WAZ mirror imaging with nodes for reservoir monitoring, Dalia pilot test.

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Summary

Repeated marine seismic data recorded with towed streamer have been proved successful for imaging reservoir productions. Unfortunately major infrastructures (FPSO) constitute a "blind zone" for the reservoir image illumination from the sea surface. Because undershooting surveys come with repeatability and HSE issues, nodes imaging appears to be a valuable solution when large infrastructures obstruct the reservoir illumination from the sea surface. In 2009 a deep water nodes surveys was acquired by Total offshore Angola.
Since "Base" surveys are acquired usually with marine streamers, the first objective of this paper is to find out how to reconcile nodes and streamer data in order to provide comparable images with both acquisitions. The second objective is to propose an azimuth compliant processing approach valid for an optimum node WAZ mirror imaging. We demonstrate that the "mirror image" has a better potential for comparison with the "streamer" image than the conventional "up-going image". Two original processing approaches are described: firstly, data cross-matching is done in angle domain in order to provide similar ray path and equivalent sea surface offset. Secondly, we show that the concept of offset vector binning using hexagonal tiles is applicable to the nodes acquisition geometry. Mirrored data migration in common offset vector domain provides CIGs with preserved offset and azimuth information. Post-migration processing like full azimuthal residual move-out and azimuthal illumination selection can then be applied for an optimal reconciliation between nodes and streamer data.

Introduction

Repeated marine seismic recorded with towed streamer have been proved successful for imaging reservoir productions. Within a time-lapse, the image difference may be interpreted in terms of reservoir fluids variations and can contribute to the decision of new producer/injector well placement. Unfortunately major infrastructures (like FPSO) constitute a "blind zone" for the reservoir image. Undershooting strategy with independent source and streamer vessels navigating around obstacles may be chosen for compensating the lack of data, but acquisition repeatability is difficult to achieve. It often provides missing short offset illuminations and inconsistent azimuth distribution. Moreover the HSE issue cannot be neglected as streamer vessels come close to production facilities.

Alternatively, the industry is proposing a "seafloor receiver" solution using Ocean Bottom Cable in shallow/medium water depth or Ocean Bottom Station (Nodes) in deep water context for imaging and monitoring reservoirs production below infrastructures (Boelle et al., 1995). Nodes are an autonomous seismic recording system deployed on the seafloor with Remotely Operated Vehicles to ensure accurate and repeatable node positioning.

Since "Base" surveys are acquired usually with marine streamers, the first objective of this paper is to find out how to reconcile nodes and streamer data in order to provide comparable images with both acquisitions. We have to tackle two major differences between surface and OBS surveys: incident angle/offset relationship and azimuthal illumination. Essentially, the OBS survey is a wide azimuth acquisition while conventional towed streamer provides narrow azimuth illumination. The second objective is to propose an azimuth compliant processing approach valid for an optimum node WAZ mirror imaging. We will limit the presented study to P-wave imaging using the vertical component and hydrophone records only.

Data example

In a deep water context, Total has acquired in 2009 a large 3D survey deploying 480 nodes over the Dalia reservoir complex in offshore Angola. Complementarily, a pilot survey has been shot twice over a small test zone in order to study repeatability issues of node acquisitions. The 58 nodes of the pilot have been deployed on 29 locations (230m hexagonal grid). This pilot survey has been chosen to validate our approach of nodes/streamer image reconciliation and our azimuth compliant processing.

Imaging with the down-going wavefield

In OBC data processing sequences, the separation of the up-going and the down-going wavefield is performed using the summation (and the subtraction) of the pressure field P recorded by hydrophones and the calibrated vertical Z component of geophones. Details on the PZ summation process can be found in the literature (Soubaras, 1996). To simplify, the up-going wavefield is essentially composed of primary reflections directly recorded by the receiver at the ocean bottom level, while the down-going wavefield is composed of the same reflections added to an extra bounce on the free sea surface (receiver ghost). Imaging the receiver ghost has been exploited profitably in various environments (Godfrey et al., 1998, Grion et al.. 2007). As the free sea surface plays the role of a mirror, imaging receiver ghosts is often called mirror imaging (figure 1).

