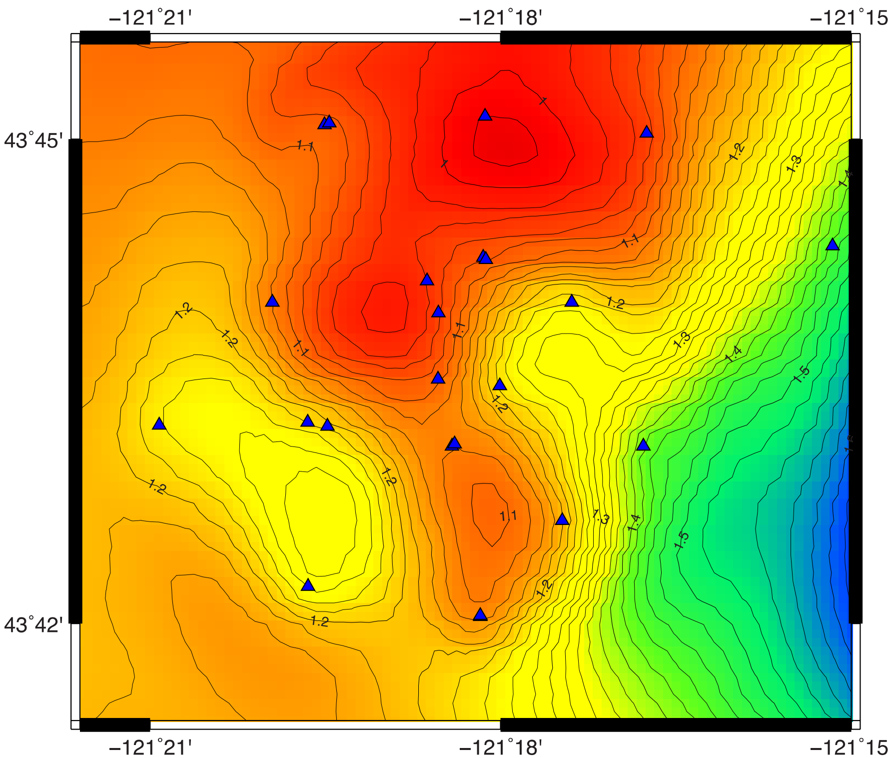
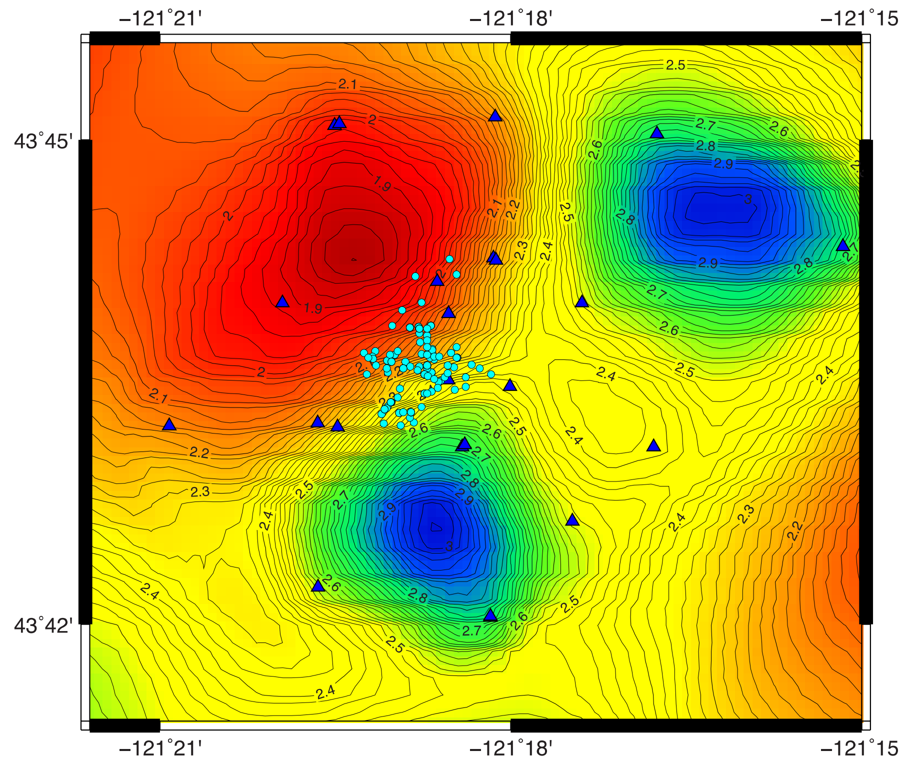
Imaging the Newberry Enhanced Geothermal Site using Seismic Interferometry

S 0.50 km



S 2.00 km



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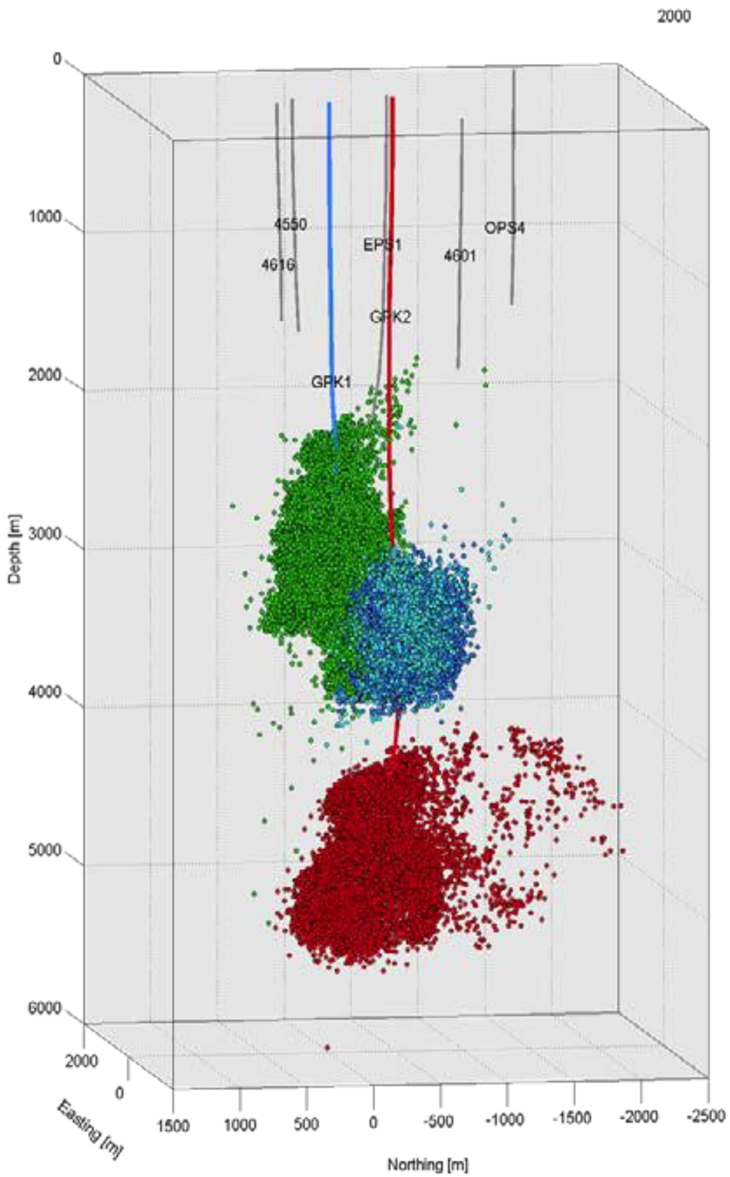
LLNL-PRES-650577

Enhanced geothermal systems involve injecting fluid into the Earth.



Induced microseismicity at Soultz-sous-Forˆets (Baria et al., 2005).

A natural response to fluid injection is the creation of microseismicity.

