Evolution of a seismic acquisition methodology through integrated testing—onshore Abu Dhabi, United Arab Emirates, 1996–2000

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Summary

For onshore seismic data the resolution at the exploration target level depends on the complex interaction of many factors. These include the survey environment, geology, acquisition configuration and data processing procedures.

When designing seismic surveys we wish to achieve the required target level resolution while minimising both cost and risk. For Vibroseis surveys, the time expended recording each source point, called the sweep effort/VP, can be a key cost factor. Uncertainty about the impact of differing options for the acquisition geometry and source point sweep effort on the target level resolution represents a risk factor.

A 3D seismic exploration methodology driven by the resolution at the target level has been implemented for onshore Abu Dhabi, United Arab Emirates, by the Abu Dhabi Company for Onshore Operations (ADCO), in co-operation with Western Geophysical.

Techniques originally developed for the on-crew processing of 2D acquisition parameter tests have been extended to 3D. Integrated data acquisition and processing tests provide fully processed, 3D migrated data volumes. Test analysis is based on the interpreted resolution at the target level, allowing direct judgements on key parameters affecting data cost and quality.

The spatial distribution of source energy, improving the trace offset distribution and increasing the CMP fold is seen as significantly more important than the sweep effort/VP.

Close co-operation between ADCO and Western's Geophysical Abu Dhabi data acquisition and processing staff ensure that complex data manipulation issues are handled in a timely manner, allowing the results of the testing to influence an ongoing 3D project.

Use of this methodology has so far provided both improvements in data quality to levels not seen before for Abu Dhabi onshore data while simultaneously reducing the cost and risk of data acquisition.

This paper summarises results from some of the key events in the development of the acquisition testing methodology:

(A) 1996 – 2D testing for 2D acquisition.
(B) 1997 – 2D testing for 3D acquisition.
(C) 1998 – Simultaneous downhole acquisition.
(D) 1999 – 3D testing for 3D acquisition.

Introduction

For the developed oil fields of onshore Abu Dhabi, 3D seismic data has been identified as a critical tool for reservoir characterisation and understanding reservoir management problems. It also promises to be useful for the exploration of currently undeveloped areas, taking over that role from 2D acquisition.

Optimising data acquisition to ensure that ADCO's demanding quality requirements are met and survey objectives realised is a significant challenge. Improving data quality through the integration of acquisition and processing testing has been an ongoing commitment.

2D tests for 2D acquisition

In late 1996, Western Geophysical started a 2D project for ADCO in a remote sand-covered area of Southern Abu Dhabi. The crew was equipped with a full capability Omega® processing system. A series of acquisition parameter tests were recorded during which an experienced data processor visited the crew. Five km of 2D line were recorded three times with different source arrays. Each 25 m source point interval was recorded with sixteen sweeps/VP. Data for each individual sweep were recorded to tape. Processing summation and decimation tests allowed the evaluation of the required sweep effort per VP.

Final processing of the acquisition tests through a full sequence was completed within the time frame of the test data collection. ADCO were able to select the optimum recording parameters for the rest of the survey. The success of this project – that developments in technology deployed in the field made it possible to do meaningful acquisition testing – set a pattern that was subsequently repeated and refined.

A further aspect of these tests was the reaffirmation that twelve, sixteen second sweeps gave the best 2D data at the CMP stack stage. Sweeps were acquired using an areal rectangular source array of four parallel, bulldozed tracks into an areal 48-geophone array. These, and other, 2D tests have indicated that source generated noise scattered within sand dunes is better attenuated when you have many elements in the source and receiver arrays. The limitation of such noise provides improved 2D data quality.

