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A Step Change in Seismic Imaging Quality in Western Desert of Egypt - An Acquisition Case Study

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Summary

Land Seismic value has drastically improved with the addition of two key ingredients at the acquisition stage which have significantly increased the geophysical information captured in the seismic recordings. The first one, on the seismic source side, corresponds to the broadening of the seismic bandwidth with the addition of at least two octaves at the low frequency side of the spectrum, thanks to advances in seismic vibrator technology. These additional low frequencies reveal deep structures which were not possible to observe before and lead to sharper and more stable seismic wavelets which are more suitable for reservoir characterization applications.

The second one is related to higher signal-to-noise ratios achieved through denser data acquisition. This was made possible by the development of cost-effective high productivity acquisition solutions allowing a dramatic increase in the number of measurements that can be produced per day using a given set of equipment. This communication aims to review notions like seismic bandwidth and octaves, subsurface reflectivity and impedance imaging, for a good understanding of the value these new developments bring to the knowledge of the subsurface. This will be illustrated with a recent case study from the Western Desert of Egypt

Introduction

The "good ingredients" for high value land seismic are well known through the learnings gained from numerous field tests conducted over many places with a diversity of ground and subsurface conditions. By high value seismic we mean the ability to image structural and quantitative attributes with high resolution and high signal to noise ratio from acquired seismic data: to image equally well all geological scales with minimum uncertainty for more suitable reservoir characterization applications. The mandate of acquisition design is to maximize, under budget, time, equipment and ground condition constraints, the information value captured by the seismic experiment. In doing so, we limit the need for suggestive, uncertain interpretation a priori, in order to fill the inaccessible reservoir information from the seismic data. This is achieved by maximizing two metrics: spatial trace density and the number of temporal octaves generated by the seismic source. Trace density is a measure of the millions of active source-receiver pairs per square kilometer. The higher the trace density, the higher the Signal to Noise ratio will be, for any imaged seismic attribute, at all depth levels. There are three ways to build up trace density (fold/bin size), starting with the most influential:

- Reduced Source & Receiver Line Spacing (SLS,RLS)
- Longer active Source and Receiver Lines to increase the offset aperture.
- Smaller Source and Receiver Position Spacing (SPS,RPS) along the acquisition lines to reduce the bin size

The second metric to maximize is the frequency richness of the source, defined by the number of temporal Octaves the source is generating, each octave allowing the imaging of independent geological scales. An Octave covering the 2-4Hz bandwidth has as much information value as an Octave covering the 32-64 Hz or 64-128 Hz bandwidth. This is the reason why the octave metric (logarithmic scale) has supplanted the conventional Hertz metric (linear scale).

To achieve those goals in the real world, it is necessary to move away from conventional practices. This is what we will illustrate with this case study in the Western Desert in Egypt where a 500% trace density increase with two extra-octaves was achieved, to deliver an outstanding Imaging improvement for the 2015 3D Matruh project, compared to the previous 2009 Obaiyed project. This result was achieved by keeping the same line opening effort, with the same number of vibrators, while reducing the number of sensors by 16% and doubling the VP productivity per km^2.

Building up Trace Density

A major issue in the Western Desert is the need for mine clearance along the source and receiver lines. In 2009 areal field arrays used on the source side (SPS=50m, 4 Vibrators, ΔV_y =12.5m, ΔV_x=4.17m) as well as on the receiver side (RPS=50m, 2x12Geophones, ΔG_x=4.17m, ΔG_y=6.25m staggered), required the source/receiver lines to be mine cleared over a width of 17.10m/11.50m respectively. As a consequence of wider clearance on the source side, the source lines needed clearing every 300m instead of 200m for the receiver lines. To get closer source lines without increasing the demining effort, it was decided for the 2015 Matruh survey to use In-Line only field arrays, both on the source/receiver side (SPS=50m, 2 V, ΔV_y = 12.5m)/(RPS=25m, 6G = ΔG_x = 4.17m).