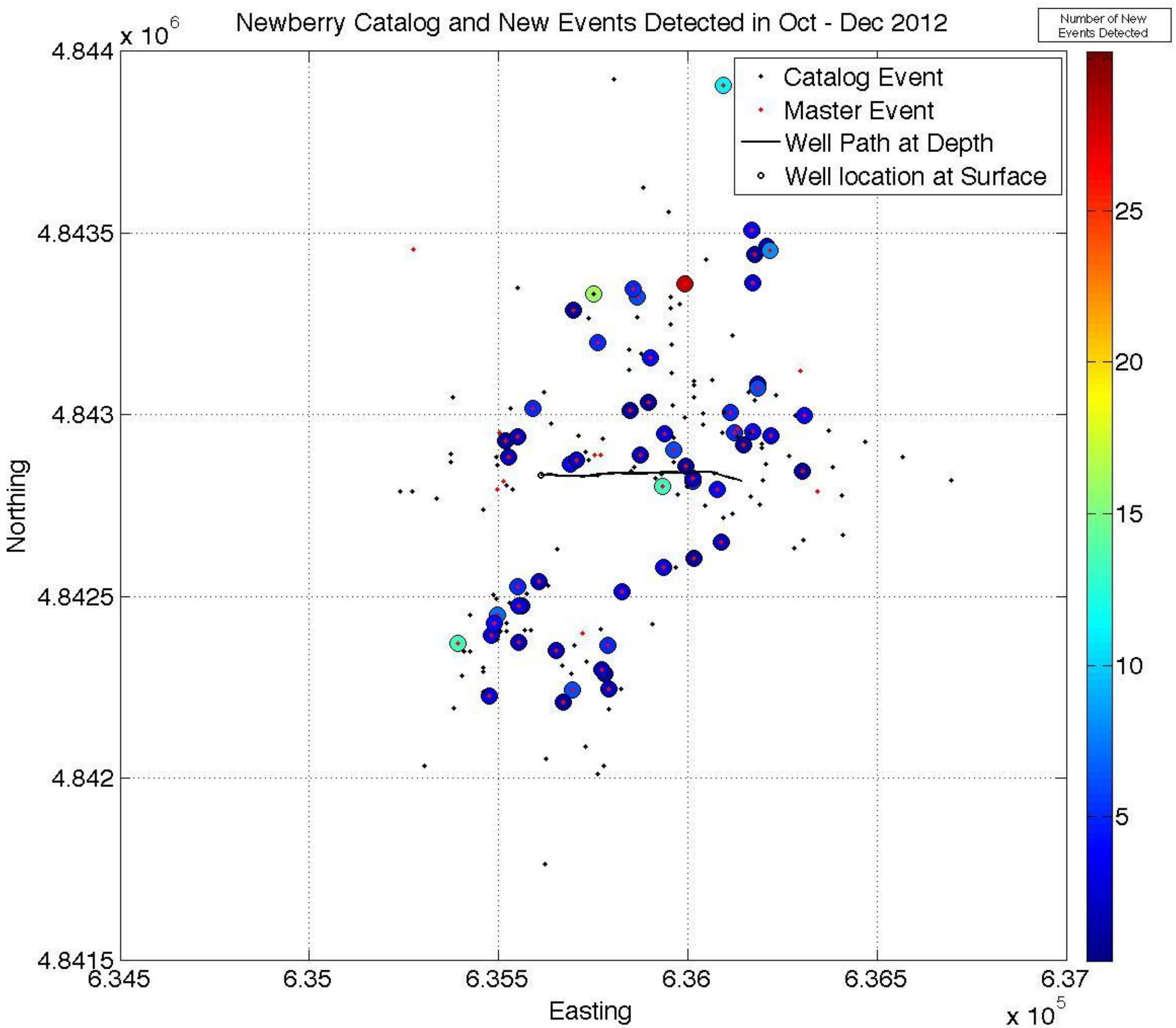
This is driven by changes in pressure

It illuminates the subsurface and allows us to:

- Observe the growth of the pressure plume.
- Identify faults.
- Identify fabric.
- Ultimately, predict the evolution of the plume as injection procedes.

We want to measure this microseismicity precisely

We want a precise image of the cloud of microseismicity and how it changes over time.



3 months of microseismicity at the Newberry geothermal injection site.

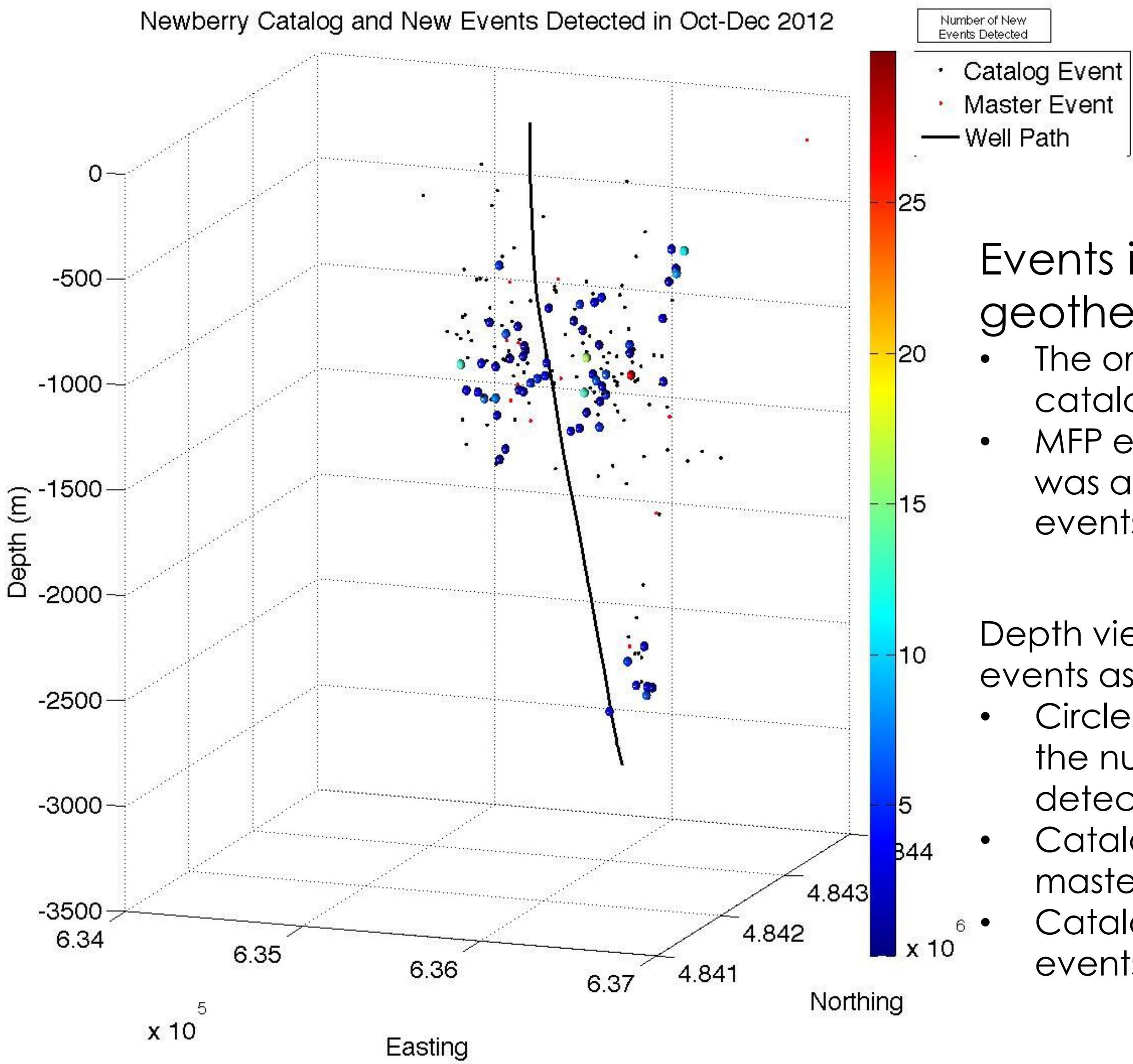
Problems:

- Crude Earth models.
- Poor earthquake locations.
- Limited ability to resolve small magnitude events.