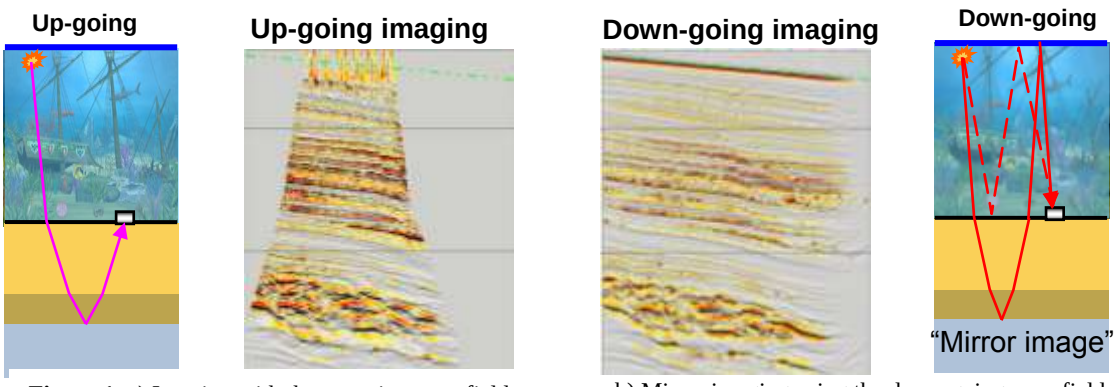


Figure 1: a) Imaging with the up-going wavefield b) Mirror imaging using the down-going wavefield
Note: The overburden is better defined

Unlike the up-going wavefield, the down-going wavefield is able to image the sea bottom reflector. However, the down-going wavefield is more sensitive to water layer properties as the seismic wave is travelling in the water three times longer than for the up-going. Consequently, the processing of "mirrored data" has to comprehend properly water layer variations such as precise tidal corrections and accurate water layer velocity measurement. Specific tools have been developed for the Dalia deep water experiment to tackle accurately node positioning and timing issues.

Reconciliation of node and streamer data

The Dalia node pilot area was fully covered with a marine streamer acquisition in 1999 and only partially in 2008 due to the presence of large floating infrastructures. For different reasons, we identified the down-going wavefield as being more appropriate for streamer dataset "reconciliation". Firstly, the overburden mirror image is very valuable for computing calibration operators, because no production effect is expected in this time window. Secondly, the down-going wavefield has less ray path difference with streamer data than the up-going wavefield. Figure 2a illustrates the evolution in depth of the reflection point for different ray paths with the same acquisition offset. A simple first order Walden relationship yields for a horizontal offset X and target two-way-time t_0 from sea surface:

$$\sin\theta_S = \frac{V(t_0)X}{t_0 V_{RMS}^2(t_0)},\quad \sin\theta_U = \frac{V(t_0)X}{t_0\left(V_{RMS}^2(t_0) - t_w V_w^2\right)} = \frac{V(t_0)X_U}{t_0 V_{RMS}^2(t_0)},\quad \sin\theta_D = \frac{V(t_0)X}{t_0\left(V_{RMS}^2(t_0) + t_w V_w^2\right)} = \frac{V(t_0)X_D}{t_0 V_{RMS}^2(t_0)} \quad (1)$$

where θ_S, θ_U and θ_D are respectively the incident angles for Streamer, Up-going and Down-going ray paths (See Figure 2a); t_w is the one way travel time for water layer and V_w the water velocity. X_U and X_D are equivalent surface offsets, as displayed in Figure 2a. We can find after a simple computation:

$$2\sin\theta_S = \sin\theta_U + \sin\theta_D \quad \text{and} \quad 2X^{-1} = X_U^{-1} + X_D^{-1} \quad (2)$$

As X is the harmonic average of X_U and X_D, it turns out that X will always remain closer to X_D than to X_U; a similar statement can be established for θ_S, θ_D and θ_U. In particular at the sea bottom level, the ratio between the equivalent surface offset and acquisition offset is 2/3 for the down-going wavefield, while it reaches 2 for the up-going wavefield. In depth, the reflection point of the down-going wavefield is always closer to the streamer mid-point than the up-going wavefield.

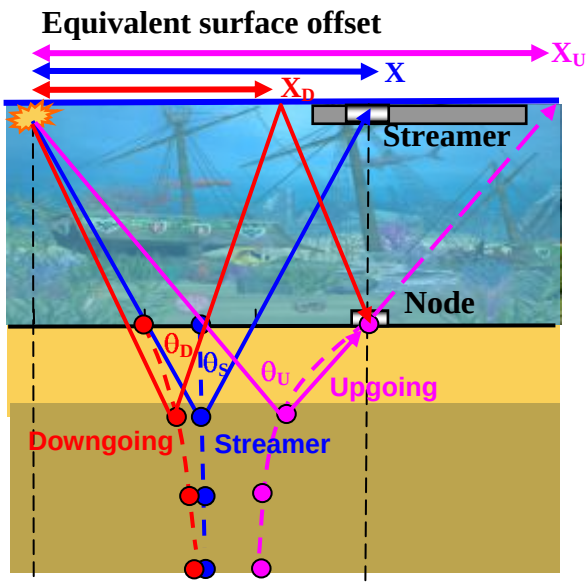


Figure 2: Evolution of reflection points in depth for a given acquisition offset. The equivalent surface offset and ray path are more similar between Down-going and Streamer.

