PS Design of the Acoustic Zoom Method for Non-Specular Backscatter Imaging of the Eagle Ford Formation*

J. Guigné[1], S. Azad[1], C. Clements[1], A. Gogacz[1], W. Hunt[1], A. Pant[1], and J. Stacey[1]

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[1]Geoscience, Acoustic Zoom Inc., Paradise, Newfoundland and Labrador, Canada (sazad@acousticzoom.ca)

Abstract

The Acoustic Zoom® (AZ) Method is an unconventional oil and gas exploration technology for 3D/4D seismic imaging that offers unique resolution and direct focusing of non-specular backscatter energy returns in land and marine environments. The AZ pilot site targets the complex geology of the Eagle Ford (Shale) and it has unique geometry. The receiver array comprises of sixteen spokes (eight lines through a hub) at ~22.5° increments. This array was deployed to intersect GGS's Wrangler 3D survey in Wilson County, Texas, over the prolific Eagle Ford, Austin Chalk, and Buda (limestone) formations. The AZ purpose-designed array - covering 12.5 km^2, encompassing over 4,000 receivers, and with recorded frequencies up to 170 Hz - acquired over two terabytes of data. Five vibroseis locations were established in a cross configuration at a quarter of wavelength separation. At each of the five vibroseis locations, 512 sweeps were generated and vertically stacked for 2,560 sweeps. This unique star-shaped dense array enables AZ to map scatterers, fractures, and diffusely reflecting boundaries via in-house AZ pre-filtering, beam forming and steering techniques.

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Introduction

The Acoustic Zoom (AZ) seismic beamforming method is an unconventional oil and gas exploration technology. The AZ answer product provides additional detail in the vicinity of geological discontinuities (e.g., faults) and enhanced resolution of the Austin Chalk, Eagle Ford, and Buda formations. The delineation of the edge of the fault zone is of commercial interest as conventional 3D seismic suffers from fault shadow ill-effects and cannot provide the desired resolution of fine features. Since the fault zone is a region that has undergone a substantial amount of brittle deformation, it is an ideal candidate for strong backscatter radiation and hence an excellent deployment site for demonstrating the AZ method.

Antenna Design Requirements

The AZ receiver array was deployed in a land-based proof-of-concept pilot study intersecting an existing 3D multi-client survey in Wilson County, Texas, over the Eagle Ford (shale), Austin Chalk, and Buda (limestone) formations. The pilot receiver array employed over 4000 receivers in sixteen lines comprising 120 wavelengths. The star array geometry provided full azimuthal coverage at 22.5° increments over 12.5 km^2. Recorded frequencies ranged from 5 to 170 Hz. The main lobe beam-width (−3 dB) was 0.5° with side lobes at −15 dB below the main lobe.

The specification of the ideal/theoretical receiver antenna is given in Figure 1. Because of land permitting difficulties, the deployed receiver antenna required some adjustments. The actual receiver array configuration is shown in Figure 2.

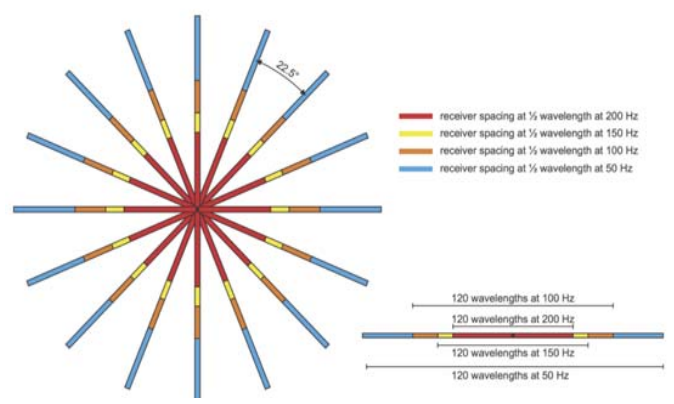

Figure 1: The receiver antenna design, specified in units of wavelengths, eliminates aliasing of received signals at the wavelengths of interest.

