Integrating seabed and towed-streamer data to mitigate the effect of surface obstructions in deep-water Campos basin

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Abstract

This paper describes the combined imaging of towed-streamer and ocean-bottom cable (OBC) seismic data in a deep-water area where surface obstructions lead to areas of poor coverage in towed-streamer data alone. We show that the workflow presented provides a high quality contiguous dataset which gives improved confidence in reservoir characterization workflows and reduced risk in well planning.

Introduction

Surface obstructions related to oil production infrastructure are common in mature fields like many of those in the Campos basin. Towed-streamer surface-seismic acquisition can be acquired very efficiently, but has a fundamental limitation in that the streamers cannot be towed close to such obstructions without the risk of damage to both seismic equipment and production infrastructure. This problem can be partially mitigated by the acquisition of close-pass and undershoot acquisition, but areas of poor coverage in the surface-seismic dataset usually remain. This in turn leads to areas of poor and variable data quality, generally in key areas of interest around producing reservoirs. Seabed seismic, on the other hand, generally requires more effort in acquisition, but allows sources and receivers to be placed closer to obstructions, giving improved coverage in these areas.

The objective of this survey is to both enhance understanding of the mature post-salt turbidite reservoirs and to provide improved images of prospective post-salt carbonates and pre-salt targets.

The survey area in this case-study is characterized by variable water-depths which range from shallow (<150 m) to ultra-deep water (>2000 m). The broad geological setting is described in figure 1 and a typical sequence of post-salt sedimentary layers, Albian carbonates, a salt layer of generally thin but variable thickness with pre-salt layers beneath.

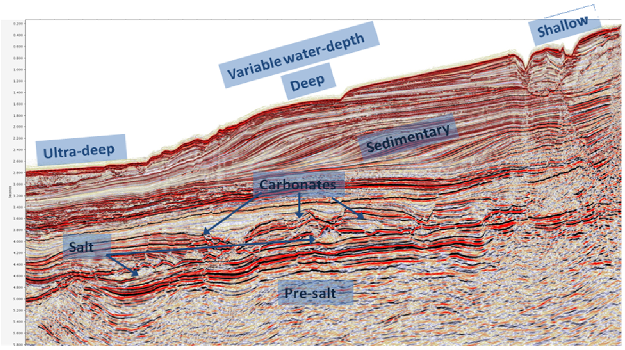

Figure 1 - surface-seismic section showing geological environment

Input data

Approximately 1000 km^2 of towed-streamer surface seismic was acquired over the area by the vessel Western Monarch during the second half of 2011. The OBC data was acquired in the first half of 2010. Table 1 compares key acquisition parameters for the two surveys. Figure 2 shows a post-plot of the towed streamer data where the effect of obstructions can clearly be seen.

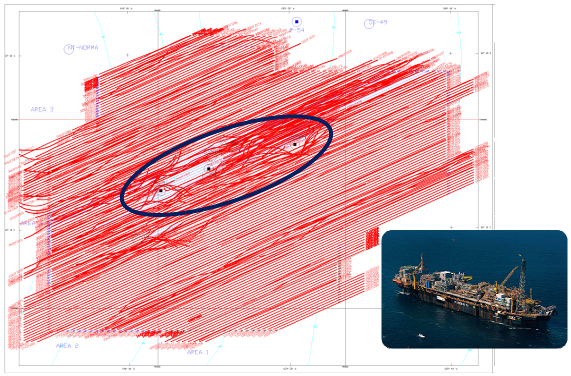

Figure 2 – towed streamer post-plot map – areas of poor and irregular coverage can be seen where obstructions like the FPSO inset were situated.

In 2011 a fasttrack pre-stack time migration was produced onboard the towed-streamer vessel. Sections and time-slices from this volume (figure 3) show the impact of missing data on the final product.

Existing, partially processed datasets (up to and including demultiple) for both the streamer and OBC data were used as input to the proposed integrated imaging workflow.