Techniques:

- Ambient Noise Correlation
- Bayesian Location
- Matched Field Processing

Newberry microseismicity: October – December 2012



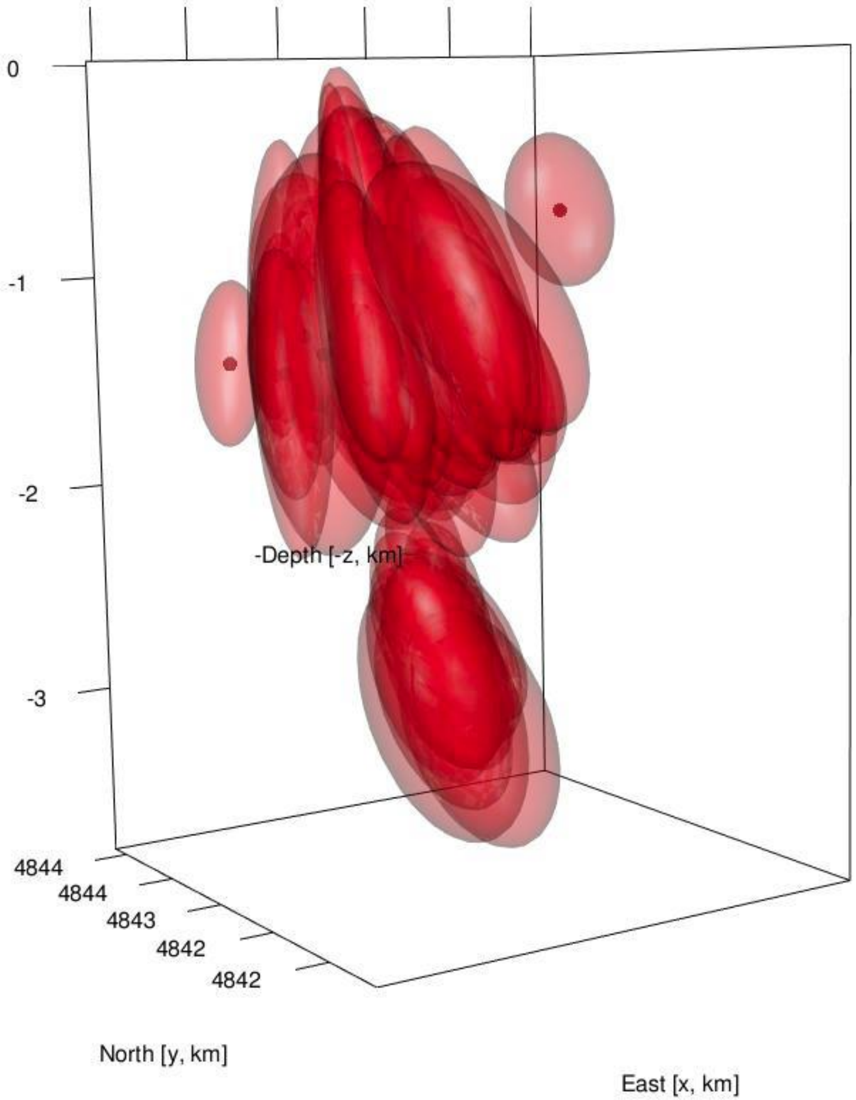
Events identified beneath the geothermal fields:

- The original Foulger Consulting catalog (207 events)
- MFP earthquake detection code was able to identify 240 additional events.

Depth view showing newly detected events as spheres.

- Circles are color coded to indicate the number of new events detected.
- Catalog events designated as a master event (red dots).
- Catalog events not used as master events (black dots).

Uncertainties in microseismic locations are very large.



Event locations with their 95% ellipsoids.

<u>MicroBayesLoc</u>

The MicroBayesLoc multiple-event locator characterizes the uncertainty associated with the seismic location.

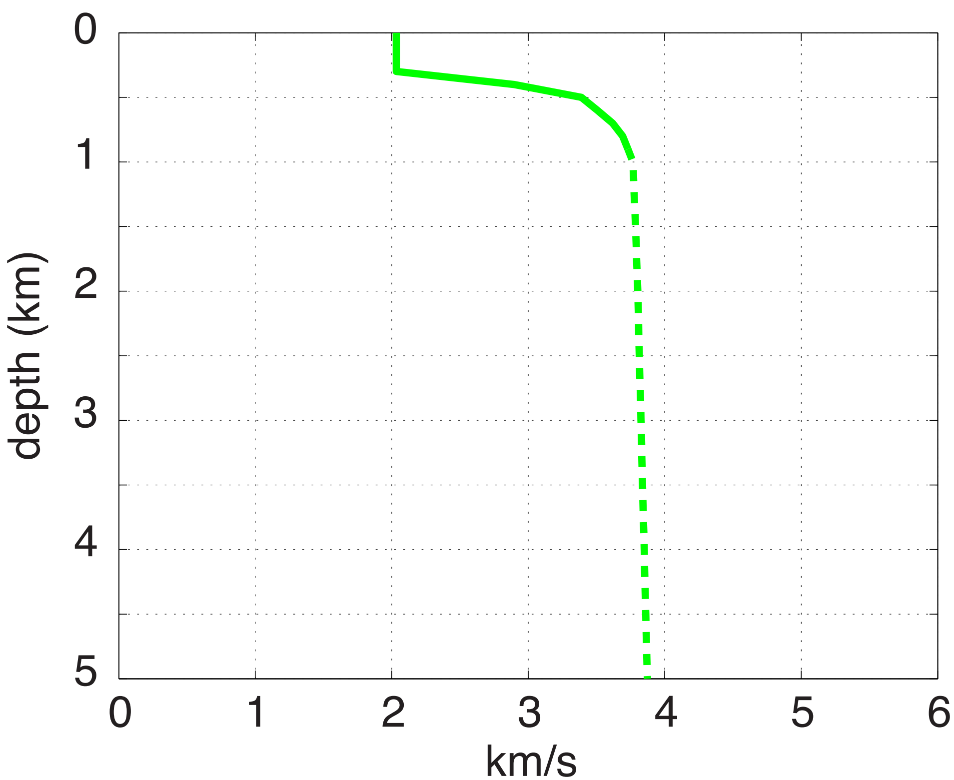
Vertical uncertainties are significantly larger than the horizontal errors, primarily due to the recording station geometry.

Two seismic swarms are most likely occurring in distinct regions of the reservoir.

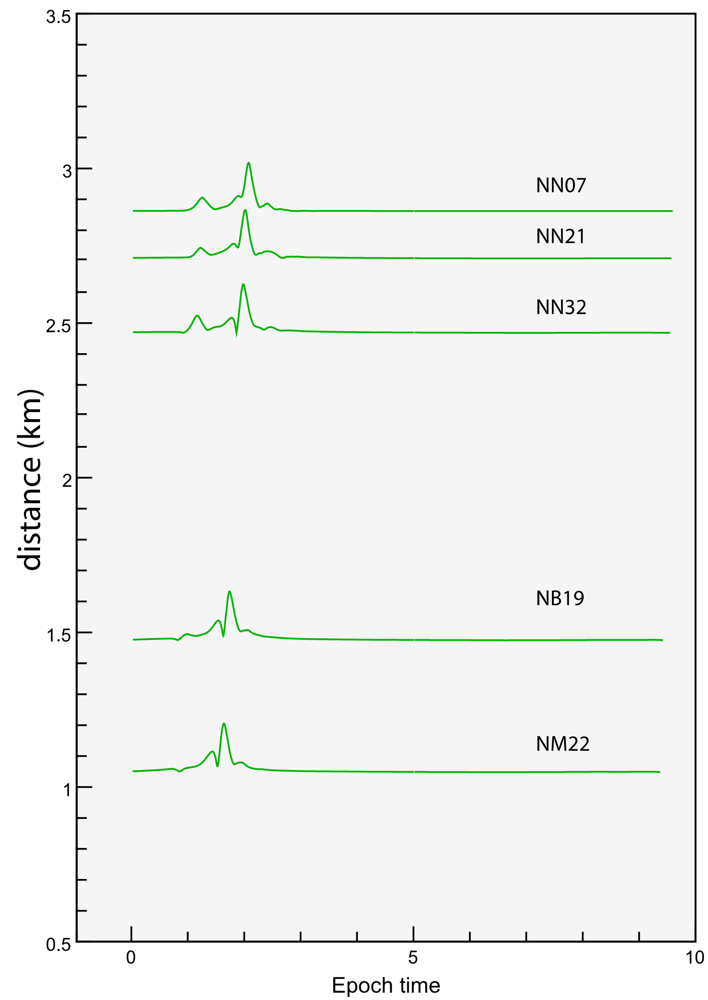
(from: Gardar Johannesson and Steve Myers)

Seismic models can be used to predict travel times and estimate location.

