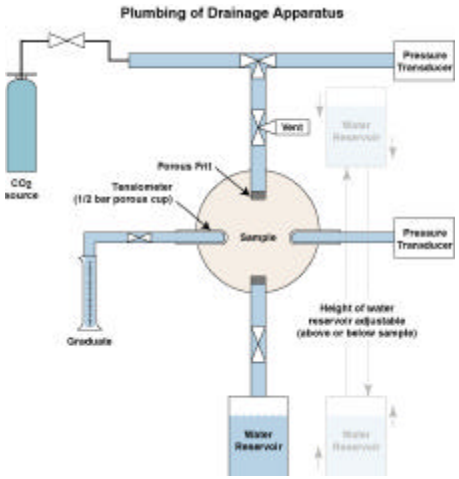
FY2002 Vadose Zone Workshop, 11-6-2001

Scientific Results for EMSP Project #70108

Effects of Fluid Distribution on Measured Geophysical Properties for Partially Saturated, Shallow Subsurface Conditions



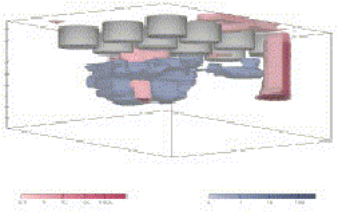
Patricia A. Berge

Lawrence Livermore National Laboratory

Outline

- Relevant Background
- Scientific Results and Accomplishments
- Implications for Vadose Zone Monitoring
- Research for FY02 and Anticipated Final Products

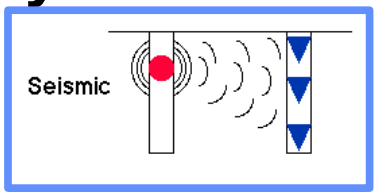
Relevant Background



- **Hanford vadose zone contains contaminants.**
- **Characterization/monitoring using direct sampling methods may be hazardous and expensive.**
- **Improving geophysical subsurface imaging may be useful for characterization and monitoring cleanup efforts at Hanford.**

Linkages to DOE EM site needs

- **Needs for improving geophysical methods for subsurface characterization/monitoring in the vadose zone, particularly for seismic imaging in shallow soils.**
  - **ID-6.1.02, ID-6.1.04**
  - **OH-F049**
  - **OK99-01**
  - **ORHY-03**
  - **RL-SS10, RL-SS31**
  - **PNNL Hanford GW/VZ Integration Project**



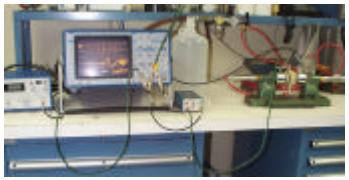
Office of River Protection

Research objective: Improve subsurface imaging

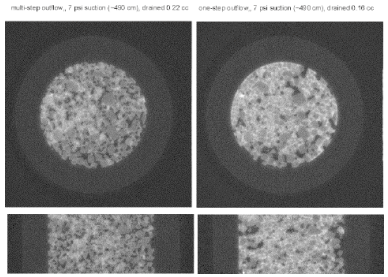
- Basic research funded by DOE Environmental Management Science Program
- Develop relationships between geophysical measurements and porosity, saturation, soil composition, fluid distribution
- Long-term goal to improve interpretation of geophysical field data at DOE contaminated sites
- End-users: geophysicists doing seismic surveys

