Seismic data acquisition developments in the last decade and in the next – a biased view

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Introduction

Almost simultaneously with the invitation to contribute to this special issue of the Recorder, the January-February 2001 issue of Geophysics happened to arrive. The latter contains a special section: "Geophysics in the new millennium", put together under the direction of Larry Lines (2001), whose name also featured under the letter I received. Fortunately, the scope of the series appearing in this Recorder is a bit more modest; nevertheless the Geophysics papers are a very interesting read, and one may wonder what there is left to be said. Actually, not all that much; therefore, this contribution is heavily biased both by a (failed) attempt to avoid overlap with the Geophysics papers and even more so by my own specific interest in 3D survey design.

Last decade

In the general area of seismic data acquisition, significant changes (not necessarily advances) have been:

- wide-spread use of 3D seismic surveys; no further comment required.
- continued increase in number of channels. Actually, this continual change already started four decades ago.
- more and more powerful seismic vessels leading to ever wider towed-streamer configurations. It seems ages ago, but even in the beginning of the last decade two boats were still being used to tow a meagre total of four streamers.
- introduction of dual-sensor technique. At the 1995 SEG Conference Barr and Sanders received the Virgil Kauffman Medal for their achievements in this field.
- revival of multi-component acquisition, especially marine. Startling success of Statoil with their SUMIC system to see through gas chimneys.
- much improved source signal estimation techniques for airgun arrays have been developed.
- much improved streamer positioning systems have been introduced, a problem really solved.
- time-lapse surveys are becoming routine.

In the more specific area of 3D seismic survey design, a few trends can be observed as well:

- gradual shake-out of fancy designs, such as button patch, pairing of sources.
- gradual change from art mixed with intuition into science mixed with experience.

Recent developments and future directions

In the last year several new techniques have been announced, many of which still need more time to mature (or to shake out again). In the following I will discuss some of those developments in the light of what factors limit quality at present.

Marine streamer acquisition

In marine data acquisition multisource multistreamer (MSMS) configurations are used to acquire 3D seismic data. The ever wider configurations produce an ever more serious limitation to quality. The reason is that the gathers with common inline offset have variable crossline offset. The wider the geometry, the more these gathers deviate from the common-offset-vector gather (COV gather, a single-fold gather with constant absolute offset and constant shot-to-receiver azimuth). Whereas COV gathers are capable of producing perfectly prestack-migrated data, the migrated common inline offset gathers of the MSMS configurations show irregular amplitude and phase behaviour. The problem can be mitigated somewhat by antiparallel acquisition, but fold and expensive processing techniques are needed to further reduce the effect.

An even more serious problem is feathering. Strong differential feathering leads to irregular illumination and requires expensive infill shooting. For a long time it was believed that feathering was a fact-of-life, but last year a major contractor introduced a streamer-steering technique, which does not do away completely with feathering, but which at least can change the feather angle by 3º. In areas with moderate feathering, this technique should ensure a much better illumination. The technique may also be used to pursue repeatability in time-lapse surveys.

Another development announced by the same contractor is the introduction of single receiver points in the streamers rather than arrays. Although sampling is not really a limiting factor in most (or all?) marine streamer acquisition (Ansink et al., 1999), the technique might still lead to lower noise levels at the low-frequency end of the spectrum.

The airgun arrays used for marine data acquisition are basically not different from what was used ten or more years ago. They were designed for optimal source strength vertically down or somewhat into the direction of the streamer being towed behind the source. Moreover, for practical reasons, the largest guns were located closest to the vessel. As a consequence most airgun arrays being used today show considerable variability of the source spectrum, both in inline and in crossline direction. I recently attended a workshop where Dave Hill of WesternGeco demonstrated the limiting effect of source directivity on data quality of marine streamer data. The effect is important for AvO, in particular for the very long offsets, which are becoming more and more important. The remedy is to design and use sources with less dependence of the spectrum on direction..

Marine data acquisition with stationary receivers

The need for isotropic sources is even greater for marine data acquisition using orthogonal or areal geometry with receivers located at the sea bed. Source arrays with less directivity should be doable.

