Using Primaries and Multiples to Extend Reservoir Illumination for Time-lapse Monitoring - Application to Jubarte PRM

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SUMMARY

A depth migration method, that uses primaries and all orders of multiples, has been adapted to produce extended 3D and 4D images in the context of seabed acquisition. The technology has been validated using the Petrobras 4D datasets acquired during the deep-water Jubarte PRM pilot. As result of its application, the reservoir illumination has been significantly expanded to more than 100 km2 from an approximate 10 km2 coverage obtained from the conventional imaging of primaries. The resulting 4D signal shows a good match with the well trajectory, validating the use of all orders of multiples for 4D imaging studies.

Introduction

Permanent reservoir monitoring (PRM) installations can be considered as the ultimate solution for detecting small seismic signal variation related to the reservoir production. Time-lapse seismic data are recorded enabling analysis of the changes in terms of fluid saturation and pressure. Since the cables are deployed permanently on seabed, the recording system ensures the best repeatability and provides effective operations for the different monitor surveys acquisition. PRMs have shown their potential in a shallow water environment.

In 2012, Petrobras installed the first deep-water optical permanent reservoir monitoring system provided by PGS/Optoseis on the Jubarte field in the Campos basin. This pilot project covers ~10 km^2 with the primary objective being to validate the fiber optic sensing technology in detecting subtle impedance changes in the reservoir. The layout of the 35 km optical cable was designed with the up-going seismic wavefield in mind. The main challenge was to optimise the geometry of the seabed recording cable and the density of multi-component receivers for ensuring sufficient illumination of the reservoir and effective 4D seismic detectability whilst avoiding any crossings of the existing subsea infrastructure, (E. Thedy et al., 2013). A total of 712 seismic recording stations distributed along two cables were successfully deployed in water depths varying from 1250 to 1350 m. The receivers are positioned every 50 m along the cable with the array comprising of 11 receiver-lines separated by ~300 m (Figure 1). A source grid covering an area of 11 km x 11 km was acquired with source locations at 25 x 25 m intervals.

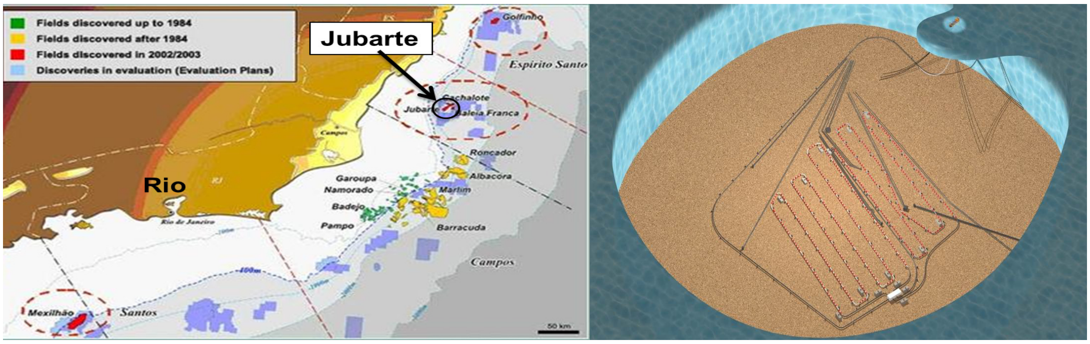


Figure 1 *Location of the Jubarte field in Campos basin and layout of the fiber optical cable.*

The first 4D signals have been observed after one year of reservoir production using the active seismic surveys completed respectively in early 2013 and early 2014. The resulting monitoring image has been limited to the area of ~10 km^2, but was sufficient for validating the deep-water pilot installation. The excellent 4D seismic results (Figure 2) demonstrate the high detectability expected from a permanent optical installation and confirm the value of extending the permanent seismic installation to the north and northwest covering more of the Jubarte field.

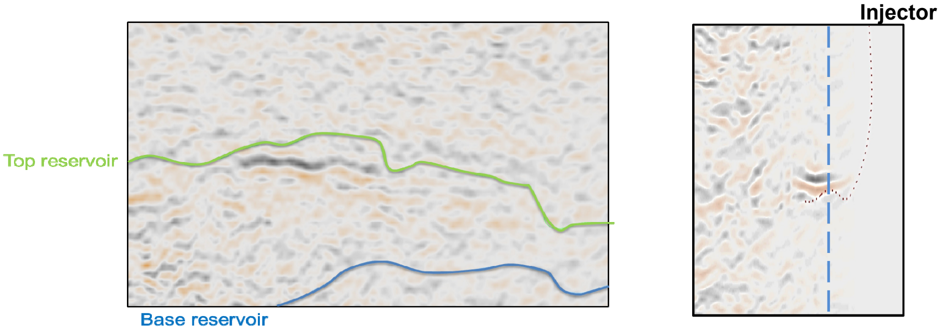
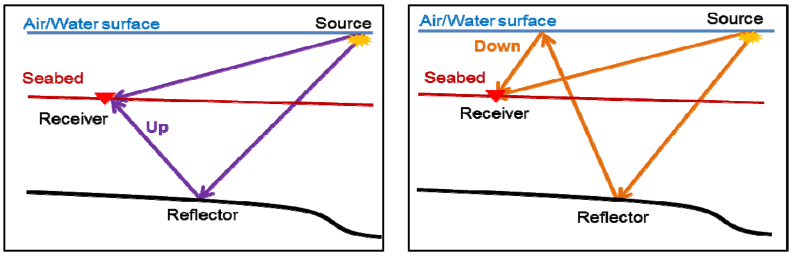


