Seismic Acquisition with Ocean Bottom Nodes

Providing full azimuth seismic images in busy oilfields

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Abstract: Ocean bottom seismometers have been used by academia for several decades to study mostly the deep subsurface. But only since recently, such ocean bottom nodes (OBN) have been used in commercial seismic surveys for oil & gas exploration and development. In the 1990s the first 2D case studies using OBNs were carried out in the North Sea, and more substantial 2D & 3D pilot surveys followed in the early 2000s in the Gulf of Mexico, the North Sea, and in West Africa. The first full 3D OBN survey was carried out in 2004/2005 in the southern Gulf of Mexico, and until 2008 only one or maximum two 3D OBN survey per year were acquired world-wide. Since 2008, about 12 OBN surveys have been acquired world-wide, and demand for 2011 onwards is increasing.

Why are OBNs chosen in favor of towed streamer or ocean bottom cables?
The main driver is the full azimuth information achieved with a typical OBN survey design which enables best illumination and imaging in complex structure, for example sub-salt and sub-basalt. Another equally important driver has been the need to acquire seismic data in congested oilfields: Oilfields can be congested both on the surface, impeding towed streamer surveys, and on the seafloor, impeding the use of ocean bottom cables. Other forces driving OBN technology have been the exceptional data quality achieved by this type of acquisition, repeatability of receiver and source positions, and advances in processing full azimuth seismic data.
Ocean Bottom Node Acquisition – What is it?

4 component seismic sensor:
3 geophones (XYZ) - also MEMS or optical for OBC
1 hydrophone
Outline

• OBN Acquisition
  • Why is it done?
  • Equipment and Node Operation
  • Roll-along Operation
  • Survey Design

• Data Quality
  • Node Positioning
  • Source Signature & Sensor Responses, Low Frequency
  • Raw Data Analysis
  • Direct Arrival – First Break Analysis
    • (Clock Drift)
    • (Sensor Orientation)

• Data Processing
  • OBN Data Processing Flow
  • Mirror Imaging
OBN Acquisition

Why is it done?
OBN Acquisition – Why is it done?

Complex imaging with full azimuth broad band data

Figure 6. Comparison of narrow-azimuth towed streamer (A), and receiver-migrated OBS node (B). The node images benefit from an improved salt model.

Source: Atlantis, Node data acquired by Fairfield (phase 1) & Seabird (phase 2)
OBN Acquisition – Why is it done?

High resolution both vertically and laterally

![Comparison of extra-salt images at the Miocene level at Atlantis. Higher resolution and improved fault definition are apparent in the OBS wide-azimuth node image on the bottom compared to the narrow-azimuth towed streamer image above.](image)

Figure 6: Comparison of extra-salt images at the Miocene level at Atlantis. Higher resolution and improved fault definition are apparent in the OBS wide-azimuth node image on the bottom compared to the narrow-azimuth towed streamer image above.

Source: Atlantis, Node data acquired by Fairfield (phase 1) & Seabird (phase 2)  
Howie et al SEG 2008
OBN Acquisition – Why is it done?

4D Repeatability

Comment on first node-on-node 4D survey:

“Time-lapse noise measurements [...] are among the lowest in BP’s experience even when compared to permanent installation surveys.”

Reasnor et al, SEG 2010

Reference data

Node A, Shot A and B

Source: Dalia, Node data acquired by Seabird

Node A and B, Shot A

E.Ceragioli et al, EAGE 2010
OBN Acquisition – Why is it done?

Infill under obstructions, congested oilfields

Illustration of the main surface and subsea obstructions on the Dalia field: OBN will be located on the seabed very close to obstructions.
OBN Acquisition – Why is it done?

Converted wave imaging

Shown are classic OBC examples
Why Converted Waves?  

*PP & PS = Improved reservoir characterisation*

PP AVO inversion → P impedance  
PS AVO inversion → Shear impedance  

..also better handle on density.

Strong shear impedance contrast from lithology change within reservoir zone.

*Source: Kvitebjorn  
Ao & Areklett, TLE 2010*
Why Converted Waves?  

