Deep water Ocean-Bottom Node processing; a West of Shetland case study

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Abstract

As Ocean-Bottom Node (OBN) full-azimuth surveys becomes ever more popular in deep water environments, so processing algorithms and workflows have been, and continue to be, developed to maximise data quality. A full processing sequence in this West Of Shetland case study addresses key issues such as clock-drift, node positioning, correction of water column variations, directional deconvolution, and free-surface multiple attenuation. To give complimentary insights, the downgoing wavefield was mirror-migrated in addition to imaging the upgoing wavefield. Challenges relating to the acquisition geometry were encountered and addressed.
Introduction

Ocean-bottom seismic (OBS) surveys have historically been conducted for improved sub-gas and sub-salt imaging, as well as in areas where acquiring towed streamer data has been impractical; conventional streamer data, with large cable configurations, cannot be safely acquired close to platforms and other surface infrastructure. With the seismic industry increasingly appreciating the advantages brought by wide-azimuth and broadband imaging there has been a significant recent uptake for ocean-bottom node acquisitions in deep water environments, with perceived advantages for both 3D imaging and time-lapse monitoring.

In recent years many studies have demonstrated the advantages of seismic imaging with wide-bandwidth and wide-azimuth data. Deep water ocean-bottom nodes are among the acquisition systems that most naturally offer data rich both in azimuthal content and broadband response (Bouska, 2008). With Remotely-Operated Vehicles (ROVs) able to deploy nodes with accuracy of a few metres, and for fields with significant current or anticipated obstructions, OBN systems are also recognised as highly appropriate for time-lapse imaging (Cantillo et al, 2010). These properties, together with the low ambient noise environment on the deep sea floor, have made OBN particularly appealing for high-fidelity imaging required for reservoirs entering their production and development phases, which justify the cost associated with deployment and retrieval of nodes in deep water.

Whilst the theoretical advantages of acquiring deep water OBN are persuasive, including access to converted wave imaging through 4-component nodes, data processing solutions have been relatively immature when compared to towed streamer data. Workflows have therefore had to be developed and adapted to the specificities of node acquisitions, such as the offset-vector binning used in processing land surveys (Lecerf et al, 2010). With a comprehensive range of node-specific workflows and algorithms now implemented, the benefits of OBN are today being fully realised.

Here we outline a processing case study for OBN data acquired on the UK continental margin, West of Shetland. The data, processed through a depth imaging sequence to exploit the full-azimuth content of the dataset, provide high quality broadband images in a structurally complex area (Figure 1).

*Figure 1: Migrated downgoing wavefield (a) exhibiting characteristic broadband nature of OBN data, with comparison to equivalent re-processed towed streamer (b) using the same velocity model (derived from the OBN data), and associated amplitude spectra (c).*
Acquisition

The data were acquired in water depths in excess of 1km in two separate phases. The total area covered by the node deployment was approximately 175km², with a first phase of approximately 750 nodes and a second phase of 1200 nodes. Receiver nodes were placed on a sparse but regular square grid of 300m by 300m which was complemented by a dense shooting geometry of 30m by 30m. The acquisition contractor provided tilt values measured in situ for all the nodes. Whilst in general both phases of the acquisition went as planned there were nonetheless some nodes which had to be retrieved early and replaced due to battery depletion.

Pre-processing

Unlike conventional towed streamer operations, OBNs are autonomous recording devices that record data continuously during their deployment, with time gauged by an internal clock. The clock timing is measured on retrieval of the node and, with reference to the measurement made prior to deployment, a clock-drift function is estimated and applied to each node. Particular attention had to be paid in processing when merging the data retrieved from the pairs of nodes affected by early retrieval/late deployment as they potentially would be affected by different clock-drifts. ‘Sub-sample’ corrections also had to be applied, accounting for the data being harvested from the continuous recording the data at discrete samples.

Positioning information for the nodes is often from measurements taken from the ROV. However with significant variations in water velocity encountered in deep water environments, and being dependent on accurate bathymetric information at extreme depths, traditional methods of re-positioning can be subject to significant error. For this reason a repositioning algorithm was used which was developed specifically for the deep water node case (Cantillo et al., op cit). This data-driven technique utilises the dense shot sampling and is independent of water velocity variation.