Figure 2 *4D signal results: Left: the OWC changes; Right: Water injection. Because the injector (red dot line) is located at the edge of the recording system (vertical blue dashed line), one part only of the 4D signal (with smiling effect) is visible using the primary reflexions of up-going wavefield.*

New methodology using high-order multiples for reservoir monitoring

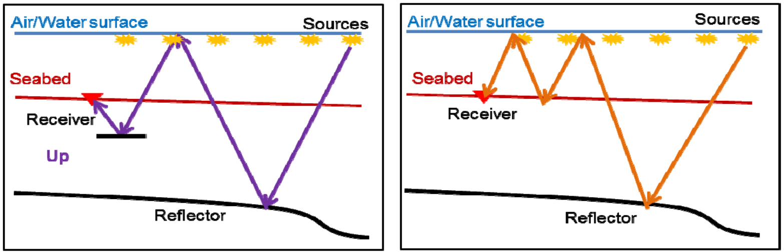
The 4D Jubarte datasets, provided by the Petrobras PRM pilot, were used for validating an original 4D multiples imaging technology. Using primaries and all order sea surface multiples, the technology is derived from a seismic imaging technique developed for dual-sensor streamer acquisition. (N.D. Whitmore et al., 2010). In order to apply the imaging process using multiples recorded by seabed sensors, the source-receiver definition has to be reversed using the reciprocity theorem. The imaging principle includes wavefields de-convolution at the imaging conditions. Kinematically, the common ray path between two traces belonging to a common receiver is cancelled out; while the difference between two rays is preserved for imaging. In fact, the principle converts every shot-pair included into a receiver gather into a virtual sea-surface receiver-source couple.

Figure 3 describes examples of wavefields used for imaging the reservoir with seabed acquisition datasets. Conventional OBC imaging techniques use only the up-going wavefield (a) or alternatively the down-going wavefield (b). By exploiting high-order multiples described in (c) and (d), the illuminated part of the reflector can be significantly extended. The number of multiples utilized in the imaging process is governed by the water depth and the record length.



a) Directs and Up-going primaries

b) Directs and Down-going (receiver side peg-leg)



a) Up-going multiples

b) Down-going multiples

Figure 3 *Schematics describing wavefields used by the new OBC imaging technology for imaging the reservoir. Conventional OBC imaging techniques are using only the up-going a) or alternatively the down-going b) wavefields.*

This new methodology has numerous advantages when compared to conventional seabed data processing.

- Extending target illumination

Because every order of multiple has different reflection points, the illumination area is significantly extended compared to conventional imaging using up-going primary reflections only and mirror imaging using first order receiver peg-leg only (down-going). By transforming every shot pair into a virtual sea-surface source-receiver couple, the area illuminated is essentially defined by the surface distribution of the seismic source and the maximum order of multiples recorded. Figure 4 shows the comparison between an image provided by conventional up-going primary reflections and an image computed from all order multiples available in the up-going wavefield. The reservoir target is delimited by the circle. It can be noticed that the up-going primary reflection image is limited by the receiver array (~3 km x 3 km) when the image using high-order multiples is defined by the source area (~11 km x 11 km).

- Improving source repeatability

The imaging principle includes wavefields de-convolution at the imaging conditions stage providing an estimation of the interface reflectivity. The source term is then reduced because all wavefields share the same convolutive source signature. Consequently, the signal is automatically zero-phased and the bubble effect is cancelled on the output by the imaging process. This is especially effective for 4D surveys where repeating the seismic source between seismic vintages is usually an important requirement. The repeatability between vintages is critical in 4D and is significantly improved with the new technique.

- Fast turnaround

Except PZ-summation/subtraction, the workflow does not include any de-multiple process which can be complex and computing intensive. The imaging principle makes use of direct arrivals, primary as well as higher orders of reflections included inherent in the up-going and down-going wavefields.