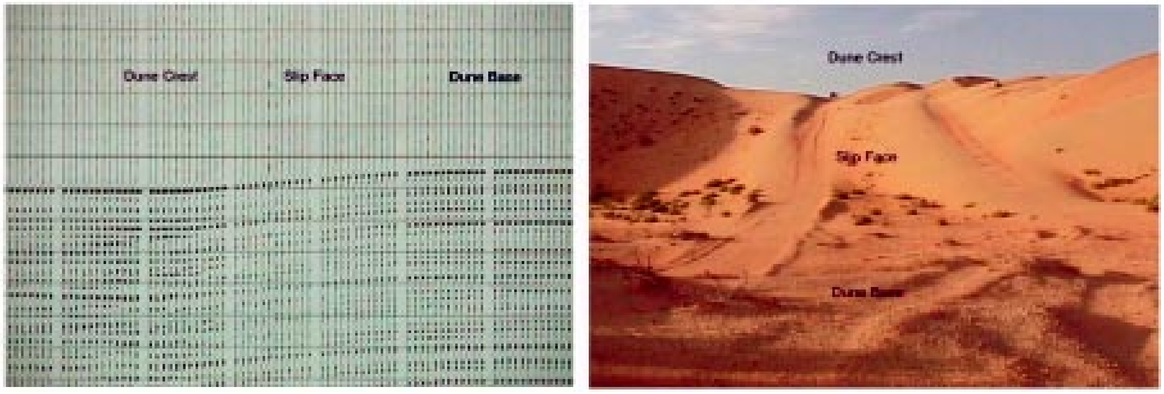

Figure 1 Vibrator fleet traversing the slip face of a sand dune (left-to-right, dune crest-to-base). For scale, the object at the top of the left track is a Toyota Landcruiser. Note the approx. 60% decrease in amplitude of the traces from sweep positions as the vibrators move down the dune slip face. There is also 20 msec. differential arrival time across the twelve sweeps from a single surface VP.

The conclusion that a relatively heavy sweep effort was required for optimum 2D data in sand dunes influenced thinking for 3D surveys then in the planning stage.

2D tests for 3D acquisition

Acquisition of a 700 km^2 3D seismic survey over a developed onshore oil field, in a sand dune area, commenced in the later part of 1997. To optimise the 3D design ADCO conducted a pre-survey feasibility study. Eight months before the 3D acquisition an extensive program of 2D tests were conducted in the oil field area. The tests required eleven days of field crew time.

The primary issue addressed was sweep length. Could fewer, longer sweeps be used to boost crew productivity? Eleven kilometres of a 2D line was recorded twice, first with twelve 16 second sweeps per 25 m interval, then with six 32 second sweeps. The recording of data files for individual sweeps allowed processing with differing numbers of sweeps/VP.

Secondary issues tested included:

24 or 48 geophones per group – for the 32 second sweep acquisition, the receiver spread was configured as two lines each with 24 geophones per receiver station.

Recoverable frequency bandwidth – a segment of line was re-shot with sweep frequencies up to 125 Hz.

Array sizes – data were acquired at 25 m source and receiver intervals. Various types of decimation and summation in processing allowed comparison of 25 m and 50 m array lengths.

A full data processing sequence was performed on the crew. This included refraction and reflection statics, surface consistent deconvolution, velocity analysis and migration. Acoustic inversion processing was done by ADCO.

The tests yielded numerous 2D sections for comparison of Sweep length, number of sweeps/VP, vibrator array pad spacing, CMP fold reduction, frequency content and, total source and receiver array lengths. Inferences were drawn on how the various parameters interacted with the 2D CMP stacking operators to affect the final data quality.

As with previous 2D tests, a key factor was the number of elements in the source and receiver arrays. The relative width of the array was also significant. Wider arrays helped. The tests provided much useful information, and met their immediate objectives. However, it was recognised that limitations exist when extrapolating results from 2D data to 3D acquisition.

Subsequent acquisition of the production 3D survey, using twelve 16 second sweeps/VP, was highly successful. The potential benefits of high-quality onshore 3D seismic for reservoir delineation and management were realised. The Western Geophysical Abu Dhabi Data Processing Centre was awarded the 3D processing contract and became involved in the data acquisition test processing.

Downhole data recording

Some further insight into issues affecting surface seismic acquisition was gained during the recording of the 3D survey in early 1998. In a joint operation, Western Atlas Downhole Seismic Services recorded downhole data with three-component geophones simultaneous with the surface seismic. The Western Atlas wireline recording system operated as a 'slave' system to the Western Geophysical Surface Seismic recording system.