After correcting for a systematic source positioning error location, identified during routine QC, a final timing correction was required to account for the variation in the water column properties between sail-lines. The methodology uses the well-behaved nature of the direct arrival in the deep water environment to estimate variations in timings attributable to water velocity variations. Using measurements made at all nodes a map was constructed that described the spatial change in average water velocity to which appropriate shotline-oriented smoothing was applied before deriving the final corrections. Solving for these variations in the water column is particularly important for retaining high frequencies in the downgoing wavefield, due to the additional travel path involved.

Wavefield separation

The 3-component geophones were rotated on the basis of the in-field measurements which were QC’d using a methodology based on evaluation of the direct arrival. After application of deterministic filters to correct for instrument responses, each vertical geophone then had to be calibrated prior to separating into the upgoing and downgoing wavefields. In order to assess geophone calibration both the hydrophone and vertical geophone data were transformed into the 3D tau-px-py domain, after appropriate shot interpolation. A series of wavefield separations was then performed using a variety of scalar values to apply to the geophone. As by definition the downgoing wavefield contains no upgoing energy above the first water bottom multiple (Schalkwijk et al., 1998), the resultant scan could be automatically evaluated to determine the scalars which best minimised the upgoing energy for each receiver, therefore providing the correct wavefield separation.

The upgoing wavefield is used for conventional processing and imaging using primary reflections, whereas the downgoing wavefield makes use of the first-order free-surface multiple for further processing. Both wavefields are complementary; whilst the downgoing wavefield results in more even near-surface illumination (Grion et al., 2007) the upgoing wavefield is often preferred at greater depths where the ray density is higher.
Processing the upgoing wavefield optimally nonetheless still requires the downgoing data for up-down deconvolution (Wang et al, 2010) which attempts to simultaneously remove free-surface multiples and recover the reflectivity series of the Earth (Figure 2). After the subsequent tau-px-py reverse transform to the t-x-y domain, residual multiple attenuation was performed using a surface-related multiple modelling (SRMM) and adaptive subtraction technique (Pica et al, 2006), which used the downgoing data as the reflectivity model. Due to the specific challenge of the free-surface multiple overlying the target, extreme care had to be taken in obtaining optimum attenuation of the multiple without harming the underlying primary data. Whereas the upgoing data has an implicit directional source designature applied in the up-down deconvolution process, the downgoing data had explicit directional deconvolution operators derived and applied in the tau-px-py receiver domain. The data were then reverse transformed and SRMM for 2nd and higher-order multiples applied (Figure 3).

**Velocity model building and depth imaging**

The acquisition geometry provides a significant challenge for model building – the nominal common-offset vector (COV) binning generates 600m x 600m tiling. This generates common-image gathers (CIGs) with only a handful of traces at target depth, for the expected maximum offset, which would be insufficient for accurate tomographic updates. The velocity model was therefore derived with 300m x 300m COV’s, utilising the Kirchhoff migration operators to interpolate ‘missing’ data within the common-offset vector volumes (Figure 4). This enabled residual curvature to be picked for robust azimuthal tomographic updates of the velocity model using the downgoing data.

Final TTI Kirchhoff depth migrations were performed in the COV domain with the natural 600m x 600m vector tiling, for both upgoing and downgoing wavefields. Additional common receiver TTI RTMs gave complimentary straight-to-stack images. Post-imaging processing was then applied.

**Conclusion**

The anticipated advantages of OBN surveys for P-wave imaging in deep water environments are many. They offer full-azimuth content which aids construction of accurate velocity and anisotropy models in structurally complex areas; improved imaging through azimuthal diversity within the stack process; and broadband data for better interpretation and inversion. The processing of this West of Shetland full-azimuth dataset, whilst challenged by the effects of sparse receiver sampling, has
confirmed these significant benefits by delivering outstanding broadband images with frequency content greater than that of the re-processed conventional towed streamer data (Figure 1a and 1b).

As OBN datasets become increasingly common, including 4D monitor surveys, so the processing tools will continue to evolve and mature. But with a comprehensive range of node-specific workflows and algorithms already implemented, the benefits of OBN acquisitions are now being fully realised.

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References


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