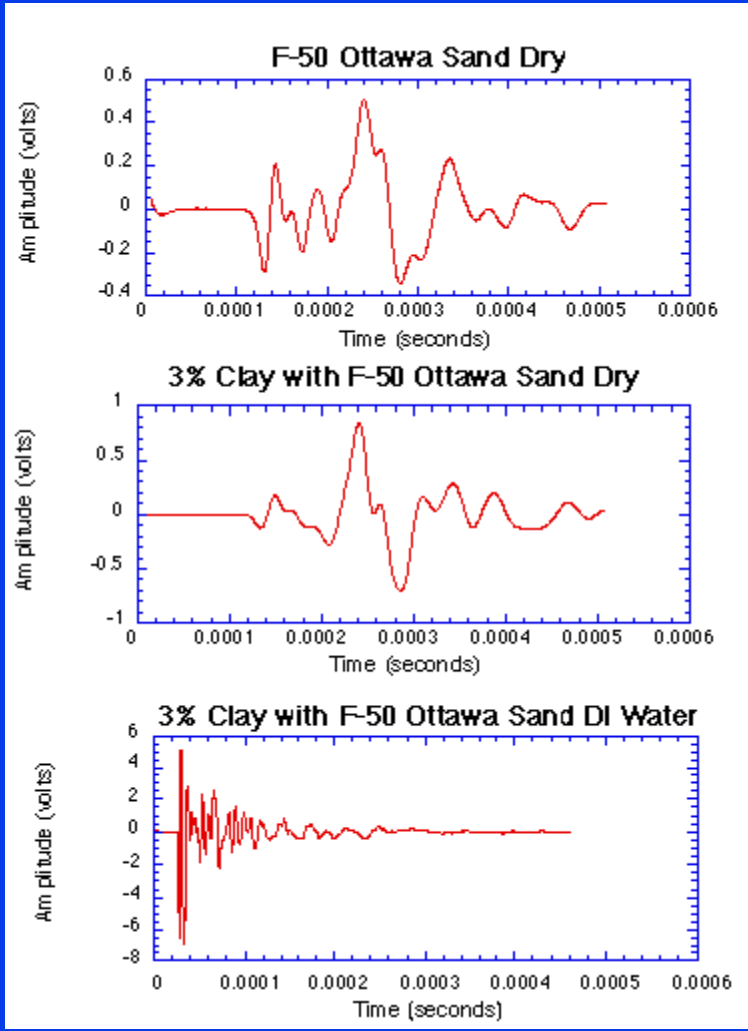
- **Rock Physics Theories**

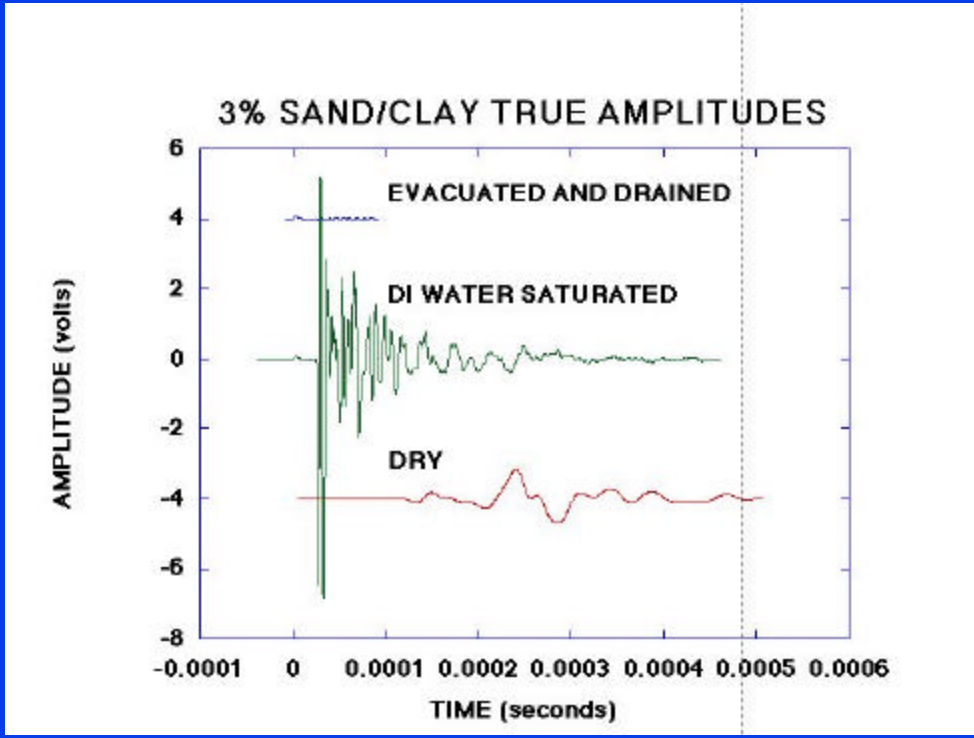
  **--Relate measured velocities to fluid, clay content and distribution**