**PP & PS = Better anisotropic velocity model building**

- **PP reflection, isotropic NMO correction**
- **PS reflection, isotropic NMO correction**

**Double Scan**

- **PP**
- **PS**
- **PP & PS**

Note polarity reversal at critical angle
OBN Acquisition

Equipment and Node Operation
OBN Equipment – Nodes

**Option 1**  Throw node overboard, let it float up by itself

- Typically glass or titanium sphere
- Disposable heavy anchor
- Internal or external sensor package
- Mostly used for academic research
OBN Equipment – Nodes

**Option 2**  Hand-place node, pick it up manually

- Node can be custom shaped
- Recorder in cylindrical pressure vessels
- Internal or external sensor package
- Mostly used for commercial 3D surveys
OBN Equipment – Node

Node Unit/recorder:

- Microprocessor
- A/D: 24-bit
- Data Storage: 75 days @ 2 ms
- Clock: High-precision oven-controlled quartz oscillator
- QC data Link: High-speed acoustic modem
- Battery: >65 days
- Physical size: 91 x 87 x 38 cm
- Weight: 150/70 kg in air/sea
- Depth rating: 3000m

4 component (4C) sensor:

- Hydrophone
- 3 Geophones (8 Hz)
- 2 Inclinometers
OBN Equipment – Sensor technology

Geophone sensors

Hydrophone sensor

- **Hydrophones** need to be exposed to outside
- **Geophones** need to couple to seabed (in order to record shear waves)

- MEMS accelerometers or optical sensors are not suitable for autonomous nodes due to high power consumption of the sensor itself or of other system components
- Others, such as piezo-electric sensors are also an option
OBN Equipment – Vessel

Seabird Hugin Explorer
OBN-Source-ROV vessel

ROV
Second ROV
Node deck
Dual source
OBN Equipment – Node Handling
OBN Operation – Node Placement
OBN Operation – Node Placement

- Sensor skirt (cutaway view)
- Unperturbed soil
- “Added mass” contribution from soil
OBN Operation – Node QC

- Recorder status
- Battery status
- Hard disk status
- Power usage
- Tilt values
- Seismic data RMS amplitudes
- ...various other system information
OBN Acquisition

Roll-along Operation
OBN Survey – Node and Source Area

- Boundary of shot grid (surface) 588 sqkm
- Boundary of node grid (ocean bottom) 229 sqkm

Another example:

Node/shot area is optimised
OBN Survey – Node Layout

- 1595 total node positions
- Node grid: 390m x 390m
• 648,648 total shot positions
• Shot grid: 30m x 30m
• Shooting vessel acquiring one shot line at a time
OBN Survey – Roll-along Acquisition
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Example OBN survey layout:

Source grid: 50m x 50m

Node grid: 400m x 400m

Area of full surface azimuth/offset coverage
OBN Survey Design

Target horizon, node area.
OBN Survey Design

Ray-tracing, PP mode
OBN Survey Design

Ray-tracing, P-to-S conversion
OBN Survey Design

PP illumination – **Near to mid offsets 0-3km**
OBN Survey Design

PP illumination – **Mid to far offsets 3-6km**

Best illumination for this model
OBN Survey Design

PP illumination – Very far offsets 6-9km
OBN Survey Design

PP illumination – All offsets (0-9km)
OBN Survey Design

Contributing receivers/shots for two example bins:

Centre bin

Corner bin

Shot area

Node area

Bin

Shot area

Node area

Bin

Node locations

Shot locations
OBN Survey Design

In traditional azimuth and offset diagrams, OBN survey seems to have poor near offset fold.

Rose diagram – Azimuth-offset fold

(different but similar OBN survey)

Poor near offset fold??

Offset fold for two example bins

Important mid offsets
OBN Survey Design

OBN offset/azimuth fold is best viewed in so-called “common-offset vector tiles”.

For any CMP bin, contributing shot-receiver pairs are evenly distributed on a regular offset/azimuth grid. ➔ Pre-stack migration is best performed in common offset vector tiles.
OBN Acquisition

Node Positioning
Node Positioning – Systems

Standard sub-sea positioning systems

• USBL – Ultra Short Baseline
  – Vessel based transceiver acoustically interrogates remote beacon to determine a range/bearing and computes relative position from vessel GPS. Average accuracy is a function of water depth/slant range.

• INS – Inertial Navigation System
  – Comprised of Inertial Measurement Unit (IMU) and software Kalman filter. IMU senses motion and direction, with Kalman filter, to maintain accuracy away from control points.