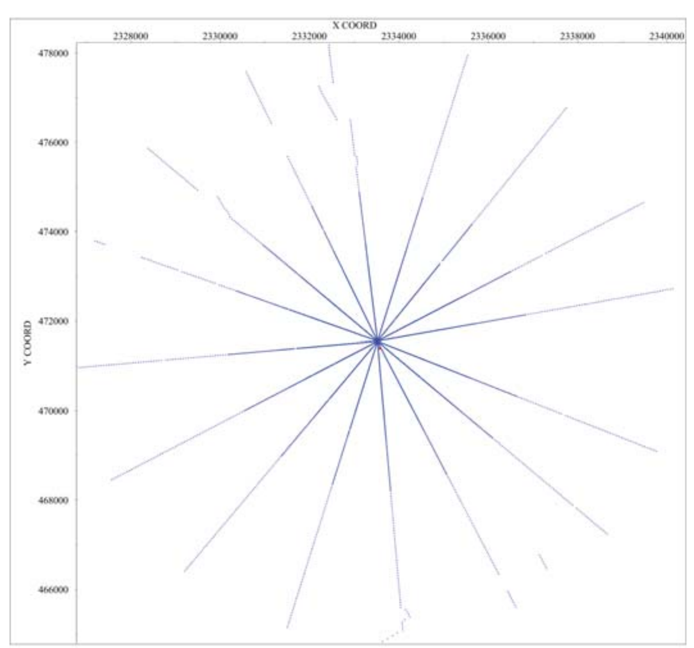

Figure 2: A plan view of the final geophone positions for the Acoustic Zoom array shows the 16 lines and full azimuthal coverage at 22.5 degree separation between lines.

Source Requirements

The source energy was injected using a modified vibroseis truck. Five vibroseis locations were established at $\frac{1}{4}$ wavelength separation in a cross configuration. At each location 512 sweeps were generated and vertically stacked. Over two terabytes of data was acquired. The source array was located 45.7 m to the south of the centre of receiver array to avoid a buried gas pipe crossing the centre of the receiver array.

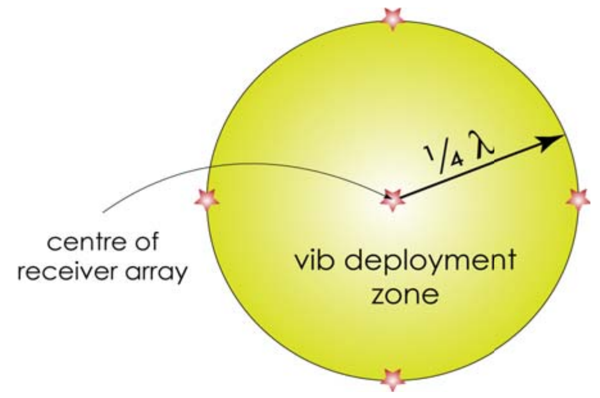

Figure 3: Vibroseis deployment configuration.

Description	Value
Vibrator Type 1	ION 364
Number of Vibrators	1
Vibrator Electronics	Sercel VE432
Sweep Length	40 Seconds
Start Frequency	5 Hz
End Frequency	170 Hz
Start Taper	500 msec Cosine
End Taper	500 msec Cosine
Number of Sweeps/File	1
Non-Linearity	+4 dB/octave
Drive Level	∼ 50%
Number of Sweeps/Vibe Location	512

Table 1: Actual acquisition Vibroseis parameters.

Figure 4: A modified vibe truck injected seismic energy into the earth at five single shot locations arranged in a cross configuration.

Spatial Response

The spatial response of the AZ array is illustrated in Figure 5. The main lobe beam width is 0.5 degrees. Side lobes are up to −15 dB below the main lobe.