	2010 Seabed	*2011 Surface*
Type	Vectorseis OBC inline shooting	Q-Marine
Azimuth	246°	246°
Nominal bin	12.5 x 25 m	6.25 x 12.5 m
Cable geometry	4 x 6000 m or 6 x 6000 m rolling	12 x 6000 m towed
Cable spacing	300 m	50 m
Cable depth	Variable (seafloor)	8 m
Sources	2x 3990 in^3 (flip-flop)	2x 5085 in^3 (flip-flop)
Source depths	7 m	6 m
Source line moveup	100 m	250 m

Table 1 - acquisition parameter summary

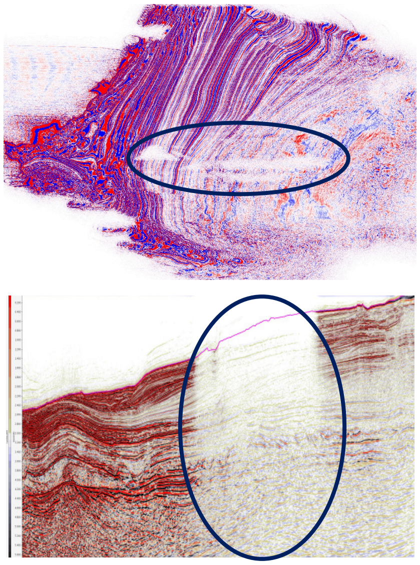

Figure 3 - Time slice (top) and inline section (bottom) from 2011 onboard processed pre-stack time migration of the streamer-only dataset. The effect of missing data can clearly be seen.

Integrated imaging

Several issues arise when attempting to integrate seabed and towed-streamer data in a deep water pre-stack depth imaging workflow. The main challenge is to address the different recording datum for the two acquisition types (illustrated in figure 4). In addition the matching and regularization workflows need to be carefully considered.

Re-datuming

In order to output both datasets at a common datum (mean sea level), we need to compensate for the differences in ray-path between the two acquisition techniques. There are two possible approaches to achieve this. The first is an explicit wave-equation re-datuming of the OBC data prior to migration and the second is to use a dual-surface migration workflow. The former has the benefit that it only needs to be done once, after which the OBC and streamer data can be treated in the same way. This allows any migration algorithm to be used, but requires adequate sampling of receivers. The latter (used here) is a more complex workflow, but does not rely on receiver sampling and is expected to give the most accurate result.

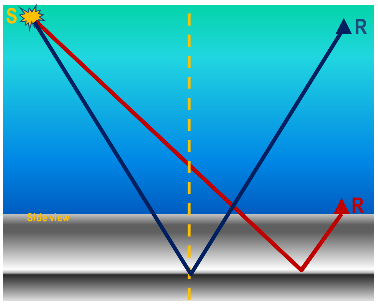

Figure 4 - cartoon showing the difference in raypath between seabed (red) and towed streamer (blue) recording. Note that for deep water and shallow reflectors the midpoint (yellow dashed line) is far from the reflection point for OBC data

The integrated Kirchhoff pre-stack depth migration workflow is described in figure 5 below. Streamer and OBC migrations are performed separately using a common velocity model prior to combination. Travel-time computation for the OBC data is treated separately for source (constant depth) and receiver (water-bottom datum). Output from the dual-traveltime migration is at mean sea level allowing the streamer and OBC data to be merged correctly.

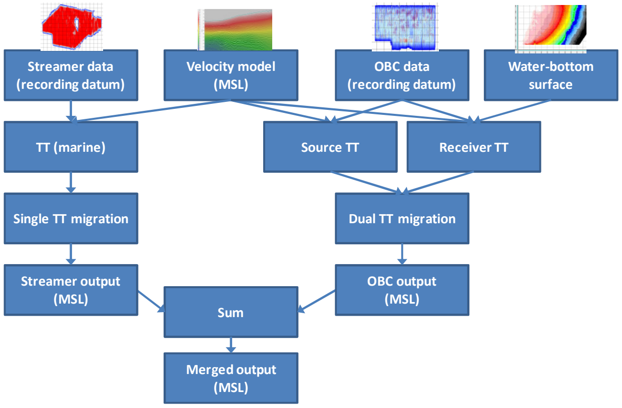

Figure 5 - schematic of the migration workflow designed to output both datasets at a common datum prior to merging

Matching

For an optimum combination, the OBC and streamer datasets need to match well in terms of amplitude, phase, timing and bandwidth. The majority of such differences are expected to come from different source characteristics and different receiver and recording system responses. These can be compensated for deterministically by computing matching operators from the far-field signatures of both sources (see figure 6). In this case, the streamer data was matched to the OBC data which was richer in low-frequency energy.

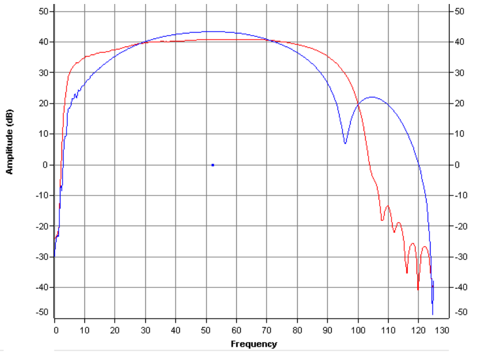

Figure 6 - comparison of far field signatures (OBC red, streamer blue). Note the broader bandwidth of the OBC data.

