Recent Developments in 3-D Acquisition Techniques in Oman

Jan Wams and Justus Rozemond
Petroleum Development Oman

ABSTRACT

Acquisition of 3-D seismic surveys in Oman commenced in earnest in 1987 and has been continuous until today. Improvements in data acquisition have been made over the years, be it in small steps and based on similar geometries. A study was carried out to try to further improve data quality and/or efficiency. Two alternative acquisition techniques, ‘wide-line’ and ‘slip-sweep’, were identified and have been the subject of field tests. The results indicate that efficiency of vibroseis seismic acquisition can be substantially increased without, as far as the limited tests indicate, an appreciable impact on quality.

INTRODUCTION

Three-dimensional seismic data plays an important role in the exploration and exploitation of hydrocarbons in Oman and is now routinely used by Petroleum Development Oman (PDO) for exploration purposes (e.g. Gardham and Moeshart, 1989; Al-Kindy, 1993; Onderwaater et al., 1996).

Acquisition of 3-D seismic surveys in Oman commenced in earnest in 1987 and has been continuous until today. A large number of geometries have been employed over the years to image subsurface targets ranging from 0.20 to 2.50 seconds. The variations in geometry also reflect developments in the recording equipment and the general understanding of sampling criteria.

Over the years data were recorded with more channels, longer offsets, varying zig-zag source geometries all resulting in improved data quality or enhanced efficiency of the recording crews.

A recent study resulted in the identification of two alternative acquisition techniques which have been the subject of PDO’s annual field tests. This paper presents the initial results of these experiments. Initial evaluation indicates that efficiency can be substantially increased without an appreciable impact on quality.

HISTORICAL OVERVIEW

The first 3-D seismic survey in Oman was recorded in 1984 over the Suwaihat field in Central Oman (Figures 1 and 2). The results, when compared to existing 2-D seismic data, were disappointing, probably due to acquisition geometry and low fold. As a result of this, continuous acquisition of 3-D surveys was not started until 1987 with a total of some 26,500 square kilometers (sq km), roughly 21% of PDO’s current acreage, recorded by early 1996 both for production and exploration purposes (Figure 2).

The early surveys (Table 1 and Figure 3) were recorded on the Eastern flank in South Oman, where targets are in the depth range of 500 to 1,500 meters (m) subsurface, with maximum offset 1,600 m and 16 fold coverage. Anticipating wider coverage over the area, all surveys were recorded in blocks with a width determined by the amount of equipment available at the time.

The first deeper target survey in the South Oman Salt Basin was acquired with slightly longer offsets (2,400 m) and a wider line spacing (300 m).
Figure 1: Oil and gas fields of Oman. Producing fields are shown in capital letters throughout (e.g. NATIH). Names of fields which are not connected to pipelines are capitalized conventionally (e.g. Jazal). Petroleum Development Oman’s concession is shown in yellow. Other concessions and their operators are also indicated.
The search for deep gas in the north of Oman resulted in surveys in the Saih Rawl area (Figures 1 and 2) where longer offsets were required. Initially, from 1990 to 1992, surveys were acquired with a single zig-zag source geometry and an asymmetric spread, 1,600 m at one side and 4,400 m at the other side. This geometry was dictated by the availability of only 480 channels which forced a maximum offset of 6,000 m with four active geophone lines. However, to satisfy the need to image shallow objectives in this area it was required to record with this asymmetric split-spread geometry thus compromising the ability to image the reservoirs at 5,500 m depth. Improvements in later surveys consisted of the introduction of double zig-zag and later again dedicated surveys with 6,000 m offset (Figure 4).
## Table 1

### History of 3-D Survey Design

|                        | Single/Double Zig-Zag | Fold | Total |
|------------------------|------------------------|------|-------|
| Eastern Flank          | S                      | 16   | 22    |
| Split Spread 1.6 km    | D                      | 32   | 1     |
| South Oman Salt Basin  | S                      | 16 & 24 | 8    |
| Split Spread 2.4 km    | D                      | 48   | 3     |
| Dual Targets           | S                      | 30   | 8     |
| Split Spread -1.6/4.4 km | D                  | 60   | 30    |
| Deep Targets           | S                      | 30   | 2     |
| End off 6.0 km         | D                      | 60   | 15    |
| Others                 | various                |      | 15    |

**Figure 3: History of 3-D survey design.**

### REVIEW OF THE 'ZIG-ZAG' TECHNIQUE

The majority of land 3-D seismic surveys are recorded with the shot and receiver lines in an orthogonal fashion. From a logistics point of view this is quite satisfactory for surveys using explosives as a source; but for vibroseis operations in relatively flat terrain, this method is undesirable because of the 'dead' time spent traveling from one traverse to the next. A continuous 'zig-zag' operation is geophysically similar and logistically preferable.

