New signal: ambient seismic

Can ambient seismic (AS) provide information on subsurface fluid reservoirs?

Talk outline

General introduction to ambient seismic data

- Definition & examples
- Recent, common applications to oil & gas exploitation

Ambient seismic for fluid characterization in reservoirs

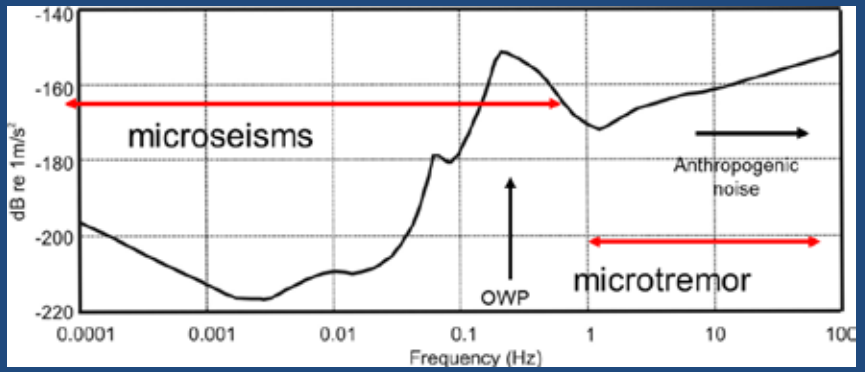
- Field data examples
- Laboratory data
- Theory and modeling
- History, challenges, and outlook

Ambient seismic for fluid characterization evolved from field observations

Ambient seismic data

Characteristics of ambient or passive seismic

- No impulsive source (i.e. dynamite, vibrator, weight drop, etc.)
- Source is generally uncontrolled as to timing
    - Ocean waves
    - Anthropogenic noise
    - Earthquakes
    - Hydraulic fracturing
    - *Secondary reservoir-related signals*



U.S. Geological Survey *low noise model (Peterson 1993)*

The figure demonstrates the general spectral profile of the ambient seismic wave field

O&G industry is (re)discovering ambient seismic applications

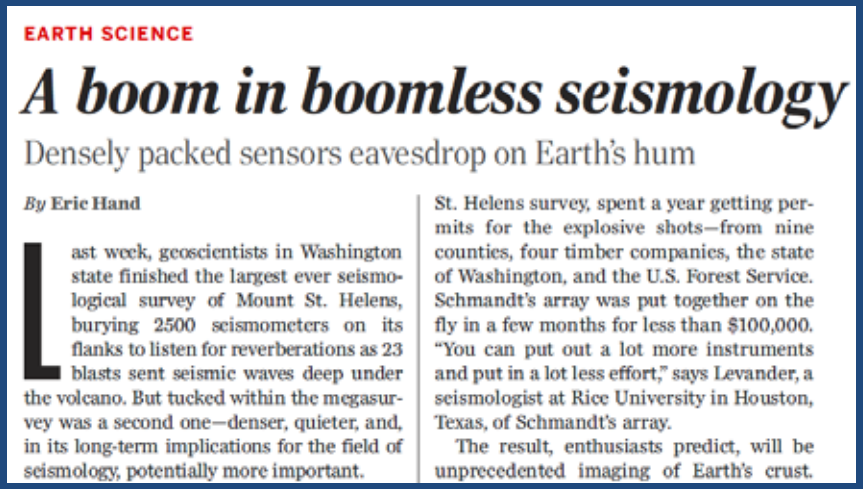
Microseismic monitoring to better understand hydraulic fracture completions

Earthquake monitoring for risk management

Production and subsidence monitoring

Recording of surface waves for characterizing the near surface

Interferometric imaging of passive seismic data for structure interpretation



EARTH SCIENCE

A boom in boomless seismology

Densely packed sensors eavesdrop on Earth's hum

By **Eric Hand**

Last week, geoscientists in Washington state finished the largest ever seismological survey of Mount St. Helens, burying 2500 seismometers on its flanks to listen for reverberations as 23 blasts sent seismic waves deep under the volcano. But tucked within the megasurvey was a second one—denser, quieter, and, in its long-term implications for the field of seismology, potentially more important.

St. Helens survey, spent a year getting permits for the explosive shots—from nine counties, four timber companies, the state of Washington, and the U.S. Forest Service. Schmandt's array was put together on the fly in a few months for less than $100,000. "You can put out a lot more instruments and put in a lot less effort," says Levander, a seismologist at Rice University in Houston, Texas, of Schmandt's array.

The result, enthusiasts predict, will be unprecedented imaging of Earth's crust.

Eric Hand, Science, 2014

Low cost, quality passive seismic systems have contributed to renewed interest

Monitoring hydraulic fracturing

This passive seismic came center stage in last decade

Data is acquired

- Deep boreholes
- Shallow boreholes
- Surface

Uses: definition of stimulated volume, well spacing, characteristics of fractures, etc.

Courtesy of Spectraseis

Microseismic monitoring is performed on less than 10% of drilled horizontals

Induced seismicity monitoring

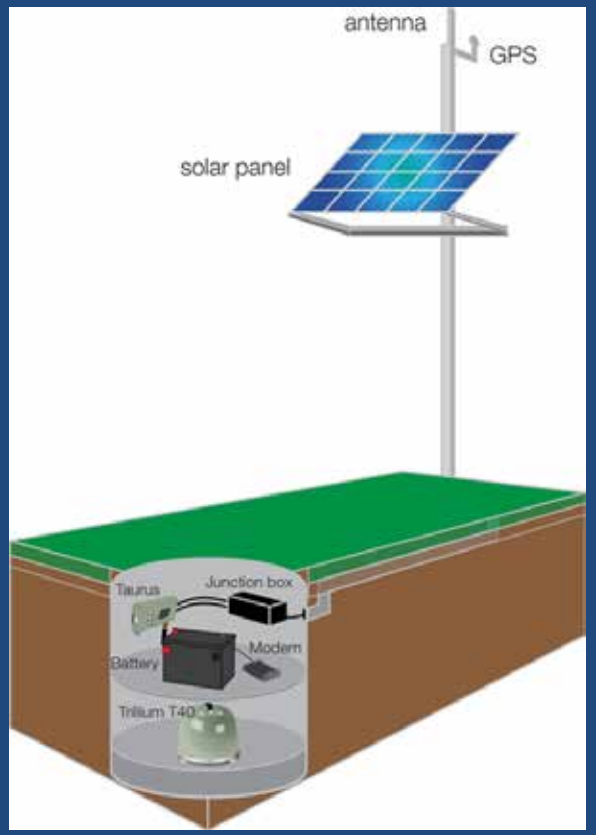
A relatively recent application in oil & gas industry