After the application of deterministic matching filters, it is desirable to check the match statistically through cross-equalization. This requires the separate migration of the streamer and OBC data to give fully migrated, co-located lines from the two surveys. Bulk amplitude, phase and timing corrections can then be computed and amplitude spectra compared. Matching parameters in this case were very small, with an amplitude scalar of 0.05, phase correction of 9 degrees and timing correction of 0. Figure 7 shows streamer and OBC migrations and the difference between them.

Regularization and merging

In shallow water, streamer and OBC data merging can be performed using midpoint assumptions (ie assuming that the trace's midpoint location is close to the reflection point). This means that missing coverage in the streamer data can simply be replaced by data with the required midpoint and offset from the OBC data. Regularization techniques also rely on this assumption and should be treated with care.

In deep water the midpoint assumption breaks down for OBC (see figure 4) and a different strategy is required. Figure 8 shows the regularization and merging workflow employed. The two datasets were overlapped to ensure continuation of reflection energy, and Voronoi weighting was applied to compensate for variations in trace density.

Depth Imaging

After the matching and regularization of the two datasets, anisotropic velocity model building proceeded in a conventional manner using reflection tomography based on depth delays picked from combined Common Image Point (CIP) gathers output from the Kirchhoff pre-stack depth migration workflow described in figure 5.

For the purposes of model building, the section was divided into four zones; water-layer, post-salt, salt, pre-salt and basement. It was thought that it might be necessary to separate the post-salt carbonate layer from the sediments, where there is known to be a velocity contrast. However it can be seen from figure 9 that global tomography in the post-salt layer confined velocity updates to this layer very well without the need for this.

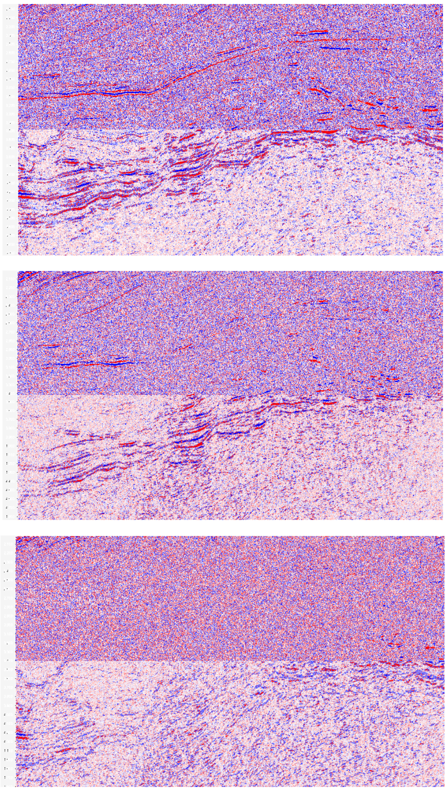

Figure 7 - streamer migration (top), OBC migration (middle) and difference after matching (bottom). Although signal-to-noise characteristics are different between the datasets, they are well matched in time, phase and amplitude

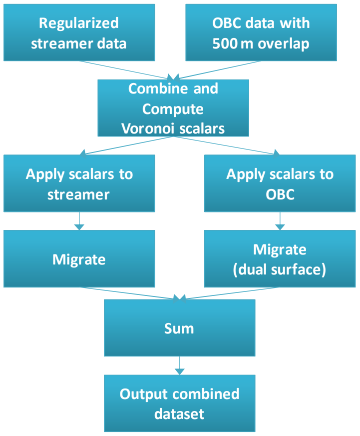

Figure 8 - regularization and merging workflow

The initial model for the post-salt layer was derived from pre-stack time migration velocities. To update the model, four iterations of tomography were run in the post-salt zone with one intra-salt and one pre-salt.