The dual-sensor technique looks like being overtaken by the four-sensor technique. It is difficult to find dual-sensor cables with less than 50 m station spacing, because contractors prefer to invest in the 4C systems (3 geophones plus hydrophone). The 4C cable techniques have advanced considerably in recent years, the depth limitation has eased somewhat and coupling has improved. Yet, some argue that the cable dimensions lead inevitably to vector infidelity with the inline geophone reacting differently to an incoming seismic wave than the crossline geophone. (A seismic acquisition system exhibits vector fidelity when it accurately records the magnitude and direction of a seismic wave in 3 dimensions.)

As an alternative to cables, node systems have been proposed. Nodes are containers with three geophones and a hydrophone planted by a subsea robot and can be operated in almost any water depth. These systems have better vector fidelity in the sense that the two horizontal geophones show exactly the same behaviour. The system itself may still affect the signal to be recorded in case its density is not matched to the density of the sea bed. Until recently the nodes were still connected by a cable to a recording vessel, but now self-contained node systems have been introduced as well. These systems record all data locally at the sea bed. Because of the expense of the units, they can only be cost-effective when deployed in areal geometry (sparse distribution of nodes, dense distribution of shots).

The advantage of 4C acquisition is that shear-wave information is recorded for a better assessment of the subsurface. The disadvantage is that this information comes in the form of converted waves, which show asymmetric behaviour. For azimuth-dependent analysis a wide-azimuth geometry is required, either orthogonal or areal. Orthogonal geometry introduces a strong directivity in the measurements because resolution and subsurface illumination are asymmetrical. The 3D receiver gathers acquired with areal geometry do not have a directional bias, hence may be better suited for azimuth-dependent analysis. The disadvantage of low converted-wave illumination fold of this geometry is partially compensated by a large signal-to-noise ratio improvement in the prestack migration process (the high signal-to-noise ratio is caused by the high trace density in the illuminated areas). A beautiful opportunity of areal geometry acquisition is to acquire simultaneously a short-offset 3D cube by towing a short streamer behind the shooting vessel.

The converted waves may be very successful in revealing the structure where P-wave data fail due to gas chimneys, but a disadvantage is that they suffer from serious loss of high frequencies. A large part of these frequencies is absorbed in the first few meters of the muddy sediments that often form the sea bed and where shear wave velocities are very low. Eventually, subsea robots may be used to bury the 4C sensors, thus mitigating the loss of high frequencies in the last part of the raypath.

Land data acquisition

The majority of 3D seismic surveys is still aimed at acquiring P-wave data only. In the process, ground roll, shear waves and guided waves are being acquired, but these are considered noise. This noise in P-wave data acquisition is the main limiting factor in data quality. Yet, much of the noise could be removed by using finer station intervals. In the past, 2D acquisition has experienced tremendous improvements in data quality by a changeover to smaller station spacings, in the order of 20 or 25 m. This produced awfully looking monitor records, but allowed noise removal by dedicated processing techniques rather than by inadequate field arrays. The same sampling requirements apply to 3D data. Yet, we still see many surveys with 50 or even 60 m station spacings, thus inhibiting the use of sophisticated prestack noise removal techniques in processing.

About a year ago, single-sensor systems were announced by a major contractor, whereas others are also offering systems with potentially high channel counts. Introduction of these systems for P-wave acquisition would definitely constitute a quantum leap forward, but I have the feeling that it skips over a phase with the application of 20 m station spacings and corresponding shot and receiver arrays. This phase might already give data quality as fit for purpose as can be.

Another potentially limiting factor for data quality is the terrain condition with various obstructions, often forcing deviations from the planned station locations, in particular of the sources. Conventionally, alternative locations are selected on basis of an "offset and skid chart" (Cordsen et al., 2000), which does not take into account that source positions should as much be related to each other as receiver positions. The objective should be to acquire common receiver gathers which are smooth and continuous in much the same way as shot gathers are acquired normally (Cordsen et al., 2000, Vermeer, 2001). The extra effort required to find such solutions is well spent, because only then spatial discontinuities will be reduced to a minimum.