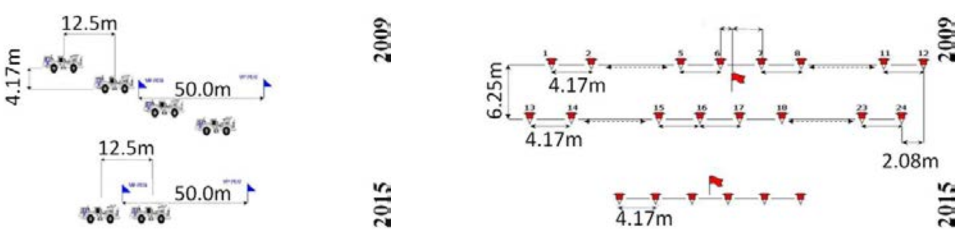

Figure 1 *From Areal (2009) to In-Line only (2015) Source and Receiver array*

Doing so, both source and receiver line were mine cleared over a width of 9.40m to allow for an SLS=RLS=200m without additional de mining work. To further increase the trace density, it was decided to add more active channels over the receiver spread going from 2304 in 2009 to 7680 in 2015, increasing receiver lines from 12 to 16, *Figure 2*, combined with an extended active aperture from 9550m to 11976m and a reduced RPS from 50m to 25m. Along the source lines the SPS was kept the same, 50m, but acquired over a longer distance from 2x2450m to 2x3200m. Altogether, for the same mine clearance effort, the same number of vibrators and fewer geophones, the trace density was increased by 5. To absorb the doubling of the SP effort with the same number of vibrators (16) we also moved from 4 source fleets of 4 vibrators (2009) to 8 fleets of 2 vibrators combined with a slip time reduction from 11s (2009) to 6s (2015).

3D Geometry	2009 3D Obaiyed	2015 3D Matruh
Number of RL	12	16
RL spacing	200	200
RP spacing	50	25
Number of channels	2304 (12*192)	7680 (16*480)
SL spacing	300	200
SP spacing	50	50
R Array	2x 12 G	1x6 G
S Array	4 V (2D)	2 V (1D)
S Line Aperture	2x2450	2x3200
#traces/Km2	0.3 10^6	1.5 10^6

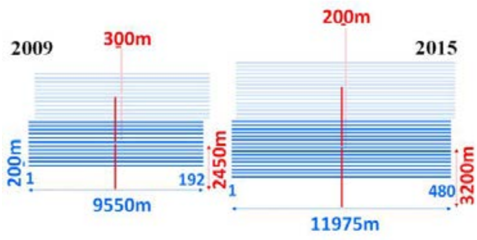

***Figure 2** Evolution of 3D acquisition parameters between 2009 and 2015*

Building up Broadband

To Image the subsurface over a large range of geological scales it is necessary for the seismic source to generate a source signal with a large range of temporal octaves, *Figure 4a, b*. For Obaiyed, 2009 the vibrators were conventionally used with a frequency invariant pilot force which does not allow generating frequencies lower than 8 Hz: the sweep being bounded by the highest frequency at which the force reaches the vibrator mechanical/hydraulic limits, see *Figure 3a*. For Matruh, 2015, a CGG EmphaSeis^{TM} sweep, *Figure 3b*, was used which continuously maximizes the pilot instantaneous force level, according to the frequency dependent vibrator limitations, with an adjusted sweep rate to deliver the required force spectra (a lower sweep rate over the low frequencies compensated by a higher sweep rate over the high frequencies).

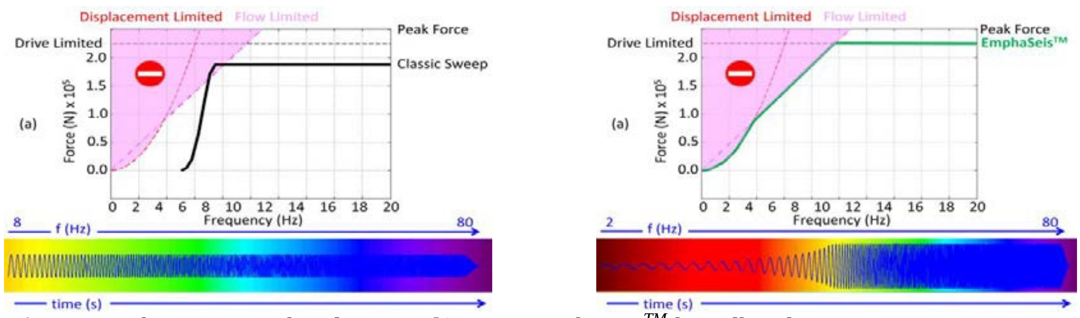

***Figure 3a** Classic narrowband sweep **3b)** CGG EmphaSeis^{TM} broadband sweep*

Although the addition of a lower frequency range comprising between 1.5 Hz and 6 Hz seems small, it corresponds to two highly valuable additional low frequency Octaves, which allow the illumination of deep targets, reduction of seismic wavelet side lobes and detailed velocity models from the modelling/inversion of diving, reflecting and surface waves. It also allows reconstruction of Impedance models with clearer differentiation between geological units, *Figure 4c, d*. The low-frequency octaves are nowadays recognized as an absolute acquisition requirement for performing reliable seismic-driven inter-well rock properties interpolation. Unfortunately the generation of extra low frequencies brings additional harmonic distortion noise leaking into the data, illustrated on *Figure*

5a with the desired pilot force in blue, the generated ground force in black and the difference between the two in red.