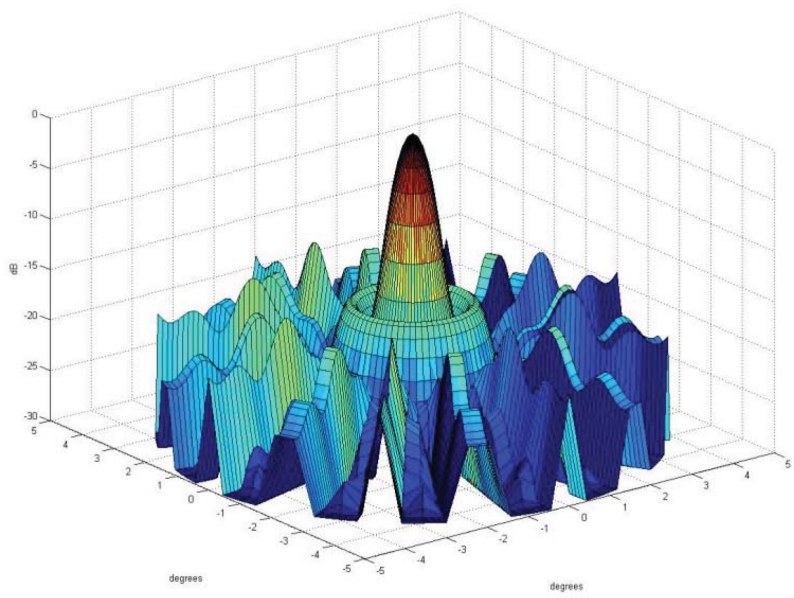

Figure 5: The spatial response of the Acoustic Zoom array has a beam width of 0.5 degrees and side-lobe power levels below -15 dB.

Sweep Characteristics

A shot gather from the radial line 1009 was analyzed to determine the spectral content. The analysis window ranged between 1100 ms to 1700 ms and a 45 traces wide window, outside the ground roll contaminated shot gather. The shot gather was AGCed to balance the analysis window temporally. The windowing function used was of Tukey type with 50% flatness and cosine tapers. The centre of the window was selected to overlap the formations of interest, namely, the Austin Chalk, Eagle Ford, and the Buda formation. Recorded frequencies ranged from 5 to 170 Hz.

