Introduction and field description

The giant Al-Shaheen field is located off the northeast coast of Qatar, in Block 5. The field was discovered in 1992 by Maersk Oil and is now operated by North Oil Company, a JV between Total Golfe and Qatar Petroleum. The main reservoirs, laying 800m to 1400m below seabed, are thin cretaceous carbonates layers: Kharaib, Shuaiba, and Nahr Umr formations producing oil. It is expected to produce for several decades, hence, the requirement to optimize the production. In 2006, the full block was covered by 2500sqkm streamer survey (Fig. 1). Only dedicated localized ocean-bottom cable (OBC) small patches have been acquired around platforms and installations. Several processing campaigns (Pedersen-Tatalovic et al., 2009; Bovet et al., 2019), demonstrated that seismic measurements were valuable to understand the static and dynamic reservoir behaviour. Beyond this, acquisition of a full-azimuth OBN survey was planned for 2019.

High-density OBN survey acquisition

The new high-density OBN survey aims at delivering extra information not available with the existing streamer survey: undershooting the numerous platforms, providing full azimuthal illumination, long offsets, low frequencies, PS-wave recording and reference for future seismic monitoring. All these items combined are expected to deliver higher-quality seismic results than the existing legacy data. The survey was acquired between February and December of 2019 covering a shot and receiver area of 1152 and 1020 km². Approximately 140,000 nodes were deployed on the seafloor between 30 and 80m of water depth on a 50-m by 150- m grid. The source grid being 25-m * 25- m nominal interval using a flip-flop pattern. The offset azimuth distribution obtained was a minimum of 1.8km crossline and 3.2km inline.

Figure 1 Block5 location offshore Qatar (left), Bathymetry map over Block5 with OBN outline shown in dash blue, P-wave early-out polygon (black) (centre), crossline seismic section from legacy 2017 reprocessing showing reservoir levels (right).

OBN data processing: P- and PS-waves early results

OBN surveys are mostly acquired for their well-known benefits with respect to P-wave imaging, while the PS-wave often remains unprocessed. In shallow water and horizontally layered environment, a few key PS-wave processing steps are becoming less complex to handle (Grimshaw et al., 2014), e.g., shear-wave splitting; therefore, valuable results from PS-waves are expected to be easier to achieve (Maili and Negulescu, 2009). Shear log information availability and dense node coverage also helped to weight values for processing PS-wave on the Al-Shaheen field in parallel to P-waves.

First, the principal focus of the processing has been the processing of a P-wave early-out structural stack, a subset of the full survey located in the northwest corner (Figure 1). This was delivered one month prior to the end of acquisition. Aside from this early-out delivery, the main processing path consists of both P-wave and PS-wave data sets, processed in parallel to reach simultaneously the joint tomography velocity model building stage. Both data sets will be migrated and processed for
extensive seismic studies including interpretation, elastic inversion, amplitude variation with azimuth (AVAz) analysis, diffraction imaging.

Primarily, the initial part of the processing aimed at compensating node-related corrections: repositioning of node and center of source array, residual clock drift, and sensor orientation. Due to the large number of node positions to be handled, beyond standard QC techniques, statistically oriented procedures had to be implemented to provide meaningful and effective QCs. Then, P-waves and PS-waves were split in two different flows.

**Figure 2** Left: Hydrophone receiver gather (A), its corresponding geophone gather before (B) and after (C) shear noise attenuation. Right: Early PS-wave common conversion point (CCP) stack sub-volume with main PS horizons (left), and PS-wave CCP stack inline section showing layer used for initial shear-wave splitting correction(right).

Regarding the P-wave processing: a well-known challenge with OBN data is the noise recorded on the vertical geophone. Prior to any hydrophone and geophone summation (PZ summation), undesirable noise must be removed from the geophone records. Along with surface waves, shear noise was attenuated through several cascaded passes of linear noise attenuation (Figure 2). Octave panel QCs allowed detailed analysis of the process efficiency. Once vertical geophone data had been cleaned, calibration to the hydrophone was applied using a hybrid approach based on water depth: Upgoing refractors were used when water depth allowed, otherwise, in shallower water, a cross-ghosting approach was applied. It allowed PZ summation to be performed and generated Upgoing ($P_{up}$) and downgoing ($P_{dwn}$) P-wavefields. For purpose of the early-out delivery, only $P_{up}$ was processed.