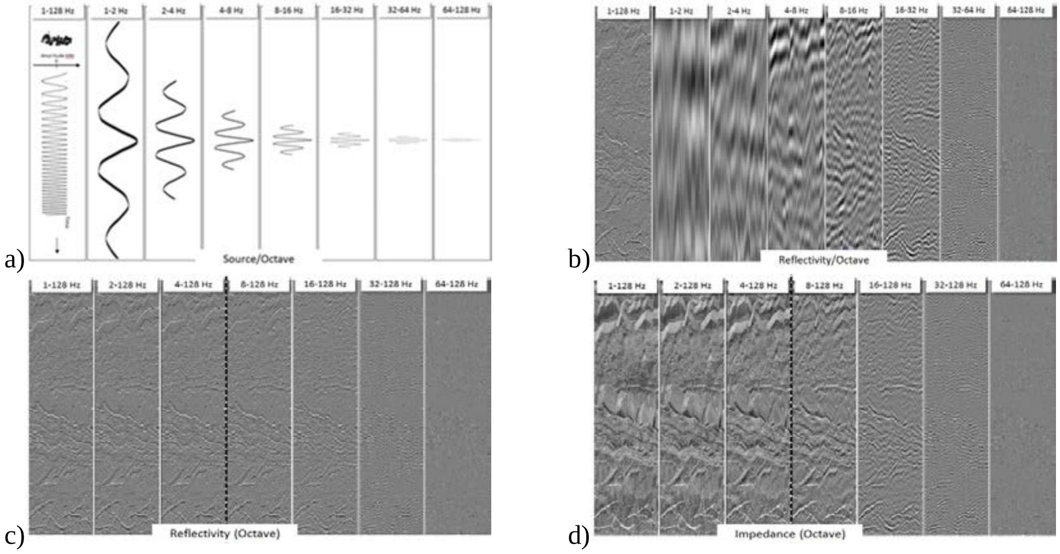

***Figure 4** The Octave logarithmic metric a), b) has supplanted the traditional Hertz linear metric as it is a direct measure of the range of accessible geological scales. Higher the number of octave, higher the seismic resolution is. Low Frequency Octaves are instrumental for outstanding Reflectivity (c) derived Impedance (d) key for successful seismic driven cross well interpolation of rock properties.*

Note that the distortion noise is responsible for elongated distortion tails that precede the shot records and contaminate the previous shots. This contamination increases with decreasing slip time. To allow the use of a 6s slip time for the 2015 project instead of 11s in 2009, without compromising the quality, the implementation of CleanSweep™ was required, *Figure 5a),b).* This technology is a highly efficient harmonic noise cancelation solution performed during sweep generation. CleanSweep™ is used in place of the conventional CGG HPVA™ in-field processing solution.

Source	**2009 3D Obayied**	**2015 3D Matruh**
Frequency band	7-60 Hz	1.5-60 Hz
Sweep Length	16s	20s
Sweep type	Linear upsweep	EmphaSeis™
Anti-Distortion	HPVA™	CleanSweep™
Slip Time	11s	6s
#Vib/VP	4	2
#Sweep/VP	1	1

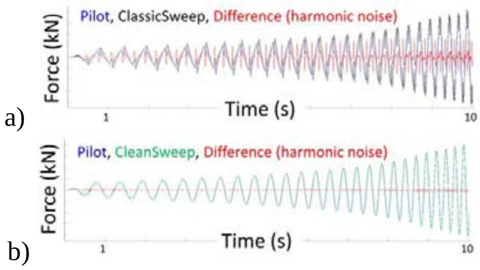

***Figure 5** 2009, 2015 source parameters;5a) ground force distortion in the absence of distortion compensation, 5b) CleanSweep™ ground force free of distortion. CleanSweep™ is an anti-distortion solution during sweep generation. It allows a closer match of the ground force with the pilot force to the benefit of reduced slip time without additional noise contamination.*

Conclusion

The value of a 500% increase in trace density combined with the addition of two Octaves in the low end of the spectra is impressively illustrated when comparing Obaiyed, 2009 and Matruh, 2015 Imaging results, *Figure 6* (Depth section converted in time). The value of the additional low-frequency octaves to shallow, deep and sharp reflectivity imaging is illustrated through an octave decomposition of the Image (*Figure 7*) as well as with the sharp resolution observed on a time slice at 2s (*Figure8)*.These results confirm the importance of the spatial trace density and octave metrics. It also illustrates that it can all be achieved using the same equipment (Vibrators & Geophones) better distributed, combined with a high source productivity solution. The use of even smaller field arrays, of even higher productivity acquisition and even broader sources is definitively the way forward. It is a significant change compared to historical approaches but the reward is high. We hope these results will contribute to improving land acquisition practices in Egypt and elsewhere.