Figures 1 and 2 illustrate the raw seismic response recorded by the vertical component of a wall-locked geophone tool located 2331 m below surface as the 3D surface seismic data was acquired. One downhole trace was recorded for each of the twelve vibrator sweeps per VP. The data order reflects the progression of the Vibrator fleet along a source line. For each sweep the vibrator array consists of a box of four

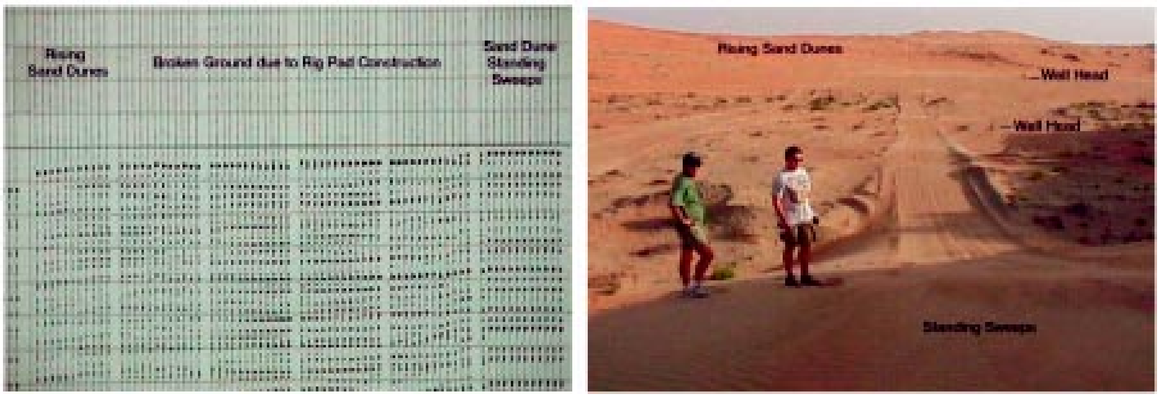

Figure 2 Vibrator fleet traversing an area of ground previously subject to rig pad construction. There are apparent short period variations in the character of the first energy arrivals within individual VPs. The rightmost panel of 12 traces were recorded with no move-up between sweeps.

units, two per track with inline spacing of 12.5 m. The tracks are 25 m apart. The separation of each trace represents a move-up of 4.66 m between sweeps. Horizontal timing lines are 100 msec apart.

The data shown here has not undergone wavefield separation. For times later than the first energy arrivals up-going reflected energy is present. Nonetheless, some general observations may be made from the direct arrivals.

The above data raised questions on the common practice of source array-forming by the vertical summation of multi-sweep/VP data in the recording system. How might application of further processing steps before the summation improve data quality: e.g. differential source elevation statics, refraction statics. surface-consistent deconvolution or amplitude corrections? Would it be better to defer all the summation to the CMP stack?

An important question was also outstanding from the previous 2D testing: how did the basic signal-to-noise ratio of each individual sweep interact with the 3D acquisition geometry and processing sequence to affect data quality and resolution?

Answering these questions required a full 3D acquisition and processing testing procedure.

3D testing for 3D acquisition – Phase 1

The next onshore 3D project to be acquired was a 980 km^2 survey, also over a large developed oil field in a sand dune area. ADCO and TOTAL conducted a feasibility study for survey design optimisation. The procedure included 3D data volume simulations from 2D data, for a range of candidate geometries. Al Jeelani *et al.* (1998) described the results.

Sweep effort per VP was a critical factor affecting the cost of data acquisition and the time required to complete the survey. Following the feasibility study, in March/April 1999, a series of 2D and 3D acquisition tests were performed to investigate the balance between the sweep effort expended on each VP and the effects of the spread geometry.

A 12 km 2D line was recorded four times with sweep lengths of 4, 8, 12 and 16 seconds. Each VP had twelve sweeps/50 m VP interval. Suitable modification of the sweep end-taper lengths ensured a consistent amplitude spectrum for the Correlation Pilot signal. Following processing, an 8 second sweep length was selected for the 3D phase of testing. For this area, varying the sweep length did not have much effect on the final data quality for the range tested.

The 3D phase of testing investigated using 100 m vs. 200 m Source line spacing with varying numbers of sweeps/VP. A 19.2 km^2 surface area, 5.7 km^2 full fold, was recorded with the proposed 3D acquisition geometry: Split-spread centred on the VP. 16 receiver lines of 150 channels each. 2400 channels total. Receiver interval 50 m. Receiver line spacing 200 m. Source lines on 26.56° diagonal. Source point spacing 50 m. Source line intervals 100/200 m for 300/150 nominal CMP fold.