Scientific approach

- Lab geophysical measurements for soils

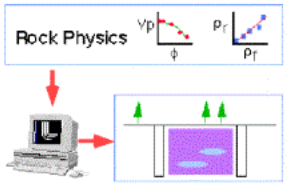


- X-ray computed tomography

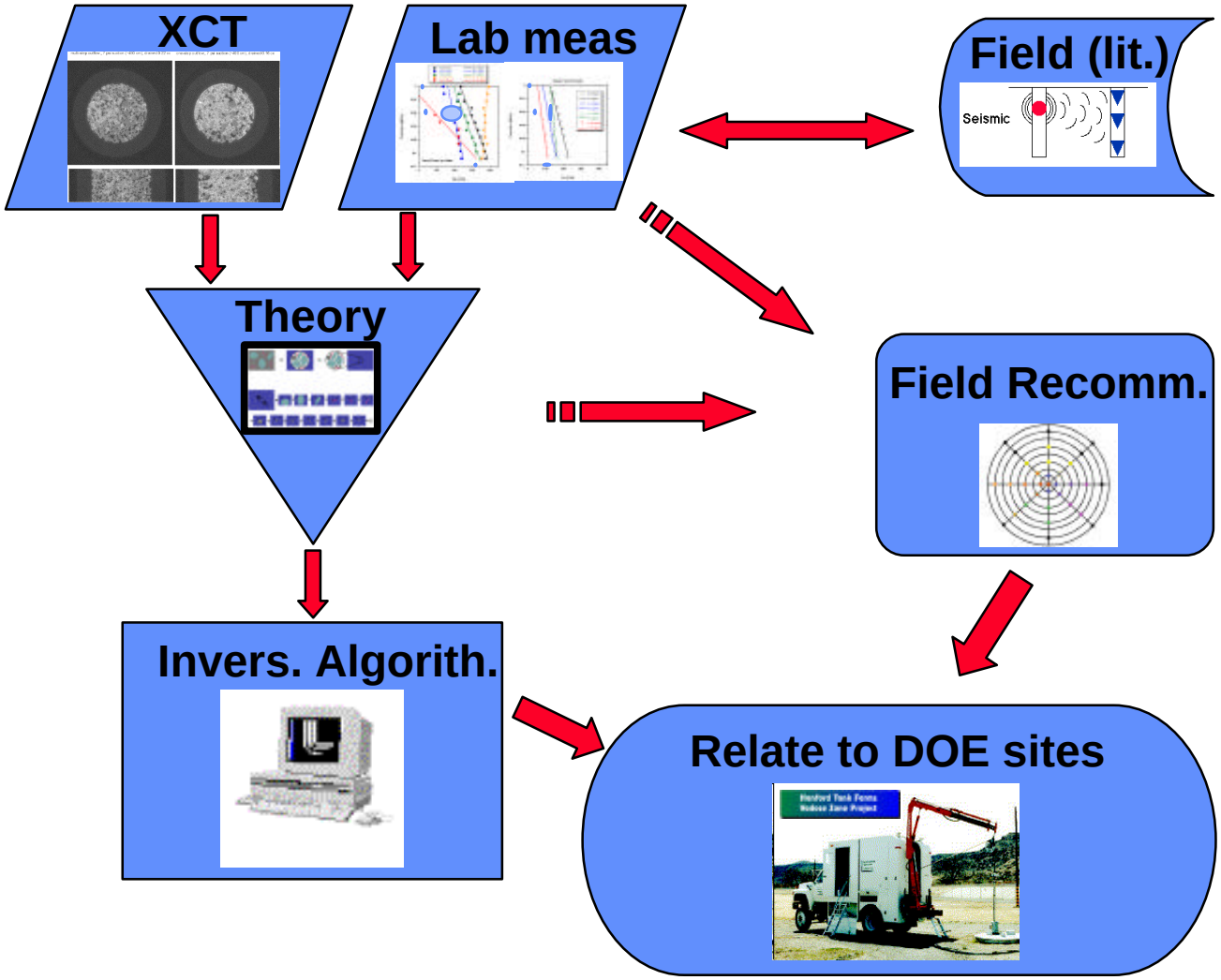


- Rock physics theories and modeling

- Develop algorithms

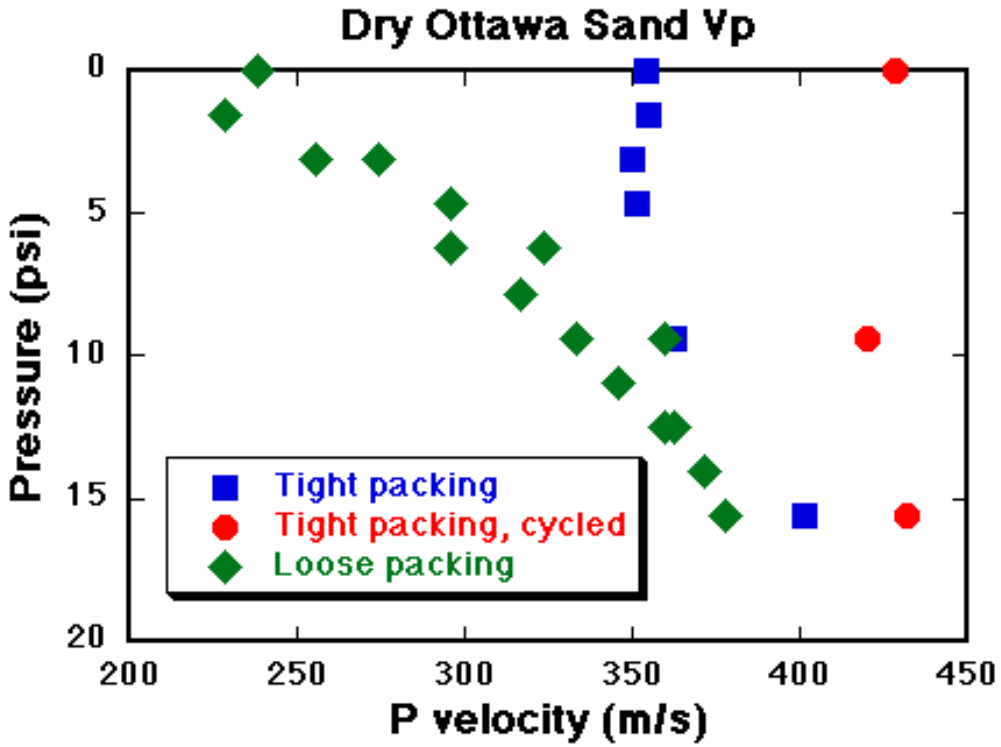


Putting it all together:



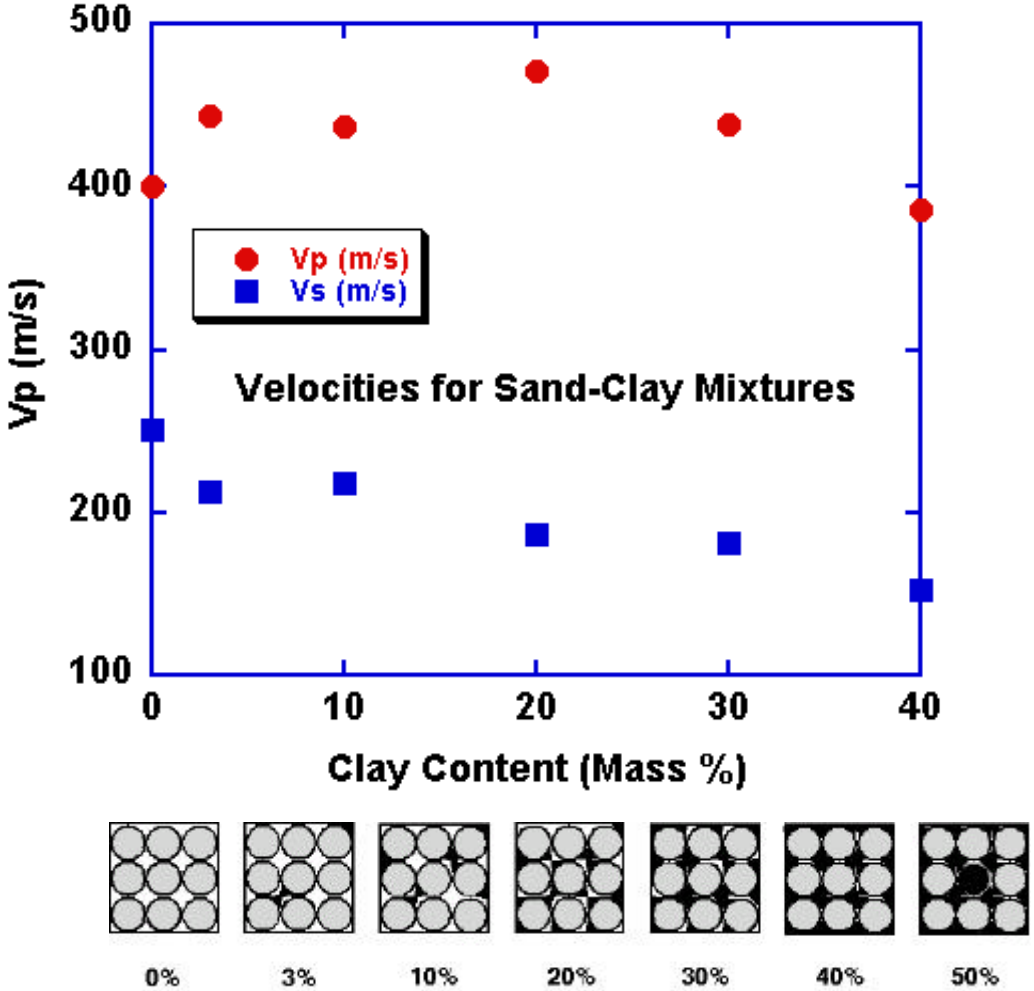
Lab meas. results: Velocities depend on packing