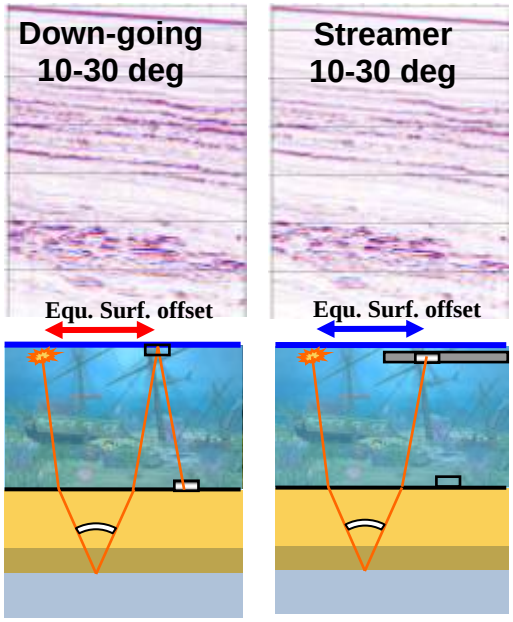


Figure 3: Two seismic sections within the same incidence angle range. In angle domain, ray paths and equivalent surface offset are comparable.

Because the up-going wavefield always illuminates reflectors with a larger angle of incidence, the up-going CIG presents more stretch effect and higher residual cinematic correction than others. It is clear that illumination similitude makes the down-going wavefield the best "candidate" to be compared with streamer data and has the best potential to yield a comparable image. However, some disparities

remain between "mirror CIG" and "streamer CIG" in term of ray path geometry and azimuthal illumination for a given acquisition offset.
We suggest cross-processing both datasets in the angle domain in order to compare similar ray paths. In our processing sequence, the angle transform process is done post PSTM by computing independently for each CIG the angle/offset/time correspondence from the migration velocity field. According to the time variant relationships, the offset CIGs are then regularised within the same angle trace value distribution. Figure 3 presents mirror and streamer images for 10-30 degrees angle stacks.

Azimuthal processing: Hexagonal Offset Vector Tiling

The second discrepancy between streamers and nodes comes from acquisition geometry. Nodes are recorded with wide azimuth illumination whereas towed streamers have a narrow azimuth distribution. This creates different azimuthal illumination for both surveys and may lead to an inappropriate amplitude difference when images are compared. Inspired by dense WAZ land data processing in offset vector tile (OVT), we have defined hexagonal tiles adapted to the nodes acquisition geometry for the pre-migration binning step. The OVT processing has the advantage of preserving offset and azimuth information even after migration. The offset vector binning ensures an optimum distribution of seismic traces in each common offset vector (COV) volume: one trace per bin. Sectoring approaches may provide cubes with holes and over folds.
Figure 4a represents offset vectors for a given "shot stripe" (purple) and an OBS receiver line (blue).
In this sketch binning has been performed following the usual mid-point rule, a more rigorous approach will lead to a depth varying binning according to the X_D variation (see Figure 2a). In the present study as the reservoir depth is equivalent to the water layer thickness, the correct value is close to 0.4 from the source location; we assume that the slight over fold due to approximate binning might be correctly taken into account by a correct weighting in the migration scheme.
All single bin traces defined in a hexagonal tile are associated with a nominal offset and azimuth which are preserved through the migration according to offset vector coordinates. It can be noted that the hexagonal shape assures a minimum offset range variation within azimuths. Each COV volume is migrated independently. For example, Figure 4b shows the migration result for the COV (-1,2).

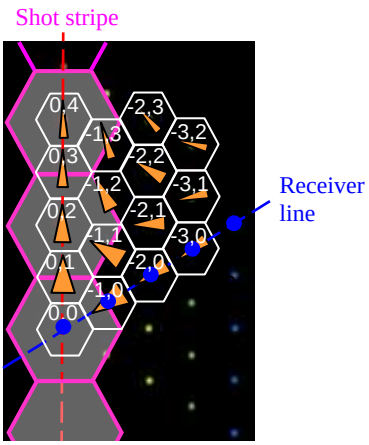
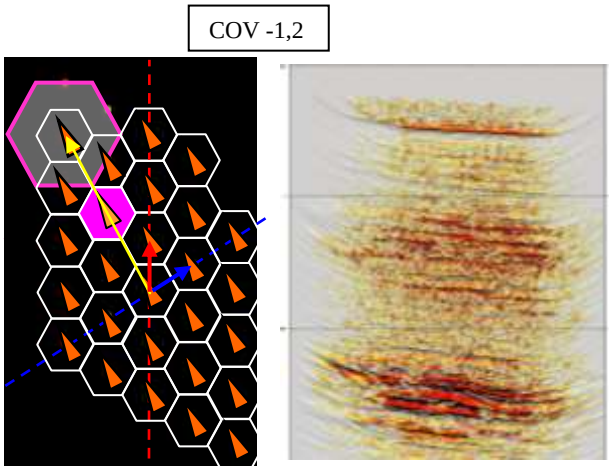