VPs on source lines 200 m apart were recorded with twelve sweeps/VP, individual files for each sweep being written to tape. The 200 m source lines were in-filled to a 100 m line separation with VPs using six sweeps/VP. The recorded data set allowed the generation of a series of data volumes of variable sweep effort/VP and source line spacing. Each volume had full 3D processing, migration, and inversion to acoustic impedance.

The results of these tests were mainly evaluated for data quality at the exploration target level. After full processing, there was very little difference between using six or twelve sweeps/VP at a 200 m source line spacing. A significant difference was noted between six sweeps/VP at 100 and 200 m source line spacing, with the 100 m line spaced data superior. Comparisons between using one, three or six sweeps/VP at 100 m line spacing showed very little difference between three

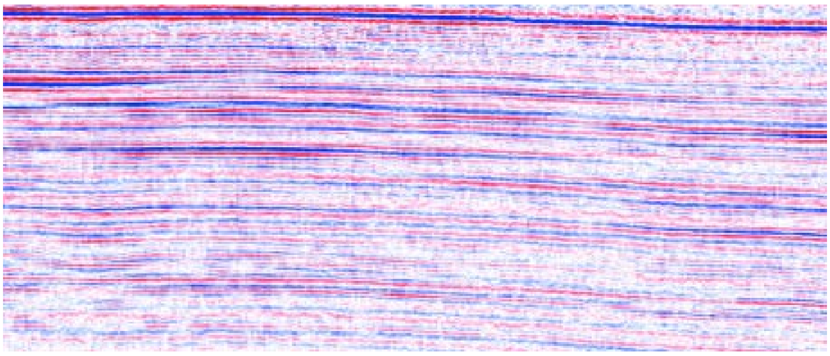

Figure 3 Six sweeps/VP, 200 m source line spacing. No differential source elevation statics applied before sum of sweeps.

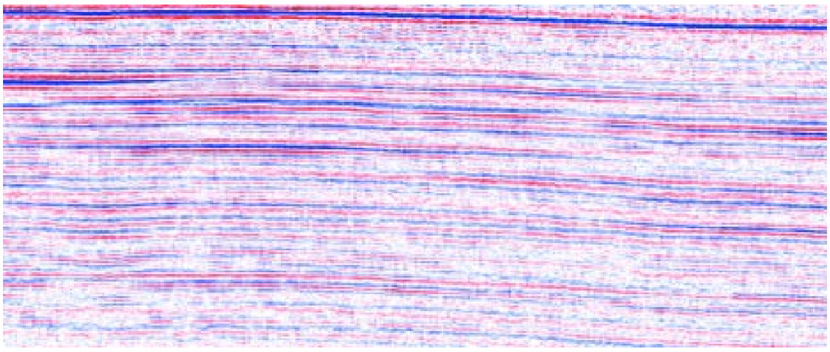

Figure 4 Three sweep/VP, 200 m source line spacing. No differential source elevation statics applied before sum of sweeps.

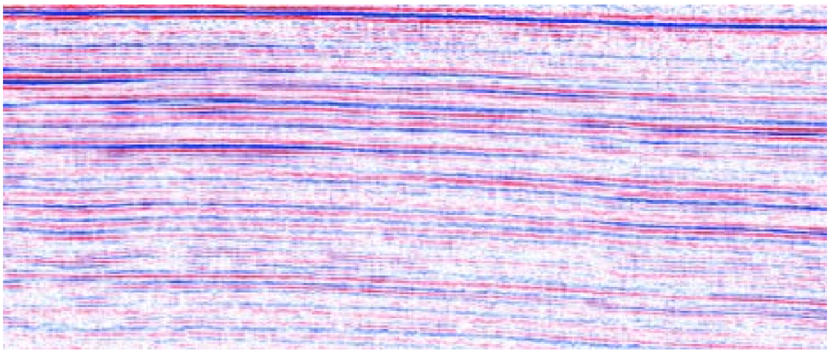

Figure 5 Three sweeps/VP, 200 m source line spacing. Differential source elevation statics applied before sum of sweeps.

and six sweeps/VP and that the one sweep/VP data was only marginally poorer

The geometrical effect of increasing the fold and improving the offset distribution by a better spatial distribution of the source energy was more significant than the effort applied at each source point. Shooting more source points, each with less effort was indicated as a means to reduce costs and improve data quality.