# New Apparatus for Measuring P and S Velocities in Sediments at Low Pressures

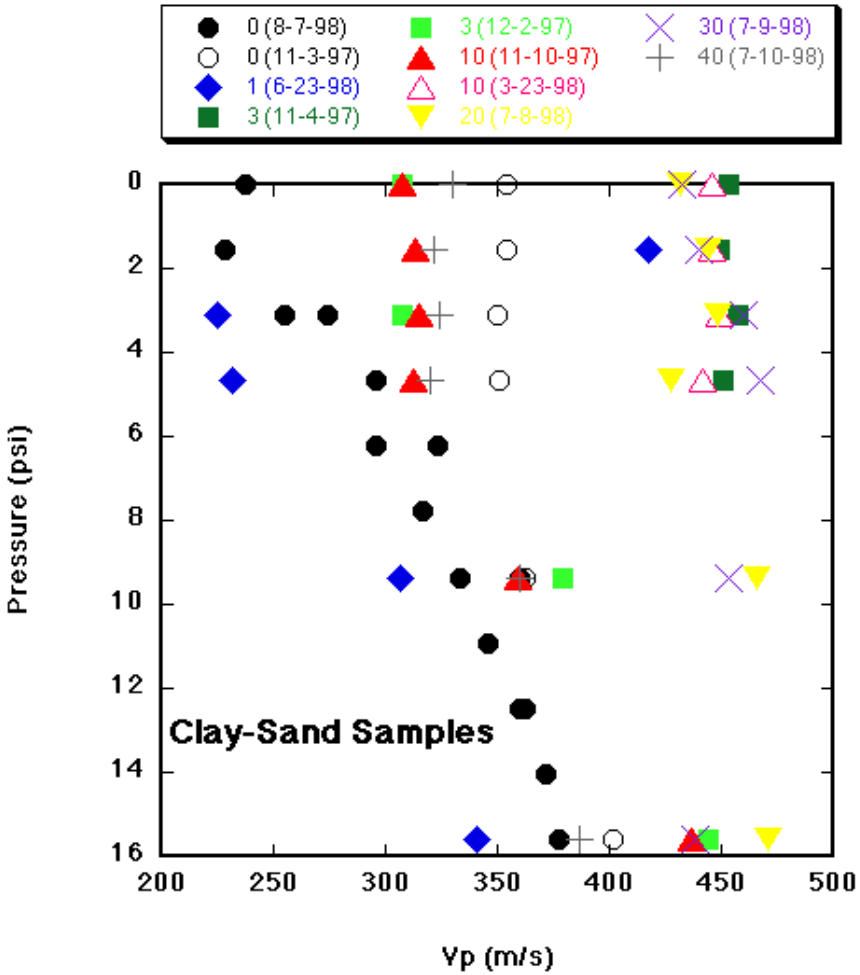


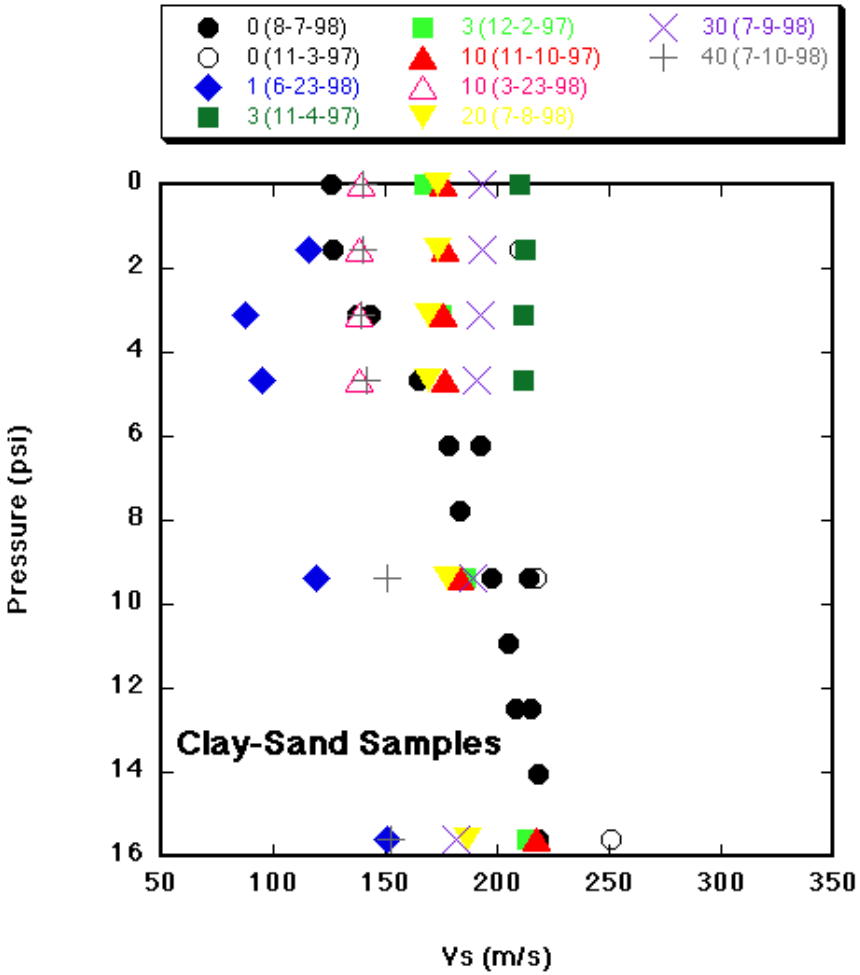
# Waveform Dependence on Clay, Fluid Content



