9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-525

# Lessons taught and learnt in a DISC course on seismic acquisition

***Julien Meunier****, *CGGVeritas*

***Summary***

*An instructor essentially teaches. The two main messages that I tried to communicate to audiences around the world were that, for prestack migration, the source and the receiver line intervals are two key parameters for spatial sampling and that we need to revisit our notion of S/N ratio especially for modern high density 3D seismic surveys. But the instructor also learns and not only while preparing the course. Most importantly, I learned that I did not know much. I also learned that geophysical advances are often connected to new developments in other domains and I learned that conservatism has been one of our constant characteristics. Perhaps it is time to change?*

***Keywords****: Seismic Acquisition, Resolution, Spatial sampling, Signal-to-noise ratio, Sweep rate,*

## Introduction

The first seismic survey took place in Ireland in the mid nineteenth century (Weatherby, 1940). I learned that story when preparing my DISC course and I was amazed when I realized that most of the components of modern seismic surveys (surveying, drilling, shooting, receiving and recording) were gathered by Robert Mallet (Figure 1) for the first seismic experiment.

Figure 1: Robert Mallet, Irish geophysicist (1810-1881), undertook the firs t seismic experiment in 1851.

He did observe seismic waves and could measure their velocity. He found a velocity of 825 ft/s in the sand, much slower than the actual velocity. The cause of his failure, lack of sensitivity of his instruments, was very similar to the causes of some of our modern failures. I learned many other stories and I cannot tell them all here. I shall rather report on the three main lessons that I learned during the preparation of the course: First and most importantly, I discovered how little I knew of things I believed I knew. Then, it has become very clear in my mind that most progresses obtained in our industry are related to advances in other fields of activity. And also I was very surprised by the contrast between our thirst for innovation and our conservatism, which takes many years to recognize genuine innovation. These learnings seem very different from what I have tried to teach to others during the same course. The two main messages were that we need to revisit our notion of Signal-to-Noise ratio and that line intervals are a key parameter in a seismic survey. The developments below are essentially extracted from the book I prepared for the DISC course (Meunier, 2011).

## Lessons taught.

It would be more correct to talk about lessons intended to be taught. I would have liked to unify all the messages into a single one: Seismic acquisition is the first and most important step of seismic imaging. Sampling of the observation domain, and Signal-to-noise ratio, which control respectively aliasing limits and achievable quality of the seismic image are defined during this phase. No matter how clever a processing geophysicist may be, he will always need an assumption to replace or interpolate missing data and he will always find it more difficult to extract an acceptable image from noisier data.

*CGGVeritas, 27 avenue Carnot, 91341 Massy Cedex, France.*
*Email : julien.meunier@cggveritas.com*

***Sampling requirements*** are well understood for zero-offset data, which, in practice, do not exist. We no longer accept CMP stack as an approximation of zero offset data. To construct high fidelity images, we need prestack migration but do we fully realize that sampling requirements are not the same for post-stack and pre-stack migrations? The later necessitates adequate offset sampling in each bin. Even more, we have recognized that wide azimuth seismic acquisition will result in better seismic images; consequently, azimuth also must be adequately sampled. Gijs Vermeer (1998) and Peter Carry (1999) have shownthat in 3D, the Source-receiver vector should replace the (arithmetic) offset, which we have been using so far. They called it offset-vector. To preserve, as much as possible, offset and azimuth information throughout prestack migration, They have proposed to use Offset Vector Tiles (or OVT) for prestack migration of orthogonal 3D geometry. OVT are subsets of cross-spreads illuminating an elementary cell between two source and two receiver lines. Unless (source and receiver) line intervals are identical to (source and receiver) station intervals, there will be discontinuities in the arrival time surface corresponding to the observation of a given diffracting point through OVTs. The periodicity of these discontinuities is the (source and receiver) line interval and the amplitude of the discontinuities is proportional to the line interval. Two OVTs corresponding to a sparse and a dense geometry are represented on figure 2.

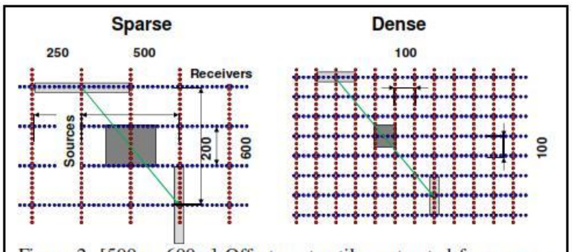

Figure 2: [500m -600m] Offset vector tiles extracted from sparse and dense acquisition geometries.