1D reference seismic velocity



Reference 1D synthetics

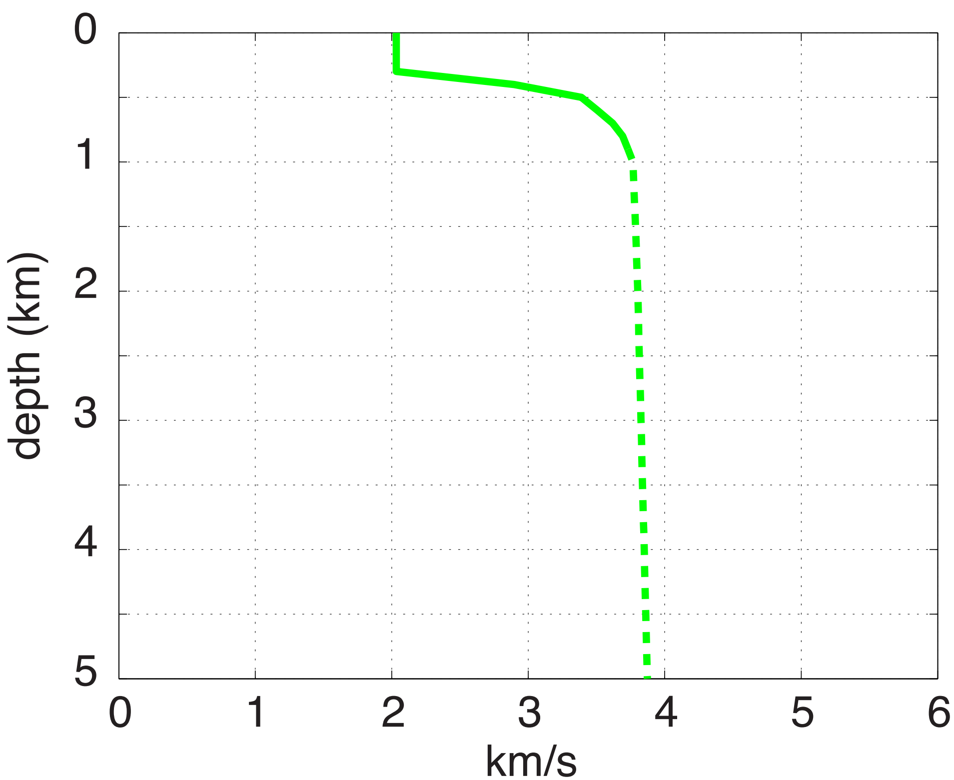


12/01/2012 event at 3.2 km

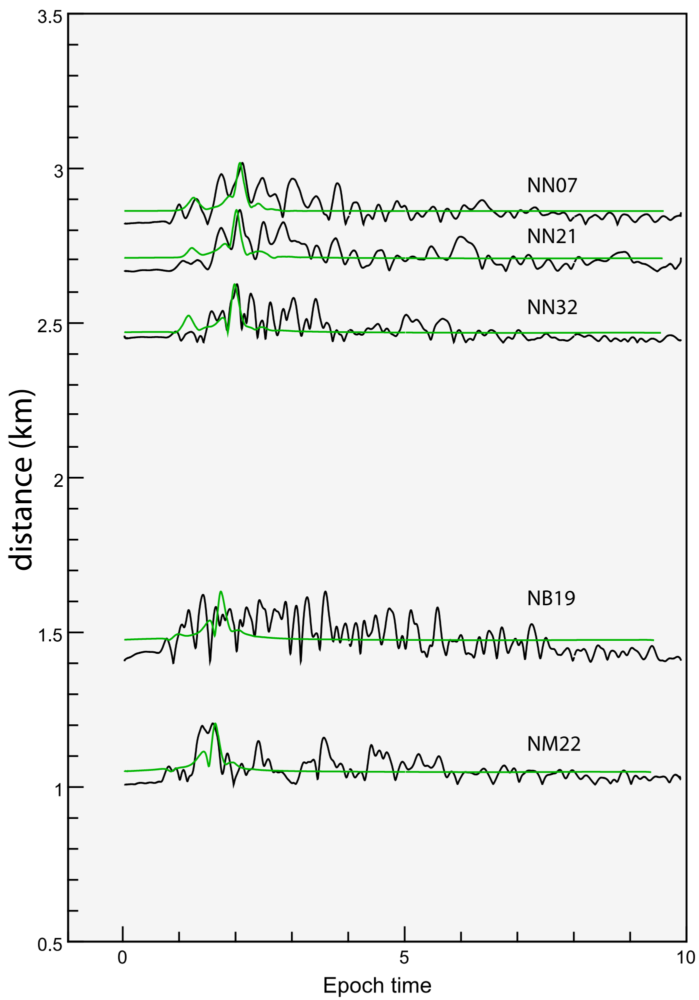
Prediction of P and S arrivals.
Used to calculate location of the microseisms.

Data are much more complicated than the predictions

1D reference seismic velocity



Newberry data vs Reference 1D synthetics

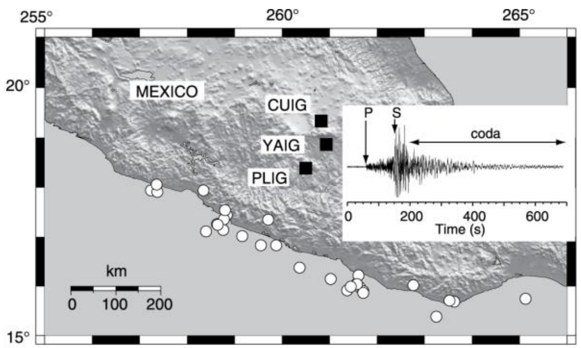


12/01/2012 event at 3.2 km

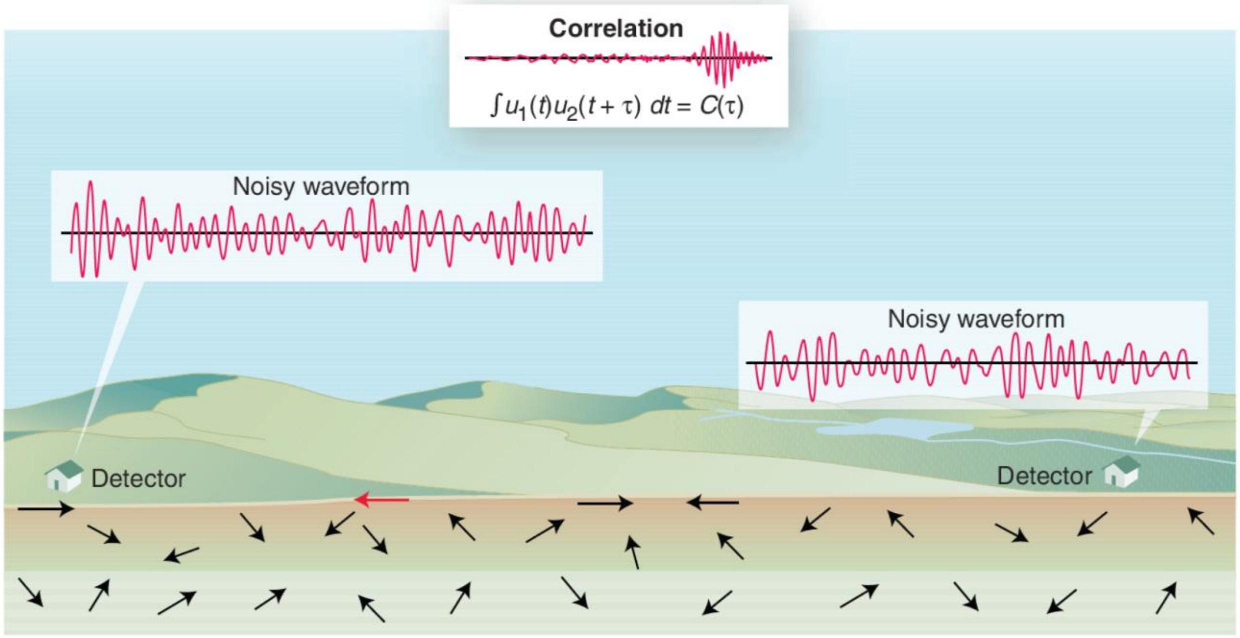
Very simple models only explain a fraction of the seismic record

Seismic Interferometry : ambient noise correlation

Previously discarded as noise;
The ambient seismic wavefield and the scattered energy that makes up the seismic coda have now proven to contain significant sensitivity to Earth structure.