- Low velocities, can have high gradients



Lab meas. results: Velocities depend on clay content

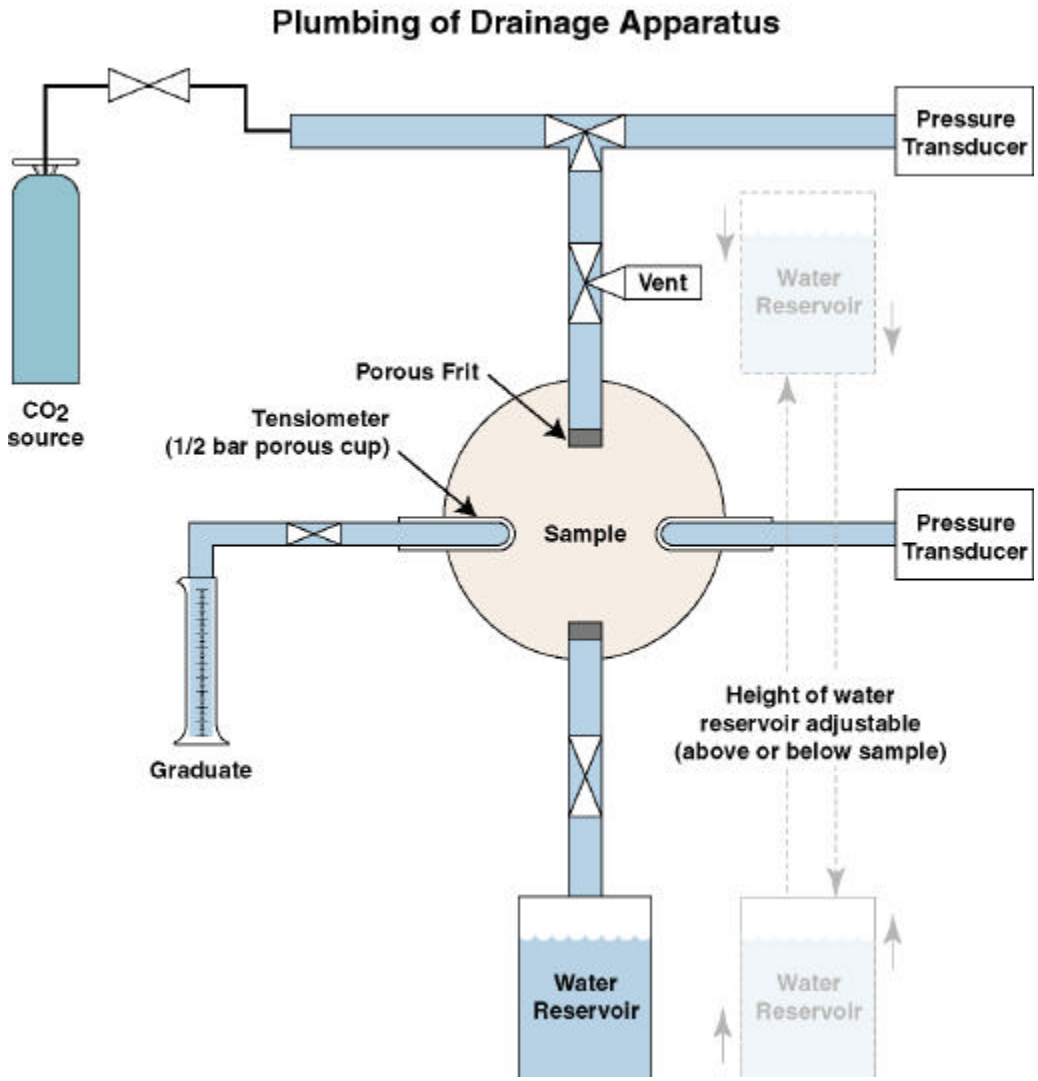
Dry Sand-Clay Samples



Lab meas. results: Vp/Vs, Poisson's ratio depend more on clay content than on pressure