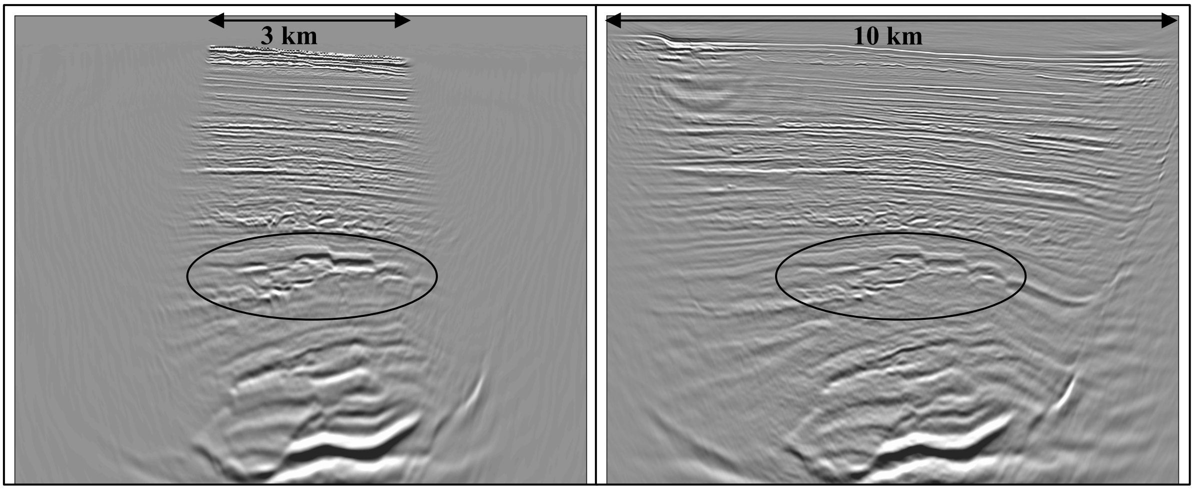


Figure 4 *Left: image provided by the up-going primary reflections. Right: image provided by all orders of multiple included into the up-going wavefield. The reservoir target is delimited by the circle. The image is significantly extended for all reflectors.*

Can multiples be used for 4D studies?

The technical validation for a reservoir monitoring system has to be demonstrated using a 4D signal related to the reservoir production. In the PRM pilot area, a water injector is located on the edge of the receiver array. Using the up-going primary wavefield, conventional 4D processing was able to detect the 4D signal only around the foot of the injector (Figure2). The 4D signal is clearly limited by the illumination of the primary reflections. The challenge was then to provide the continuity of the same 4D signal outside the receiver array using primaries and all orders of multiples. In Figure 4, base and monitor images are displayed alongside the 4D difference at the water injector level. The dashed lines represent the limit of the conventional up-going 4D image.

The 4D signal extracted from the multiples imaging technique is clearly visible on the right panel. The perfect continuity across the limits and the good match with the well trajectory validates the use of the high-order multiples for 4D imaging studies.

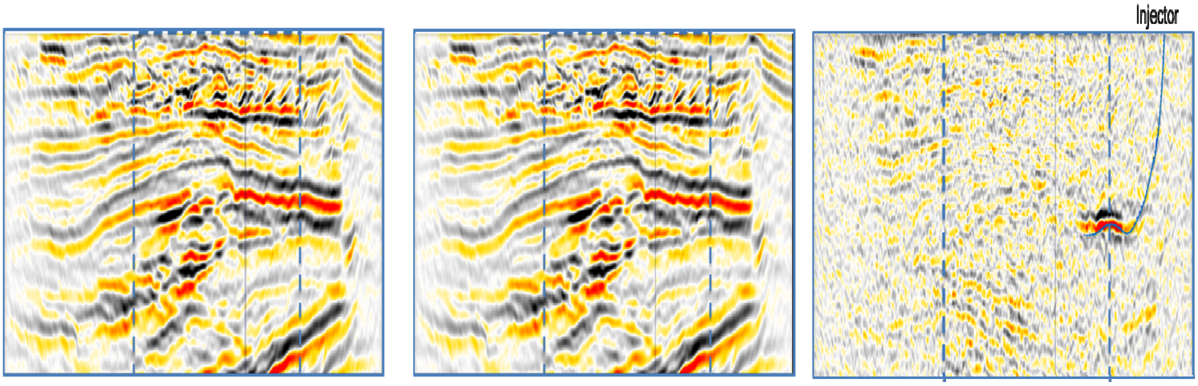


Figure 4 *Left: Base image using multiples. Center; Monitor image using multiples. Right: 4D difference with the injector well trajectory overlaid. The dash lines represent the limits of the conventional image obtained by imaging the up-going wavefield using only primary reflections.*

Conclusion

We have demonstrated that the imaging technique using all orders of multiples is appropriate for seabed datasets in both 3D and 4D contexts. The methodology offers numerous advantages over conventional seabed data processing; the target illumination is significantly extended, the source repeatability is improved and the processing sequence is optimized by removing fastidious de-multiple processes.The new technology has been validated using the Petrobras 4D datasets acquired for the deep-water Jubarte PRM pilot. By exploiting primary and high-order multiples, the reservoir monitoring illumination has been expanded from ~10 km^2 with conventional imaging to ~100 km^2. For future seabed acquisition, the use of this imaging technique gives more flexibility in the design of the receiver layout allowing sensors to be located on quiet seabed environment for better 4d signal detectability without compromising the target illumination.

Acknowledgements

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References

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