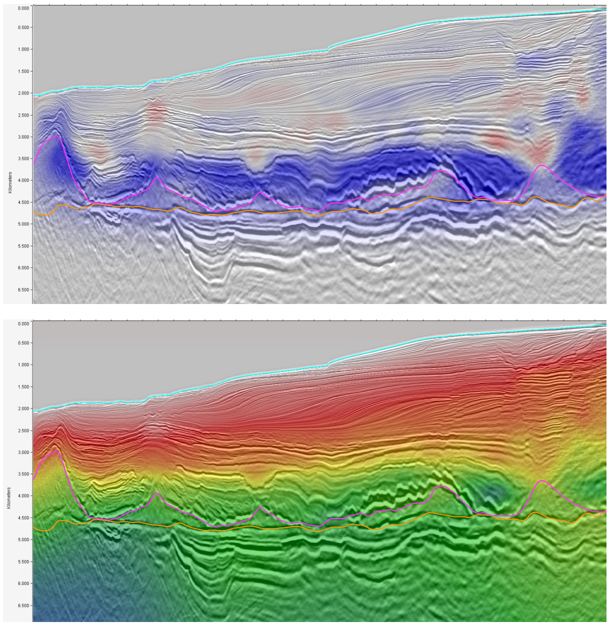

Figure 9 - accumulated updates from post-salt tomography (top) show strong updates confined to carbonate structures. Final model (bottom) shows good geological consistency

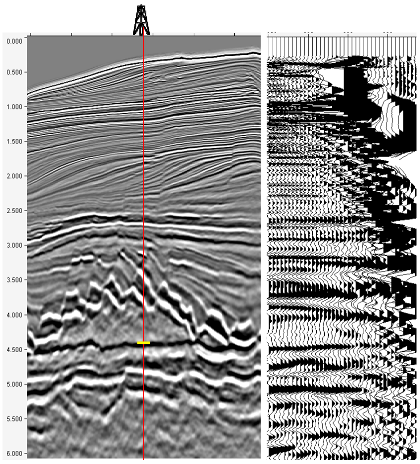

Figure 10 - salt flood migration with base of salt marker overlaid (yellow) and CIP gather at well location (right). Close well ties and flat gathers verify model accuracy.

Results

While the final depth imaging work is still in progress, figure 11 shows images from an intermediate salt-flood depth migrated volume. While the effect of the OBC data can be seen in the shallow, where the water-bottom is not recorded, deeper in the section and in the depth slice there is little evidence of a merge.

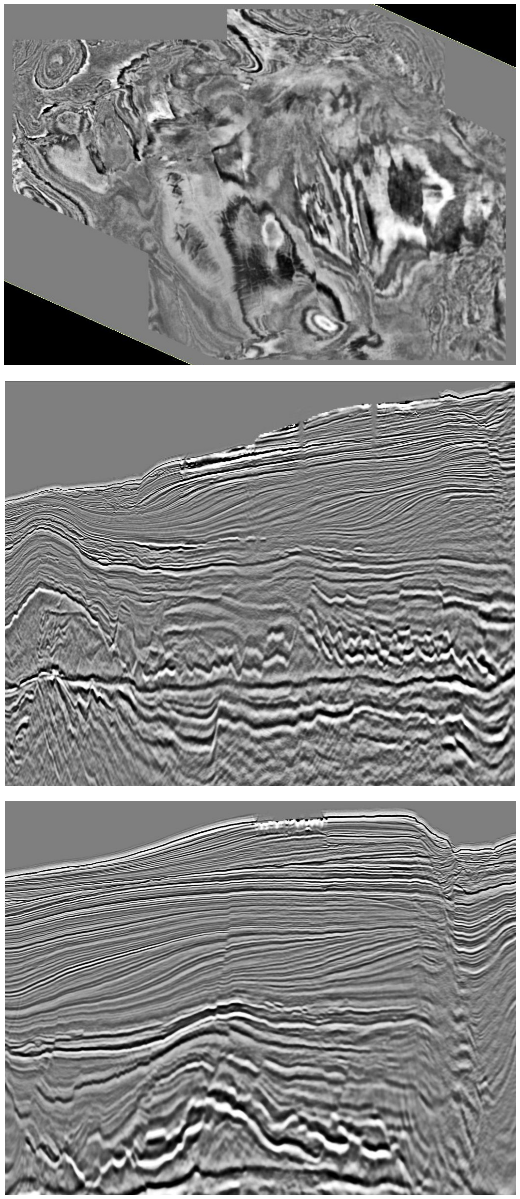

Figure 11 – Depth slice at 3300m (top), inline (middle) and crossline (bottom) from an intermediate anisotropic depth migrated volume.

Conclusions

We have demonstrated a workflow for integrating seabed and towed-streamer seismic in a depth imaging workflow in a deep water environment. The resulting dataset provides a seamless dataset for interpretation and reservoir characterization in the presence of surface obstructions.

Acknowledgments

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