There are references to supporting observations in the recent literature. For example, Thomas & Hufford (1998) discuss using analysis of processed 3D data to reduce the number of sweeps/VP. Burger *et al.* (1999) observed a case where a larger stacking operator appears more important than the energy per VP.

For the production acquisition an effort equivalent to a 100 m source line interval, three sweeps/VP was selected. Environmental and operational considerations related to the bulldozing of vibrator access tracks suggested that an alternate but equivalent geometry would be more efficient. The 200 m source line spacing was retained while the receiver line interval was reduced from 200 m to 100 m. This implied a doubling of the crew channel requirements. A 'double-offend', rather than split-spread, shooting configuration was implemented, each source point being shot twice.

3D testing for 3D acquisition – Phase 2

The first phase of 3D test acquisition took place in the Northern area of the oil field where the terrain is characterised by

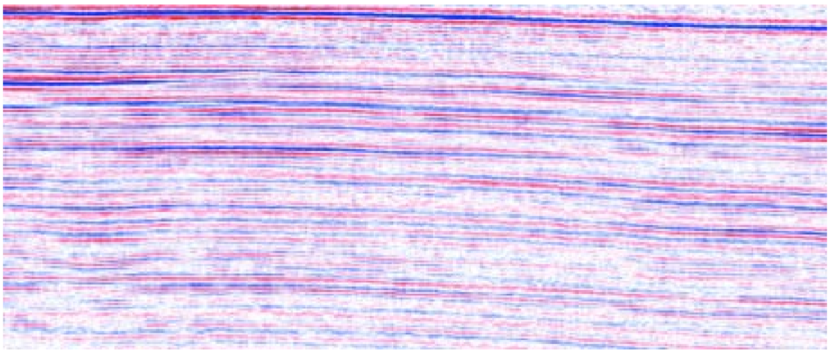

Figure 6 Three sweeps/VP, 200 m source line spacing. Each individual sweep processed through the full sequence.

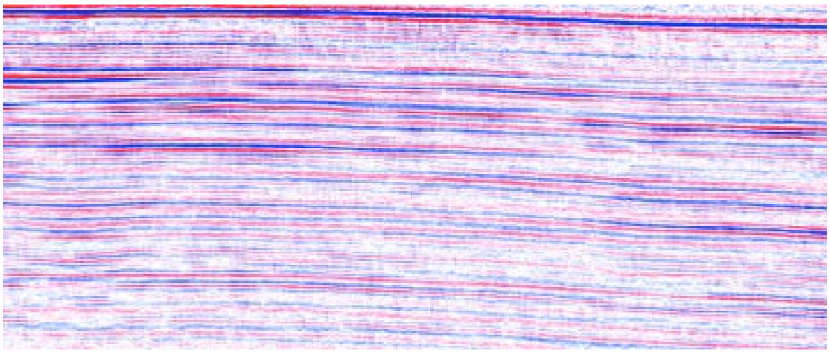

Figure 7 One sweep/VP, 100 m source line spacing.

rolling sand dunes, typically of elevation less than 30 m. Production acquisition for the survey commenced in November 1999 in Southern part of the oil field where the sand dunes are significantly higher. The geology of the southern exploration target area is also rather different. Concern that there might be energy penetration problems associated with the increased sand cover and a desire to investigate further the possibilities for improving the data quality led to a second phase of 3D test acquisition.

A 28.8 km^2 area of the first two production swaths was acquired with six sweeps/VP on source lines 200 m apart and with three sweeps/VP on in-fill lines for a 100 m spacing. Receiver line spacing was 100 m. CMP bin size was 25 m × 25 m.

Files for each individual sweep record were put to tape allowing a range of processing comparisons to be performed, including:

- three vs. six sweeps/VP at 200 m source line spacing.
- three sweeps/VP at 200 m summed with and without differential shot elevation corrections.
- three sweeps/VP at 200 m summed vs each sweep individually processed.
- one and two sweeps/VP at 100 m vs. three sweeps/VP at 200 m source line spacing.

