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Towards Improved Time-lapse Seismic Repetition Accuracy by Use of Multimeasurement Streamer Reconstruction

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SUMMARY

It is widely accepted that accurate repetition of source and receiver locations between surveys is key to time-lapse seismic data quality. Whilst the source locations of marine streamer time-lapse surveys can be accurately repeated, exact repetition of receiver locations can still be challenging. The introduction of multimeasurement streamer technology has enabled repetition of receiver locations by reconstruction of the recorded wavefield at the desired coordinates. Two or more multimeasurement surveys may be reconstructed at common locations, or a multimeasurement monitor survey may be reconstructed at the receiver locations of a previous conventional marine streamer dataset. Apache North Sea Limited acquired, in 2012, test lines over the Forties field using multimeasurement streamer technology. The initial results of these tests suggest that a conventional marine streamer survey can be accurately repeated with multimeasurement streamer technology, and work is ongoing to qualify the technology for routine time-lapse seismic acquisition.

Introduction

Monitoring producing hydrocarbon reservoirs by time-lapse (4D) seismic measurements has become routine, and it is widely accepted that accurate repetition of source and receiver locations between surveys is key to time-lapse seismic data quality. Most time-lapse seismic surveys are acquired with marine streamer techniques. Whilst the source locations of these surveys can be accurately repeated (Paulsen and Brown 2008), exact repetition of streamer locations can still be challenging.

Eiken et al. (2003) introduced the concept of interpolating, to desired receiver locations, the recorded seismic wavefield of repeated multistreamer shots. Interpolating to the same locations for each survey resulted in very well-repeated time-lapse seismic data. Unfortunately, accurate interpolation required the use of such small crossline streamer separations that the technique was uneconomic for large-scale monitoring. Multi-domain interpolation techniques (eg. Sharma et al. 2011) show promise, but have not so far eliminated the need to accurately repeat source and receiver locations.

The introduction of multimeasurement streamer technology (Robertsson et al. 2008) enabled wavefield reconstruction from data with economically feasible streamer separations. Two or more multimeasurement surveys may be reconstructed at common locations, or a multimeasurement monitor survey may be reconstructed at the receiver locations of a previous conventional marine streamer dataset. This paper demonstrates the latter application using multimeasurement streamer test lines acquired by Apache North Sea Limited over the Forties field.

Reconstruction of multimeasurement marine streamer seismic data

The multimeasurement streamer used by Apache contains densely spaced hydrophones and accelerometers that enable recording of the pressure wavefield and the vertical and crossline components of the particle motion vector. The inline vector is derived from the spatial derivative of the pressure recordings. Commercial surveys acquired in 2012 used eight multimeasurement streamers, typically with 75 m crossline streamer spacing, and towed at depths of between 15 and 20 m to minimise streamer noise.

Vassalo et al. (2012) showed how the Generalized Matching Pursuit (GMP) algorithm could be used to reconstruct, from each multistreamer shot record, shot-by-shot upgoing and downgoing pressure wavefields sampled on a dense 6.25 m inline by 6.25 m crossline grid. The streamer array records signal energy over an apparent velocity range of roughly -1480 to +1480 m/s, implying that the densely sampled reconstructed wavefield supports spatially unaliased signal for temporal frequencies up to about 120 Hz. This is more than sufficient for most reservoir imaging applications. The GMP algorithm can also perform a 3D redatuming of the output datasets to transform the reconstructed data to any desired datum.

Duplicating a conventional marine streamer survey with multimeasurement streamer data

The multimeasurement monitor survey should accurately repeat the source locations of the base survey. The streamer spread width must be sufficient to enable reconstruction of the base survey receiver locations, taking into account any feather mismatch that occurs during acquisition. GMP generates densely gridded shot gathers for the up- and downgoing pressure wavefields at the datum of the base survey. These are combined to create the total pressure wavefield, which is then interpolated to the X,Y coordinates of the receiver locations of the equivalent base survey shots.