Utilizes existing earthquake monitoring and analysis technology

Strong demand for real time data

Challenges are in understanding possible links to oil & gas activity

NRC report on *Induced Seismicity in the Energy Industry, 2012*



Courtesy of Spectraseis

There is considerable interest, but limited industry investment in this application

Long Beach passive seismic survey

In 2011, Signal Hill Petroleum deployed 5300 sensors in an active seismic acquisition

Science, August 15, 2014 by Eric Hand

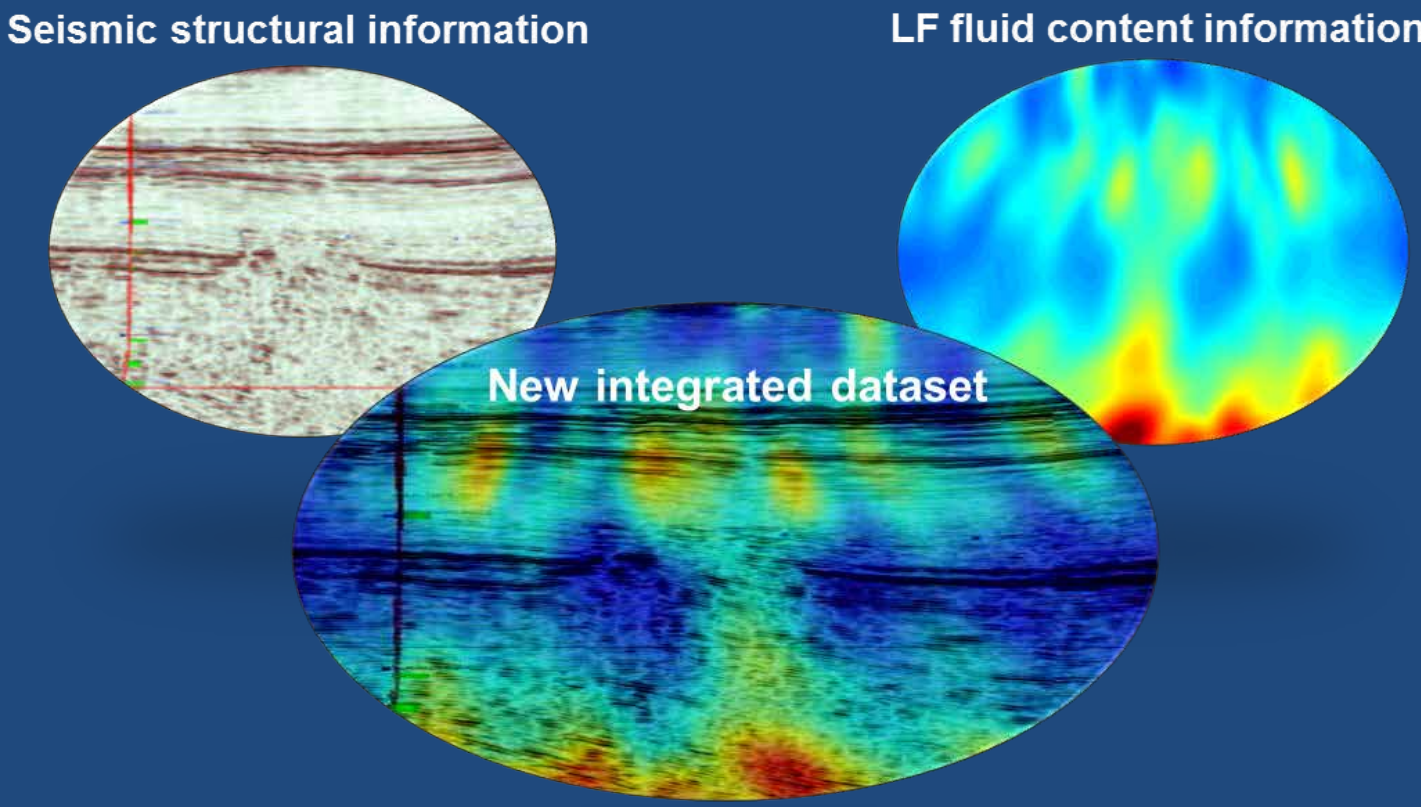
This also provided a large, high quality passive seismic data set