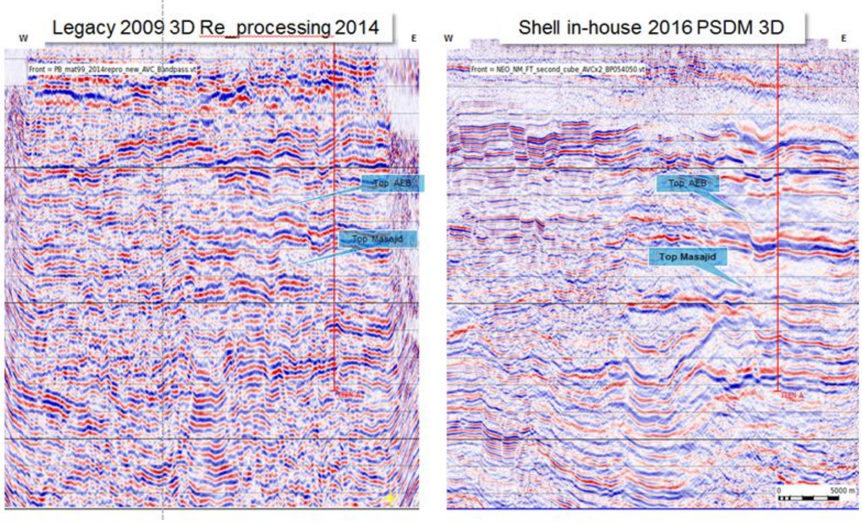

Figure6 *Imaging improvement brought by higher trace density and broadband source*

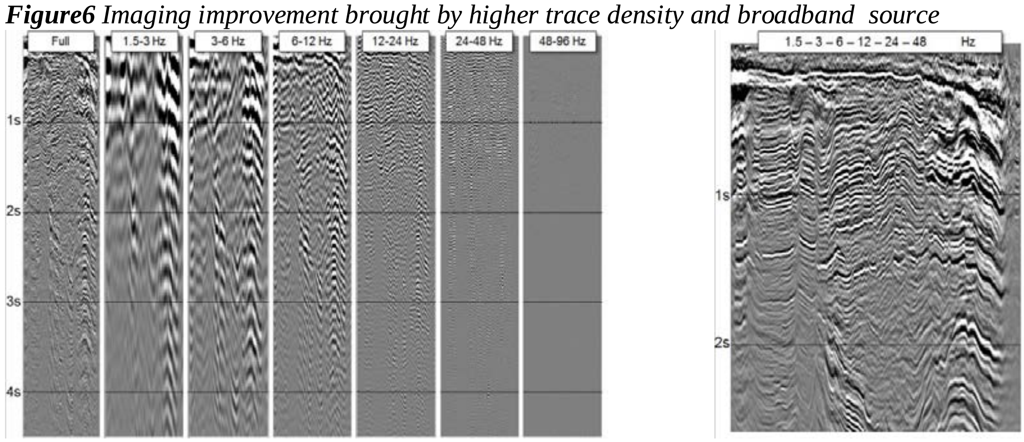

Figure 7a *An octave decomposition of the left-most column illustrates the value of each octave from shallow to deep.* ***7b*** *zoom of the left-most columns over the first 3 seconds.*

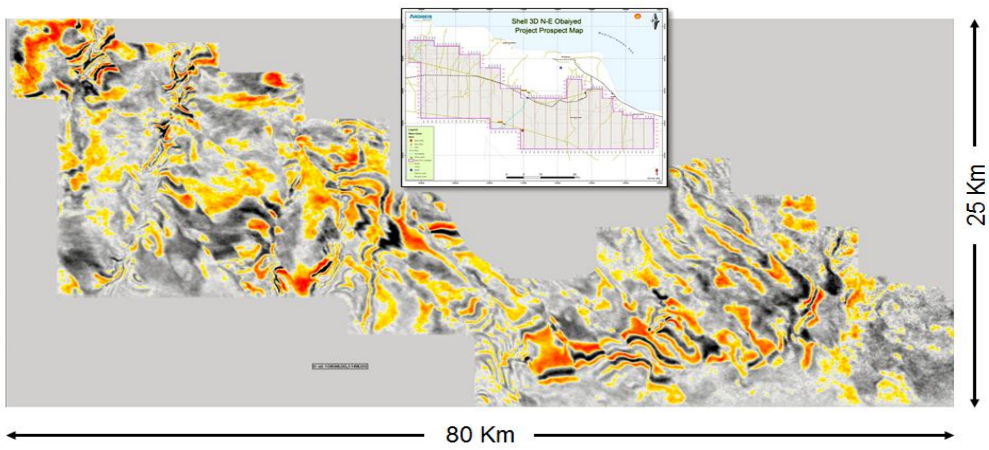

Figure 8 *Time slice (2s) revealing sharp geological features*