Time-lapse seismic monitoring of the Forties field

The Forties field is located in the North Sea, about 175 km east of Aberdeen, and was discovered by BP in 1970. Apache North Sea Limited bought the field in 2003, by which time production had declined from a peak of 500 000 barrels per day in 1979 to about 35 000 barrels per day. An intensive re-evaluation defined more reserves and increased production to about 60 000 barrels per day. Time-lapse seismic data was an important component of this success.

Marine streamer seismic surveys were acquired over Forties in 1988, 1995, 2000 and 2010, with all four surveys being co-processed in 2010 using the flow summarized in Table 2. The 2010 dataset is substantially oversampled (see Table 1) relative to the 2000 survey to maximize the chances of accurately repeating receiver locations. During processing, time-lapse binning was used to select the best repeated traces from the 2010 survey and to discard the redundant ones. The results clearly image where water has replaced oil in the reservoir (Rose et al. 2011).

An additional dataset, incorporating all acquired data, was created from the 2010 survey, and showed improved signal-to-noise ratio at low frequencies. The additional useable low-frequency energy helped better delineate the thicker turbidite channel sand complexes of the Forties reservoir. Apache therefore decided, in 2012, to test whether acquisition with a multimeasurement streamer system could accurately repeat the previous surveys whilst simultaneously enabling the creation of data with broad spatial and temporal bandwidths.

Acquisition date	**2000**	**2010**	**2012**
Acquisition system	Syntrak	Q-Marine	IsoMetrix
Heading (degrees)	13 / 193	13 / 193	13 / 193
Sail line interval	300	300	n/a
No. of sources / separation (m)	2 / 50	2 / 50	2 / 50
Shotpoint interval (m)	12.5 (flip-flop)	12.5 (flip-flop)	12.5 (flip-flop)
Source volume (cu.in.) / depth (m)	3090 / 5	3147 / 6	3147 / 6
Number of streamers / separation (m)	6 / 100	11 / 50	8 / variable
Streamer length (m) / depth (m)	3000 / 7	3600 / 7	3000 / 18
Trace interval (m)	12.5	6.25	6.25

Table 1 - *The acquisition parameters for the 2000 and 2010 Forties time-lapse seismic surveys, and for the 2012 Forties multimeasurement streamer test lines*

Step	**Processing**
Reformat & data reduction	Reformat, nav-seis merge, resample to 4 ms, truncate to 3000 m streamer length, tidal static corrections
Data conditioning	Low-cut filter, tau-p first break removal, swell noise attenuation
Wavelet processing	Calibrated Marine Source deconvolution (WG surveys only), deterministic zero-phase conversion and debubbling
Data conditioning	Receiver motion correction
Multiple & noise attenuation	Deterministic Water layer Demultiple, shot & receiver domain tau-p filtering, anti-alias filter & trace drop to 12.5 m trace spacing (WG surveys only)
Static corrections	Time-shift decomposition to remove line-by-line timing differences
Survey matching	Frequency-variant global match filter
Wavelet processing	Phase-only inverse Q filtering
Binning	Offset sort and expanded-bin time-lapse binning
Regularization & imaging	Azimuth moveout, Kirchhoff 3D prestack depth migration
Stack	Inner & outer mute, cmp stack
Survey matching	Frequency-variant global match filter
Poststack processing	Exponential gain, 3D FXY interpolation to 12.5 x 12.5 m grid

Table 2 – *the Forties 2010 time-lapse seismic processing flow*

The 2012 Forties multimeasurement marine streamer acquisition test

Two of the 2010 sail lines were reacquired in 2012. The streamer spread configuration, shown in Figure 1, was designed so that some of the 2010 streamer positions would be accurately repeated by multimeasurement streamers and others would not. This facilitated evaluation of how the accuracy of the reconstructed data would vary with distance from the nearest multimeasurement streamer. The source array was identical to that used in 2010.