These data were analyzed by Robert Clayton, seismologist at CalTech

Surface waves were used to evaluate the top kilometer of the subsurface

This urban environment provided a high energy source of passive seismic energy

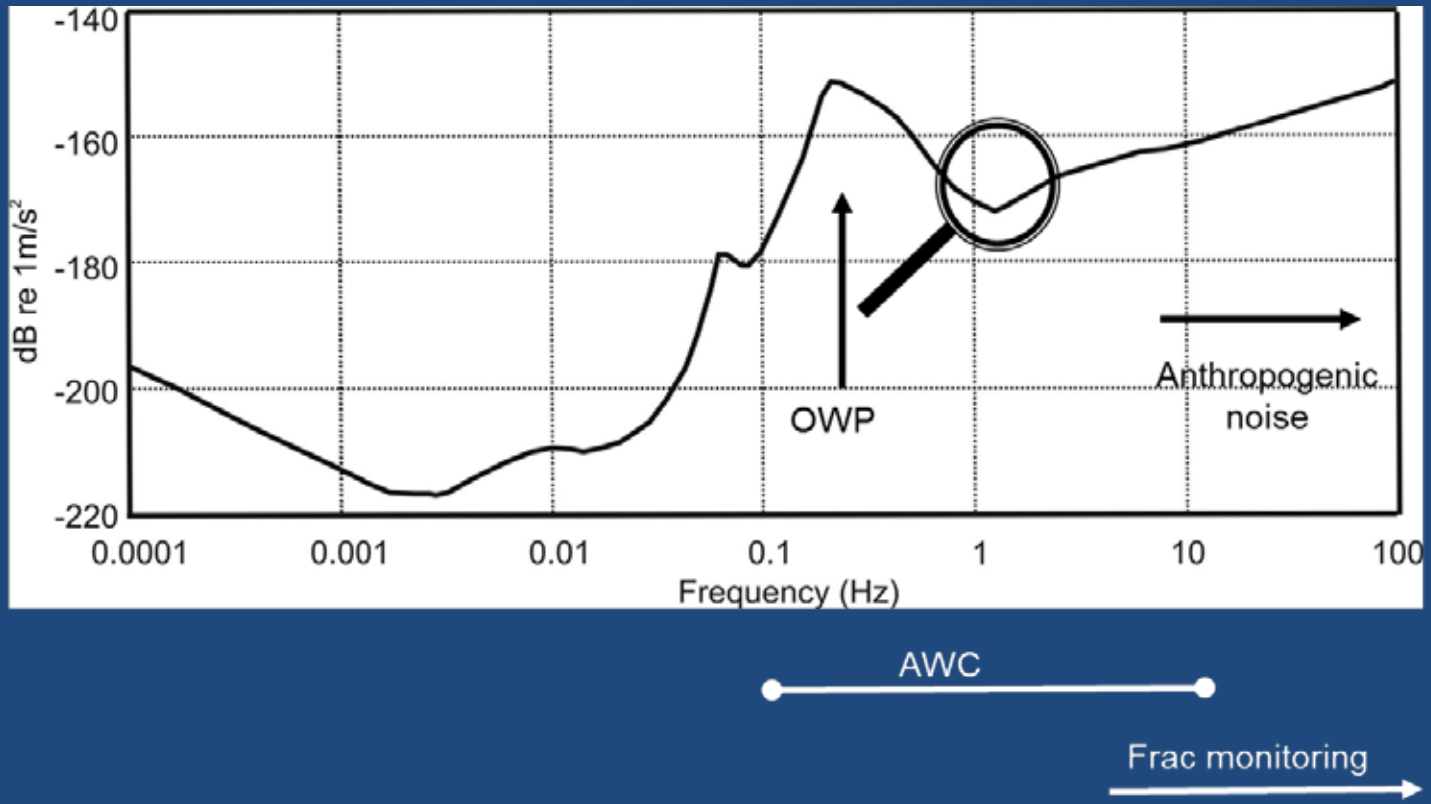
Ambient Seismic for fluid detection?



An inexpensive method of providing fluid information would be very welcome

Where do we look for fluid signal in ambient seismic?

U.S. Geological Survey low noise model (Peterson 1993).



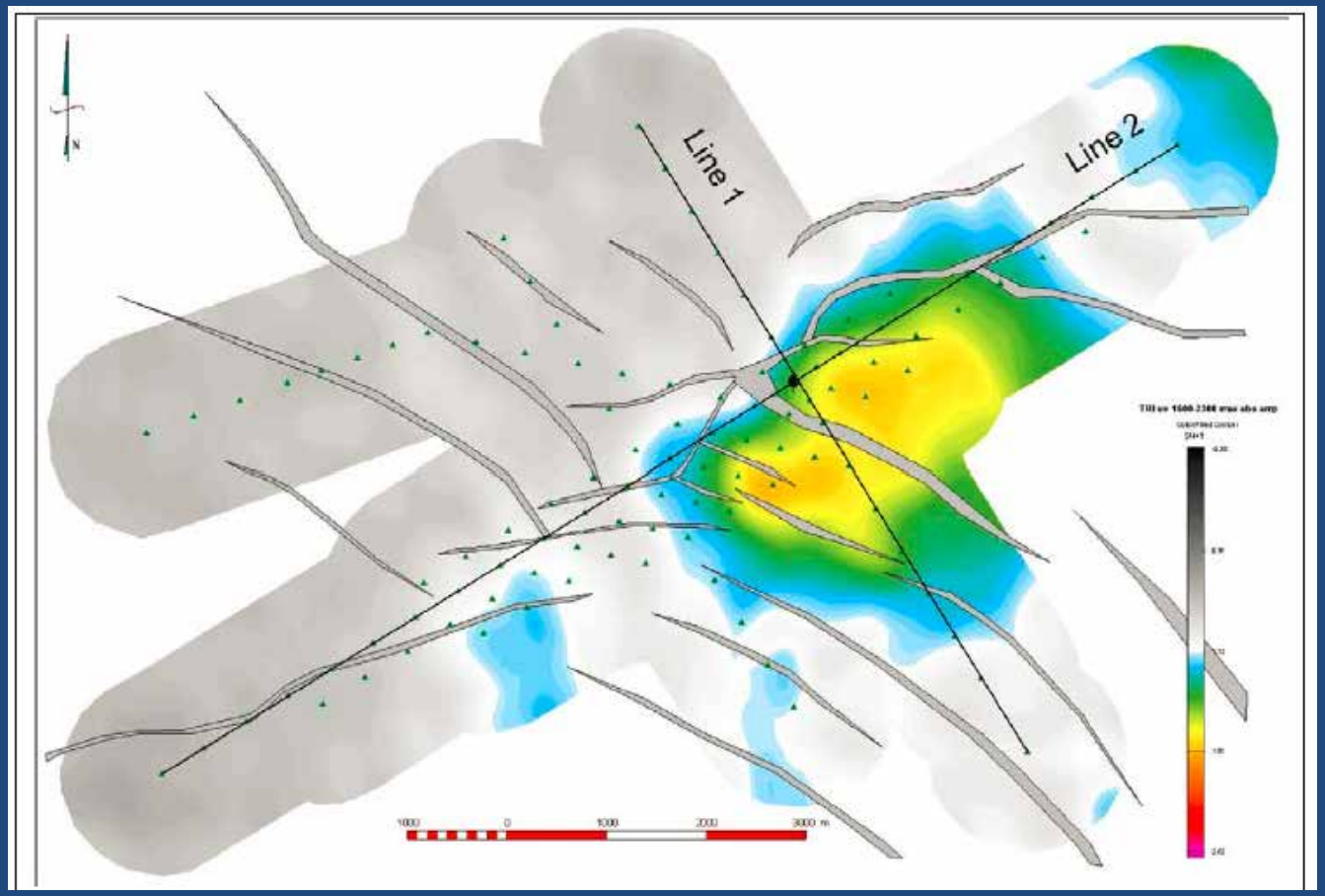
The investigation to date has been in 1 to 10 Hz range