• LBL – Long Baseline
  – Comprised of an array of N transponder beacons placed at the seafloor which are calibrated in a relative manner. Unambiguous fix requires at least 3 ranges. Independent of depth.
  – Costly and time consuming operation
Node Positioning – Systems

High-fidelity sub-sea positioning system

- **HiPAP & SSBL**
  - High Precision Acoustic Positioning using Super Short Baseline
  - Hull mounted unit & ROV transducers

- **HAIN**
  - Hydro-acoustic Aided Inertial Navigation System
  - Inertial Measurement Unit (3 gyro compasses & 3 accelerometers)
  - Doppler Velocity Log (ROV speed)
  - Pressure & heading sensor
  - Kalman software filter
Node Positioning – Accuracy

- SSBL: +/-6m @ 1500m (~0.4%)
- USBL: +/-12m @ 1500m (~0.8%)

Graph showing the relationship between accuracy and water depth for different systems.

Water depth [m] vs. Accuracy [m]
Node Positioning – Accuracy

...with high accuracy inertial system

SSBL + HAIN: +/-1.4m @ 1500m
(~0.1%)
Node Positioning – Accuracy

Real OBN survey #1:

- 750 nodes
- Water depth 1095m-1135m
- Mean misplacement of
  - 1.2m (real-time)
  - 1.9m (first break solution)
- → 0.2% of water depth
Node Positioning – Accuracy

Real OBN survey #2:

- 1600 nodes
- Water depth 1160m-1820m
- Mean misplacement of
  - 3.1m (real-time)
  - 3.3m (first break solution)
- → 0.3% of water depth
OBN Acquisition

Source Signature & Sensor Responses

• What is put into the ground and what is recorded
• How to boost low frequency energy to give broad band seismic
Ideal source wavelet & recording transfer function

On the source side, what we really want is to generate an energy spike which is then convolved by the earth’s reflectivity series.

On the receiver side, what we really want is to record the arriving wave field without distortion or filtering, i.e. with a white transfer function.
Real source signature

**Real source wavelet**
- Band limited
- Low frequency reverberations from air bubble and source ghost

**Real source spectrum**
- Band limited due to source output, anti-alias filter and sensor response
- Ripples at low end due to air bubble
- Regularly spaced notches due to surface source ghost
Ripples are *bubble* effect

Notches are *ghost* effect

Decay is both natural and due to *anti-alias filter*

\[
   n \lambda_{\text{notch}} = 2 z_{\text{source}}, \quad n = 0, 1, 2, \ldots
\]

\[
   f_{\text{notch}} = \frac{v_{\text{water}}}{\lambda_{\text{notch}}} = \frac{nv_{\text{water}}}{2 z_{\text{source}}}
\]
Receiver ghost, vertical incidence

Vertical sensor:

\[ n_v \lambda_{v, notch} = 2 z_{source}, \quad n_v = \frac{1}{2}, \frac{3}{2}, ... \]

\[ f_{v, notch} = \frac{v_{water}}{\lambda_{v, notch}} = \frac{n_v v_{water}}{2 z_{source}} \]
Sensor response/source signature wavelet

Zero-phase equivalent wavelets, vertical incidence

- 8Hz geophone, anti-alias, example source signature @ 12m
- 8Hz geophone, anti-alias, source ghost @ 12m
- 8Hz geophone, anti-alias
- 8Hz geophone

10ms
Seismic Airgun Source

Seismic source array layout:

...almost fully symmetrical → isotropic response
Source Signature Processing

In data processing we will try to compress the recorded seismic wavelet as much as possible, equivalent to flattening/whitening of the spectrum.

- Care needs to be taken to avoid boosting noise in ghost notches
- De-bubble operator to remove bubble oscillations
- Full source de-signature operator
- Modelled versus data derived source signature wavelet
Source Signature Processing

Typically in OBN surveys...
- Deriving the source wavelet from the recorded data works well
- Modelled and data derived wavelets match well
- The bubble is not modelled so well, so it is preferred to use the data derived wavelet for source de-signature operator design

Courtesy of Geokinetics
Source Signature Processing

Data derived source signature spectrum

Desired output spectrum after de-bubble operator

Courtesy of Geokinetics
Source Signature Processing

Input data

De-bubble operator
Modelled signature

De-bubble operator
Data derived signature

Courtesy of Geokinetics
Boosting low frequency energy

Why do we need low frequency information?