They have the same average offset vector (X = 500m, Y = -600m). The sparse geometry uses a 250-m source line interval and a 200-m receiver line interval. The dense geometry uses 100-m for both source and receiver line intervals. Figure 3 represents vertical slices of a diffracting point image observed through these 2 OVT. The few large discontinuities of the sparse geometry have resulted into significantly larger artifacts than the many small discontinuities of the dense geometry.

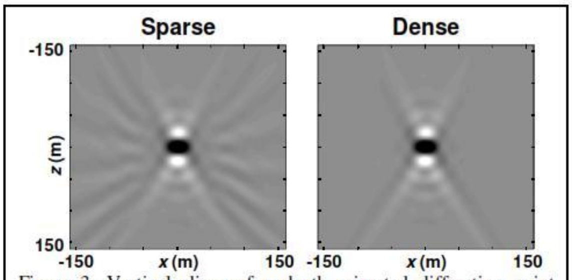

Figure 3: Vertical slices of a depth migrated diffracting point observed through the Offset Vector Tiles of figure 2.

It is remarkable that line intervals also control the periodicity and the amplitude of residual ground roll and multiple reflections that leak through 3D stack and migration. For both a signal and a noise reasons, they are a key parameter of 3D spatial sampling.

***Signal-to-Noise ratio.*** Source Strength is a seismic acquisition parameter that becomes more and more critical. Large source arrays are not compatible with resolution increase, which is a constant concern of seismic interpreters. Since it is very difficult to concentrate a large amount of source energy in a reduced area, source strength is more and more often being reduced. Can a relatively weak source (reduced size air gun array offshore or minihole array and single vibrator onshore) provide enough signal to illuminate a given target? In 2D seismic surveying, the answer to this question can be provided by field tests: Various source strengths are compared by recording a short 2D line with various source strengths. The corresponding data are often processed overnight and the decision is made by comparing seismic images reasonably similar to final images that would have been actually obtained using the various source strengths. Such an approach is considerably more difficult in 3D seismic surveying. Recording the 3D data needed to create a 3D (migrated) image would take significantly more time and processing these data would necessitate weeks or even months instead of days. Therefore, a different approach is needed. Signal-to-organized-noise ratio does not depend on source strength: larger source strengths will result in larger signal amplitudes and in larger ground roll and multiple reflections amplitudes, in the very same proportion. Source strength only affects Signal-to-ambient-noise ratio. A way to estimate the effect of acquisition parameters on signal to noise ratio of the seismic image is to consider this image as a sum of seismic traces in an area around the image point. If the number of traces in this area is increased, the Signalto-noise ratio of the seismic image will improve. If ambient noise recorded on each of these traces is uncorrelated, the improvement will be proportional to the square root of the number of traces. Signal-to-ambient-noise ratio at any given frequency f, must be evaluated over one unit of the observation surface using the following formula:

$$SSE(f) = SS(f)\sqrt{Sd\,Nr\,Ngeo} \qquad (1)$$

where *SSE* is a signal strength estimate, *f* the frequency, *SS* the source strength, *Sd* the source density, *Nr* the number of receivers per station, and *Ngeo* the number of geophones in the receiver array. Note that trace density is the product *Sd Nr*. Also note that the parameter *Ngeo* is only correct when the interval between geophones is large enough. The example shown on figures 4 to 6 supports this formula: the same AVO effect

$$A(\theta) = r_0 + k\sin^2(\theta) \quad (\text{with } r0 = 1 \text{ and } k = -1.5)$$

is observed in identical noise situations through 2 different acquisition geometries:

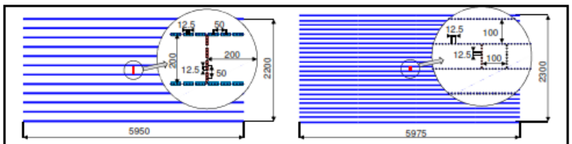


Figure 4: Acquisition geometry

| | A Conventional | B Point source point receiver |
|---|---|---|
| Group interval | 50 m | 12.5 m |
| Number of groups/line | 120 | 480 |
| Line interval | 200 m | 100 m |
| Number of lines | 12 | 24 |
| Receiver Array | 4 over 50 m | point receiver |
| Source interval | 50 m | 12.5 m |
| Source line interval | 200 m | 100 m |
| Source Array | 4 over 50 m | point source |

(A) is a conventional geometry with 4 holes per SP over 50m and 4 geophones per receiver over 50m, The (source and receiver) line intervals are 200 m, the bin size 25 m, and the fold 90. (B) is a point-source-point-receiver geometry with twice the number of lines and 4 times the number of receivers per line. The line intervals are 100 m, the bin size is 6.25 m and the fold 360. If the charge used is the same as the elementary charge in each hole of geometry A, the source strength of geometry B is divided by 4. Consequently, the SSE of geometries A and B are identical. Figure 5 represents 1 CMP of geometry A and 16 CMPs of geometry B (representing the same 25*25m² area) recorded in the same noise conditions. The S/N ratio in each trace of A is 8 times the S/N ratio in each trace of B. There are 90 traces in the CMP of geometry A and 64 times more traces in the 16 CMPs of geometry B. The data are sorted by increasing offset.