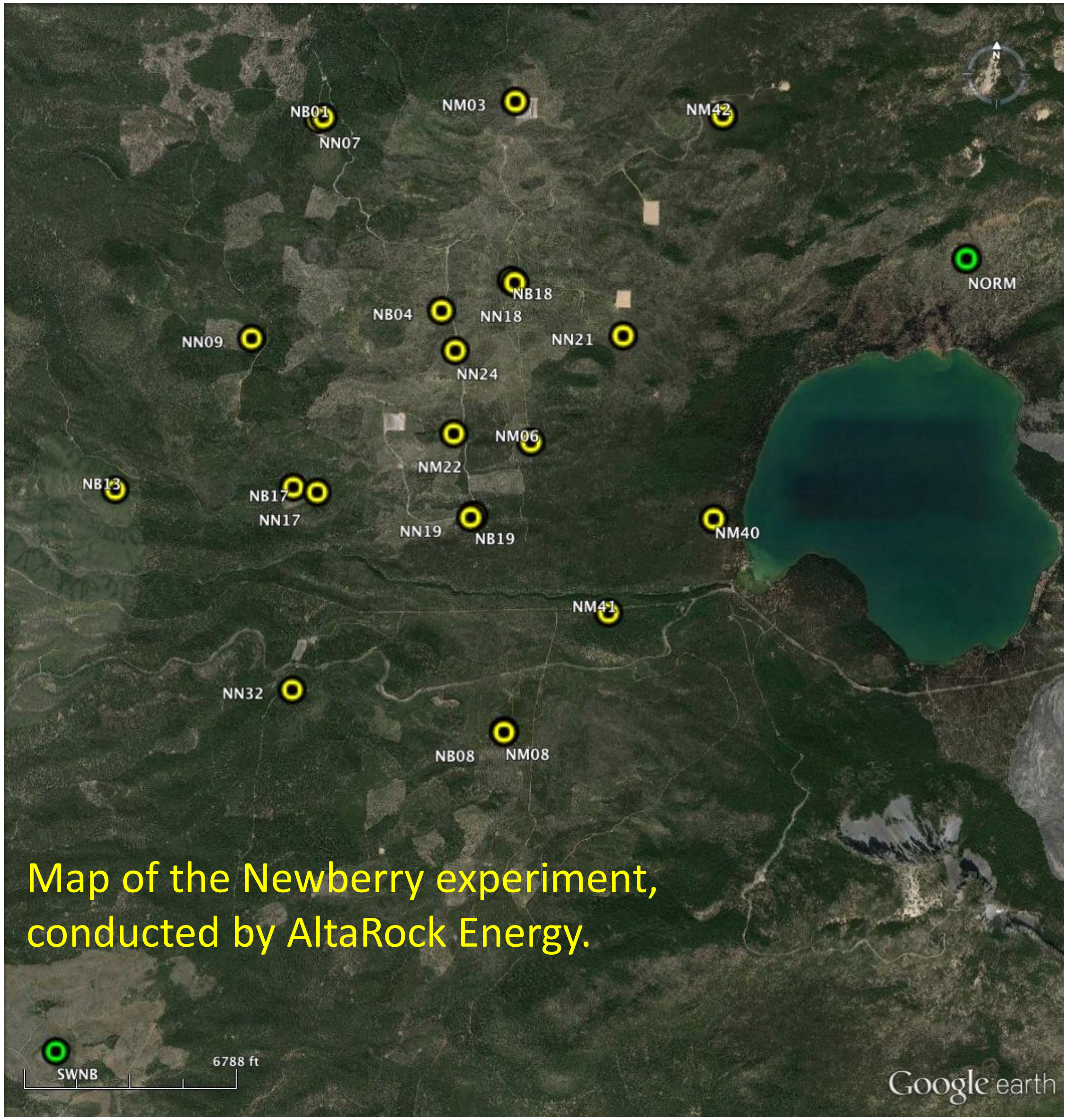
www.sciencemag.org SCIENCE VOL 299 24 JANUARY 2003
Michel Campillo* and Anne Paul



Using noise in seismology. When a diffuse wave field is generated by distant sources and/or by multiple scattering, detectors report random signals. Occasionally a ray (for example, the one shown in red) passes through both detectors. As a result, the signals are weakly correlated.

Richard L. Weaver 11 MARCH 2005 VOL 307 SCIENCE www.sciencemag.org

Creating a 3D image of the Newberry geothermal site



Ambient noise correlation

- 1 month of data
- 22 Newberry network
- 12 CC, UO, UW stations

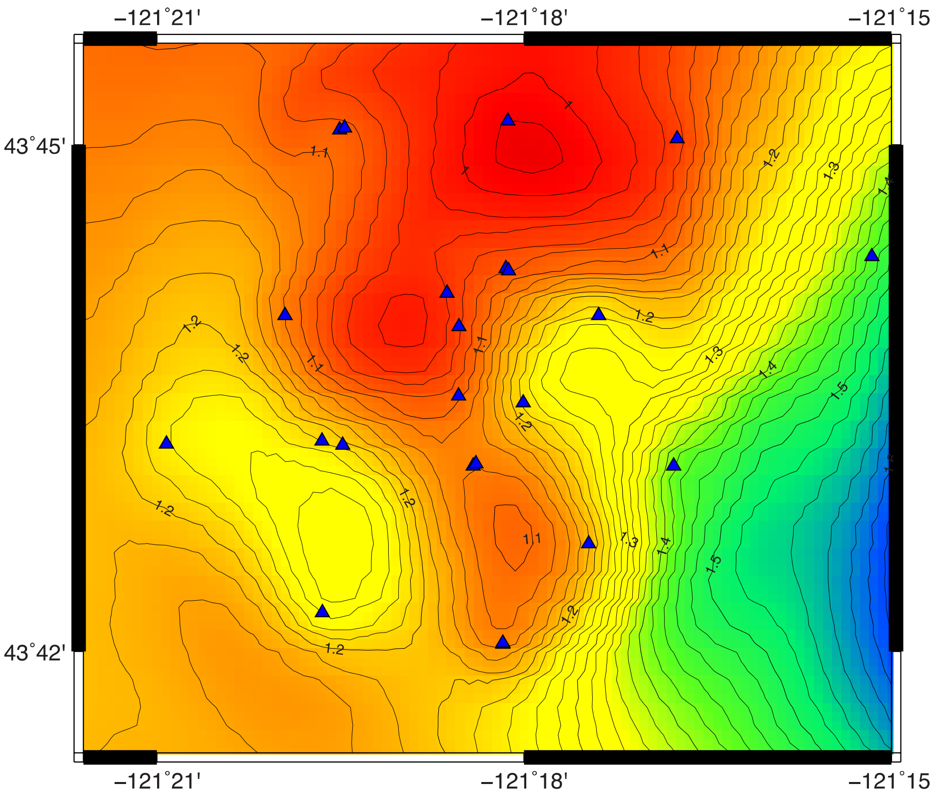
- 231 paths in network
- 402 unique paths total

- 0.1 – 2 Hz : long paths
- 0.5 – 8 Hz : 5 – 10 km paths
- 0.6 – 15 Hz : short paths