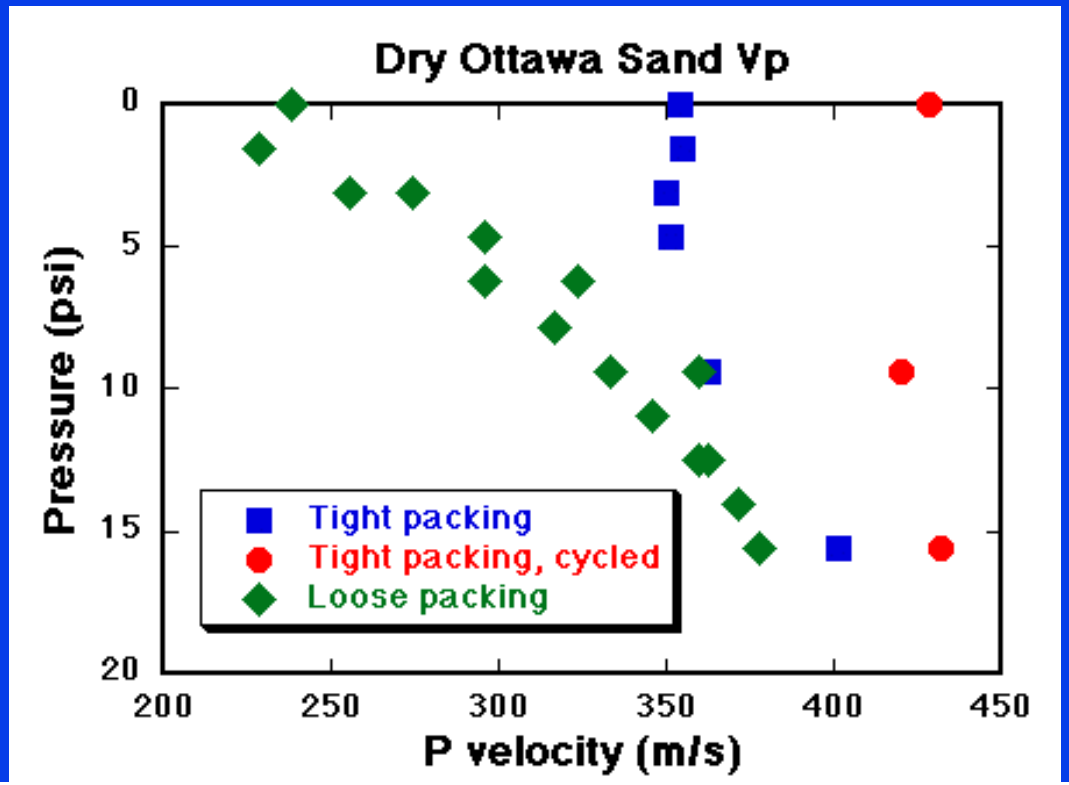
# Laboratory Velocity Data: Dry Sand-Clay Mixtures



# Velocity Measurement Results

- Low velocities, high gradients
- Strong dependence on packing, microstructure, fluid amount and distribution



# Microstructure Affects Measured Geophysical Properties

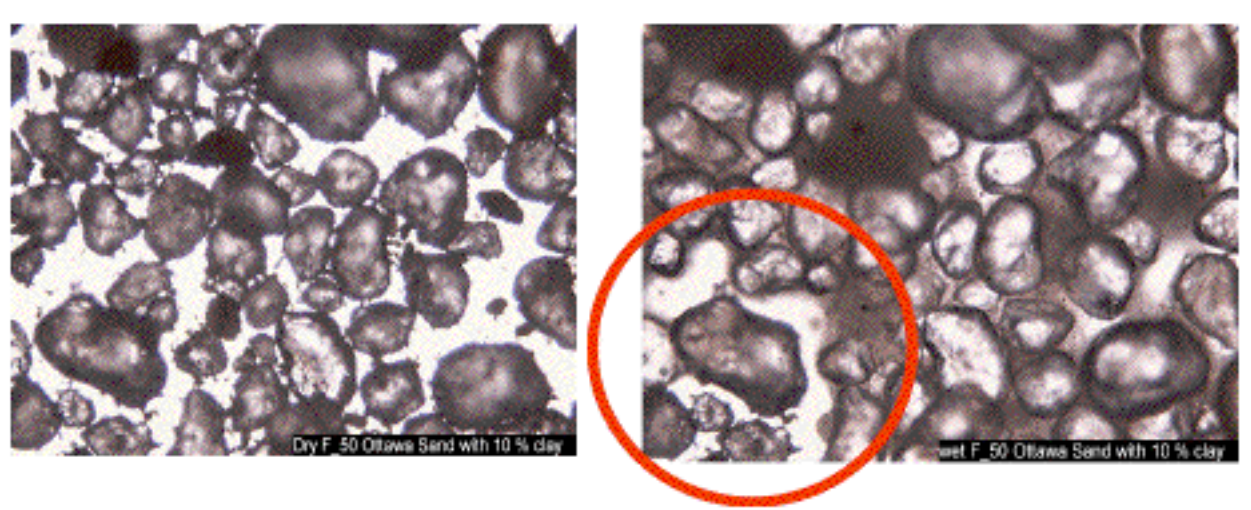
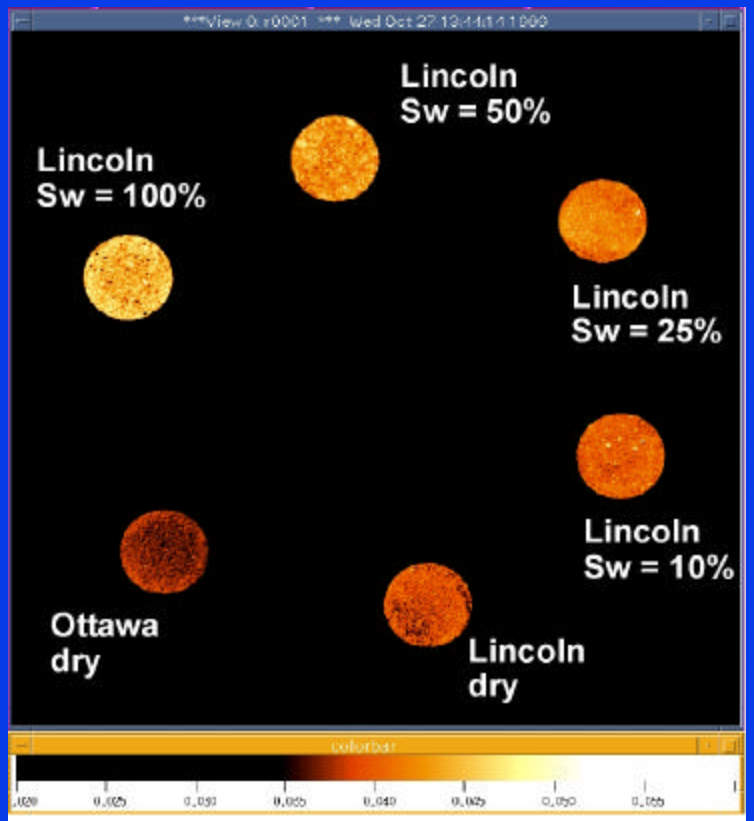



Figure 6. Photomicrographs of sand with ten percent clay. The grain size of the sand ranged from 74-420 microns with a mean of 273. The mixture in the left photograph is dry. The right photograph shows fluid advancing into the mixture. The circled area shows the boundry between fluid and gas phases.