The single zig-zag technique (Figure 5a) resulted in rather noisy data and left a considerable acquisition imprint on the data. This was attributed to the 'paired' offset distribution resulting in inadequate suppression of the ground roll and/or multiples. After extensive testing the '90 degree' double zig-zag technique was introduced (Figure 5b). This was economically feasible by introducing two vibrator groups operating in flip-flop mode resulting in much higher production rates thus keeping the cost per sq km similar. The better offset distribution and higher fold resulted in much improved data quality (Figure 4).
The efficiency and quality improvements made over the years (Figure 6) have all been incremental and based on the same basic geometry. Little attention had been paid to investigate if there were radically different techniques or approaches that might result in a breakthrough performance. Therefore a project was initiated to investigate alternatives to our current acquisition technique.

The approach to find alternatives was twofold:

(1) improvements on the double zig-zag technique, and

(2) different acquisition geometries which give better and/or cheaper data.

Using proprietary software, a host of geometries were generated. The most impractical surveys were eliminated and the remainder examined for stack-fold, offset distribution, multiple suppression, maximum shortest offset and minimum longest offset. The study and its follow-up studies yielded two opportunities for improvement: slip-sweep and wide-line.
Figure 5: Standard 3-D acquisition geometry and resulting offset distribution: (a) single zig-zag, and (b) double zig-zag.

Figure 6: Vibroseis cost and quality improvements.
Slip-Sweep Recording

The idea behind slip-sweep recording (Rozemond, 1996) is unnervingly simple: a vibrator group starts sweeping without waiting for the other group’s sweep to be completed. After correlation, a long composed record will result, which can be cut at the appropriate time-zeroes to extract the individual correlated records (Figures 7a and 7b).

The slip-sweep method was tested twice in a prospect in the north of Oman. The test data were recorded with all parameters identical to the production survey (same sweep, same acquisition geometry, same instrument settings). As current hardware cannot accommodate the slip-sweep method, a modified version was employed for the first test. Only two ‘slipped’ sweeps were recorded into one record (rather than ‘continuous’ recording). The data were recorded uncorrelated, the correlation (using one pilot sweep only) was done post-recording. The delay was 8.5 seconds, the sweep length 15 seconds, the listening time 6 seconds, resulting in a total record length of 29.5 seconds before and 14.5 seconds after correlation.

![Diagram of Slip-Sweep Recording](http://pubs.geoscienceworld.org/geoarabia/article-pdf/2/2/205/5438144/wams.pdf)

Figure 7: In the slip-sweep technique the vibrator groups sweep in non-overlapping time-frequency windows. The individual records are recovered by correlation with the vibrator sweep.
The second test was conducted by recording single uncorrelated sweeps and adding them together in the processing center with random delays around 8 seconds. This long record was then correlated with a single sweep and cut at the appropriate times. The second test is considered more realistic in simulating continuous recording.

Figure 8: Comparison of production to slip-sweep technique in north Oman resulted in very similar seismic sections. The line was recorded with the same sweep, acquisition geometry and instrument settings. The four enlarged windows show detailed comparisons from the two sections corresponding to the four arrows.
Figure 8a shows data from the production survey and Figure 8b shows the second test data set. There are very small differences on loop-scale, but neither data set is clearly better than the other, leading to the tentative conclusion that the slip-sweep method does not lead to deterioration of data-quality.
Figure 9: Comparison of production to wide-line technique in north Oman. The wide-line survey, with 8 lines spaced one kilometer apart, is noisier but is less contaminated by multiples.
Wide-Line Recording

The second idea investigated wide-line and ultra-wide-line geometries (up to 10 lines per swath, one kilometer spacing) for dedicated deep target surveys. Test results suggest that data for these acquisition geometries are of at least similar quality (at target level) as standard narrow-geometry surveys (Figures 9a and 9b). Wide-line geometries are more economical than narrow geometries, because once cross-line source offsets are allowed, more cable lines can be laid out, thus allowing the source point density to drop for a fixed fold. On the receiver side the efficiency increase of wide-line geometries is even more spectacular, with the number of channels to be laid out inversely proportional to the receiver line spacing.