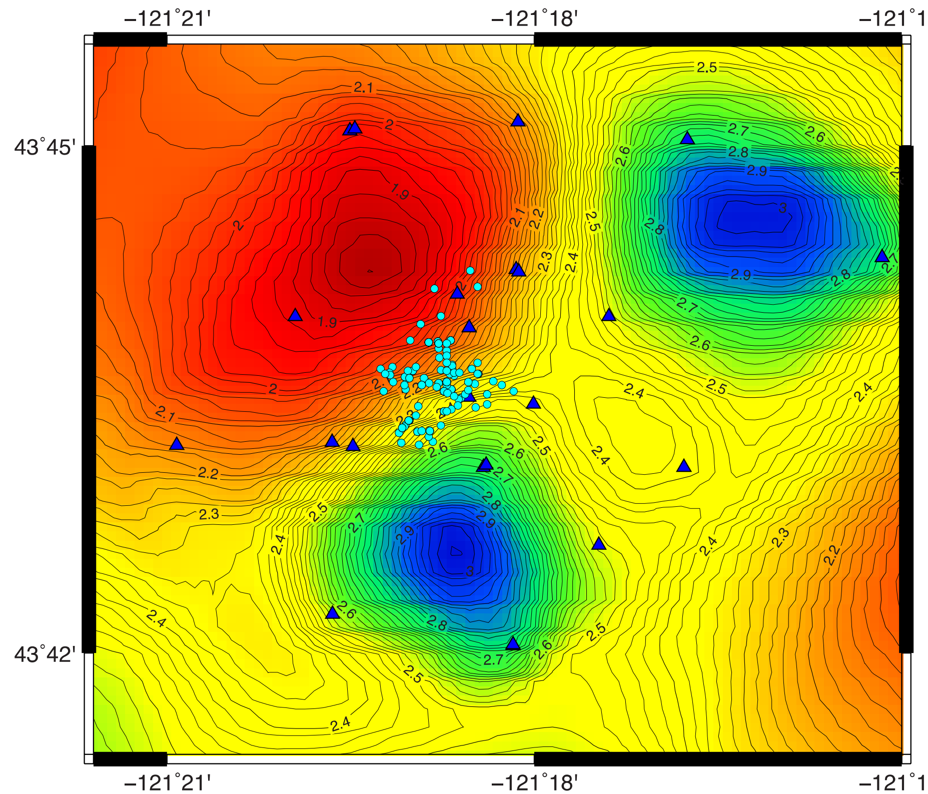
- Depth resolution 5 km
- Vp, Vs, estimate of Qs

