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

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

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

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

Eric Hand, Science, 2014
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.

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

Courtesy of SpectraSeis
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*

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

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?

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

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

Red is Ambient Seismic attribute

Blue is normalized hydrocarbon production attribute

Birkelo, et.al, 2011, EAGE Vienna
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

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?

- 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

Courtesy of Spectraseis
Modeled Rayleigh wave propagation

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

Courtesy of Spectraseis
Total wave field minus Rayleigh wave only

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

Courtesy of Spectraseis
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 calculated 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.