

OBC Shows Merit For Deep Exploration

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HOUSTON—As the oil and gas industry extends exploration and production to ever-deeper plays in offshore areas in the Gulf of Mexico, West Africa and other areas, significant challenges must be overcome to provide seismic data that are as useful as the data acquired for shallower targets.

The most significant challenge for deep target acquisition is the very weak, low-frequency nature of seismic returns from depths greater than 10,000 meters (32,800 feet). A full-scale experiment was conducted in the Gulf of Mexico using a new four-component, microelectric-mechanical (MEMS)-based ocean-bottom cable (OBC) acquisition system to provide an "apples-to-apples" comparison of several air gun source techniques specifically designed to improve depth of penetration. The test also addressed methods to maximize the capture of weak, low-frequency reflection signals, and compare the uplift from new state-of-the-art acquisition systems and techniques with conventional marine streamer acquisition.

Data examples show that 4-C, MEMS-based OBC technology provides significantly better deep (>10,000 meters) data than conventional streamer acquisition. At very low frequencies, the ambient noise level controlled the recoverability of the reflection data. For all techniques (deep tow, tune on bubble, simulated over/under and "acoustic blanket"), the brute stacks produced similar results in the deep section when compared prior to source designation processing. The acoustic blanket technique provides promise for modifying the source signature for conventional air gun arrays.

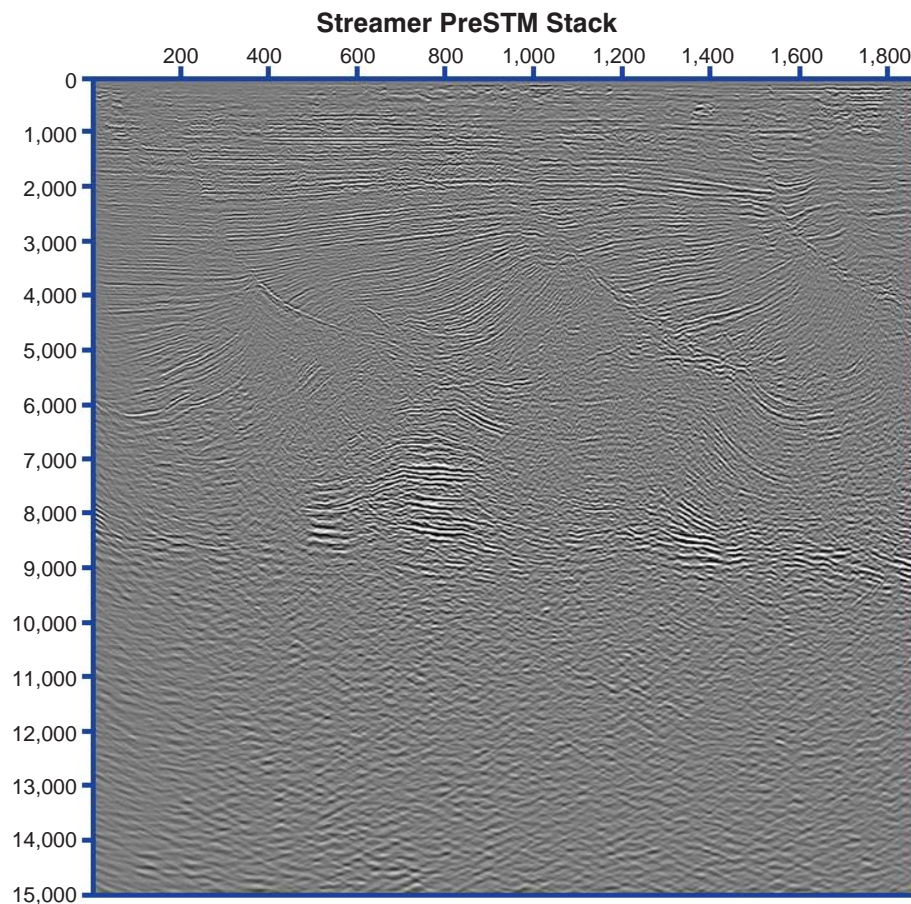
Traditional seismic data acquired by streamers are generally deficient in frequencies below 10 Hertz. Among the issues associated with low frequencies are how to record them and how to get them from the field recording to the final stacked sections and data volumes.