Literature suggests promise

Studies in literature indicate lower frequency reflectivity differences in hydrocarbon reservoirs. Examples include:

- Castagna, et al., The Leading Edge, 2003
- Korneev, et al., Geophysics, 2004
- Chapman, et al., Geophysics Journal International, 2006
- G. Goloshubin, et al., The Leading Edge, 2006
- Sanger, et al., Geophysics, 2009

Field data example demonstrates promise (1/2)

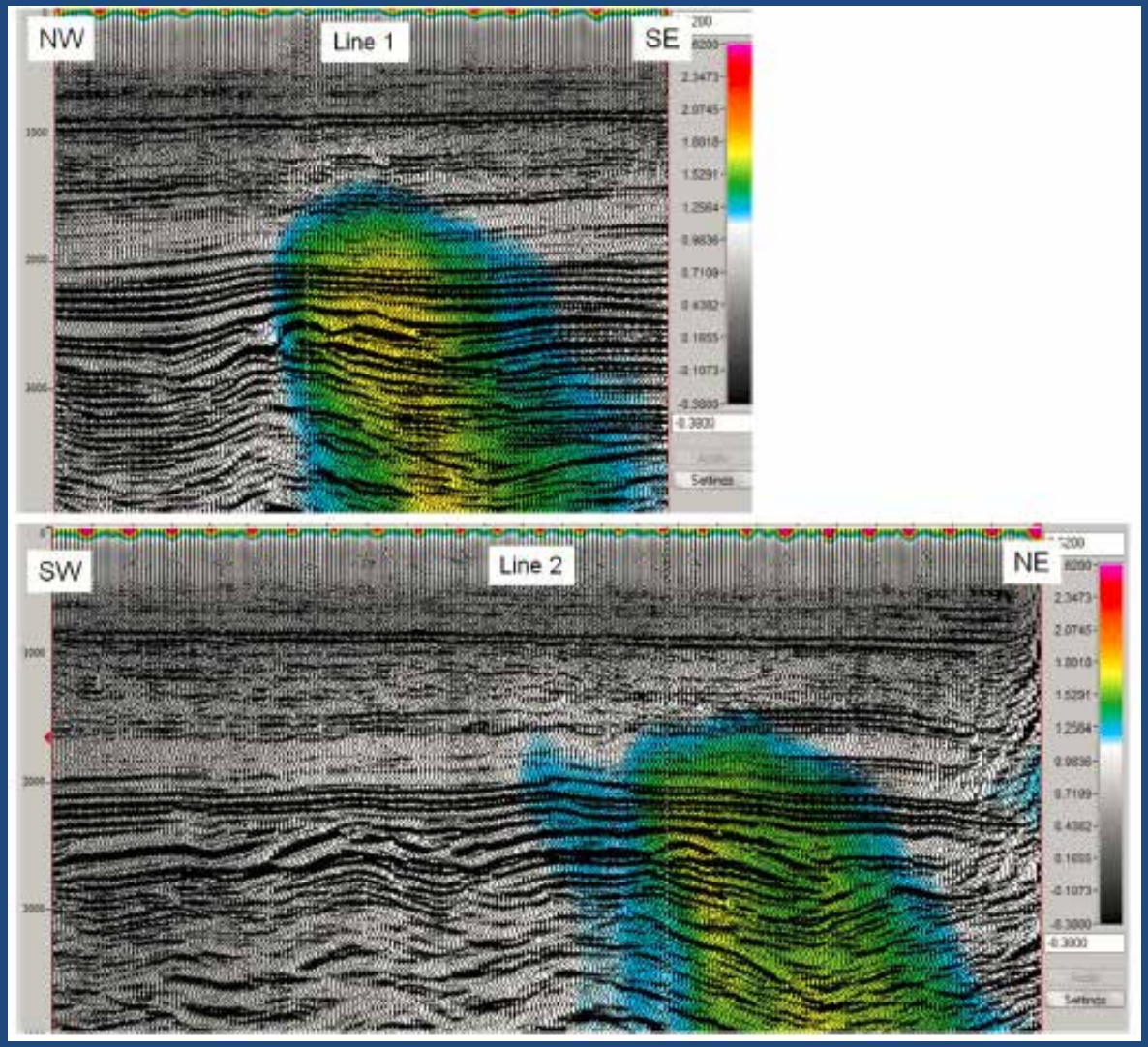


A discovery well was drilled at the intersection of Line 1 and Line 2.