• Improved resolution from broad band seismic
• Deep, complex structural imaging, in particular:
  – Sub-salt imaging
  – Sub-basalt imaging
  – Generally, penetrating high velocity layers and rugose interfaces
• Velocity model building
• Inversion
Boosting low frequency energy (1)

Boost low frequency energy by...
  • ...using a bigger source array

Downside
  • Limit to maximum source size, longer re-charge time, more shot generated noise
Boosting low frequency energy (2)

Boost low frequency energy by...
• ...towing source array deeper

Downside
• Introduces notch(es) within seismic signal band
Boosting low frequency energy (3)

Boost low frequency energy by...
- placing sensors deeper, ideally at seabed

Downside
- Towed streamer, or OBS in very shallow water: Introduces notches within seismic signal band
Boosting low frequency energy (4)

Boost low frequency energy by...
- ...performing de-ghosting / wavefield separation

Downside
- Requires more costly acquisition:
  * Ocean bottom seismometers, over/under streamers, or others

Limited at low end only by
- Sensor response
- Sensor depth
Boosting low frequency energy (5)

Boost low frequency energy by...
• ...using velocity sensors with high sensitivity and wide dynamic range at low end

Downside
• Low natural-frequency geophones are not omni-directional, i.e. they are sensitive to tilt
The figure below illustrates that MEMS accelerometers have lower effective dynamic range at low end of seismic signal spectrum:

We cemented 12 digital 3-C accelerometers together with analog vertical geophones and hydrophones in a 7-inch well at depths ranging from 140 to 200 m. Figure 3 compares analog geophones and digital accelerometers. It confirms that below 50 Hz, conventional geophones are quieter than digital accelerometers and that above this frequency, the situation is the opposite: The three noise bursts recorded between 2 and 4 o’clock can be observed up to 200 Hz on the digital accelerometers. Another obvious advantage of digital sensors is their total immunity to electrical leakage. This experiment was conducted in a gas storage area close to
Boosting low frequency energy – Summary

Recorded low frequency energy can be boosted by...

1. Using a big source array
2. Towing source array deep
3. Towing streamer deep, or better: Placing sensors at seafloor
4. Using acquisition technique allowing receiver side de-ghosting / wavefield separation
5. Using broad-band sensors that are highly sensitive at both low frequencies and high frequencies

Ocean bottom node acquisition technique is optimal with respect to all of the above.
OBN Acquisition

Raw Data Analysis
Continuous recorded data

- Active shots need to be extracted from continuous record, using shot time
- Shot time needs to be mapped to time of internal clock
- Clocks used in OBNs are very accurate, but still drift by several 10ms per month
Spectral analysis

- Spectral analysis
  - "1/f" noise
  - Ocean wave noise
  - Decay due to sensor responses & diminishing shot energy
  - Active shot energy. Ripples due to bubble

Graph: Atlantis Seatrial 2009 - Average spectra Log Scale, all offsets (0-6000m), station 100210021, node 1

- dB to 1uBar^2/Hz
- Frequency [Hz]

Lines:
- Geophone X
- Geophone Y
- Geophone Z
- Hydrophone P
Spectral analysis

Continuous data spectra – 4 minute traces

X Component

- Shot fired
- Seismic interference
- Ocean wave noise
- Shot lines
- Test shots
- Recorder noise
- Ship
- ROV placing node at 5m distance

Hours

Continuous data FX power spectrum - Xcomponent
Spectral analysis

Continuous data spectra – 4 minute traces

Y Component

- **Shot fired**
- **Seismic interference**
- **Ocean wave noise**
- **Shot lines**
- **Test shots**
- **Recorder noise**
- **Ship**
- **ROV placing node at 5m distance**
Spectral analysis

Continuous data spectra – 4 minute traces

Z Component

- Shot fired
- Seismic interference
- Ocean wave noise
- Shot lines
- Test shots
- ROV hoisted on deck
- Recorder noise
- Ship
- ROV placing node at 5m distance

Continuous data FX power spectrum - Z component
Spectral analysis

Continuous data spectra – 4 minute traces

Hydrophone

Shot fired
Seismic interference
Ocean wave noise
Shot lines
Test shots
ROV hoisted on deck
Recorder noise
Ship
Spectral analysis

