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Maximizing Information Content of Seismic Data through Optimized Acquisition Design - A Case History from South Tunisia

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SUMMARY

The objective of this Land seismic case study is to share the learnings ENI and CGG gained from a field test performed in the course of a production project located in South Tunisia. The objective of this study was to evaluate how to optimally use the available field equipment to Maximize the information content of the seismic data for the purpose of enhanced structural and quantitative interpretation. The use of single vibrators, of smaller receiver arrays and reduced slip time, did allow, using the same equipment, to efficiently acquire the seismic data with a trace density significantly higher than conventional coverage. Final Imaging results illustrate that Trace density and not source strength, is the key parameter that controls the qualitative and quantitative seismic Imaging value of the Subsurface

Introduction

Numerous evaluations, conducted on various sites, converge towards a shared conclusion: that the geophysical value of an acquisition is primarily driven by the density of traces acquired in the field. To confirm this principle also applies in North Africa, ENI and CGG agreed on a technical collaboration. The objective of the collaboration was to demonstrate, on a crew operating in the South of Tunisia that, without additional equipment, using modern high productivity schemes it was possible to efficiently increase the conventional Trace Density by a factor of 10 to 50 with a significant increase in geophysical value all throughout the processing, imaging and interpretation steps.

From Heavy & Sparse to Light & Dense

With the objective of building up trace density without additional field equipment we choose to move away from the conventional heavy field layout involving 4 vibrators per source position and 12 geophones per receiver location to a lighter geometry with a single vibrator per source position and 6 geophones per receiver location. As expected, one can observe on *Figure 1* that by lowering the source strength, the weaker seismic signal moves closer to the ambient noise amplitude level. This has been the historical motivation for using a heavy layout in the field. Heavy layout of field arrays has the undesired side effect of monopolizing a lot of equipment, and slows down crew progression and so reduces productivity. Consequently heavy layout often implies sparse acquisition. The heavy layout approach is questionable when it is recognized that ambient noise is of secondary importance compared to the near surface shot generated waves which contaminate the weak reflections from the reservoir levels. This near surface shot generated "noise" comprises direct and back scattered ground roll, near surface guided waves as well as all of the near surface generated multiples, amplitude and phase corruptions which distort the reservoir reflected signals.

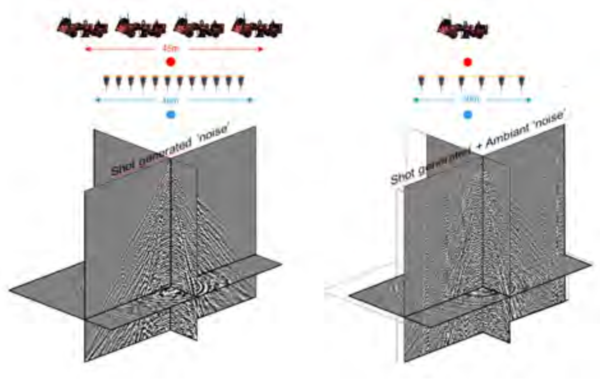
One can easily understand that using a heavy layout does not avoid these contaminations. As a matter of fact the use of four vibrators per source point increases the amplitude level of the reflections by four but also increases by four the amplitude of the shot generated near surface contaminations.

The most appropriate way to solve the shot generated near surface contamination is made obvious once you realize there is a move out difference between the fast subsurface reflections and the slow and near surface wave fields. This move out difference allows for an efficient signal and noise separation either by stacking along the noise directions to extract a noise model, while cancelling the signal which is not aligned (3D Linear Noise Attenuation), and/or by stacking along the signal directions to extract the signal while cancelling the unaligned noise (3D pre-stack migration). The effectiveness of this move out based separation increases with the number of traces involved in the summation process and so with the number of traces acquired per unit of acquisition surface: the so called Trace Density (TD). Advantageously, TD also allows reducing the ambient noise while performing both the 3D LNA and 3D pre-stack migration.

The trace density is expressed in millions of traces per km^2. This number can be easily computed by dividing the fold by the bin area expressed in m^2 (number of traces/m^2 = millions of traces/Km^2). To illustrate the benefit of a Light & Dense acquisition compared to a Heavy & Sparse acquisition we acquired one dense data set, from which two decimated data sets were produced.