For this reason, wide-line geometries are an ideal match for the slip-sweep method: the former speeds up the deployment of the spread, the latter speeds up the sources. If a combination of both methods indeed proves successful, a crew could easily produce 7 times the amount of square kilometers for a cost increase of only 40%! This gives rise to opportunities to greatly reduce cost or increase the quality (Figure 10).

Of course, not all PDO surveys are dedicated to deep targets. However, for other surveys the reduced cost per sweep can be reinvested into quality: with spare source capacity the number of stations per square kilometer (and hence the fold) can be doubled or tripled, multiple sweeps per station can be used to build an improved source array, or the sampling in the common receiver domain can be improved, all for the same cost. Such modifications would be fully in line with the current drive in PDO for quality rather than quantity.

CONCLUSIONS

There is still great scope to increase the efficiency of vibroseis acquisition or to greatly enhance data quality at economic rates. Wide-line geometries offer an attractive alternative for exploration 3-D surveys with deep targets or could replace some 2-D surveys. The slip-sweep recording technique offers a potential increase in efficiency which can be translated into reduced cost or enhanced quality which is applicable to any acquisition geometry. Examples shown of these early tests indicate that slip-sweep recording does not deteriorate the data quality.
ACKNOWLEDGMENT

The authors acknowledge the contribution of various PDO geophysicists over many years who have contributed to the development of the various acquisition techniques. The Ministry of Petroleum and Minerals of the Sultanate of Oman is thanked for permission to publish the paper.

REFERENCES

Al-Kindy, I.H. 1993. Application of 3-D Seismic Technology: Two Case Histories. Organization of Arab Exporting Countries-Institut Français du Pétrole Joint Workshop, Paper 22.

Gardham, R. and W.W. Moeshart 1989. 3-D Seismic Ihsan/Jameel Area (Oman): Results and Implications. Proceedings of the Society of Petroleum Engineers, 6th Middle East Oil Show, 11-14 March, 1989, Bahrain, SPE 17995, p. 717-724.

Onderwaater, J., J.H.H.M Potters and J. Wams 1996. Geophysics in Oman. GeoArabia, Middle East Petroleum Geosciences, v. 1, no. 2, p. 299-324.

Rozemond, H.J. 1996. Slip-Sweep Acquisition. Presented at the 66th Society of Exploration Geophysicists Meeting, 10-15 November, 1996, Denver.

ABOUT THE AUTHORS

Jan Wams graduated in 1975 from the University of Delft in Medical Acoustics. He was drafted into the Dutch Army in early 1976 where he researched laser- and night-vision equipment. Jan joined Shell in 1978 and shortly after was transferred to the UK to take up a position in seismic data processing, followed by postings in Thailand and Brunei as a Seismic Interpreter. Jan was transferred back to Holland in 1988 to head the Land Acquisition group, followed by a posting to Yemen as Chief Geophysicist. After a further year in Holland as an advisor on acquisition matters, he joined PDO in 1993 to head the geophysical operations department.

Justus Rozemond graduated in 1988 from the University of Utrecht in Geophysics. He completed his education in Hydrocarbon Exploration at the Institut Français du Pétrole (1990). In the same year Justus joined Shell Internationale Research Maatschappij. He worked on seismic acquisition in the Shell EP Research Laboratory in Holland until 1994, after which he was posted to Oman, where he now works as an Operations Geophysicist for Petroleum Development Oman.

Paper presented at the 2nd Middle East Geosciences Conference and Exhibition, GEO'96, Bahrain, 15-17 April 1996

Manuscript Received 20 January, 1997
Revised 27 April, 1997
Accepted 5 May, 1997