# X-ray Imaging Results

- **Fluid distribution, saturation**
- **Sample heterogeneity, composition**

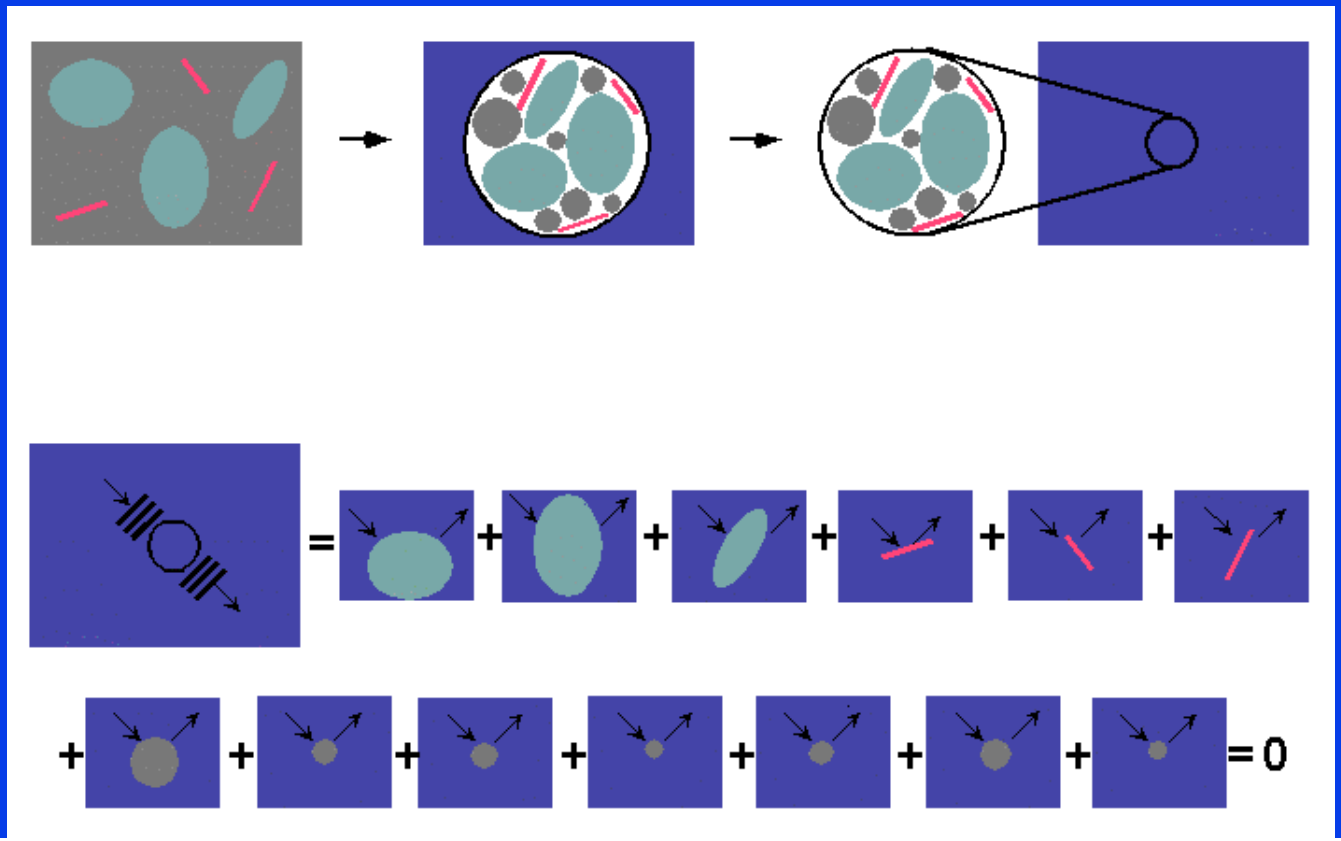



Water saturated samples, 160 kV

# Theoretical Modeling and Algorithm Development

- **Model velocities using rock physics theories**

**Self-consistent effective medium theory (Berryman, 1980)**



# Theoretical Modeling and Algorithm Development

- **Compare measurements to theoretical velocity dependence on fluid distribution**