V1 field test

The V1-CP field test (Light & Dense), involved a single vibrator (V1) per source location (CP for CarPet shooting) with a sweep length of 20s over the (2-100Hz) bandwidth while the CONVentional way to acquire the data (Heavy & Sparse) involves four vibrators per source location with a sweep length of 36s over the (3-72Hz) bandwidth. The Source/Receiver Line Intervals (SLI/RLI) as well as the Source/Receiver Increment along those line (SI/RI) are described in *Figure 2*. The important point to notice here is that the V1-CP data set has a Trace Density that is 50 times higher when compared with the CONVentional acquisition. From V1-CP we were able, through source & receiver decimation, to simulate a Cross Spread (V1-XS) and a NoDal (V1-ND) acquisition with a trace Density 10 times higher when compared to the conventional acquisition.



Design	Sweep (Hz)		SLI (m)	SI (m)		RLI (m)	RI (m)	BS (m²)	Fold	Trace Density
CONV	3-72	4	280	40	12	280	40	20x20	145	0.36 (x1)
V1-CP	2-100	1	30	30	6	150	30	15x15	4100	18.22 (x50)
V1-XS	...	....	150	30	....	150	30	...	842	3.74 (x10)
V1-ND	....	....	30	30	....	150	150	...	842	3.74 (x10)

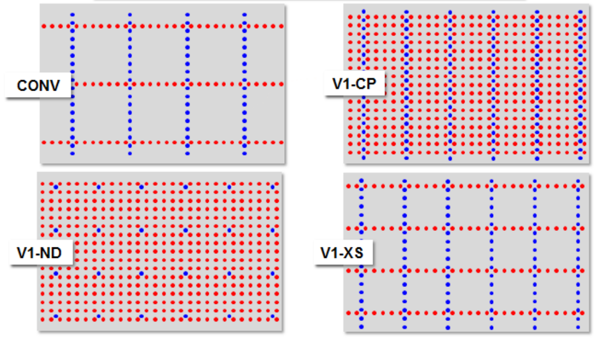


Figure 1 *CONVentional acquisition on the left involves 4 vibrators per source location and 12 geophones per receiver location. V1-CP acquisition test utilized 1 vibrator per source location and 6 geophones per receiver location.*

Figure 2 *Acquisition geometries related to the CONVentional seismic acquisition and the dense field test V1-CP.V1-XS, V1-ND are the decimated datasets derived from the V1-CP data.*

Value of trace Density before Pre-Stack Migration

The value of Trace Density on the data pre-conditioning before imaging is illustrated in *Figure 3* with the Signal to Noise Ratio (SNR) measured on NMO stack sections after 3D Linear Noise Attenuation (LNA). Although SNR levels are significant on the low frequencies one can observe degradation at higher frequencies. There is a crossing frequency, fc, at which noise levels pass above the signal levels. With increasing TD, it is observed that fc, shifts from 30Hz towards higher frequencies and is at 50Hz for V1-CP dataset. The SNR improvement due to TD is of great value for the computation of the surface consistent operators (residual statics, gain and deconvolution operators) aimed at correcting the near surface distortions. With increased TD, these operators exhibit much less variability and better spatial zonation, which indicates a signal driven rather than a noise driven solution. Through better signal driven surface consistent corrections, TD is expected to improve the vertical resolution of the Seismic image.
As a side comment, we have observed slightly more efficient 3D LNA on back scatter ground roll removal when performed on 3D Receiver Gathers (V1-ND) compared to 3D Cross Spread Gathers (V1-XS), in line with J. Meunier, 1999 analysis

Value of trace Density after Pre-Stack Migration

Pre-stack migration has a major positive impact on SNR levels, it is therefore important to consider the combined effect of 3D LNA and 3D pre-stack imaging for a meaningful SNR comparative analysis between various acquisition scenarios (an analysis solely based on elementary shot gathers is not relevant). After pre-stack imaging, *Figure 4*, noise levels are now below signal levels over the entire seismic bandwidth of interest. One can still observe significantly higher SNR over low frequencies compared to high frequencies. TD effectively increases SNR especially towards high frequency. These observations suggest that we could rebalance SNR between LF and HF by reducing the source strength through an increased sweep rate over the LF to further improve on the HF either by spending more time on the HF or even better by reducing the source point increment. Although already noticeable and measurable on Full Pre-STM stacks, the benefits of TD is reinforced, at all depth levels, from the shallowest to the deepest horizons, when looking at the Pre-STM angle stacks used in AVO analysis.