Continuous data spectra – 4 minute traces

Hydrophone

5 hours of recording

Earthquake/Seaslide

Same spectrum, zoomed in 0-0.7 Hz

5 hours of recording
Spectral analysis

Continuous data spectra – 4 minute traces

Note “ripples”
Spectral analysis – Explaining frequency “ripples”

- Assume moving source close to sea surface emanating constant amplitude band limited energy with random phase
- Model all water arrivals up to 20 bounces (2D ray tracing)
Spectral analysis – Explaining frequency "ripples"

Modelled signal, direct ray path only

Modelled signal, up to 20 bounces in water
Raw data analysis

Example raw receiver gather, deep water (~1km)
Raw data analysis

2D node gather from one shot line, displayed with true relative amplitude and constant water velocity NMO correction.
OBN Acquisition

Direct Arrival & First Break Break Analysis
Direct arrival

Usages for recorded direct arrival wave = Parameters that can be derived from first break pick times:

1. Node positions
2. Source positions (to limited extent)
3. 3C sensor orientation angles
4. (Average) Water velocity
Direct arrival – First break times

**Direct arrival travel time equation:**

\[ t = \sqrt{(x_r - x_s)(y_r - y_s)(z_r - z_s)} \frac{1}{v(z, t)} + t_0 + d(t) \]

- \( x_r, y_r, z_r \): Receiver/Node position
- \( x_s, y_s, z_s \): Source position
- \( v(z, t) \): Average water velocity (at best function of depth and time)
- \( t_0 \): Residual time shift
- \( d(t) \): Clock drift (time variant)

**Assumptions:**
- *Straight ray path*
- *No global position biases*
- *First break pick represents true travel time*
- ...
First Break Times

Example 2D receiver gather, hydrophone channel

- Raw data
- Linear moveout correction
- Refraction
- Direct arrival
- 1st multiple
- Bubble energy
- ...zoomed in
First Break Times – Sensitivity Analysis

\[ t = \sqrt{(x_r - x_s)(y_r - y_s)(z_r - z_s)} \frac{1}{v(z, t)} + t_0 + d(t) \]

Fictitious node survey

Difference between computed direct arrival travel time and first break picks:

- Residual clock drift, linear -1ms to +1ms
- Node X/crossline position error, 2m
- Node Y/inline position error, 2m
- Node Z/depth position error, 2m
- Source X/crossline error <2m, constant for each line
- Source Y/inline position error, 2m
- Source directivity (affects FB pick)
- Tides, ±2m
- Water velocity error, 1m/s
- Water velocity variation, linear -½ms to +½ms
- All error terms except source position errors and tides.

Different scaling
Water velocity profiles taken over the same area at different times and locations:

...illustrates that in general, water velocity is invariant neither in space nor in time.
Direct Arrival Polarisation

Recording of direct arrival showing linear polarisation

Recording of direct arrival showing non-linear polarisation
Direct Arrival Polarisation

The maps to the right show that...

1) Direct arrival is clearly isotropic and linearly polarised → very good vector fidelity of direct arrival

2) There is very good control over sensor 3D orientation (better than 1°)

Difference between first break polarisation and source receiver azimuth, plotted at each shot position.

As-laid sensor orientation

Data derived orientation.
Corrections:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Azimuth</td>
<td>-0.04°</td>
</tr>
<tr>
<td>Tilt X</td>
<td>-0.98°</td>
</tr>
<tr>
<td>Tilt Y</td>
<td>-0.73°</td>
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</tbody>
</table>
Direct Arrival Polarisation

Polarisation error – average over many OBC sensors:

Single node, different survey, similar seabed depth & conditions:

Unburied OBC

Buried OBC

Olofsson & Massacand EAGE 2007
OBN Acquisition

3C Sensor Orientation
3C Sensor Orientation

Purpose of 3C orientation analysis is to find the 3 orientation (Euler) angles that rotate as-laid sensor components to survey-wide Inline/Crossline/Vertical coordinate system.

Example definition of orientation angles.