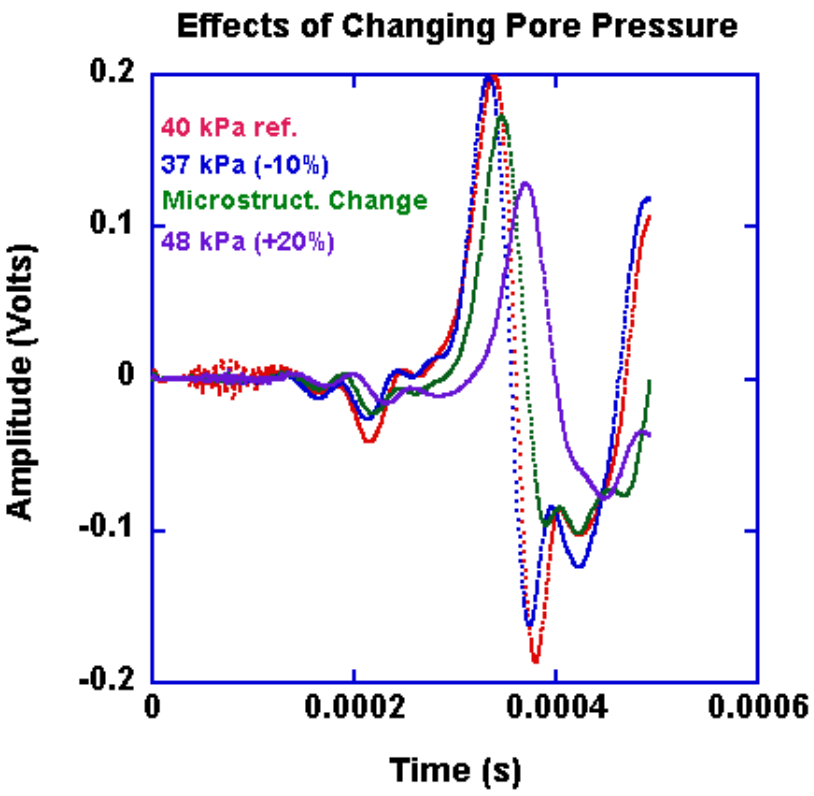
Clay content	Pressure	Vp/Vs	Poisson's ratio
0%	~0 MPa	1.7 - 2.2	0.23 - 0.36
0%	~0.1 MPa	1.6 - 2.1	0.18 - 0.36
1%	~0 MPa	3.6	0.46
1%	~0.1 MPa	2.3	0.38
3%	~0 MPa	1.8 - 2.2	0.29 - 0.36
3%	~0.1 MPa	2.1 - 2.2	0.35 - 0.37
10%	~0 MPa	1.8 - 3.2	0.26 - 0.45
10%	~0.1 MPa	2.0 - 3.2	0.33 - 0.45
20%	~0 MPa	2.5	0.4
20%	~0.1 MPa	2.5	0.41
30%	~0 MPa	2.2	0.38
30%	~0.1 MPa	2.4	0.4
40%	~0 MPa	2.4	0.39
40%	~0.1 MPa	2.5	0.41

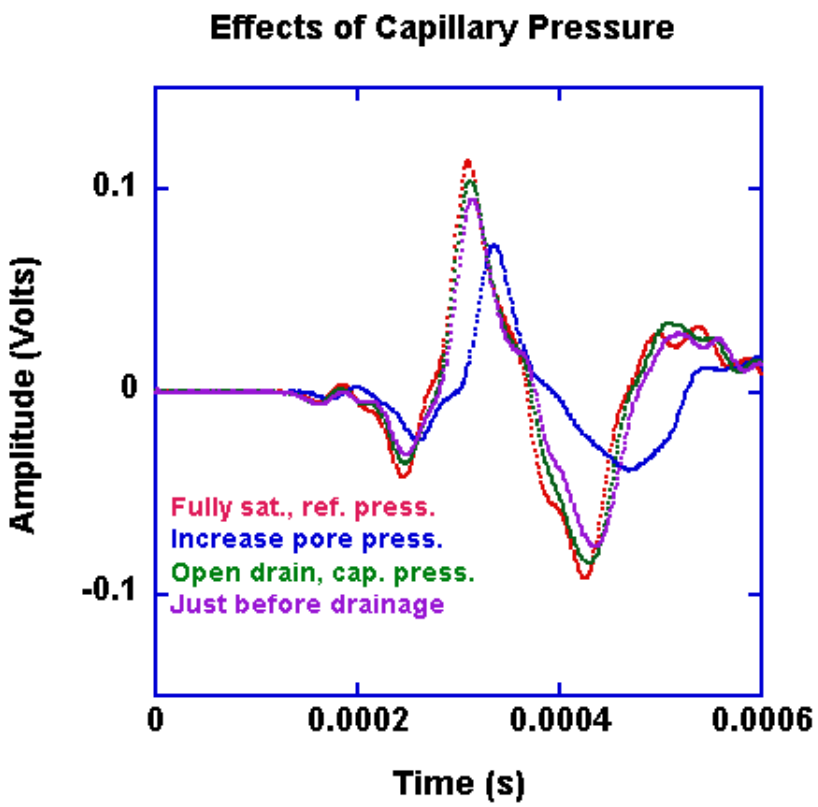
Pore fluid pumping system and tensiometers



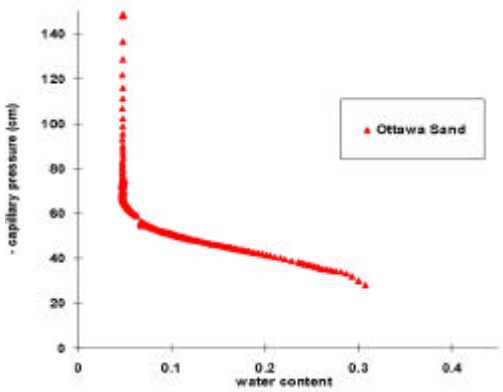
Lab meas. results: Waveforms depend on pore fluid pressure, grain contacts

- **Shear velocities and amplitudes change with internal pressure in the sample**

