Maximizing the value of the existing seismic data in Awali field – Bahrain, by utilizing advanced 3D processing technology.

Eduard Maili* (OXY - Tatweer), Scott Burns (OXY), Neil Jones (Consultant, OXY)
Fabienne Pradalie, Sylvie Baillon, Dominique Verneau (CGGVeritas)

Summary

As seismic processing technology advances, it always opens opportunities for further improvements of existing data-sets. This is especially important in the case of survey areas that may no longer be accessible for new seismic acquisition. The onshore Awali Field (in the Kingdom of Bahrain) is just such a case because, since the original acquisition of a 3D seismic data-set in 1998, subsequent massive urban development precludes any large-scale reshoot effort. The application of new 3D azimuth-friendly processing techniques to the Awali data-set has indeed substantially improved imaging of both shallow and deep reservoirs. Further, utilizing that subset of the data-volume that is near-surface/near-offset (in a ‘wide-azimuth’ sense) has provided better fracture characterization of key shallow oil reservoirs. Here, we describe the main processing steps that resulted in these image improvements, and we provide an example of how the azimuthal data improved fracture characterization.
Introduction

Awali, one of the world’s giant oil and gas fields, is located onshore the Kingdom of Bahrain. It is the oldest discovery in the Gulf of Arabia and has been in production for over 75 years. The oil and gas come from multiple reservoirs, stacked on a large salt-cored anticline. The structure is extremely faulted and fractured and most of the reservoirs are very heterogeneous. In such a complex setting, the seismic data can play an important role in building more accurate geologic and reservoir models, providing subsurface information for (i) more efficient drilling, (ii) optimizing the waterflood and steam injection projects and (iii) for finding under-developed and by-passed oil areas.

The Awali 3D seismic survey was originally acquired and processed during 1998-1999. It is a vibroseis, 68 fold survey, with cross–spread geometry and 50x50 meter shot and receiver interval. The initial processing was simple, essentially a Post-Stack Time Migration (PSTM) flow. The data were reprocessed in 2005 through a Pre-Stack Depth Migration (PSDM) flow, improving the image considerably but, as the main objective at that time was the deep gas reservoir, it overlooked the shallower section where most of the oil reservoirs reside. Further, the vertical resolution from the depth migration was relatively low, and the depth-to-time conversion itself imparted some distortions in both travel-time and amplitude. These issues consequently prohibited any further inversion work.

The main goal of the reprocessing was to better resolve both shallow and deep reservoirs by applying new technology. Further, that the elements of the processing flow should preserve azimuthal travel-time and amplitude information – so that the resultant azimuthal data (gathers and stacks) could provide information necessary for fault illumination and fracture characterization in the shallow section beneath the crest.

In order to ensure these goals could be achieved, a pilot study was initially conducted with several contractors using a limited portion of the Awali data-set. Based on the results of the pilot, the entire volume was passed through the preferred processing flow. This paper describes the latter flow, its results and the ultimate impact on interpretation and well-planning.

Advanced 3D time reprocessing flow

An advanced flow was designed and carefully followed during the entire processing. (shown schematically in Figure 1):

![Figure 1: The main reprocessing flow](image-url)

Refraction Statics step: The first step of the flow was to build a near surface velocity depth model from first break picks via refraction tomography (Taillandier et al., 2010). The near-surface velocities were seen to vary from 1500 m/s to 3500 m/s (Figure 2a). A reference datum of 200m below elevation...
was chosen and statics were calculated using a replacement velocity of 3000m/s. These primary statics (varying from -3ms to -40 ms) improved the long/medium wavelength character of the structures in the stack (Figures 2b/2c).

Coherent Noise Attenuation step: In an advanced time processing sequence the algorithms are 3D and consequently designed to protect azimuthal information. The first step in terms of signal enhancement was linear noise attenuation using a 3D FKxKy conical filtering in the cross-spread domain. To better handle aliased linear noise, an interpolation was performed of shots and receivers along the shot and receiver lines within each cross-spread gather. The interpolated traces were dropped after filtering to retrieve the original shot and receiver sampling.

Surface Consistent Corrections step: Thereafter, signal enhancement took the form of surface-consistent waveform harmonization. 3D surface consistent amplitude compensation was computed and applied; this included careful editing of noisy traces, bursts, spikes plus an extra pass of frequency dependant noise attenuation. Further, a 3D surface consistent deconvolution (with statistical pre-stack zero-phasing) was run and finally, residual reflection statics were calculated and applied. The latter values were found to vary from -3 ms to +3ms.