**Velocity parameter plots for homogeneous vs. patchy saturation in sandstones (Berryman et al., 1999)**

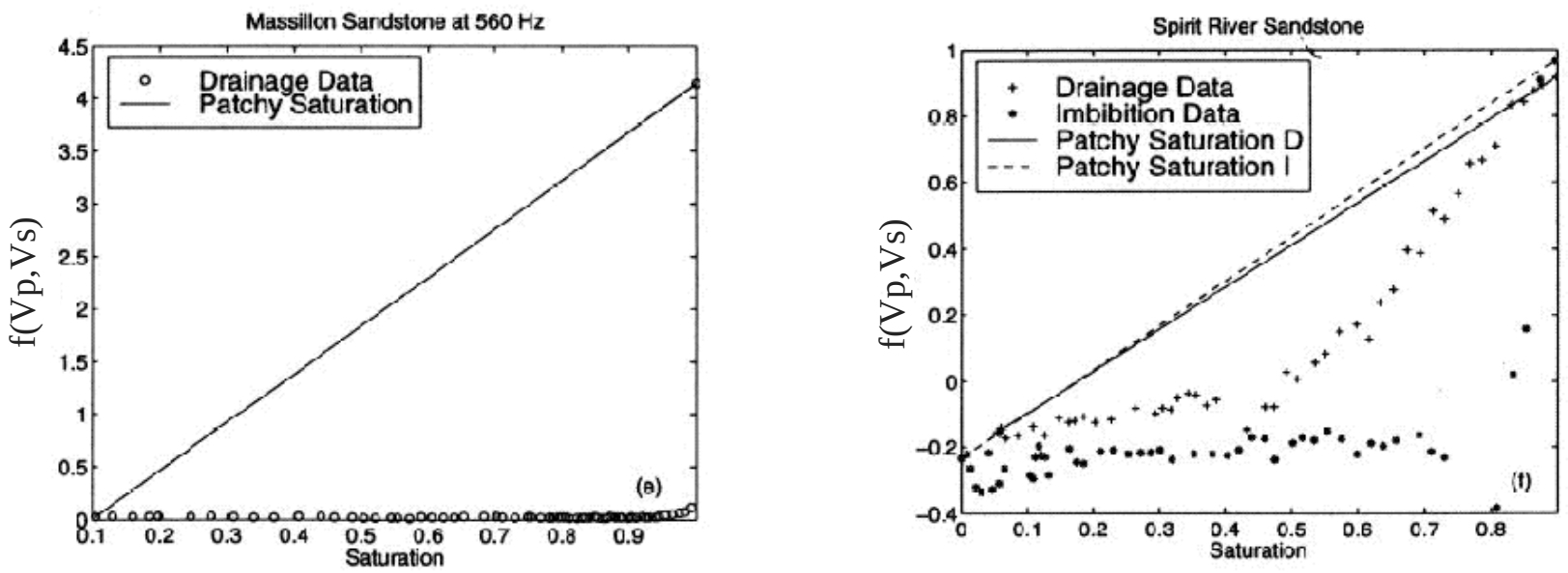



Figure 1: Compressional and shear velocities for Massilon sandstone measured by Murphy (1984) and for Spirit River sandstone measured by Knight and Nolen-Hoeksema (1990).

# Combining Different Geophysical Data Sets

- Modeling and Theoretical Work to Understand the Physics, Controlling Processes

  --e.g., previous EMSP projects of Berge, Carrigan

- Sophisticated Empirical and Statistical Approaches

  --e.g., recent work by Carle, Steefel at LLNL

- Multiple Field Data Sets Provide Additional Constraints

# Combining Geophysical Data Sets

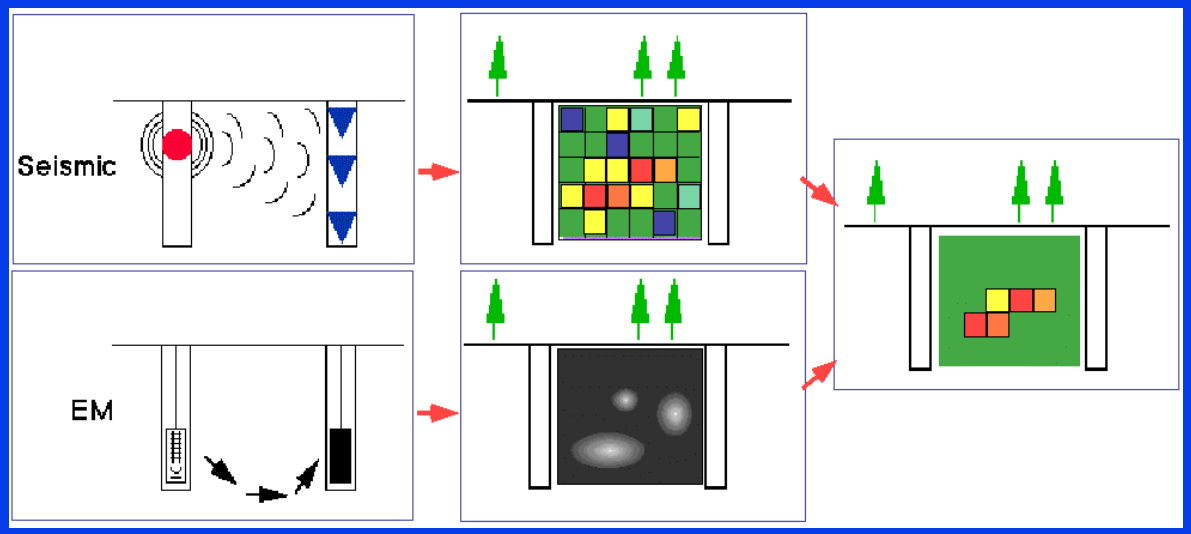
- 1996-1999 EMSP Project #55411: Joint Inversion of Geophysical Data for Site Characterization and Restoration Monitoring

- LLNL PI's: P.A. Berge, J.G. Berryman, J.J. Roberts, D. Wildenschild

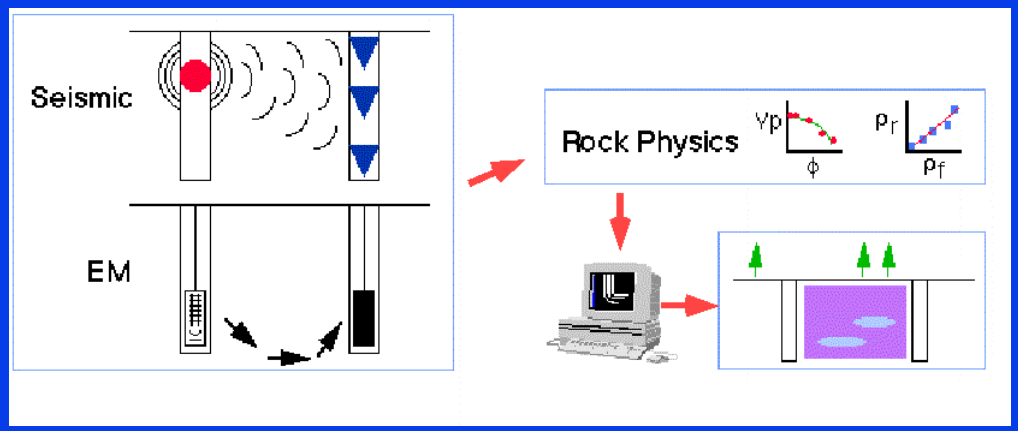
- URL: http://www-ep.es.llnl.gov/www-ep/esd/expgeoph/Berge/EMSP/