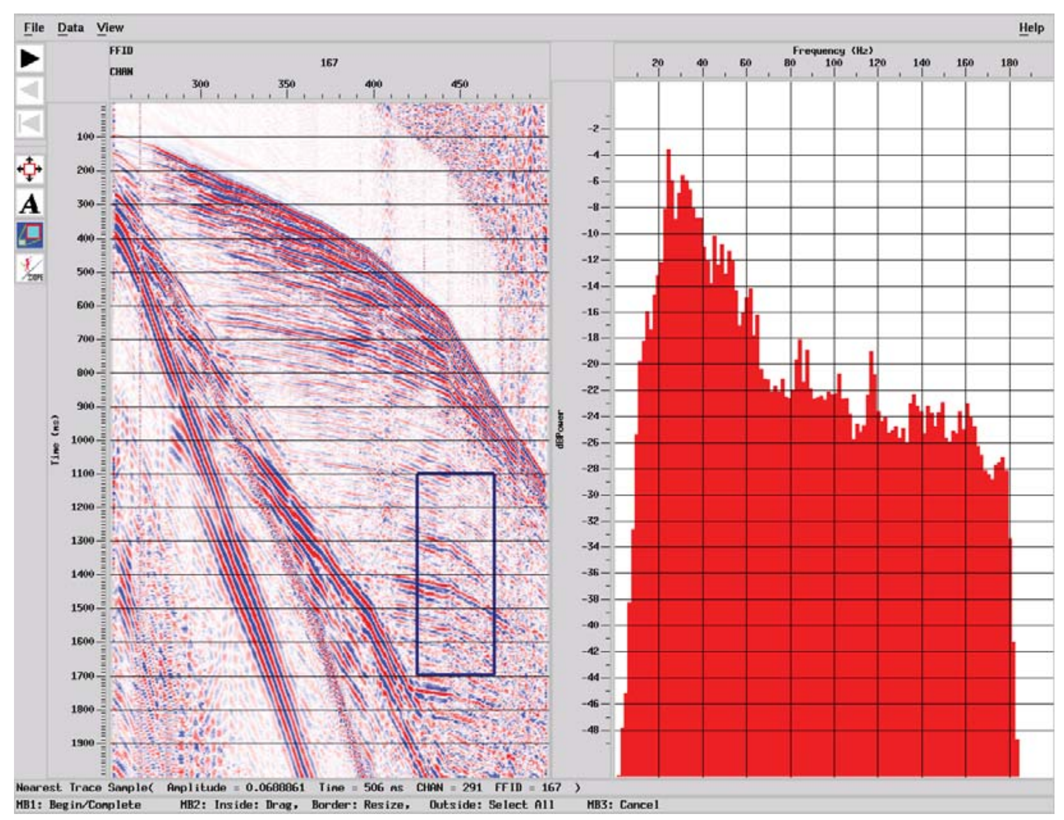

Figure 6: The frequency spectrum (right panel) for the indicated time window of raw shot gather output (left panel) lies outside sources of coherent interference due to ground roll and air waves.

Ambient Noise Reduction

The spectral content of the coherent signals observed at 1.5 sec two-way travel time shows an increasingly suppressed noise floor and enhanced signal at vertical stacking folds of 1, 200, 300, 400, and 512 shots (see Figure 7). The ambient noise floor was verified below −45 dB at maximum fold assuming a flat (white) noise power spectrum. The exponentially decaying (attenuated) power spectrum is estimated as >99.99% coherent. Spectral whitening was applied to the vertically stacked traces to flatten the high frequency content of the acquired dataset.

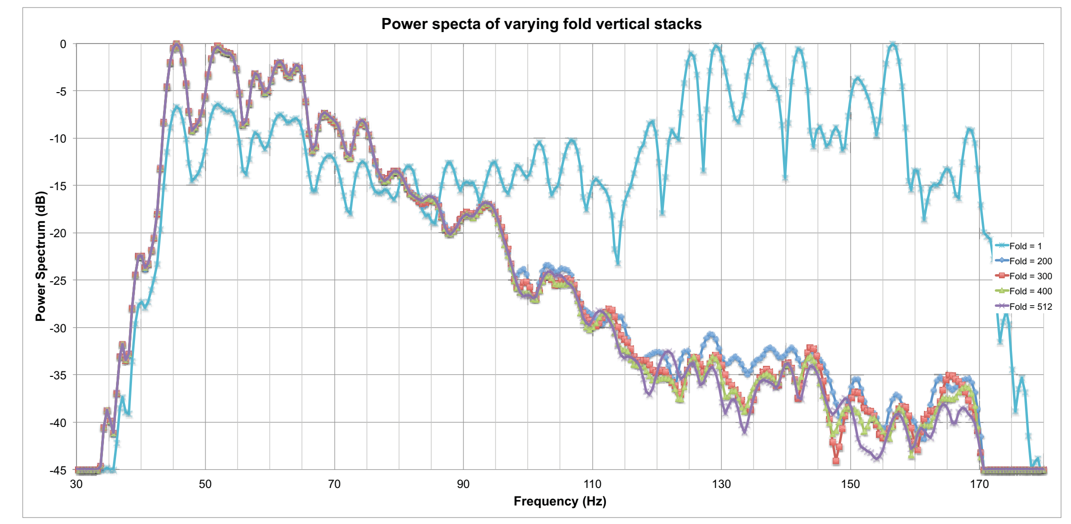

Figure 7: A shot gather and the power spectrum of the signal contained within the blue outlined box (5 to 180 Hz)

Conclusion

A strong emphasis on data collection requirements is key to enabling the AZ method. The use of a stationary array configuration yields the highest signal fidelity prior to imaging. Early common-receiver (vertical) stacking gains from multiple shots at each vibe location lowers the incoherent, uncorrelated noise floor over a broad frequency spectrum, including higher frequencies at depth. In this way, a high signal-to-noise ratio is established prior to imaging, enabling subsequent beam-forming and spectral balancing.

References

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