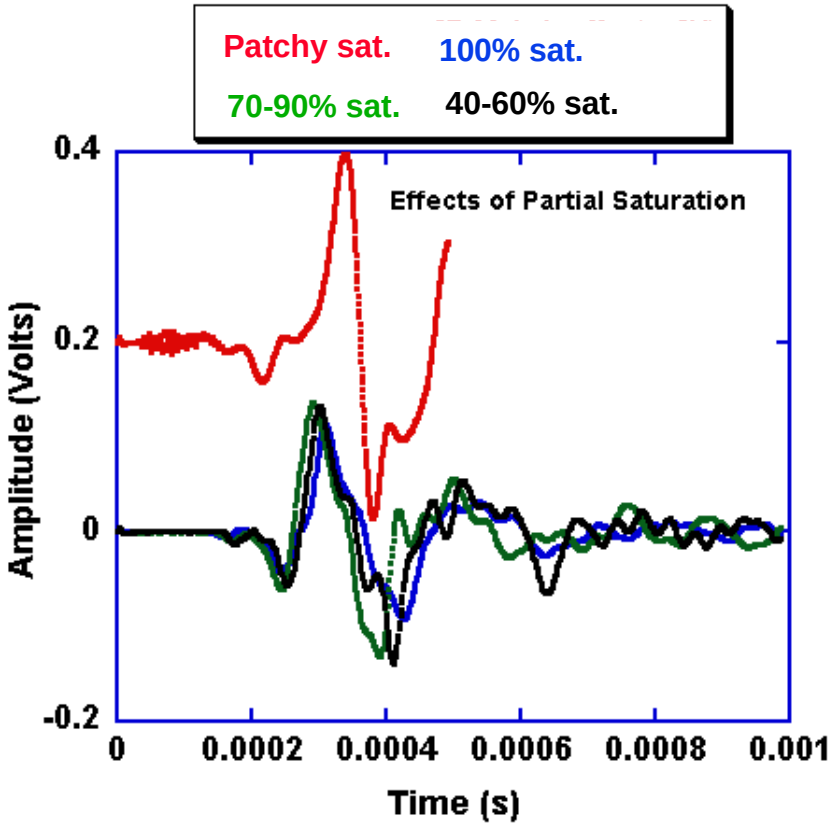




Lab meas. results: Velocities, waveforms depend on saturation



Water retention curve for sand



Drainage of sand sample

Lab meas. results: Velocities, waveforms depend on saturation

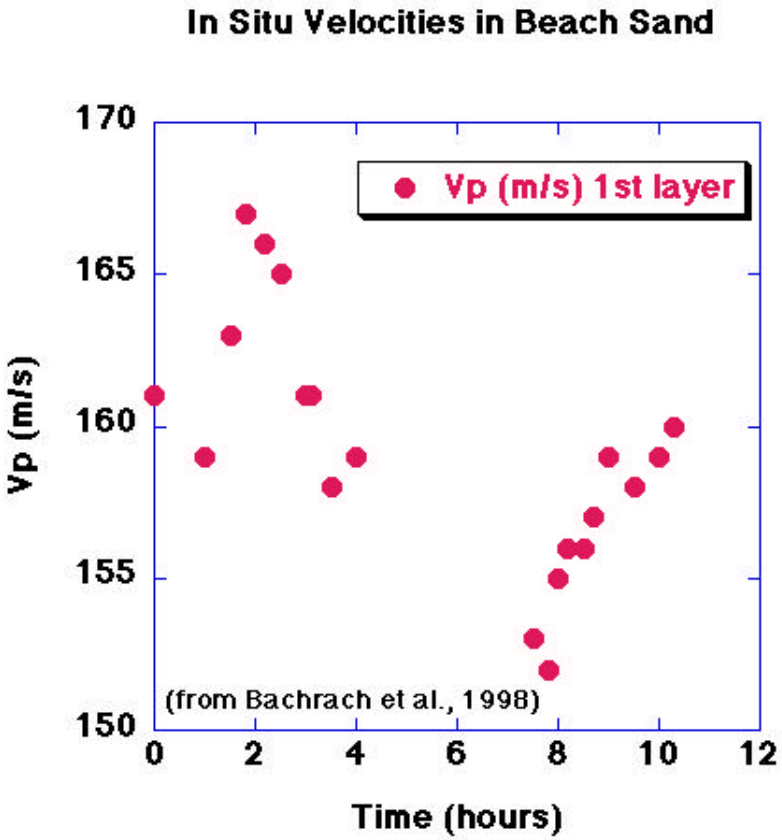
LLNL velocity results for partially-saturated sand samples at 40 kPa load

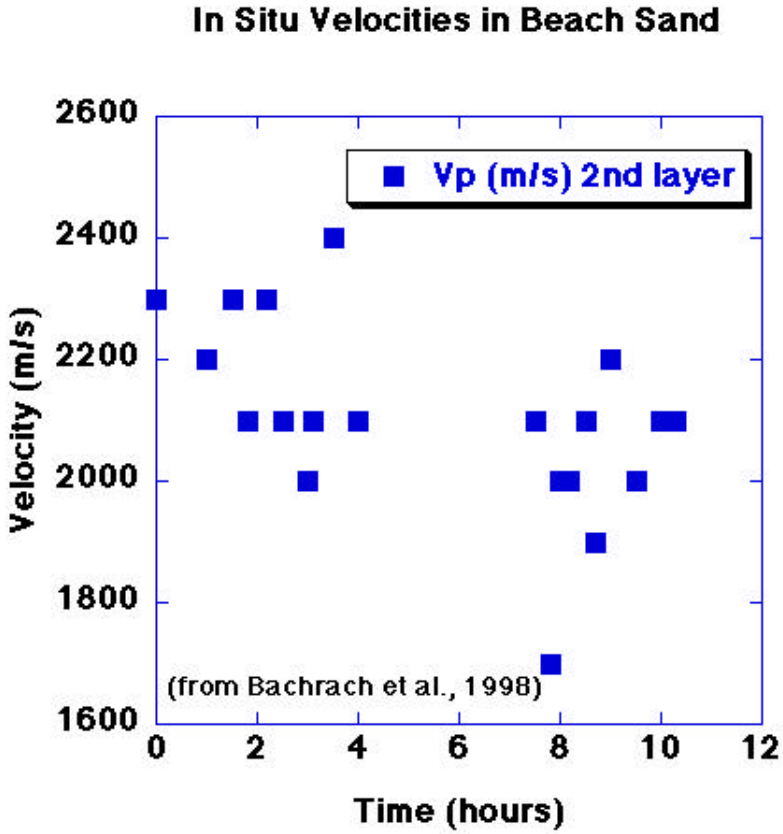
Waveform	Vp (m/s)	Vs (m/s)	Poisson's ratio	Notes
Sample 1:				
6/27/00 #1	375 ± 75	232 ± 6	0.19	Saturated, but some bubbles. (Vp =1500 ± 40 through sat. patches)
Sample A:				
6/29/00 #2	357 ± 30	214 ± 10	0.22	Saturated, no visible bubbles
6/30/00 #1	308 ± 10	214 ± 10	0.03	Draining (capillary press = 35 cm), water content 22 to 28 %.
6/30/00 #3	326 ± 10	204 ± 6	0.18	Draining (capillary press = 44 cm), water content 13 to 17 %.
12/7/00	349 ± 8	249 ± 20	~0	Dried (chemical alteration probable)