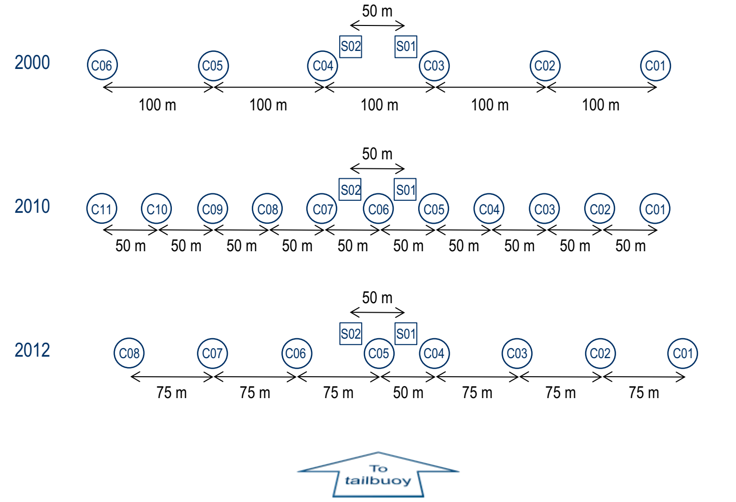

Figure 1 - A schematic diagram showing the relative source and streamer positions for repeated sail lines of the 2000, 2010 and 2012 surveys. S01, S02 represent the source locations and C01, C02, and so forth, represent the streamer locations

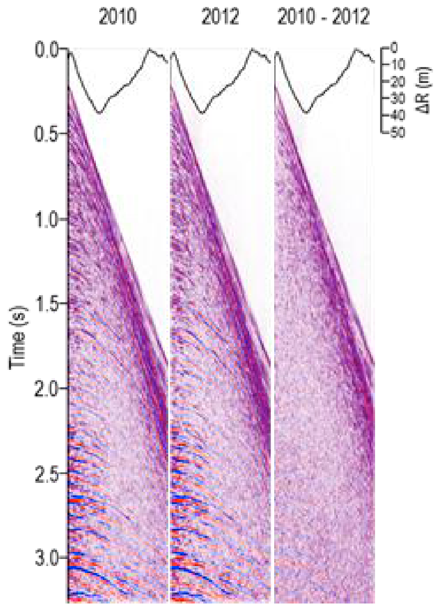

***Figure 2** - An example shot gather from the 2010 survey, a reconstructed gather from the 2012 survey, plus the difference between the two. The graph shows the distance from the 2010 streamer locations to the nearest 2012 streamer*

The 2012 data were reconstructed at the receiver locations of the equivalent shots from 2010. Figure 2 compares a 2010 shot gather, the equivalent reconstructed shot from the 2012 dataset and the difference between them. The reconstructed shot gathers are very similar to those from the 2010 survey, even where the distance between the base and monitor streamers approaches 40 m.

The reconstructed data were processed through the flow described in Table 2, except that 2D prestack migration was used, and there was no poststack interpolation. The equivalent lines from the 2000 and 2010 surveys were processed in the same way. Collocated 2D migrated 3D stack sections from the centre of each sail line swath were created and time-lapse difference sections computed as shown in Figure 3. Time-lapse signal, caused by changes in reflector amplitude and timing, is very evident on the 2000-2010 comparison. Fewer reservoir changes are visible on the 2010-2012 comparison due to the shorter time interval between surveys. In areas away from the reservoir, coherent residual primary energy (marked by arrows) can be seen on the 2000-2010 difference, but not on the 2010-2012 difference. Figure 4 shows the same differences at larger scale. There are indications of higher random noise on the 2010-2012 difference – the origin of this is currently being investigated. The results suggest that a conventional marine streamer survey can be accurately repeated using multimeasurement reconstruction technology.