Low-frequency content is of special interest when imaging deep targets and for inversion. Earth filtering acts as a high-cut filter. As target depths increase, the high-cut filtering becomes more pro-

nounced. At large target depths, the earth filtering can reduce the recoverable frequencies to less than 20 Hertz. Issues that limit the ability to preserve low-frequency content are the energy sources, the recording equipment and the ambient noise environment. Of these issues, the recording equipment is probably the most tractable problem.

Traditionally, most marine recordings attenuate low-frequency signals at a rate of 12 to 18 decibels (dB)/octave for fre-

FIGURE 1



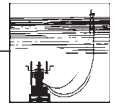
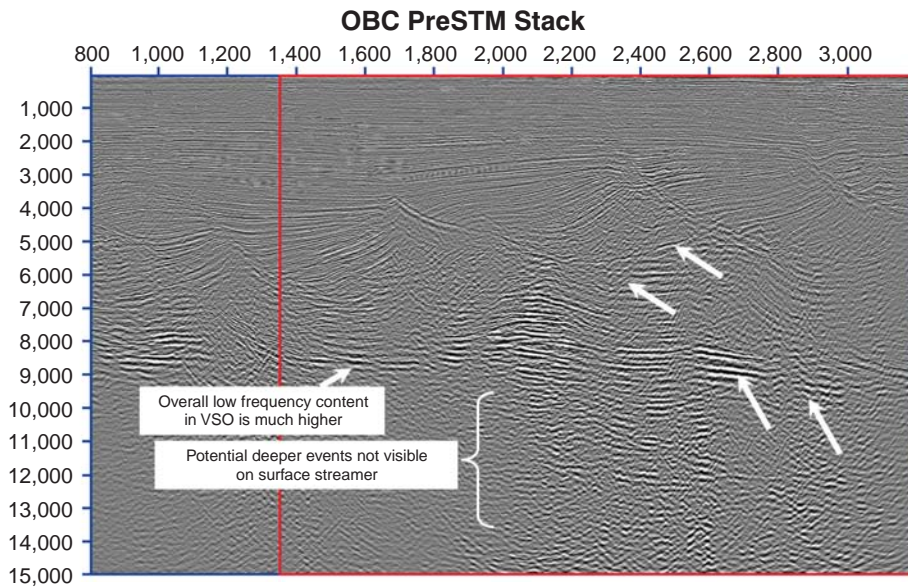


FIGURE 2



quencies below 10 Hertz. The latest generation of acquisition system filters allow signals down to 1-2 Hertz to be recorded without attenuation.

Reducing the low-frequency attenuation point is not a cure all, because not attenuating the low-frequency content can allow significant ambient noise into data volumes. In some cases, low-frequency ambient noise can dominate the dynamic range of the acquisition system, and for far offsets, the ambient noise can be more powerful than the seismic energy sources.

The ambient noise environment can dictate the low frequency that is recoverable from an air gun source. An important question is how to modify existing air gun arrays to allow more recoverable energy in the seismically important frequency band.

Deep Streamer, OBC Imaging

Figure 1 is a prestack time migration (PreSTM) of recent vintage, 2-D streamer data that was acquired in the Gulf of Mexico by GX Technology. For this data set, the 3 dB point of the total low-cut filter is 8.3 Hertz. The total filter response is a combination of the sensor, the analog instrumentation filter and the digital instrumentation filter. The stack shows 15 seconds of data. The reflections in the shallow section are well defined. The deepest reflections are on the order of eight or nine seconds, but at that time, the reflectors are not continuous and the apparent bandwidth of the reflections is significantly lower than the reflection seen at four or five seconds.

Figure 2 is the corresponding OBC 2-D PreSTM stack. The OBC line has a larger spatial extent than the streamer line. The red box in Figure 2 shows the location of the streamer line. The streamer and the OBC data sets have undergone comparable processing and utilize the same offset range, but the OBC stack contains both plus and minus offsets. The source arrays used for the streamer and OBC acquisition were conventionally tuned air gun arrays of 4,800 cubic inches at seven meters and 4,860 cubic inch-

es at five meters, respectively.