Lab meas. results: Scenario for seismic velocities in shallow sands

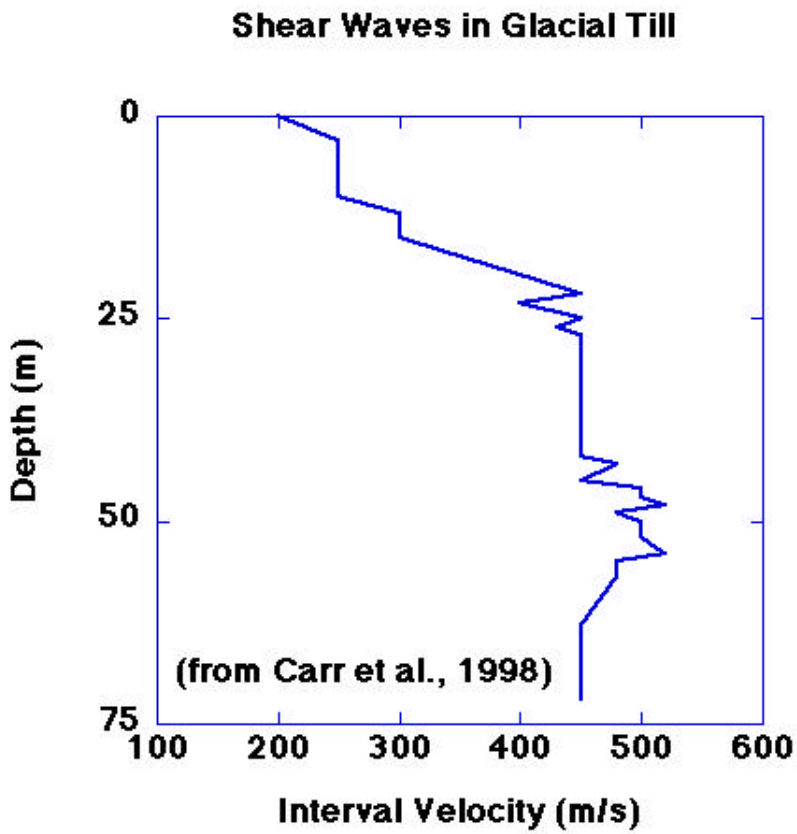
	Depth (Pressure)	Velocity profile Vp	Vs	Vp/Vs
	0m			
		350 m/s	140-250	1.6-2.2
Vadose zone	Dry – partially saturated			
	5m (0.1MPa)	500	235	2.1
Water table				
	5m (0.1MPa)	1810	244	7.4
saturated				
	50m (1.0MPa)	1938	477	4.1
	1km (20MPa)	2286	908	2.5
Bedrock				

Lab meas. results: Corroborate seismic Vp from field studies in the literature





Lab meas. results: Corroborate low velocities and steep gradients in seismic Vs in literature