Results of these comparisons confirmed the findings of Phase 1 of the 3D testing. Further, a single sweep at 100 m source line spacing provided improved data quality to that

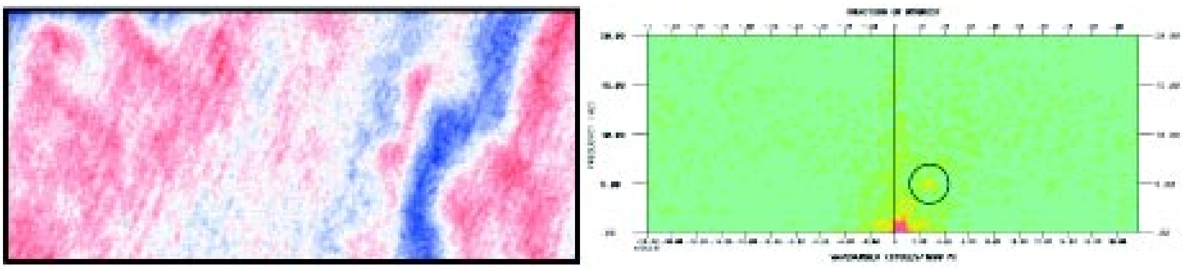

Figure 8 A 3D time-slice and Kx–Ky plot from test volume of three sweeps/VP, 200 m Source line spacing. Differential Source elevation corrections were applied before summation. Some interference from an acquisition ‘footprint’ is evident. The circled area on the Kx–Ky plot indicates the corresponding energy concentration.

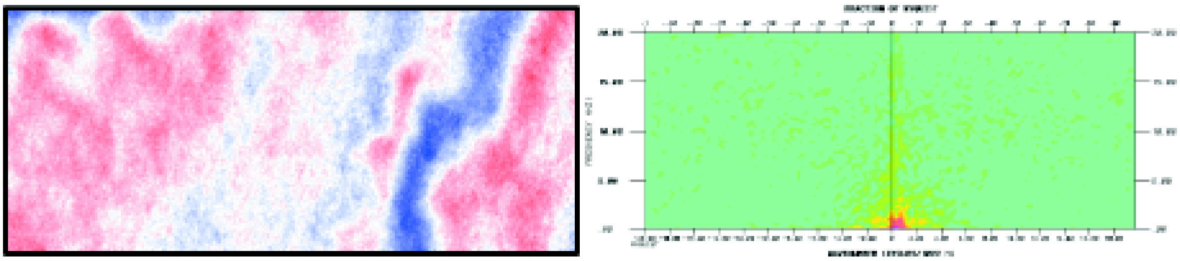

Figure 9 The equivalent 3D time slice and Kx–Ky plot for one sweep/VP, 100 m Source line spacing. The acquisition footprint has been suppressed by the field geometry.

from multiple sweeps at 200 m source line spacing. This remained true when the files for the multiple sweep data were individually processed through a full sequence.

Some examples of the type of data comparisons possible are presented in Figs 3–7. Each figure depicts a time window of the same subsurface line from a series of different 3D volumes.

Figures 8 and 9 illustrate a comparison of the 100 m vs 200 m source line data in time slice order. The acquisition 'footprint' evident on the 200 m source line spacing data can be attenuated by the post-stack application of adaptive Kx–Ky filtering. Though the data volume after Kx–Ky filtering remained inferior to the 100 m source line data, the effectiveness and relative cost of different approaches forms part of the evaluation procedure.

The availability of directly comparable 3D data volumes also allows computation of detailed signal-to-noise ratio measurements. This procedure provides quantification of any improvements or otherwise due to various processing steps. e.g. the application of differential source elevation corrections prior to summation.

Further acquisition and processing tests are ongoing.

Conclusions

For the exploration scenarios studied onshore Abu Dhabi, the geometrical effects of an improved spatial distribution of the source energy and consequent increase in CMP fold and improved offset distribution are clearly more important than the energy deployed per VP.

Understanding these issues required commitment to an integrated 3D data acquisition and processing testing program. There are significant limitations in extrapolating the results of 2D acquisition testing, even with full processing, to 3D acquisition.

An integrated testing methodology provides a means of understanding key issues relating to both the cost and quality of the acquired data and of ways to optimise them.

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