Comparing Figures 1 and 2, the OBC stack is crisper in the shallow section and the reflections at 8 and 9 seconds are much more contiguous. In general, the OBC data appear to have a broader bandwidth than the streamer data and the OBC data have an improved signal-to-noise ratio in the deeper part of the section. In the OBC stack, there are indications of reflectors below nine seconds, while the data below nine seconds in the streamer stack appears to be purely noise.

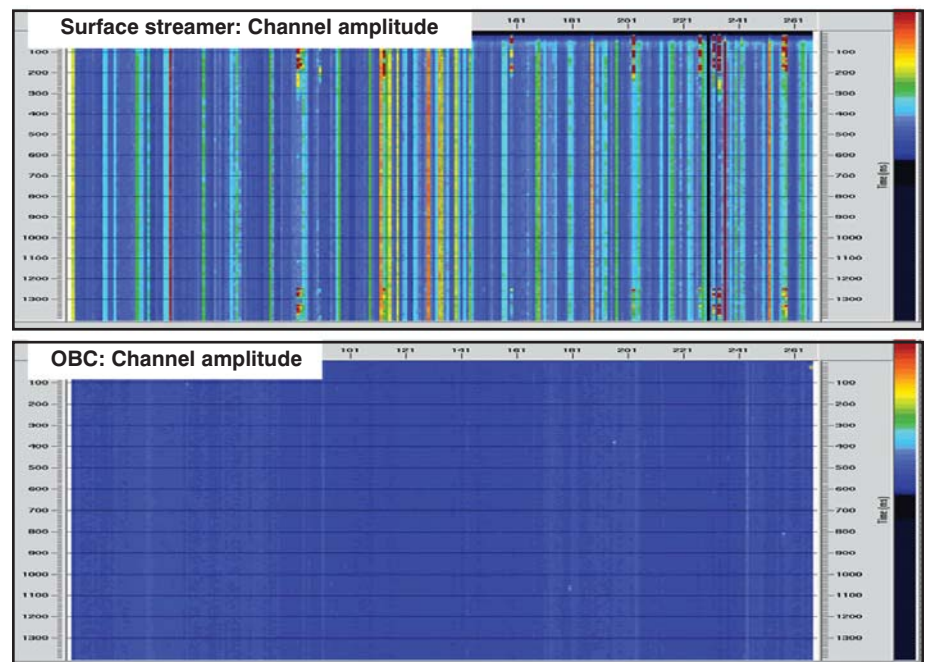
The difference in the deeper section of the streamer and OBC stacks could have resulted from the sources, the sensors, the sensor noise level, the total field filters applied, and/or the ambient noise level. In regard to the first potential difference, the air gun arrays used for the streamer and OBC data acquisitions are similar in gun volume. Because of its deeper towing depth, the streamer source array has potentially more low-frequency content.

The sensors used for the data in Figures 1 and 2 are standard hydrophones, where the OBC has a single hydrophone, and the streamer has an array of hydrophones. From this, the sources and sensors do not appear to be major contributors to the differences seen in the deep sections of the two figures.

Of the other potential differences, Figure 3 addresses the difference between the noise levels generated during