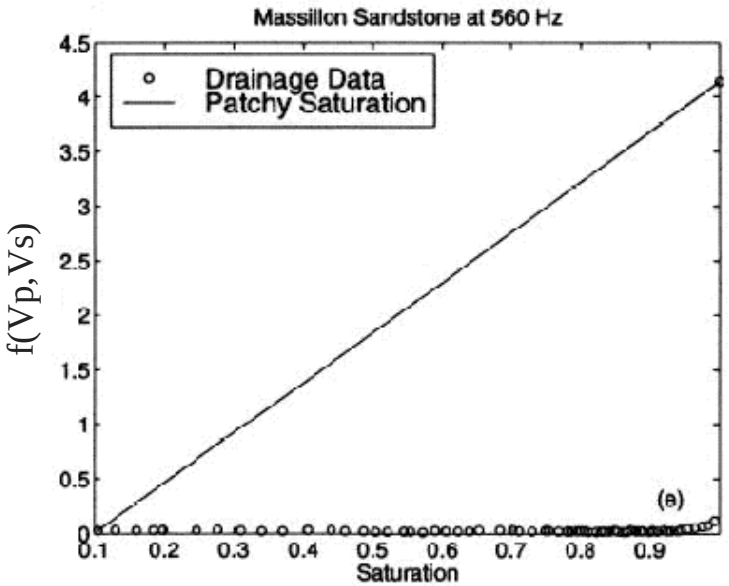


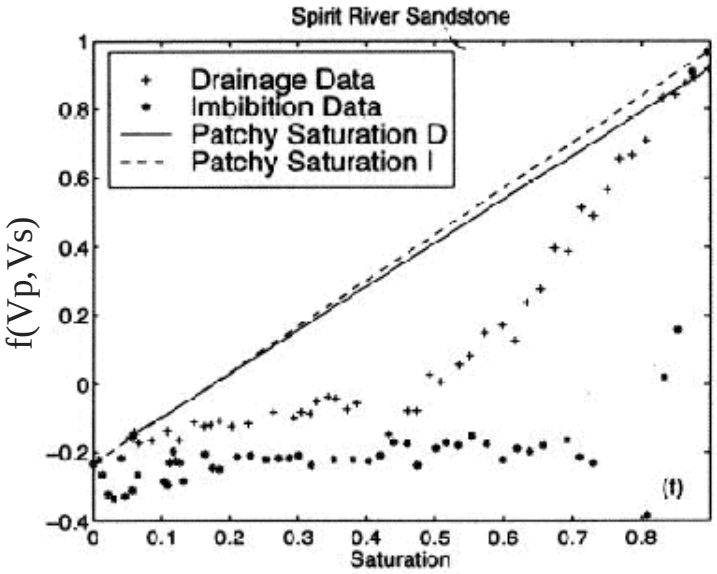
Lab meas. results: Corroborate low Vp, frequ. changes of seismic data in literature

Seismic Reflection in Arkansas River Sands (from Birkelo et al., 1987)				
Time of Record.	Reflect. Char.	Vp from Velocity Analysis	Av. Depth to Reflect.	Dom. Frequs.
Before pumping	Sharp	244 +- 5 m/s	2.7 +- 0.1 m	200-470 Hz
After pumping	Diffuse	247 +- 5 m/s	3.2 +- 0.1 m	182-397 Hz

Results from rock physics theories: Method for relating velocities to fluid content, distrib.

- **P and S velocities together provide info about fluid distribution in porous earth materials**
  - **U. S. Patent No. 6,269,311 issued to J. G. Berryman, 7/31/2001.**

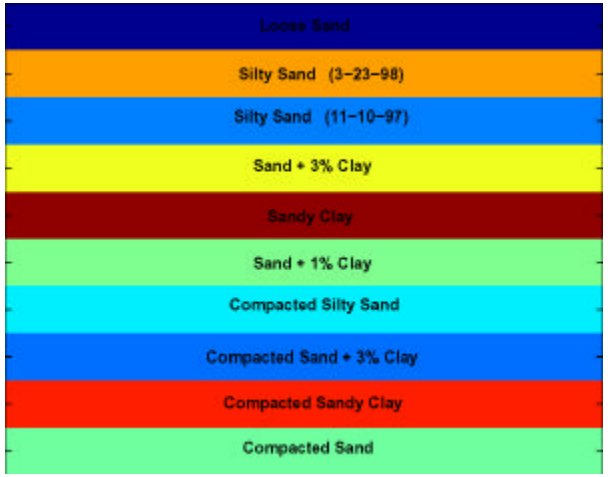




Velocity parameter plots for homogeneous vs. patchy saturation in sandstones
(Berryman, Berge, and Bonner, JASA, 2000; Geophysics, 2001)

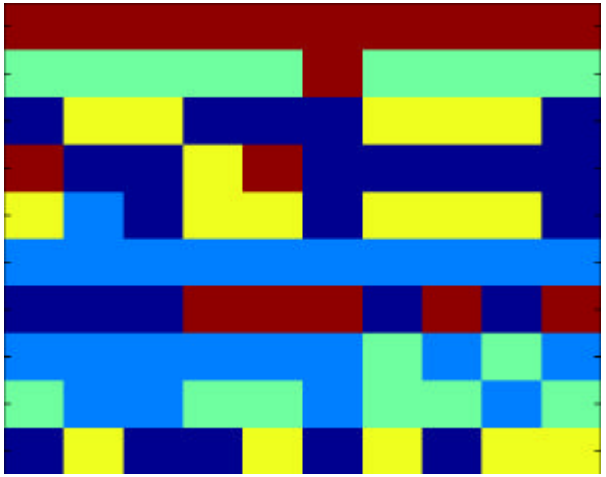
Algorithm development results: Using Vp and Vs to constrain inversion for soil composition

Soil Structure Model

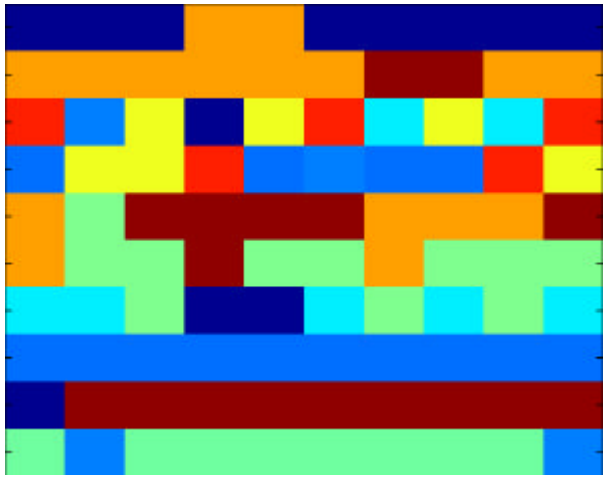


(Bertete-Aguirre and Berge, JEEG, 2001)

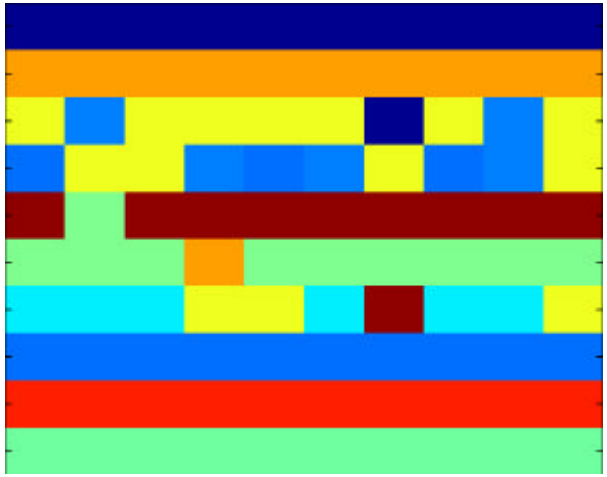
From P Velocities



From S Velocities



P & S Velocities



Results: Publications

- **Recent Journal Papers**

Berryman, J. G., Berge, P. A., and Bonner, B. P., 2001, Estimating rock porosity and fluid saturation using only seismic velocities: LLNL report UCRL-JC-135507, Geophysics, in press.