- **Roll angle $\Phi$**
  - Rotation around local Inline axis
  - $\rightarrow$ makes $Y$ component horizontal

- **Tilt angle $\theta$**
  - Rotation around local Crossline axis
  - $\rightarrow$ makes $X$ component horizontal

- **Azimuth $\gamma$**
  - Rotation around Vertical axis
  - $\rightarrow$ aligns $X$ component with survey Inline (or North...)

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Olofsson et al SEG 2007
This equation can be solved analytically for roll and tilt angle, assuming the azimuth is known.

There are two independent solutions for the roll and tilt angle, which depend on the mode of acquisition: One solution applies if sources are located above the receivers (typical seabed survey), the other one if sources are located below the receivers (land/transition zone survey).
3C Sensor Orientation

OBN sensor orientation

Three source lines only:

Estimated orientation angles mapped by source-receiver azimuth and incidence angle at seabed.

Angle 1

Angle 2

Sum over full circle ➔ best estimate
3C Sensor Orientation

OBN sensor orientation

Angle 1

Angle 2

Buried OBC

Unburied OBC

...in comparison, OBC:

Angle 1

Angle 2

Olofsson et al SEG 2007
OBN Data Processing
OBN Data Processing

Raypath geometry for a node gather:

Pre-processing is done mostly in 3D receiver gather domain.
OBN Data Processing Flow

- **SEGY input**
  - Noise attenuation/despike
    - Hydrophone
    - Geophone
      - PZ calibration (Z-to-P)
        - Source designature/ debubble
          - Vz noise attenuation
            - Wavefield separation/ PZ combination
              - Upgoing
                - up/down decon
                  - Noise attenuation
                    - TTI PSDM
                      - Radon demultiple
                        - stack
                          - post-stack processing
                - SRME demultiple
              - TTI mirror PSDM
                - Radon demultiple
                  - stack
                    - post-stack processing

- **Source designature/ debubble**
  - Vz noise attenuation
    - Wavefield separation/ PZ combination
      - Upgoing
        - up/down decon
          - Noise attenuation
            - TTI PSDM
              - Radon demultiple
                - stack
                  - post-stack processing
      - SRME demultiple
        - TTI mirror PSDM
          - Radon demultiple
            - stack
              - post-stack processing
OBN Data Processing Flow

1. **SEGY input**
   - **Noise attenuation/despiking**
   - **PZ calibration (Z-to-P)**
   - **Vz noise attenuation**
   - **Source designature/debubble**
   - **Wavefield separation/PZ combination**

2. **Source designature/debubble**
   - **Hydrophone**
   - **Geophone**

3. **Upgoing**
   - **up/down decon**
   - **Noise attenuation**
   - **TTI PSDM**
   - **Radon demultiple**
   - **stack**
   - **post-stack processing**

4. **Downgoing**
   - **SRME demultiple**
   - **Noise attenuation**
   - **TTI mirror PSDM**
   - **Radon demultiple**
   - **stack**
   - **post-stack processing**

5. **Offset/vector tile regularisation**
   - **Anisotropic velocity model building**
   - **Offset/vector tile migration**
   - **Residual azimuthal velocity analysis**
Mirror imaging

“Conventional” imaging
Primary reflections, up-going wavefield

“Mirror” imaging
Receiver side multiple, down-going wavefield
Mirror imaging

Upgoing (conventional) Image
Mirror imaging

Dowgoing (mirror) Image
Mirror imaging

Short Streamer data
Mirror imaging

P

Z

Upgoing

Downgoing

First multiple

Second multiple

Courtesy of Geokinetics
Mirror imaging

After PZ calibration, debubble operator, Vz noise attenuation and PZ combination.

Example – Raw input data

Courtesy of Geokinetics
Summary

Upsides

• Operationally, OBN acquisition is very efficient in presence of
  – Surface obstructions (impeding use of towed streamer)
  – Seabed obstructions, rugged seafloor (impeding use of ocean bottom cables/OBC)

• Ocean bottom nodes provide an ideal data set
  – Full & even surface azimuth/offset distribution
  – Low ambient noise environment
  – Ideal sensor coupling
  – Full waveform recording: P-wave and S-wave arrivals
  – Naturally rich in low frequencies, no compromise at high end

Downsides

• Autonomous recording
  – Requires elaborate clock drift correction
  – Node reliability

• Sparse receivers, limiting shallow illumination
  – Can be resolved by multiple (mirror) imaging
  – Problematic for converted wave imaging
References


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