Birkelo and Witten, SEG 2011, San Antonio

Ambient Seismic attribute correlates with single discovery in non producing field

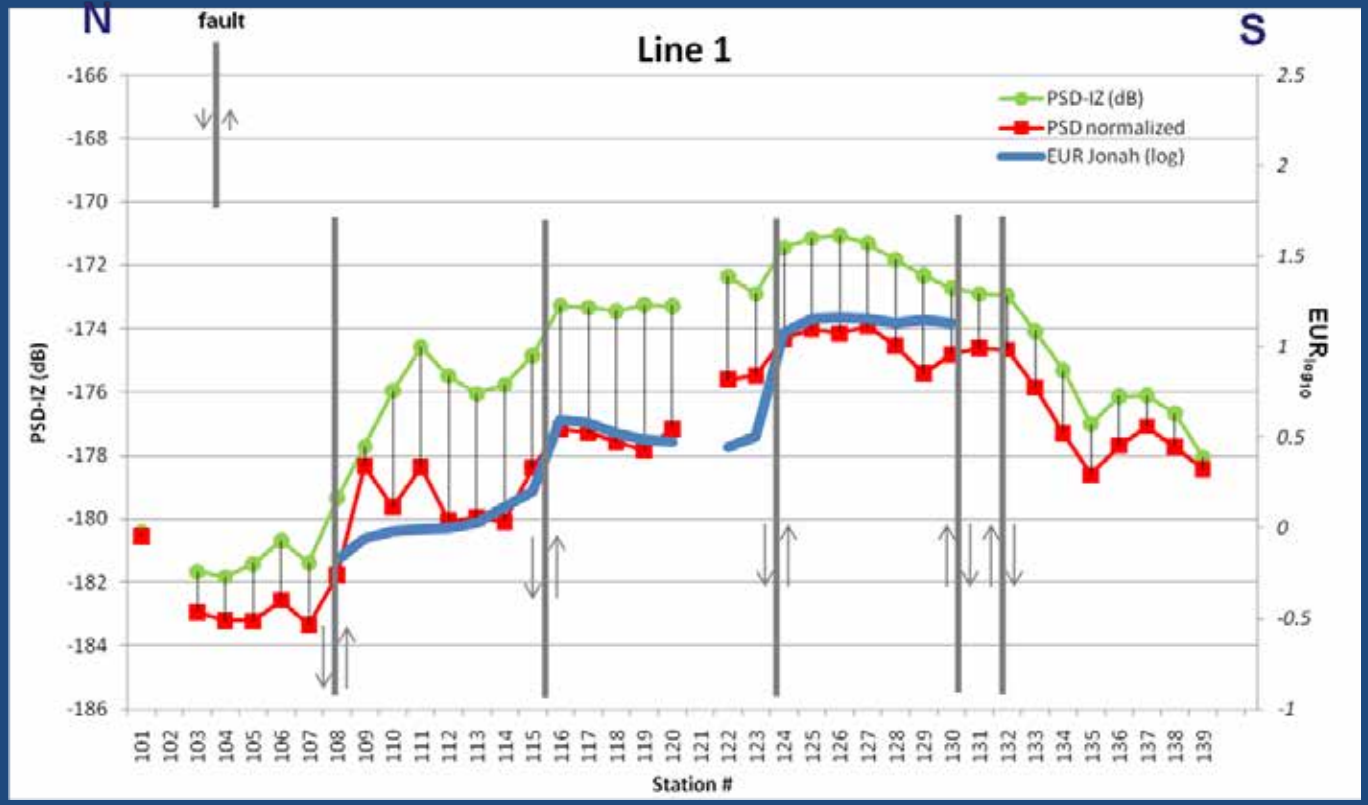
Field data example demonstrates promise (2/2)



Ambient Seismic energy focuses on only a portion of the complexly faulted geology below 2000m

Birkelo and Witten, SEG 2011, San Antonio

Quantitative comparison of AS and hydrocarbon attributes



Red is Ambient Seismic attribute

Blue is normalized hydrocarbon production attribute

Birkelo, et.al, 2011, EAGE Vienna

Profile across multiple fault blocks show good correlation between AW attribute and HCs

Laboratory measurements

Studies by Tisato and Quintal, 2014 show that

- Attenuation in dry rock is frequency independent
- Attenuation in fluid-filled rock depends on frequency, water saturation, and pressure

Frequency dependent attenuation mechanisms exist over a broad spectral range and indicate promise for fluid characterization

Tisato and Quintal, 2014, Geophysics, Vo. 79 No. 5

Fluid-based attenuation models

The model space is highly parameterized and includes models over a band from .01 Hz to 100k Hz.

- Bubble dissolution
- Patchy saturation
- Squirt flow
- Scattering
- Biot
- Viscous shear

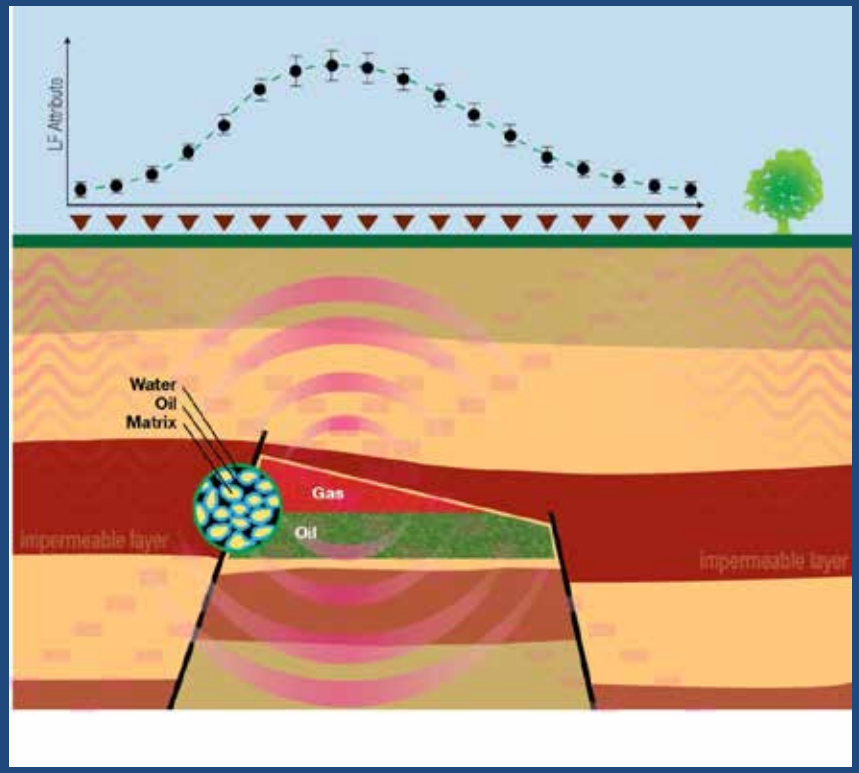
The model space is frequency dependent

Results in multiple models and highly parameterized solutions

Tisato and Quintal, 2014

Field experiments are difficult due to limited parameter control

What is a possible mechanism?