Bertete-Aguirre, H., and Berge, P. A., 2001, Recovering soil distributions from seismic data using laboratory velocity measurements: LLNL report UCRL-JC-141559, submitted to the Journal of Environmental and Engineering Geophysics.

Zimmer, M., Prasad, M., Bonner, B. P., and Berge, P. A., 2001, Measurement of velocity and attenuation in shallow soils: submitted to be included as a chapter in Near-Surface Geophysics, Applications and Case Histories, Vol. II, Butler, D. K., ed., Society of Exploration Geophysicists, Tulsa.

Results: Publications

- **Recent and Upcoming Presentations at Scientific Meetings**

Berge, P. A., 2001, Modeling Compressional and Shear Wave Velocities of Unconsolidated Sediments in the Vadose Zone: LLNL report UCRL-JC-145245-ABS, submitted to the 2001 Annual Fall Meeting of the American Geophysical Union, to be held Dec. 10-14 in San Francisco, CA.

Berge, P. A., and Bonner, B. P., 2001, Seismic velocities contain information about depth, lithology, fluid content, and microstructure: UCRL-JC-144792-ABS, submitted to the Symposium on the Application of Geophysics to Engineering and Environmental Problems, to be held in Las Vegas, NV, Feb. 10-14, 2002.

Bertete-Aguirre, H., Berge, P. A., and Roberts, J. J., 2001, Imaging Simulated Field Data for Electrical and Mechanical Properties of Shallow Environmental Sites: LLNL report UCRL-JC-145242-ABS, submitted to the 2001 Annual Fall Meeting of the American Geophysical Union, to be held Dec. 10-14 in San Francisco, CA.

Bertete-Aguirre, H., Berge, P. A., and Jeffery J. Roberts, 2001, Using laboratory measurements of electrical and mechanical properties to assist interpretation of field data from shallow geophysical measurements: submitted to the Symposium on the Application of Geophysics to Engineering and Environmental Problems, to be held in Las Vegas, NV, Feb. 10-14, 2002.

Bonner, B. P., Berge, P. A., and Wildenschild, D., Compressional and shear wave velocities for artificial granular media under simulated near surface conditions (expanded abstract): LLNL report UCRL-JC-142935, Technical Program of the Society of Exploration Geophysicists International Exposition and Seventy-First Annual Meeting, Sept. 9-14, 200, San Antonio, TX, Vol. II, 1419-1422.

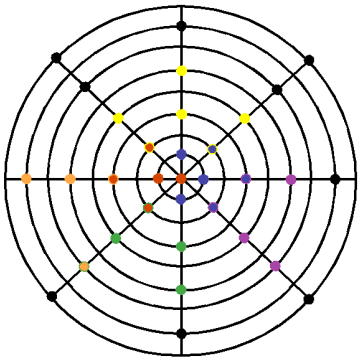
Toffelmier, D., W. Dufrane, C. Aracne-Ruddle, B. P. Bonner, P. A. Berge, B. Viani, and K. Knauss, 2001, Load Dependence of Ultrasonic Velocities for Sand and Sand / Clay Mixtures: LLNL report UCRL-JC-145264-ABS, submitted to the 2001 Annual Fall Meeting of the American Geophysical Union, to be held Dec. 10-14 in San Francisco, CA.

Results: Patents

- **Patents**
  - **Berryman, J. G., Daily, W. D., Ramirez, A. L., and Roberts, J. J., Using electrical impedance tomography to map subsurface hydraulic conductivity, *U. S. Patent No. 6,147,497, November 14, 2000.***
  - **Berryman, J. G., Discrimination of porosity and fluid saturation using seismic velocity analysis, *U. S. Patent No. 6,269,311, July 31, 2001.***
- **Patent Applications**
  - **Bonner, B. P., Boro, C., and Hart, D. J., 1999, Anti-waveguide for ultrasonic testing of granular media under elevated stress, *LLNL Patent disclosure IL-10607, and patent application, DOE Patent Docket No. S-94182, October 28, 1999.***

Implications for Vadose Zone Monitoring

- Geophysical field experiments: Seismic more useful if you collect <u>both</u> P and S velocity data, and analyze waveforms as well as traveltimes.
- Combining lab and field data may be powerful method for improving underground imaging for characterization and cleanup monitoring.
- Use modeling before seismic field experiment, to optimize receiver spacing and overall design, and assess effects of steep velocity gradients, signal attenuation, etc.



Research for FY02 and Anticipated Final Products

- More rock physics modeling to fit lab velocity data, develop relationships between velocities and fluid, clay content and distribution, etc.
- Develop more algorithms for inverting velocities to obtain lithology info and fluid content info.; include electrical properties measurements in algorithms.
- A few more lab measurements as needed.
- Final project report will be written, as well as scientific papers for FY02 results of modeling and algorithm development (SAGEEP, JEEG, Geophysics).
- Networking with people doing seismic field experiments; want to collaborate on a new proposal.

Acknowledgments

- This EMSP project is a team effort. I thank:
  - my co-PI's Brian Bonner, Jeff Roberts, post-doc Dorthe Wildenschild (now at Tech. U. Denmark),
  - LLNL collaborators Jim Berryman, Hugo Bertete-Aguirre,
  - technical support in the lab from Chantel Aracne-Ruddle, Carl Boro, Eric Carlberg, Dave Ruddle,
  - and our summer students Wyatt DuFrane, Ed Hardy, David Hart, Christie Rowe, Dan Toffelmier, and Cosette Trombino.

See the project web page at the URL
www.llnl.gov/ees/esd/expgeoph/Berge/EMSP/

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