# Improving Geophysical Imaging

- **Current methods:**




- **Improving the state-of-the-art:**



# Multiple Data Sets Provide Additional Constraints

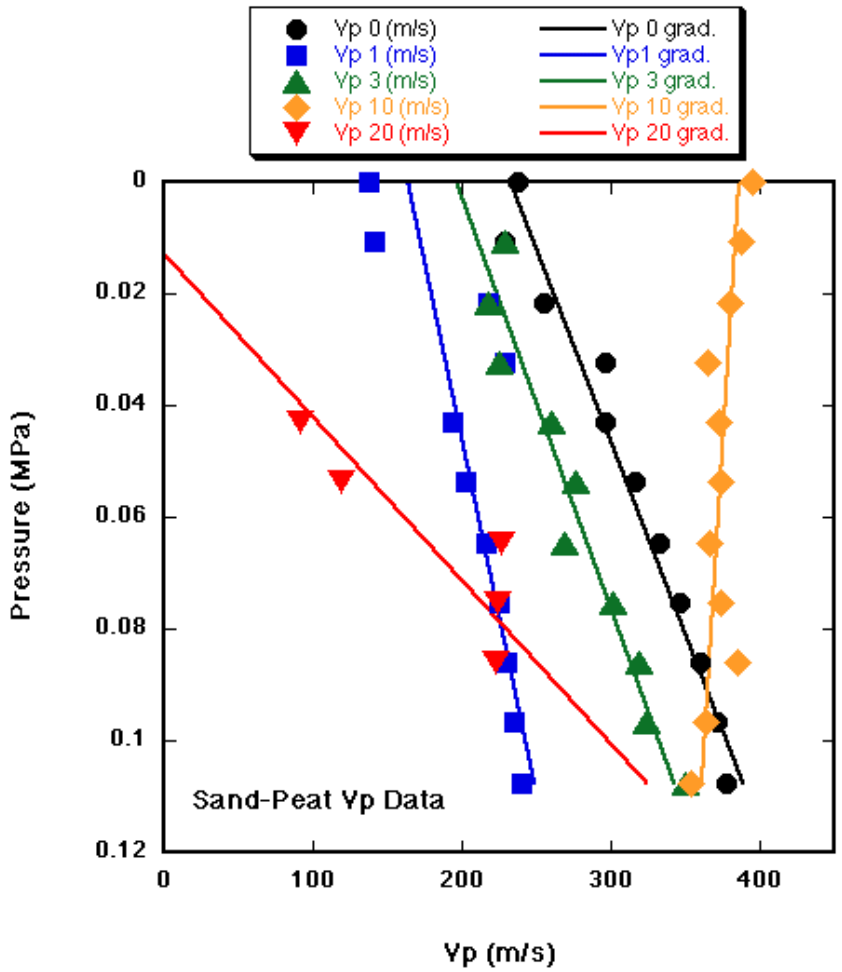
- **Having both P and S velocities significantly improves interpretation of seismic data.**

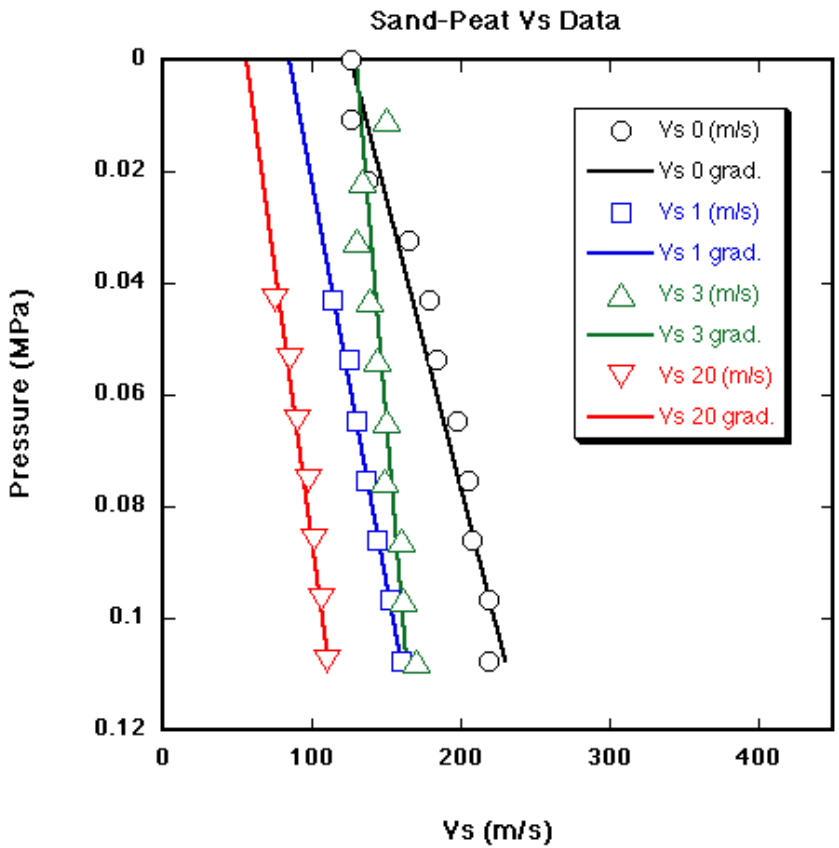
  **--Synthetic field data examples**

  (Berge, P. A., and Bertete-Aguirre, H., 1999, Laboratory velocity measurements used for inferring soil distributions from field seismic data: *LLNL report UCRL-JC-135132*, submitted to the *13th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), to be held in Arlington, Virginia, February 20-24, 2000,* sponsored by the Environmental and Engineering Geophysical Society.)

  (Bertete-Aguirre, H., and Berge, P. A., 1999, Laboratory ultrasonic measurements of sand-clay mixtures used to recover clay content in silty sands (abstract): *LLNL report UCRL-JC-135643-ABS*, 1 p., *Eos, Transactions of the American Geophysical Union, Fall Meeting Supplement, Proceedings of the Fall Annual Meeting, held in San Francisco, CA, Dec. 13-17, 1999,* 80, F395-396.)