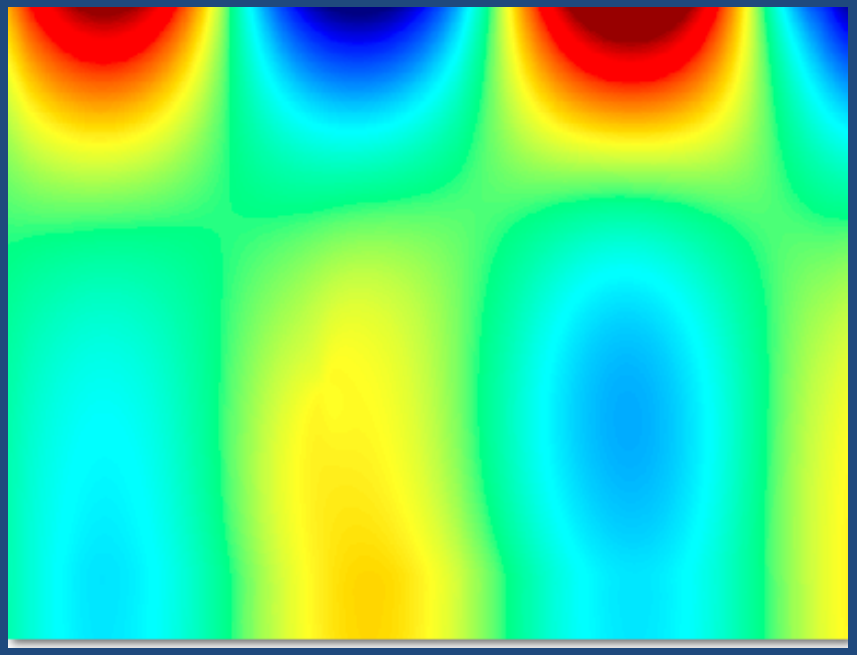


Courtesy of Spectraseis

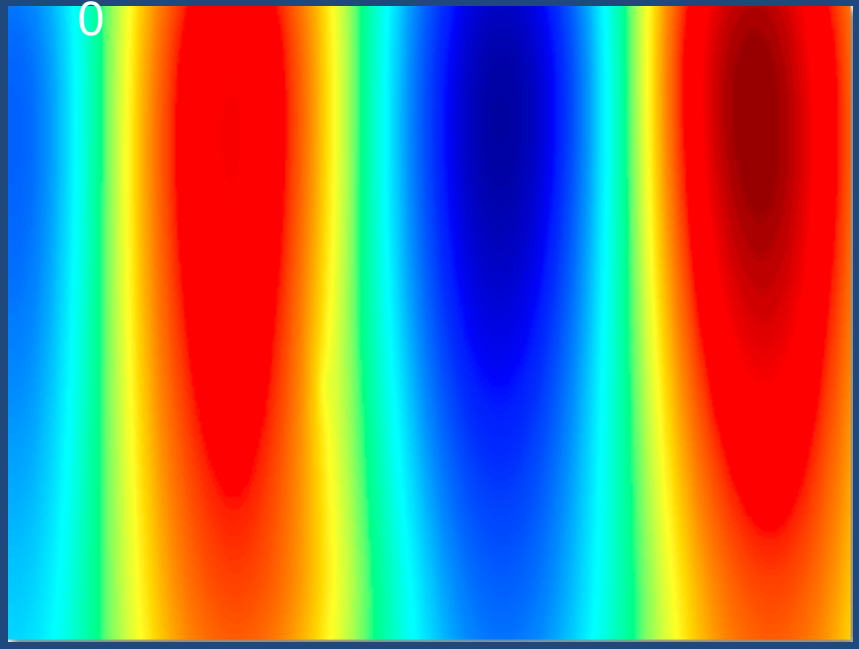
- Hydrocarbon reservoirs are unique (not 100% water saturated)
- Attenuation contrast of reservoirs causes a secondary wave field
- AS is a weak secondary with a strong surface wave field
- The goal of AS processing is to separate the reservoir signal and captures fluid information