FIGURE 3

Comparison of Streamer and OBC Noise Amplitudes



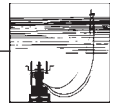
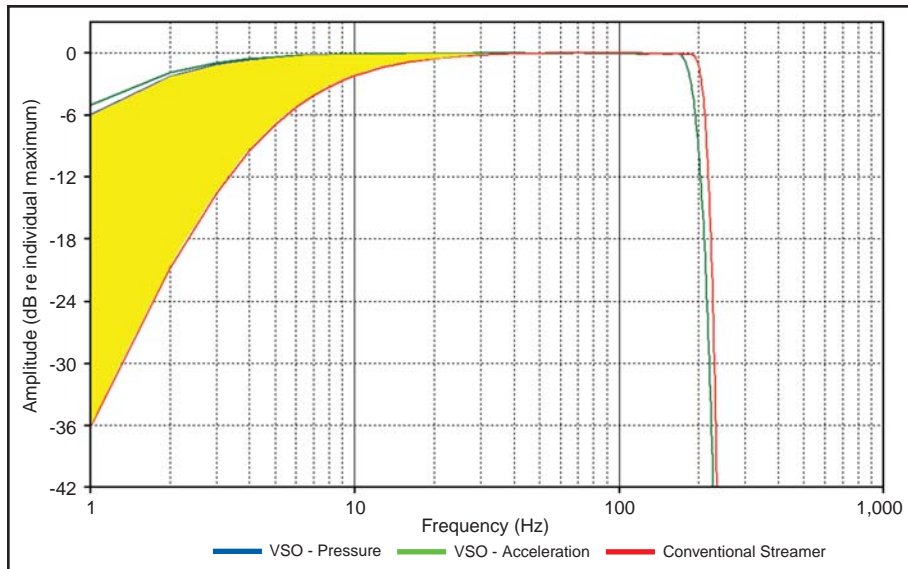


FIGURE 4
Amplitude Spectra for Impulse Responses
(Streamer and OBC Systems)



streamer and OBC acquisition. Towing streamers through the water column generates noise. This noise, although normally small in amplitude, can be significant when compared with the amplitudes of the reflection data that are returned from deep targets. Figure 3 is a comparison of the noise amplitudes observed in the streamer and OBC data sets shown in Figures 1 and 2. In addition to the streamer having higher noise levels than the OBC system, the channel-to-channel noise amplitudes on the streamer data set are much more variable.

2-D Source Tests

ExxonMobil, in collaboration with GXT

and Reservoir Exploration Technology (RXT), acquired a suite of 2-D source tests in the Gulf of Mexico. The test was in shallow water and utilized ION Geophysical’s Vectorseis Ocean™ (VSO) acquisition system. VSO is a cabled/node-style OBC system that uses 3-C MEMS accelerometers and hydrophones. The sensor housings are cabled in six-kilometer segments, and each segment is attached to a surface buoy that provides power, control, quality control facilities, and data storage for the six-kilometer segment of sensors. Of particular interest is the system’s 3-dB low frequency cut-off which is at 1.47 Hertz.

Because of the VSO’s low-cut filter response, it was possible to test the low-fre-

quency characteristics of air gun sources in a production environment. The difference between the total acquisition filters for the streamer and OBC systems is shown in Figure 4. A point of note is how well matched the VSO’s accelerometer and hydrophone amplitude spectra are. It is not shown here, but the phase characteristics of the VSO’s accelerometer and hydrophone are also well matched.

Since the deep data are dominated by low frequencies, the next potential difference between the streamer and the OBC data is the field filters that were used to acquire the data. The amplitude spectra of the impulse responses of the total field filters are shown in Figure 4. From these spectra, at 5.0 Hertz, the streamer data has seven dB more attenuation, and at 2.0 Hertz, it has 21 dB more attenuation than the OBC data. Considering the amplitude of the deep reflection data, attenuating the low-frequency data during the recording process has the potential to reduce the effective signal-to-noise ratio of the recorded data.

Ambient Noise

Four, six-kilometer recording cables were used for the long-offset, low-frequency (LOLF) tests. Three of the cables were laid in-line end-to-end to provide an 18-kilometer receiver line. At a 25-meter station interval, this arrangement provided 720 receiver stations. The fourth cable was laid parallel to and offset 100 meters from the third cable.

Noise records were taken at the beginning and end of each acquisition sequence. Figure 5A is a display of a common shot gather for cables 1 and 2, which cover an offset range of 12 kilometers.