# Laboratory Velocity Data: Dry Sand-Peat Mixtures



# Field Data, Peat Soils

| Depth | Vp (m/s) | Vs (m/s) | Source |
|---|---|---|---|
| Surface (0 MPa) | ~11 m/s ? | 7.3 m/s | pile test, seismic cone (Crouse et al., 1993) |
| 3 - 5 m | 125 m/s | | seismic refraction (Taylor & Wilson, 1997) |
| 4.5 m (0.04 MPa) | ~35 m/s ? | 30 m/s | pile test, seismic cone (Crouse et al., 1993) |
| 13 - 14 m (0.13 MPa) | | 84 m/s | downhole logs, lab. bender els. (Boulanger et al., 1998) |
| 20 m | | 100 m/s | borehole data (Nunziata et al., 1997) |
| 80 m | | 200 m/s | borehole data (Nunziata et al., 1997) |

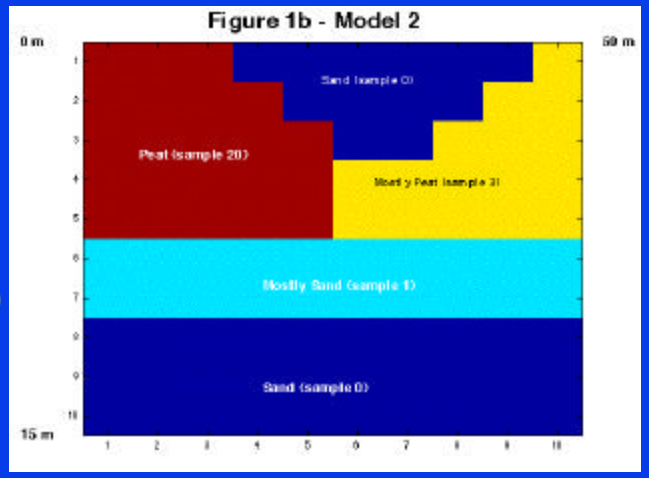
# Field Data, Continued

| Depth | Vp (m/s) | Vs (m/s) | Source |
|---|---|---|---|
| 3 m (0.02 MPa) | 240 m/s | 120 m/s | suspension P-S logging (Agbabian Assoc., 1994) |
| 13 m (0.09 MPa) | 310 m/s | 120 m/s | “ |
| 16 m (0.12 MPa) | 550 m/s | 91 m/s | “ |

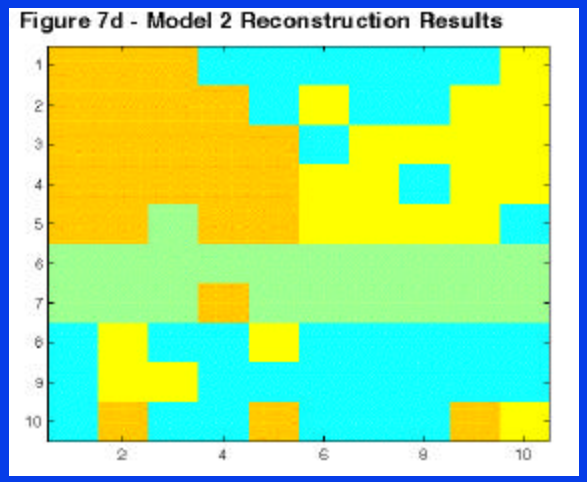
# Using Both P and S to Constrain Inversion Results

Soil Structure Model

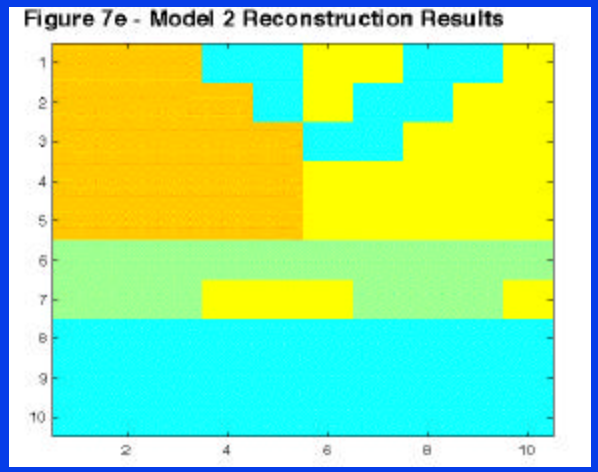
(Berge and Bertete-Aguirre, 1999)