Large variations in seismic velocity both laterally and vertically

S 0.50 km

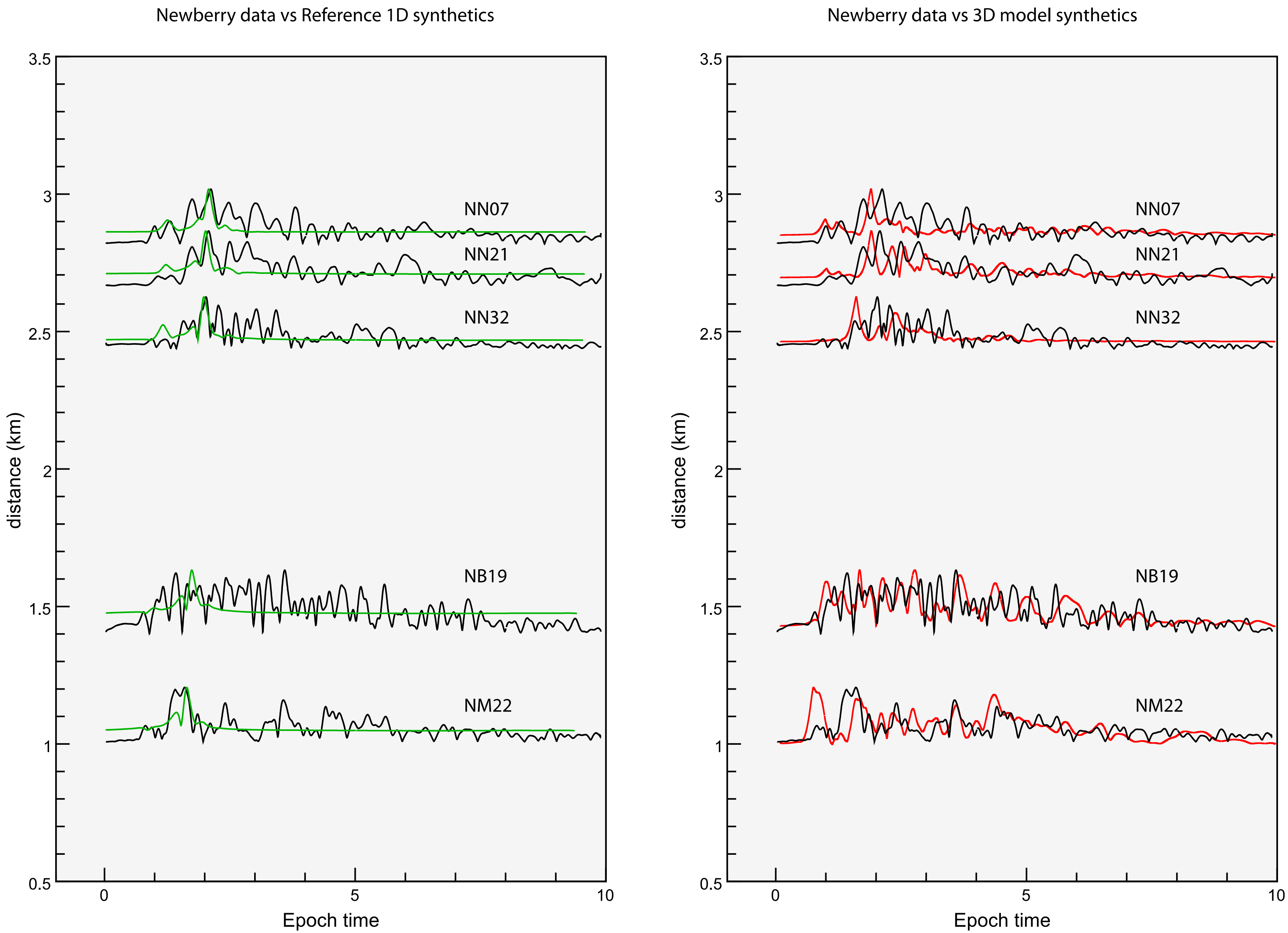


S 2.00 km

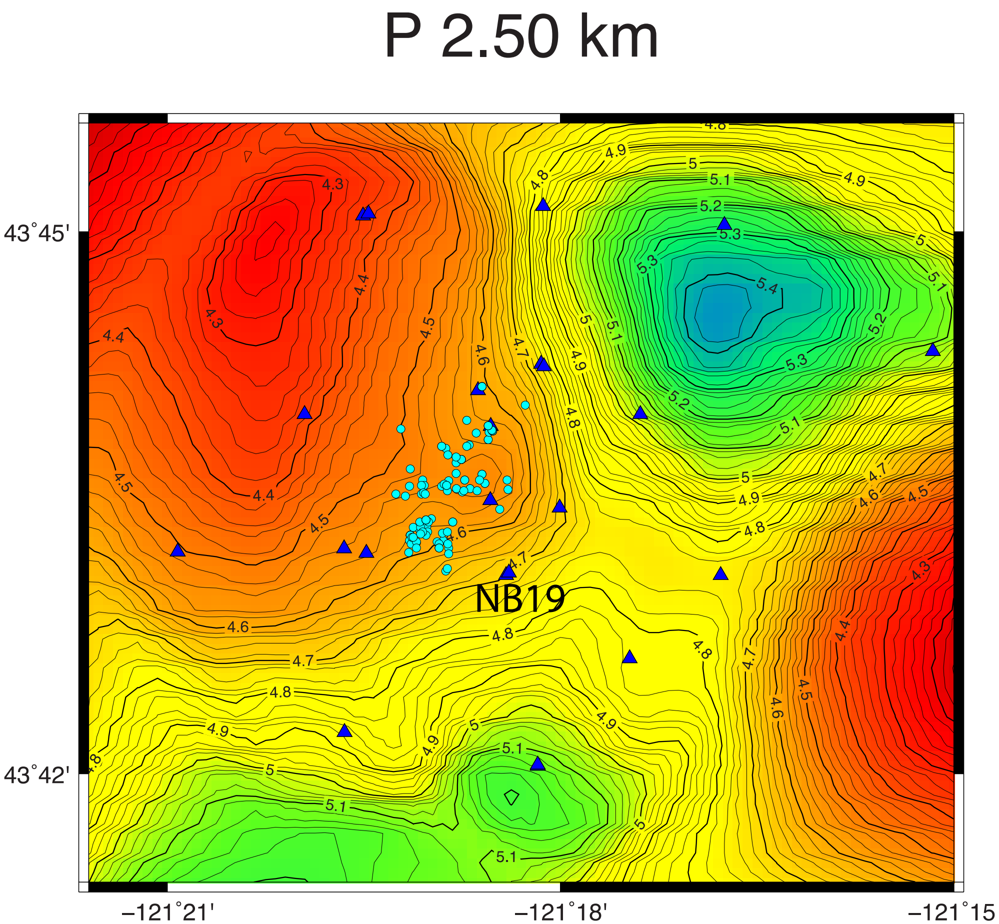


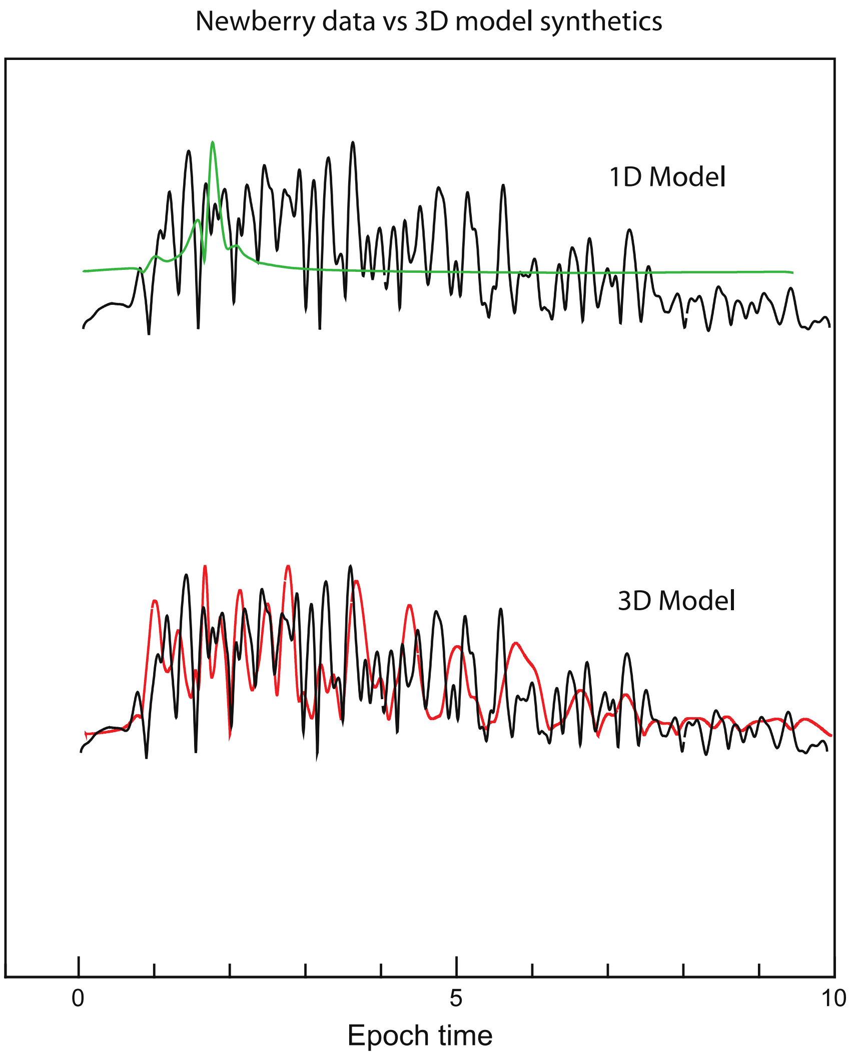
Shear velocity tomography at 0.50 km and 2.00 km below the surface of the Newberry site. (Note 50% variation in shear velocity laterally)

3D model is able to capture much of the complexity in the seismic records



Large lateral contrasts in seismic velocity create the scattered energy.

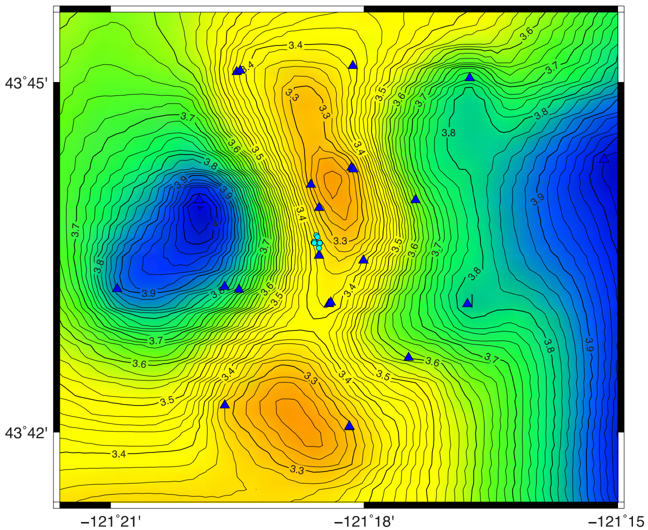




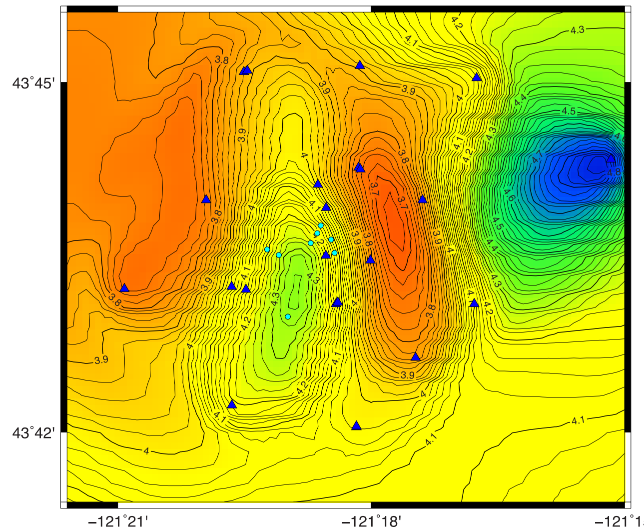
record of 12/01/2012 event at station NB19