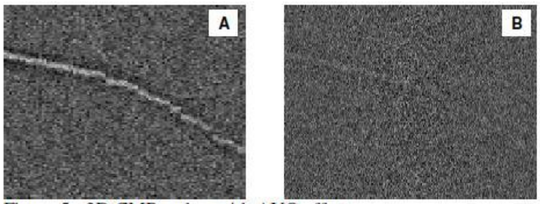


Figure 5: 3D CMP gather with AVO effect
A 1 CMP of geometry A (25*25m²)
B 16 CMPs of geometry B (6.25*6.26 m²)

Figure 6 represents 100 AVO analyses with 100 different noises on these 2 data sets. Each green curve represents one analysis. The red curve is their average and the blue curve the input AVO effect. The dispersion of the results provides an estimate of the precision of the analysis.

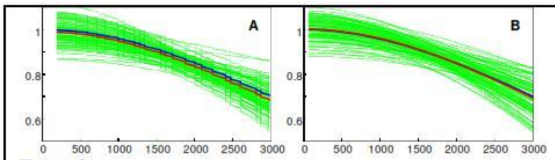


Figure 6:
A AVO of 1CMP of geometry A (25*25m²)
B AVO of 16 CMPs of geometry B (6.25*6.26 m²)
Green: Analysis of 100 realizations of noise
Red: Average realization
Blue: Theoretical curve

The same dispersion is observed for geometries A and B in agreement with the fact that they have the same SSE, which, at least in this case, is the correct indicator of relative S/N ratio expected from these 2 acquisition geometries. The difference between these analyses is the bias found for the gradient in the case of geometry A. This bias is a consequence of the relatively large field arrays (50 m), which attenuate the amplitude of traces with large offsets more that the amplitude of traces with small offsets.

## Lessons learned while preparing the course.

The following were initially not intended to be specifically taught during the course.

***Know that you do not know.*** It is more than embarrassing it can even become scary, when you are about to teach a course and suddenly realize that what you have always taken for granted is not that clear in your mind after all.

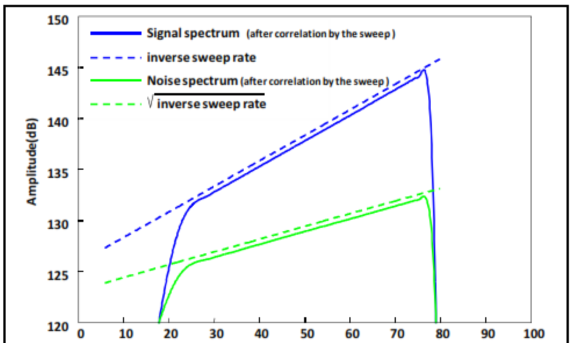


Figure 7: Signal and noise relationship to sweep rate
The signal is a 10-s logarithmic sweep with an amplification of 0.25 dB/Hz.
The solid lines represent the amplitude spectrum of the correlation of the sweep (in blue) and white noise (in green) by the sweep.
The dotted lines represent the inverse sweep rate in blue and the square root of the inverse sweep rate (in green)

This happened to me many times and in particular when I wrote on the proportionality between the inverse sweep rate and the sweep amplitude spectrum (Meunier, 2010, p 116). I had to design a logarithmic sweep rate, construct the corresponding sweep, and compute its amplitude spectrum to prove the point to… myself. (Figure 7).

I must recognize that I did not attach to Hooke's law of elasticity all the importance it deserves to understand seismic wave behavior. I found out that I was not the only one… Perhaps this poor judgment is connected with Hooke's unorthodox way of publishing his law. Instead ofpublishing it in a serious and intimidating scientific book as anyone would have done, he used the unconventional form of anagram (word formed by reordering the letters of another word) and published the following and mysterious message: CEIIINOSSSTTUV. He must have enjoyed waiting two years for someone to find its meaning. As nobody found, he gave the solution himself, in Latin: "Ut tensio sic vis" meaning "as the extension, so the force".