Figure 4: a) Hexagonal tile definition (CMP) and offset vectors distribution for a given shot stripe (purple) and receiver (line blue).



b) COV: Single trace per bin with same offset and azimuth range. Example: Mirror image for COV(-1, 2).

After "mirror imaging", the CIGs are distributed in offset vector and can be processed with offset and azimuth consideration. Then azimuthal residual move out (Lecerf et al., 2009) and offset vector selection may be applied to the nodes data in order to match the cinematic and the illumination of the corresponding streamer CIG (Figure 5).

In our pilot area, we were able to compute a 4D difference between the streamer acquisition 1999 and the node test survey 2009 using the described processing approach. The resulting base streamer and monitor nodes difference is displayed on the Figure 6 and is compared with the 4D signal computed with the base streamer and the monitor streamer. Even if we have difficulties to reach the excellent

repeatability of streamer over streamer, it can be noted that the 4D signal is comparable in the central part of the section. But residual energy remains on the sides and at the overburden level. The limited aperture of the pilot area and the small number of nodes are the main cause of these disparities. Only a reduced number of offset vectors CIGs located in the central part of the pilot area are fully populated. Repeatability would be improved using the complete node survey.

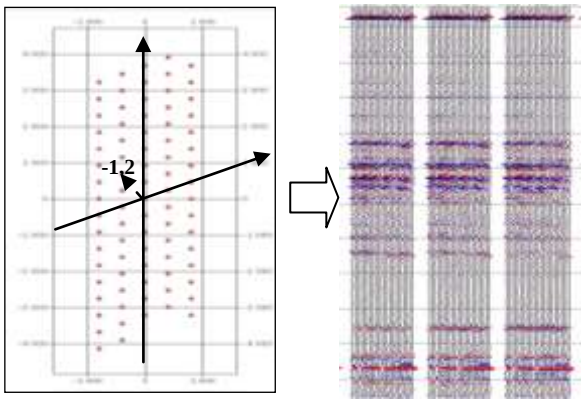


Figure 5: mirror CIGs with traces distributed in offset vector.

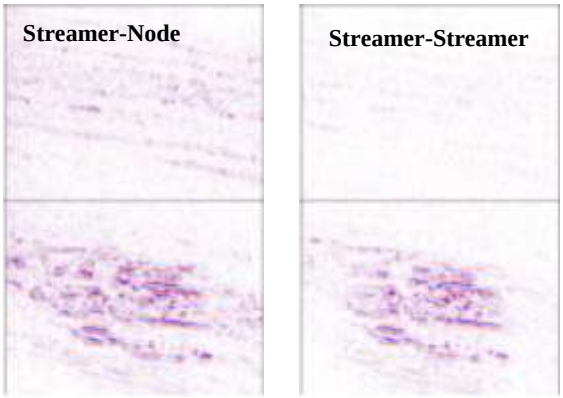


Figure 6: Comparison 4D image Streamer 99/Node mirror 09 and Streamer 99/Streamer 08

Conclusion

Nodes imaging appears to be a valuable solution when large infrastructures obstruct the reservoir illumination from the sea surface. We demonstrate that the "mirror image" has a better potential for comparison with the "streamer" image than the conventional "up-going image". Two original processing approaches have been described for optimising the mirror/streamer image reconciliation.

Firstly, data cross-matching has to be done in angle domain in order to provide similar ray path and equivalent sea surface offset. An adequate post migration offset/angle CIG transformation has been defined for each data type to regularise CIG traces in equivalent incidence angle ranges.

Secondly, the wide azimuth illumination provided by the node acquisition has to be reduced to match the narrow azimuth streamer acquisition. We have demonstrated that the concept of offset vector binning using hexagonal tiles is applicable to the nodes acquisition geometry. Mirrored data migration in common offset vector domain provides CIGs with preserved offset and azimuth information. Post-migration processing like full azimuthal residual move-out and azimuthal illumination selection can then be applied for an optimal reconciliation between nodes and streamer data. Undoubtedly, the presented approach would be optimum as well for wide azimuth imaging with nodes data only. This opens the door to possible post-migration azimuthal amplitude or cinematic analysis of nodes datasets, on fractured reservoirs for example.

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