Multiples are a well-known problem over the Al-Shaheen field (Rønne et al., 2014) as is the case for many fields in Middle East. For the P-wave early-out route, several multiples steps were applied sequentially to remove the numerous multiples affecting these data: The water-bottom multiples were tackled first using a 3D model-based wavefield extrapolation modeling approach. This was followed by a 3D surface-related multiple elimination pass to target all surface-related multiples and, finally, a 3D tau-p deconvolution step. Initial up-down deconvolution testing showed encouraging results to be pursued for the full processing route. This approach has many benefits, not to be developed here (Wang et al., 2010). With regards to interbed multiples, those will be addressed during the full P-wave processing. Prior to migration, surface-consistent processing was also applied: deconvolution and statics. Afterwards, the legacy P-wave velocity model was used to produce prestack time-migrated offset vector tiles. The post-migration sequence was mainly focused on footprint attenuation, frequency bandwidth extension, and azimuthal sectoring. This early-out path of processing delivered several sets of data: structural volumes, sub-stacks for azimuthal analysis, and elastic inversion.

In parallel to the P-wave early-out route, PS-wave processing was initiated. Preliminary vector fidelity assessment did not show any issue with the horizontal sensors; however, onboard QCs highlighted a small number of nodes laying on their edge while recording, causing partial loss of recorded shear signal. While this topic is being investigated, preliminary shear-wave splitting analysis was carried out using the shear-wave splitting intensity method (Boiero and Bagaini, 2019) prior to moving further into PS-wave processing: After radial and transverse preconditioning including demultiple, shear-wave splitting analysis pointed at an overburden layer from Rus to Laffan causing the S-wave to split.
into fast (S1) and slow (S2) shear waves (Figure 2). S-wave birefringence correction step is required prior to progressing further with radial PS-wave processing (Olofsson et al., 2003).

Along with early-out P-wave and PS-wave flows, depth velocity model building started with full-waveform inversion (FWI). Indeed, the node acquisition allowed recording long offsets in the inline direction, up to 10 km. These offsets, combined with OBN-recorded low frequencies from 2 Hz and an initial depth velocity model permitted an early FWI update down to the Rus horizon. Further FWI efforts are planned to extract the maximum value to solve small-scale velocity heterogeneities above and at Al-Shaheen reservoirs, which are the cause of undulations in the imaging of horizons on the legacy prestack time-migrated (PSTM) image.

**Figure 3** P-wave inline full stack from legacy streamer PSTM (left). Early-out $P_{up}$ OBN PSTM (right) showing overall seismic quality improvement.

**Results and observations**

The assessment carried out on the full structural stacks ($P_{up}$), 0-32º, full azimuth, delivered from the early out OBN path shows clear benefits compared to the existing legacy seismic survey reprocessed in 2017 (Figures 3 and 4). Thanks to full raypath illumination, horizons are more continuous with fewer undulations resulting from inaccuracies in the velocity model. Geological small-scale structures appear clearer (Figure 3). Comparing the OBN results with the legacy streamer data, initial evaluations show that a better level of multiple removal was reached (Figure 4). However, several key steps, not present on this early-out path, are still to be included on the full P-wave processing. Moreover, the down-going wavefield is expected to bring further illumination in the overburden to benefit structural imaging and shallow velocity model depth building.

**Conclusions**

The results obtained from the P-wave early-out processing route on a northern sub-set of the Al-Shaheen OBN are showing encouraging results which will be used to adjust interpretation. The processing route applied was mainly focused on denoising and demultiple; however, more tests are already showing significant further benefits. As a consequence, one extra early-out P-wave areas have been initiated, aiming at impacting well placements. On the PS-wave side, preliminary processing is showing good-quality signal, spatially variant; however, more work is required to assess the full value. Overall, these early results show that the HD OBN seismic acquisition over the Al-Shaheen field is starting to deliver value to interpreters. More processing efforts on P-wave demultiple, high frequencies, PS-waves, and depth velocity model building are expected to bring further value in the coming months.
Figure 4 P-wave zoom from random line full stack from legacy streamer PSTM (left). Early-out P\textsubscript{OB} N PSTM (right) shows overall seismic quality improvement.

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References


Bovet, L., Mueller, G., and Vacheyrout, A. [2019] Structural constraint through Integration of Horizontal Well Information and advanced Seismic Imaging in Carbonate Environment. 3\textsuperscript{rd} EAGE WIPIC Workshop: Reservoir Management in Carbonates.