FIGURE 5A
Noise Record for Cables 1 and 2

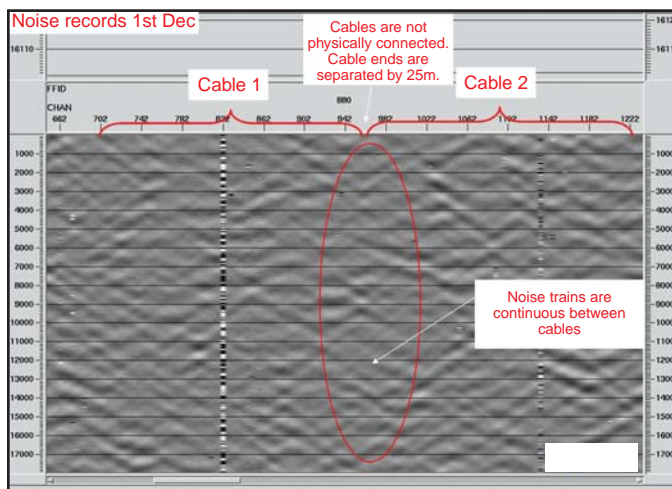
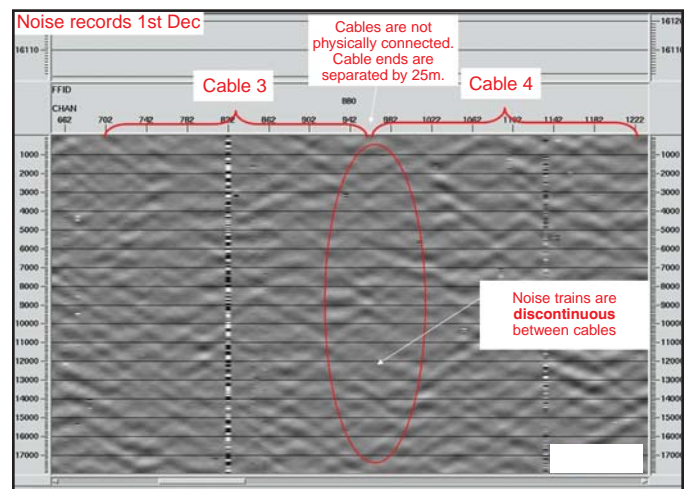


FIGURE 5B
Noise Record for Cables 3 and 4



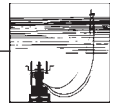
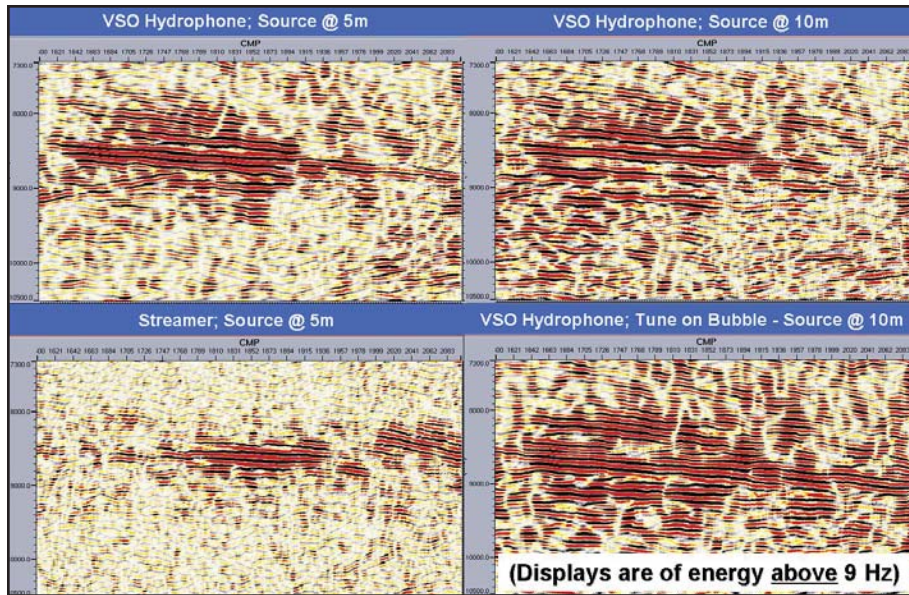


FIGURE 6

**Deep Reflector for Three Source Configurations
(High-Pass Filter = Frequencies >9 Hertz)**



Low-frequency, coherent energy can be seen traveling up and down the 2-D receiver line with a velocity of approximately 150 meters/second. The obvious question is whether this coherent energy is naturally occurring or an artifact of the acquisition system, cables or sensors.