Conclusions

The multimeasurement streamer test lines acquired in 2012 over the Forties field indicate that the multimeasurement reconstruction technology can accurately recreate data at the locations of a previous survey. The resulting time-lapse seismic differences are comparable to those created using more conventional approaches. The Forties test lines acquired by Apache in 2012 provide a rich dataset that will enable a comprehensive evaluation of the capabilities of multimeasurement streamer technology.

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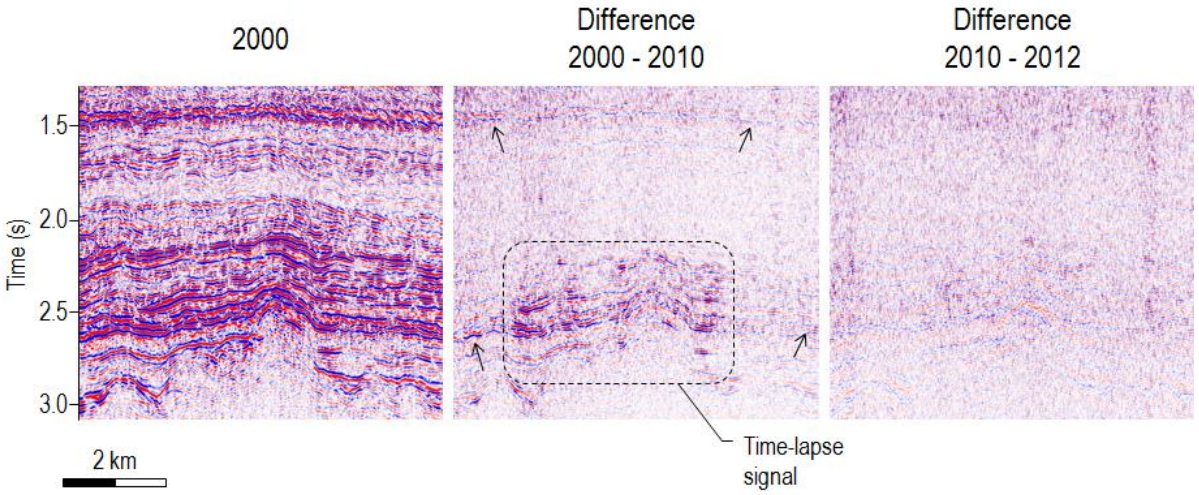

Figure 3 *– An inline section through the 2000 dataset, plus the time-lapse difference between 2010 and 2000, and the time-lapse difference between 2012 and 2010. The differences are displayed at twice the gain of the inline section.*

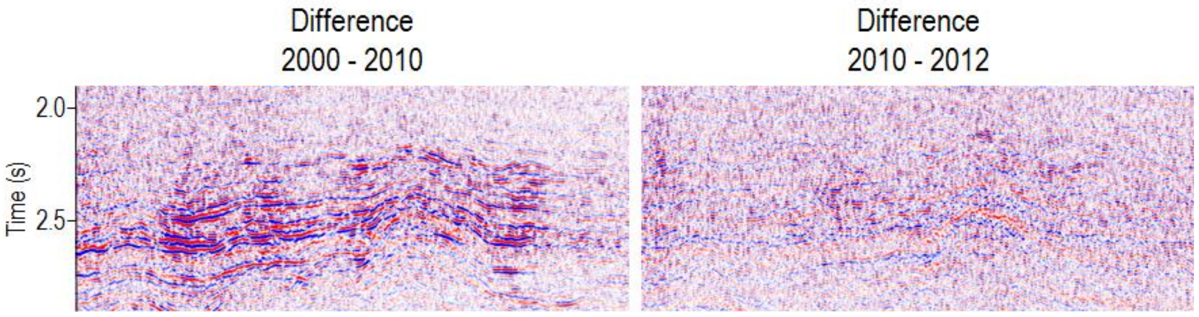

Figure 4 *– Zoom plots of the difference data in Figure 3*

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