Reservoir fluid system measured via a secondary wave field

Modeled Rayleigh wave propagation



Vx

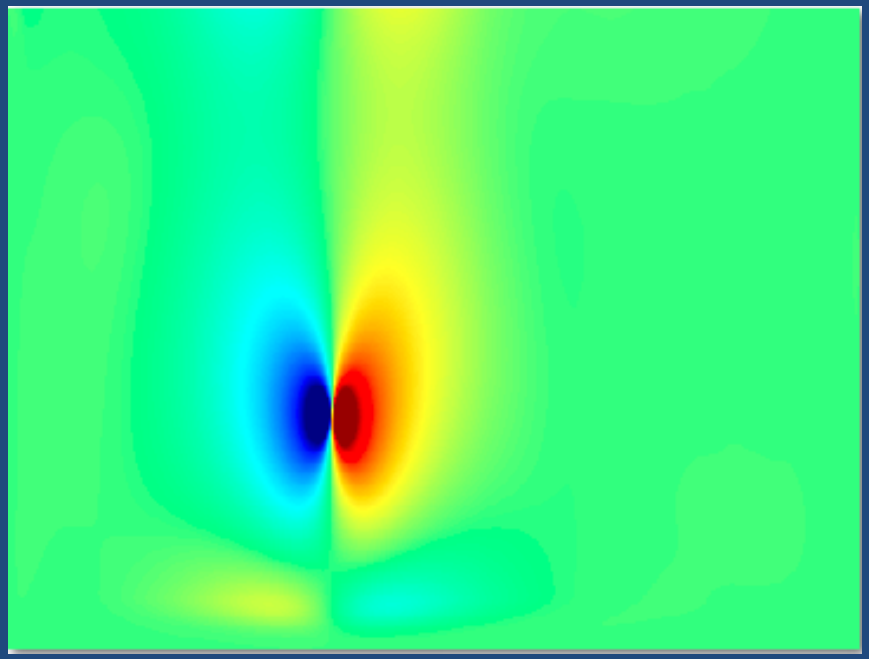


Vz

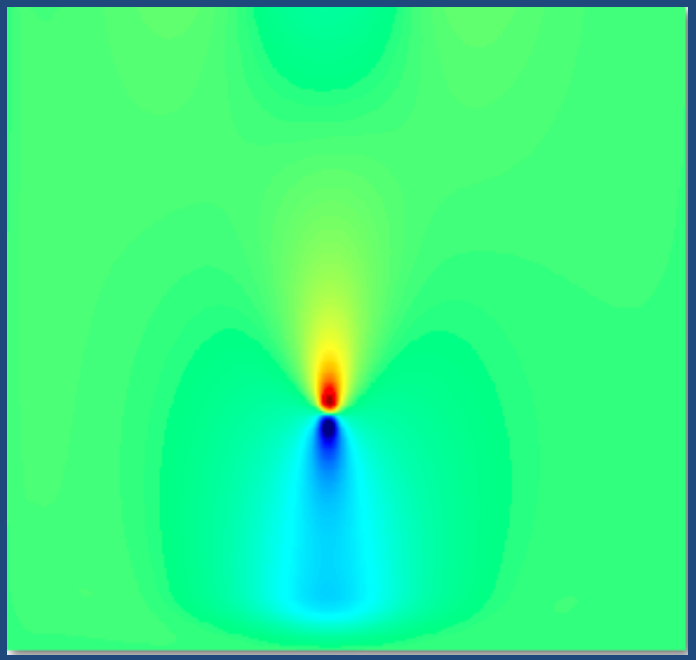
Courtesy of Spectraseis

There is a small inclusion in the middle of the model that is not visible due to strong primary Rayleigh wave

Total wave field minus Rayleigh wave only



P



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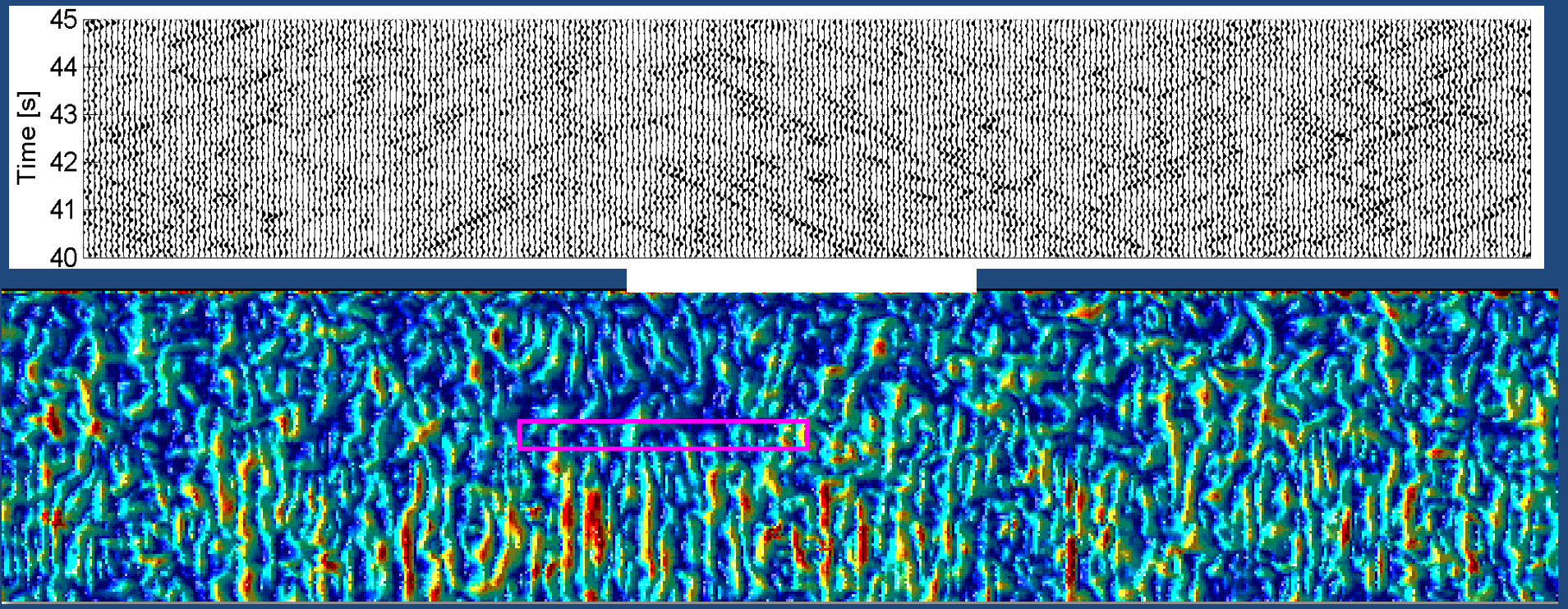
Courtesy of Spectraseis