One potential way to separate these explanations for the source of the low-frequency, large-amplitude noise is to see how the energy behaves at the junction between the physical cables. If the energy is traveling down the cables, it should be discontinuous at the junction between the cables because the cables are not in physical contact. At the junction between cables 1 and 2, the noise waves are continuous. Similarly, if one looks at the junction between cables 3 and 4 (Figure 5B), which are offset by 100 meters from each other, the energy should be discontinuous at the junction, which it is.

This behavior suggests that this low-frequency energy is traveling in the earth and not in the cables. An observation from the test was that the large-amplitude, low-frequency noise appeared to vary depending on the sea state and wind. The average spectra for noise records taken during 0.3-1.0 meter seas and a wind speed of five knots shows that all of the accelerometer signals were relatively flat above 2.0 Hertz, but rose at 30 dB/octave below 2.0 Hertz. For the hydrophone, there was a typical rise of 10-12 dB/octave for frequencies below 10 Hertz.

Average noise spectra observed in

rougher weather (2.0-meter seas and 20-knot winds) were similar in shape to the average spectra for the better weather state, but low-frequency events had a broader frequency band and a lower peak frequency, and were larger in amplitude. The low-frequency noise observed during the LOLF test is clearly driven by the sea state. It will be a limiting factor in any effort to improve the low-frequency content of seismic data acquired in this area because the output of air gun sources

start to attenuate below 8.0 Hertz.

Source Configuration

For the LOLF testing, a three-string, 4,070-cubic inch source array was used. The source array was a traditional tuned air gun array. Control lines were acquired with the source array at a depth of five meters for comparison to an existing streamer data set. The majority of the test lines were acquired at a source depth of 10 meters.

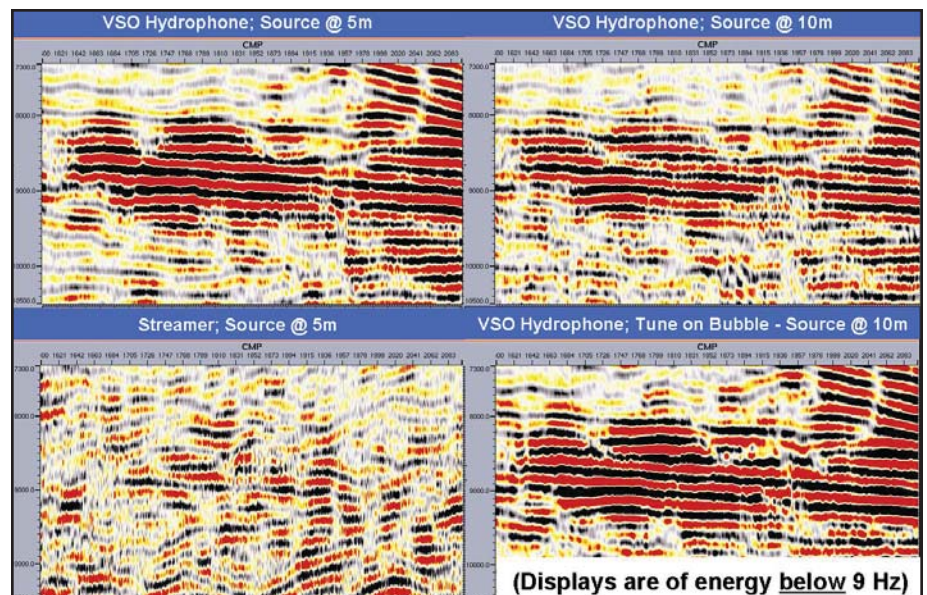
Figures 6 and 7 are from the same brute stack data sets, but in Figure 6, a high-pass filter was applied so that the frequency content is above 9.0 Hertz. For the displays in Figure 7, a low-pass filter was applied to limit the frequency content to energy below 9.0 Hertz. All of the displays show the deep part of the section (7.3 to 10.5 seconds).

The data in Figures 6 and 7 are high-quality, brute stacks. Comparable processing flows were used for both the streamer and OBC data sets. The offsets have been limited to nine kilometers and the OBC data was limited to a single azimuth to match the streamer data. To allow the effect of the different source configurations to be determined, no source signature processing has been done on the data.