Regularization step: Prior to migration and using 5D interpolation/regularization (Poole et al., 2010), the original data were mapped onto a regular base geometry to remove irregularities. As a result of the interpolation, the shot-line and receiver-line spacing were essentially halved, producing four times the number of traces input to migration. This had the benefit of not only reducing migration noise (via appropriate cancellation) but also of better defining near-surface events at gather level.

Pre-stack Kirchhoff Time Migration (PrSTM) step: Migration velocity analysis was performed using stack-scans. The resultant migration velocity field was calculated in an azimuthally isotropic sense, with particular care being taken in the choice of mute/velocity pairing in the shallow section. The PrSTM of the original data, Fig 3a, is compared with the PrSTM after 5D regularization, Fig 3b. The PrSTM was run per COV to keep the original azimuth distribution.

Figure 2: in-line 2156: a) model after Tomographic inversion b) stack with vintage static solution c) stack after new statics solution from Tomographic inversion.

Figure 3: in-line 2292: a) PrSTM of original data b) PrSTM of 5D regularized data.
Post-migration Processing step: 3D Random Noise Attenuation was applied after PrSTM on each COV volume. High density second and fourth order move-out corrections were computed and applied on four designed azimuth sectors, followed by high-resolution Radon de-multiple. The PrSTM gathers from all the azimuth sectors were stacked together to create a full-azimuth stack, while gathers within individual sectors (hour-glasses) were also stacked to create four azimuthal stacks. The orientations of the azimuthal stacks were essentially skewed 45° either side of E-W and N-S (Figure 4).

Comparing the new, all-azimuth PrSTM with the existing data, the improvement is evident for all the reservoirs (Figure 5); especially for the reservoirs in the mid-section where the reflections are much stronger and continuous. It is important to note that due to careful work during noise attenuation and by addressing azimuthally variant travel-time and amplitude variations, it was possible to widen the bandwidth and consequently to increase the vertical resolution of the data. The new data have flattened amplitude spectra with high frequencies above 70 Hz compared with about 50 Hz in the vintage data-volume.

To achieve the last main objective, fracture characterisation in the shallow section below the crest, azimuthal stacks were produced with equivalent offset/fold contributions to better balance gross amplitude levels within each azimuth-sector. Geo-statistical decomposition/filtering were subsequently applied, using the orthogonal sectors to extract the isotropic/common component (free of noise) as well as the anisotropic components (also free of noise).
Field applications

The interpretation of the newly reprocessed data has already started and the data are being used in daily operations (well planning). We show some initial applications of the azimuthal data for fault detection and fracture characterization (within the upper section). Specifically, we show an example of the use of the data to detect fractures in the Rubble reservoir, a light oil area. The FMI data from the horizontal well A, drilled before the data were delivered, showed several fracture corridors oriented NW. Looking at the well-seismic section, we can see the effect of these fractures in the azimuth that is normal to the fracture orientation (Figure 5). A fast-track amplitude-anisotropy analysis showed anomalies in the areas where fracture corridors were encountered. Based on it, fracture corridors were predicted on well B before drilling and were proved by FMI after drilling.

![Figure 6: On the left – top All Azimuth well-seismic section and the FMI image: there is no indication for fracture presence on the All Azimuth data. On the bottom left, the four azimuth hourglasses: clear amplitude indication for the fracture presence in Azimuth 2 normal to the fracture strike. On the right, the amplitude anisotropy map shows anomalies in the areas where fractures are detected on FMI.](image)

Conclusions:

Reprocessing has achieved its main objectives, resulting in better seismic imaging for all reservoirs, improving the structure and fault definition. The azimuthal data can be used for subtle fault/fracture characterization and anisotropy calculations. Initial results show very good correlation with the fracture information from borehole images (FMI). Also due to the improved bandwidth, the data show better vertical resolution. The new data-set opens possibilities for further seismic inversion work and reservoir property prediction.

Acknowledgements:
We thank Tatweer Petroleum for allowing us to show the data, the CGG specialists for their help and advice, and the management from both Tatweer and CGG for their support.

References

Poole, G., 2010, 5D data reconstruction using the anti-leakage Fourier transform: Extended Abstracts, EAGE conference.