Single-sensors may be essential for the best way of acquiring multi-component data on land. In the first place, sampling requirements for acquiring shear wave data are determined by the slower shear-wave velocities, which are close to ground-roll velocities. Hence, alias-free recording of shear waves is nearly the same as alias-free recording of ground roll and it does not make sense to use inline arrays for ground-roll suppression. Secondly, if arrays were used, the sensors would have to be lined up exactly for optimum array responses. Currently, there are systems on the market that can measure their tilt, but ensuring the correct orientation while planting is not possible (yet).

Thomsen (2001) expects that converted-wave surveys will come to replace shear-source surveys. However, converted-wave acquisition and processing is fraught with problems due to the asymmetry of the wavefield. In the near future 3C vibrators will come on the market allowing controlled emission of P- and S-waves in a much more cost-effective way as used to be possible with separate P- and S-wave vibrators. Together with the newest digital sensors, and appropriate vector fidelity, it should become possible to acquire really high quality multi-component data on land. It would be very expensive to get this high quality, but it might well pay off due to the higher resolution and better subsurface definition possible with these data.

The instrumented oilfield

An important new direction in seismic data acquisition is the so-called instrumented oilfield. As I cannot word this any better than Lumley (2001), his paragraph on this subject is copied here in its entirety:

"A final thought on the road ahead is the trend towards the fully instrumented oilfield. This concept involves wiring up an oil reservoir with every imaginable monitoring sensor in boreholes and on the earth's surface. The monitoring data would be available in near-real time so that the asset team could make a reservoir management decision and track its impact with continuous monitoring feedback. Many of the instruments for such permanent sensor applications will use fiber optics to overcome the long-term reliability concerns of electronic systems. Seismic monitoring information may not need to be as continuous and real time as borehole pressure and temperature sensors since the 3-D reservoir volume at seismic resolution does not change as fast. Soon, low-cost multicomponent P- and S-wave seismic sensors will be available to emplace in both boreholes and along the earth's surface to provide on-demand 3-D snapshots of the reservoir's condition. These seismic surveys, while probably not continuous or real time, will undoubtedly be demanded at short notice with minimum delay from the time of acquisition to the delivery of final images. These challenging cycle time and geometry requirements will drive the development of a new wave of seismic acquisition hardware, processing, inversion, interpretation, and analysis software; and multidimensional visualization capabilities for future real-time time-lapse seismic monitoring."

Seismic survey design

Seismic survey design should give high attention to acquiring data optimally suited for prestack processing, in particular noise removal and prestack imaging. These requirements are explicitly addressed by 3D symmetric sampling, which ensures proper sampling of at least two of the four spatial coordinates. Nobody would challenge the requirement of spatial continuity of stacked data as a prerequisite for artefact-free migration. Exactly the same continuity can be and should be achieved in the acquisition of the single-fold subsets (cross-spreads or 3D receiver gathers) of each acquisition geometry, thus allowing prestack migration of these subsets with a minimum of artefacts. Some artefacts are inevitable due to inevitable spatial discontinuities (cross-spread edges) in these geometries, but these have to be suppressed by extra clever processing steps or merely by the effect of fold. After all is said and done, prestack migration should produce considerably better results than poststack migration.

It may take a while, but eventually designers of 3D surveys will stop using brick geometries, skidding and offsetting charts, narrow orthogonal geometries, zigzag geometries, and perhaps even slanted geometries.

In this journal a remark should be made about the mega-bin technique. The mega-bin technique aims at as-well-as-affordable sampling of all four spatial coordinates. As a consequence, none of the coordinates is properly sampled, whereas the data do not suffer from edge effects like cross-spreads do. The coarse sampling would lead to migration artefacts throughout, except in cases where interpolation can be successfully applied to reduce the sampling intervals. Apparently this is the case in the Alberta plains, but it would be prohibitively expensive to make the mega-bin technique successful in more demanding geology like the foothills.

Acknowledgement and remark

I would like to express my gratitude to Kees Hornman for his quick review of this paper allowing me to remove some of my own biases and replace them with his'. It should be clear that in an overview like this the number of references might fill several pages. I chose to include only a short list.

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