I felt that resolution or more precisely, insufficient resolution was one of the major challenges of modern seismic images. In this domain, some remarkable progresses have been obtained especially in marine seismic surveys when I was preparing the course. My perception of resolution was very vague when I started and I had to spend some time on books before seeing some light.

***Contradiction between geophysicists thirst for innovation and conservatism.*** One of the most informative stories on this matter is the marine streamer story: in 1947, R. Paslay, G. Pavey, and P. Wipff patented the oil-filled seismic streamer. Their employer was not interested so, hoping for clients, they started their own company and acquired a wooden boat that towed an eight-group streamer (Lawyer et al., 2001). The first account of the seismic streamer that I have found in GEOPHYSICS was the 1953 report on geophysical progress by Cortes, which ends as follows:" Among the improvements are the detonation of the dynamite charges suspended within the water and the use of self-pivoting, semi-floating geophones. One method has been developed for both shooting and recording from a single ship that tows a line of hydrophones which pick up the seismic signals while moving through the water." 6 years after the patent was granted, the seismic streamer was considered less important than "dynamite charges suspended within the water and the use of self-pivoting, semi-floating geophones"… Similarly, it is very surprising that Mayne's patent on the CDP method, although its innovative character was undisputable (see figure 8), took 6 years to be granted; not to mention the time it took to fully deploy the technique.

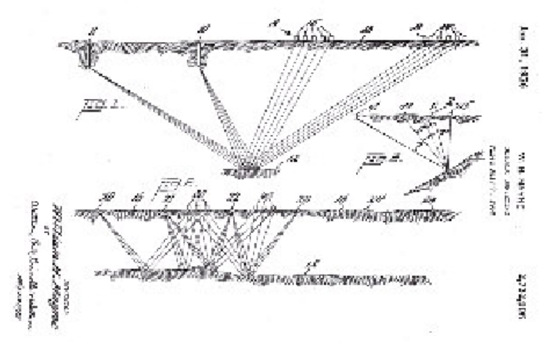

Figure 8: The CDP method, Seismic Surveying: US Patent 2,732,906 Jan 31, 1956.
The same subsurface area (12) is illuminated either by the combination of Source (10) and receivers (A) or Source (11) and receivers (B).

***Relationship between advances in various fields and progress in the seismic industry.*** The link between the computer power increase and the use of more rigorous algorithms is quite obvious because it occurs today, under our eyes. But similar links have always existed. First of all, our industry was born from the search for better earth quake understanding; it is greatly indebted to this science.

Refraction prospecting was triggered by the difficulty of gun localization using the refracted wave associated with gun firing during World War I. We owe a lot to the military. The take off of reflection prospecting received a significant boost from the extra sensitivity provided by the vacuum tube amplifier; since then, electric engineers developing seismic systems have constantly benefited from advances in professional or consumer electronics.

## Conclusions

Learning must remain an everyday concern. Learning from books and reviews published in our field of activity but also from what occurs in other fields. Sometimes, it can be fun! Geophysicists in general show a lot of enthusiasm about their work. But they often also show a lot of conservatism. I wish we keep our enthusiasm bur relinquish our conservatism.

It would be foolish to rely exclusively on algorithmic refinements to provide us with the enhanced seismic images we need to better describe the earth interior. Without adequate sampling of the observation surface, the most sophisticated imaging algorithms will still find aliasing limits. Without adequate signal-to-noise ratio, the most sophisticated de-noising algorithms will have a hard time differentiating signal from noise. Avoiding these shortcomings in the most economical way is a difficult task, to which we should dedicate a larger proportion of our most brilliant minds. It is one task of the acquisition geophysicist.

## References

Cary, P.W., 1999, Common-offset-vector gathers: an alternative to cross-spreads for wide-azimuth 3-D surveys: presented at the 69th Annual International Meeting, SEG

Lawyer,L. C., C. C. Bates, and R. B. Rice, 2001, Geophysics in the affairs of mankind: SEG Geophysical Reference Series No 10.

Mayne, W.H., 1956, Seismic surveying: U. S. Patent 2,732,906

Meunier, J., 2011, Seismic Acquisition from Yesterday to Tomorrow: SEG Distinguished instructor series n°14.

Vermeer, G. J. O., 1998, Creating image gathers in the absence of proper common-offset gathers: Exploration Geophysics 29, 636-642

Vermeer, G. J. O., 2002, 3-D seismic survey design: Society of exploration geophysicists, Geophysical references series No 12.

Weatherby, B.B., 1940, The history and development of seismic prospecting: Geophysics, 5, n°3, 215-230