The secondary wave caused by scattering from the inclusion is now visible

Modification of passive wavefield

Visco-elastic inclusion and low-velocity surface layer

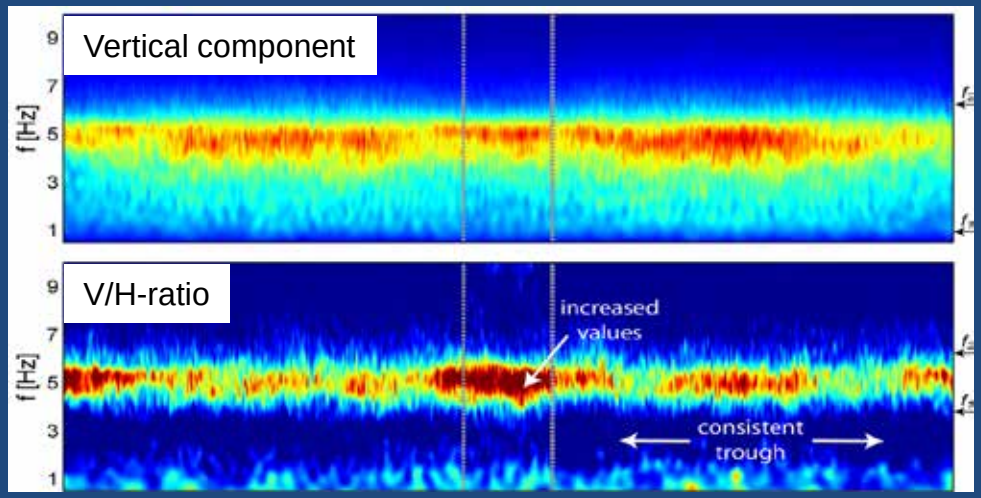
Marc Lambert ETH thesis, 2010

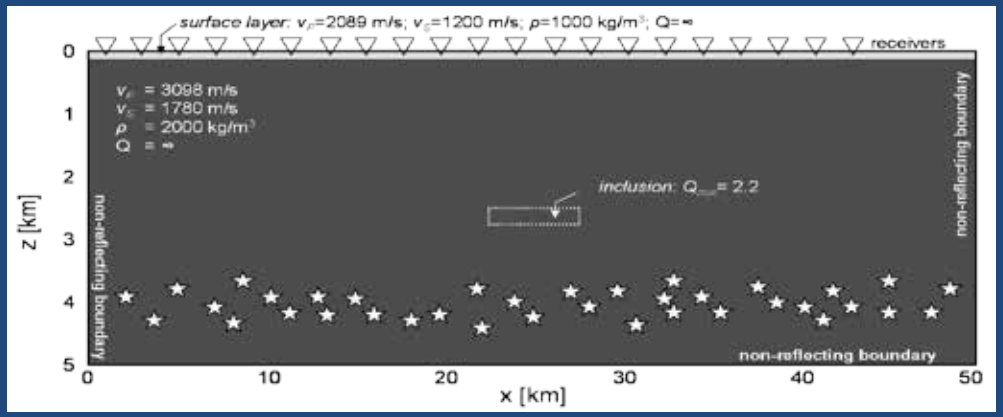


There is an attenuation anomaly in the purple rectangle, not seen in total, raw wavefield

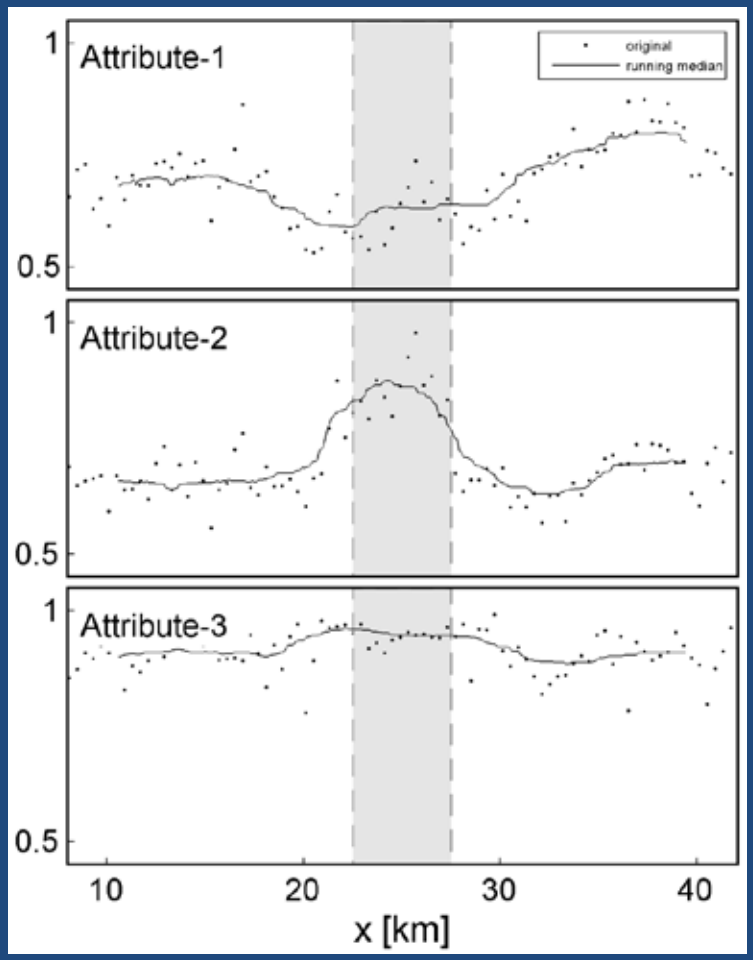
AS attribute calcuated from model data with attenuation anomaly

Marc Lambert ETH thesis, 2010





Attribute profiles



History for AS studies for fluid evaluation

Dates back at least 10 years

Significant research effort since 2007

Tens of field data sets acquired by various contractors

Field results are somewhat inconsistent and controversial

- Uncertainty in controlling model and parameters
- Data often acquired in noisy environments

Millions of dollars spent on R&D from 2006 to 2012

Outlook for AS for fluid characterization (1/2)

Promising, but case for it needs to be strengthened

Pros and cons

- Lower cost than active seismic and potential to provide new information
- Application to exploration is limited by long project cycle times and limited control
- Application to production is limited by a noisy environment

Outlook for AS for fluid characterization (2/2)

More research still required to fully evaluate

- Field experiments
- Laboratory experiments
- Theoretical models

Scope of evaluation

- Potential for success
- Predictability for where and when successful
- Understanding data to better interpret

Small companies have limited research budgets and large companies are conservative

Summary for AS/reservoir fluid characterization

- The use of ambient seismic for reservoir fluid characterization is not common in the industry
- The value is in lower cost and potential for new information
- The main challenge is in understanding when it might work and when it won’t, i.e. predictability
- Laboratory studies, theory refinement, and field tests all required to advance, with field tests the most challenging
- External funding required to advance this technology

3D seismic took a decade or more to evolve into common practice

Circle back to original question

Can ambient seismic provide information on subsurface fluid reservoirs?

Yes, but business case still needs to be made from better predictability and interpretation of the data, which will require more research.

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