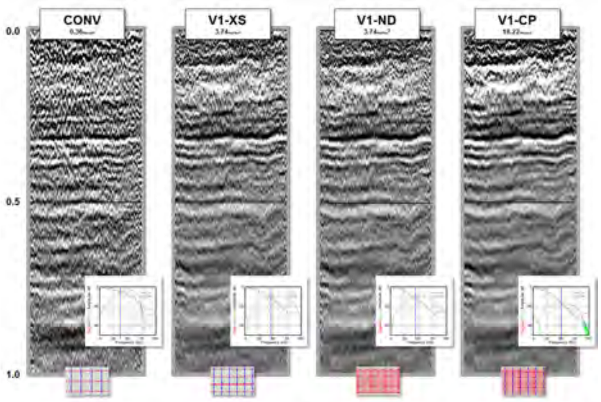


Figure 3 *3D LNA + NMO Stack.*

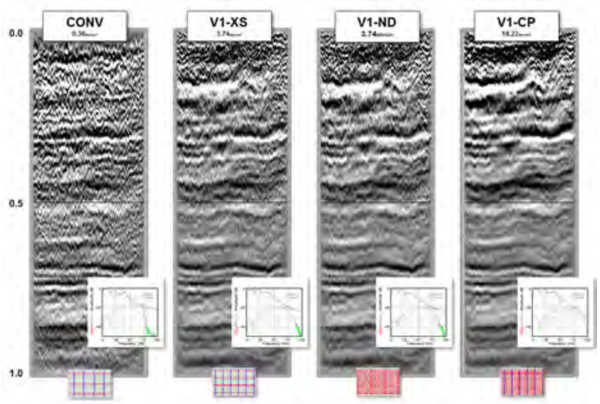


Figure 4 *3D LNA + PreSTM Stack.*

Value of Trace Density on Seismic Attributes

As promoted by Ourabah *et al*., 2014 the qualification of an acquisition scenario is best performed through the analysis of seismically derived attributes.

Let's consider first the ability for an automatic horizon picker to track an entire horizon starting from a single seed. Doing so over 3 horizons (shallow/intermediate/deep), *Figure 5*, unambiguously shows an improved propagation of the picking all along the seismic interface at all depth levels, when TD increases. As a consequence TD allows for a fully data driven interpretation, without the need for subjective, user dependent input. After interpolation, *Figure 6*, one can also realize the ability, with the highest density, to highlight the most subtle stratigraphic details. With lower TD, the residual noise left in the image leads to significant jittering in the picking which makes the identification of subtle changes difficult. This exercise can be repeated per octave with, as expected, an outstanding picking propagation & robustness on the LF which progressively degrades for increasing frequency. This reinforces the link between TD and frequencies: a higher TD is needed for good SNR on HF data.