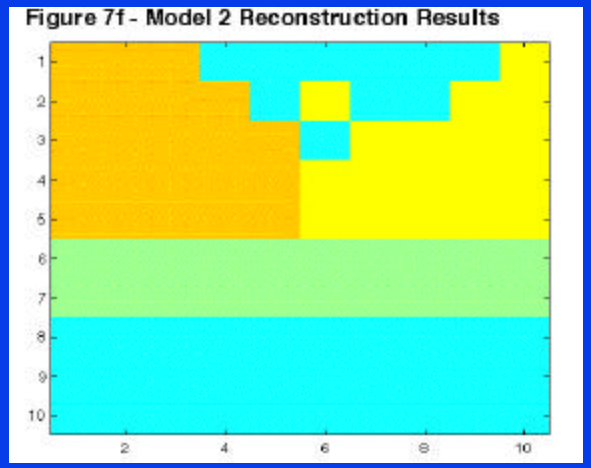

From P Velocities



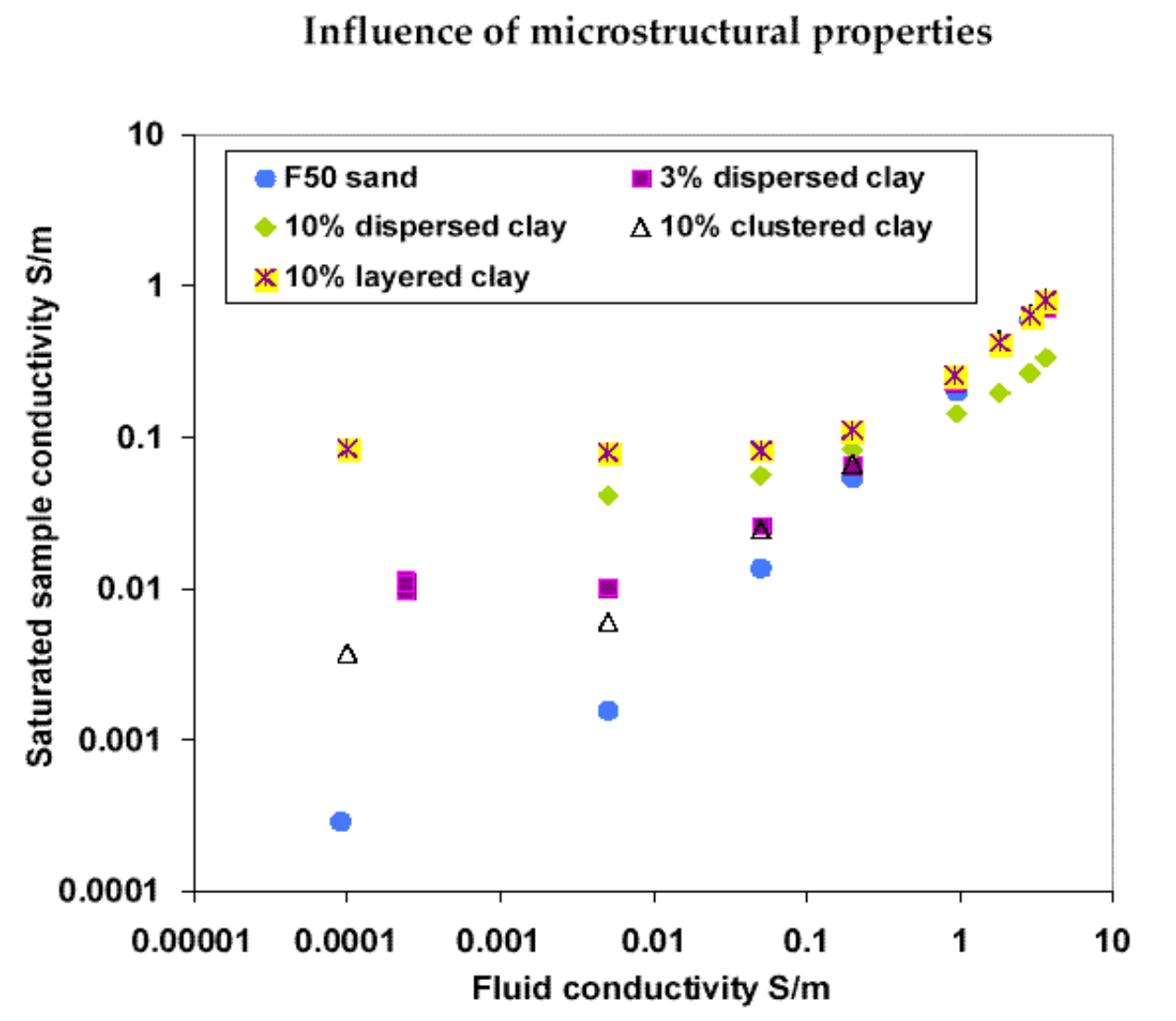

From S Velocities




P & S Velocities



# Electrical Properties Data: Additional Independent Constraints



# Recommendations for Field Experiments

- Collect both P and S velocity data.

  --Seismic: impact <u>and</u> vibrational sources (for reflection or refraction lines)

  --Borehole logging: e.g., OYO Geophysics Corp. P-S tool (high-tech), or SAIC probe from G-tunnel test (low-tech)

  --Cone penetrometer: e.g., Taber Consultants cone with instrumented tip

# Recommendations for Field Experiments

- **Avoiding casing problems:**

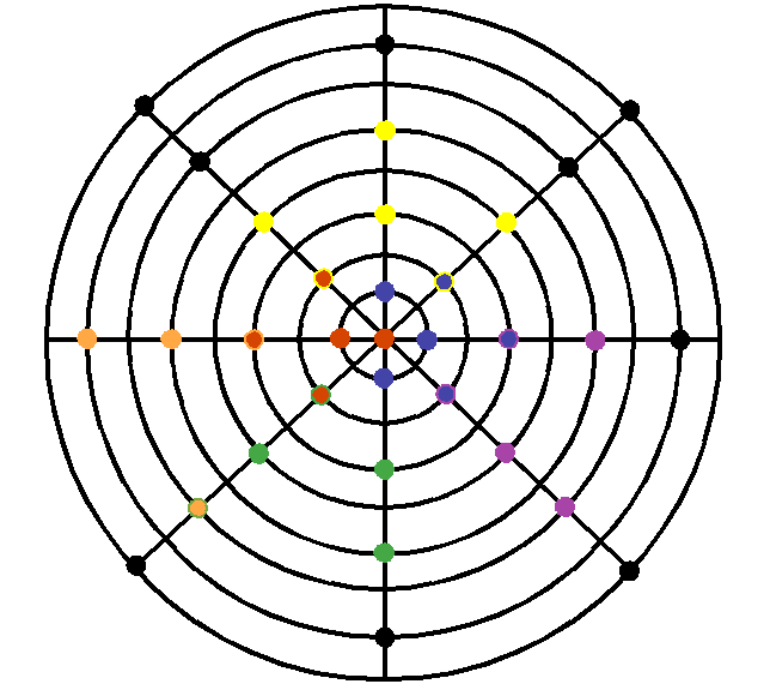
  **--Try seismic, microgravity methods.**

  **--Use modeling to design EM, gravity experiments in optimum way.**

  **--ERT (e.g., Daily's work)**

  **--Surface GPR (e.g., Knight's work)**

  **--Use LLNL vadose zone observatory as analog to understand processes.**

# Field Geometry to Overcome Signal Attenuation Problems

- Use small “sub-arrays” if signals won’t propagate far enough.
- Use sophisticated inversion software to combine results from all the “sub-arrays” to build an image beneath the entire field site.