The seismicity occurs at rapid changes in velocity gradient

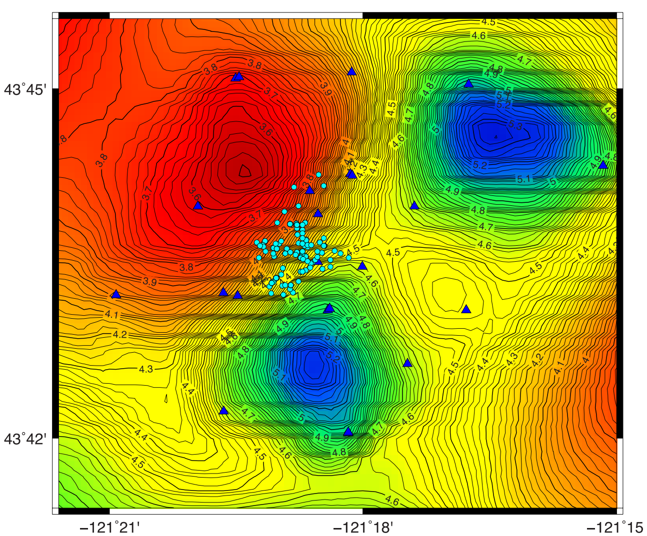
P 1.00 km



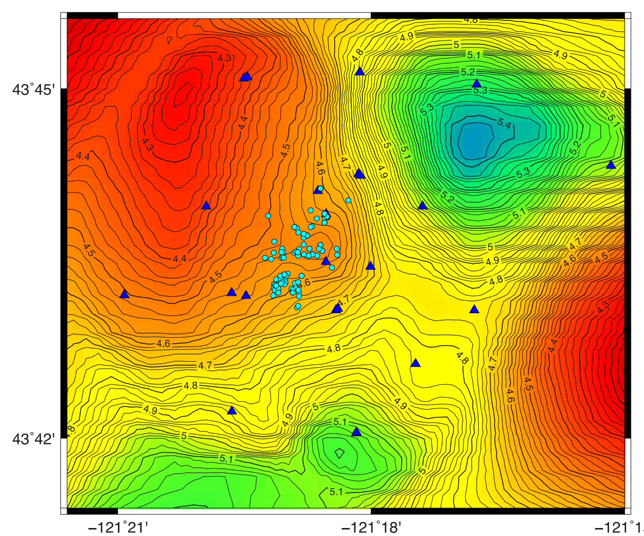
P 1.50 km



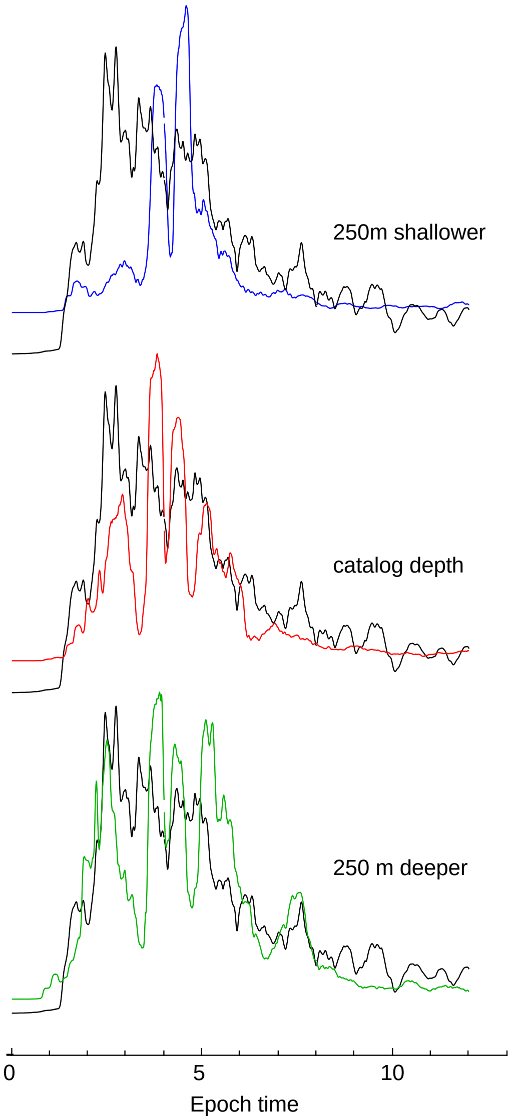
P 2.00 km



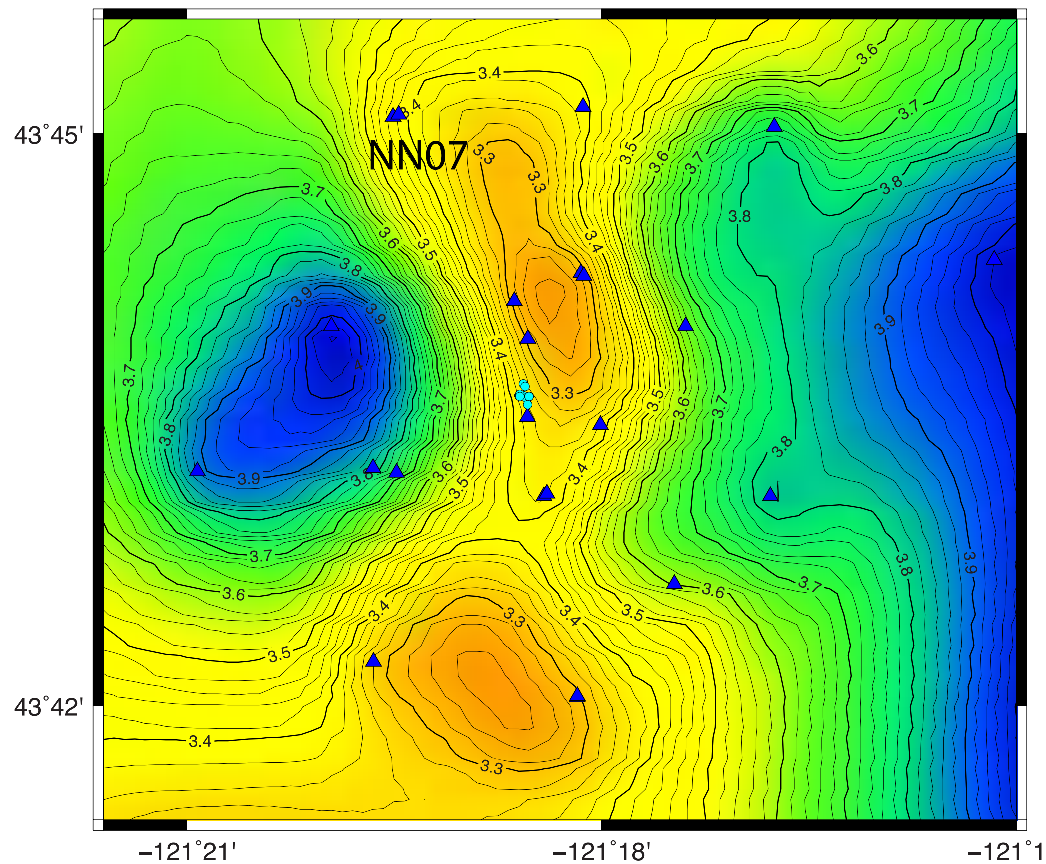
P 2.50 km



We can use subtle changes in the waveform to locate the seismicity more precisely



P 1.00 km

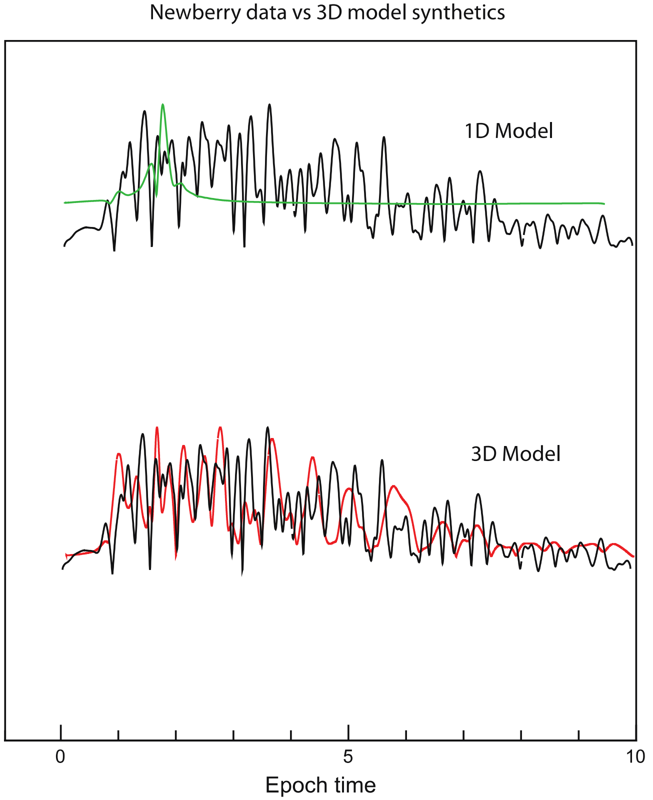


relocation in depth of event 12/07/2012
(catalog depth 722 m above MSL)

Conclusions

Ambient Noise Correlation (the "virtual earthquake" method) provides high resolution on scales ranging from hand samples (mm) to continents (1000s of km).

- It can be employed anywhere seismometers can be installed in large numbers.
- Since it completely strips away the need for earthquake or artificial sources, experiments can be designed explicitly to the problem at hand.



At Newberry, we are able to image highly detailed structures from the surface through the zone of microseismicity.

- This 3D image is accurate enough to predict the scattered energy seen in seismic records.
- This will allow us to more precisely measure the microseismicity associated with fluid injection.