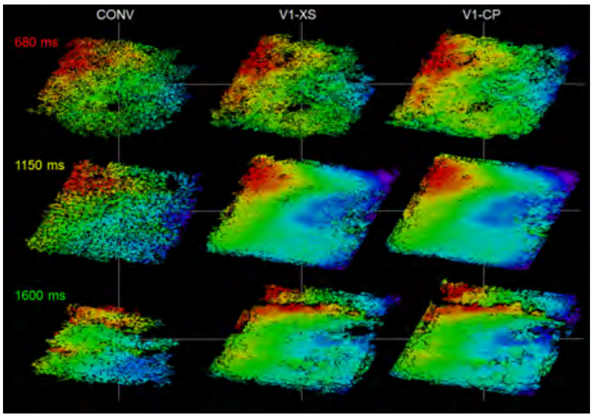


Figure 5 *Raw horizon time picks from Auto picking.*

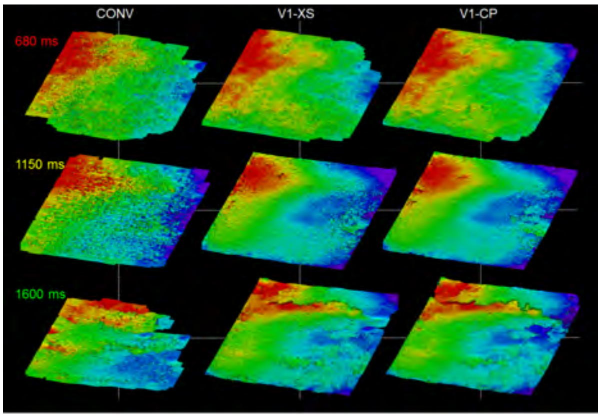


Figure 6 *Interpolated time picks.*

Let's now consider another way to quantify the geophysical value of an acquisition based on the SNR of AVO, AVAZ attributes, as a measure of the ability to use seismic amplitudes to retrieve subsurface impedance contrast and fracturation angle. In our analysis we have considered: the stack, the intercept, the isotropic and anisotropic Gradient as defined in *Figures 7, 8*. These attributes have an increasing sensitivity to residual 'noise' content in our image gathers; as such they can be used as a gradual measure of the ability of an acquisition to retrieve reservoir oriented attributes. Without any post imaging data preconditioning the CONVentional acquisition scenario shows very limited to no value in the use of the amplitudes, while with the V1-CP scenario, a direct use of the amplitudes for

AVAZ purposes brings valuable and organized information. Involving appropriate post imaging data preconditioning the situation improves the CONVentional scenario but does not allow compensating for the value of TD.

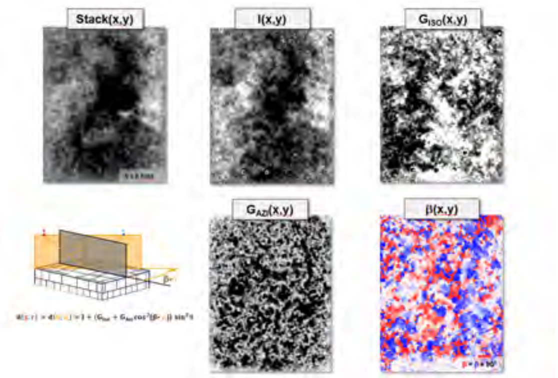


Figure 7 *CONV AVO/AVAZ Attributs at 680ms.*

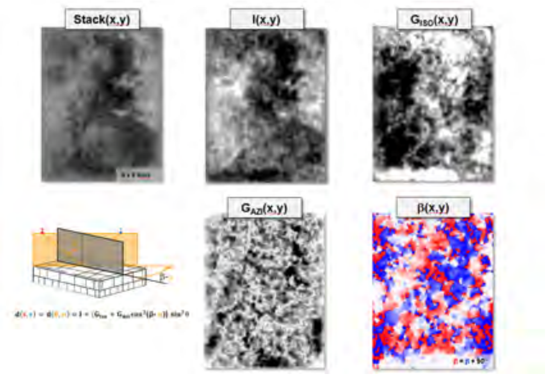


Figure 8 *V1-CP AVO/AVAZ Attributs at 680ms.*

Conclusion

Trace Density, and not source intensity, is a key ingredient which drives the geophysical value. The historical focus on source strength alone should definitively be replaced by a focus on TD. This has been nicely illustrated with a consistent increase in SNR with TD over a large range of attributes. The SNR are frequency dependent, significantly higher for low frequencies compared to high frequencies. Although Broadband sweeps are mandatory, our observation calls for a reduction of source strength, with a higher sweep rate over the low frequencies, to possibly improve the SNR over the high frequencies either by reinforcing the source strength, with a lower sweep rate on the high end side of the spectrum or even better with shorter sweeps combined with reduced source point increment. Importantly the close geophysical equivalence observed between V1-ND and V1-XS makes it clear that source density and receiver density individually are not the right metric to measure the geophysical value: only TD matters. This offers unique operational opportunities to most effectively build up TD by choosing the most appropriate source-receiver deployment that takes into account all operational constrains including permitting, obstacles and ground conditions. Equipment distribution rather that equipment clustering through field arrays should be rule, and by doing so TD becomes more attainable without additional equipment. When combined with a spectral rebalancing of the sweeps, shorter sweep time and high productivity schemes we have numerous levers for an efficient move from Heavy and Sparse to Light and Dense acquisitions. The lessons learnt from a 3 day field test are quite significant, we believe they apply worldwide.

Acknowledgement

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References

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