From the displays in Figure 6, it is evident that the source signatures vary considerably. The OBC data has significantly better continuity and a better signal-to-noise ratio than does the streamer data. Looking at Figure 7, the OBC data sets clearly con-

FIGURE 7

**Deep Reflector for Three Source Configurations
(Low-Pass Filter = Frequencies <9 Hertz)**



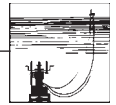
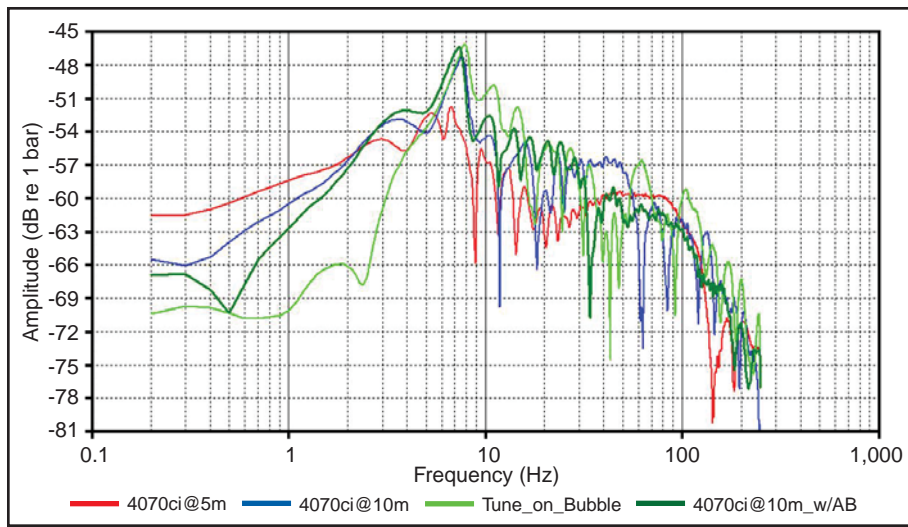


FIGURE 8

Amplitude Spectra of Signals on Shots Nearest Each Receiver Station



tain deep seismic reflections. The streamer data do contain energy below 9.0 Hertz, but that energy appears to be mostly noise with no seismic reflection energy.

An additional point to be noted from Figures 6 and 7 is the differences in the source signatures. Although the displays obviously have the same underlying geological component, the source signatures are significantly different. These differences emphasize the need for source signature estimation and removal.

The reduction in the low-frequency content of the air gun signatures can be

seen in Figure 8. One means of comparing source signatures is to select the nearest shot to each receiver station. These “nearest approach” traces are then corrected for the slant range between the source and the receiver and vertically stacked. Correcting for the slant range and stacking the nearest trace data tends to average out the geology. It should be noted that this procedure is not expected to be equivalent to a far-field signature, but it does provide a means to compare different source configurations. The average amplitude spectra of the nearest ap-

proach traces are shown in Figure 8.

Acoustic Blanket

Because air gun energy is significantly attenuated at low frequencies, a means to modify the air gun signature would be useful. One potential means of modifying an air gun signature is to place a layer of air bubbles above the air gun array. In previous work, ExxonMobil has referred to this acquisition technique as an acoustic blanket.

The acoustic blanket technique is used with a conventional air gun array. The bubble generator is towed in front of and below the air gun array. Because of the forward movement of the bubble generator and the air gun array, a layer of bubbles is created over the air gun array. This layer of bubbles interacts with the upward-traveling air gun energy to modify the source signature.

To see some of the effects the acoustic blanket had on the air gun signal, the nearest approach traces were corrected for the slant range travel time and displayed. A comparison of the 4,070-cubic inch source array at 10 meters with and without the acoustic blanket is shown in Figure 9.

The acoustic blanket clearly alters the source signature seen on the nearest trace. The red arrows identify the arrival time for the surface ghost. The acoustic blanket attenuated the surface ghost and allowed the low-frequency event at 120 milliseconds to be seen. Once the acoustic blanket allowed this event to be identified, indications of the event can be found in the section without the acoustic blanket.

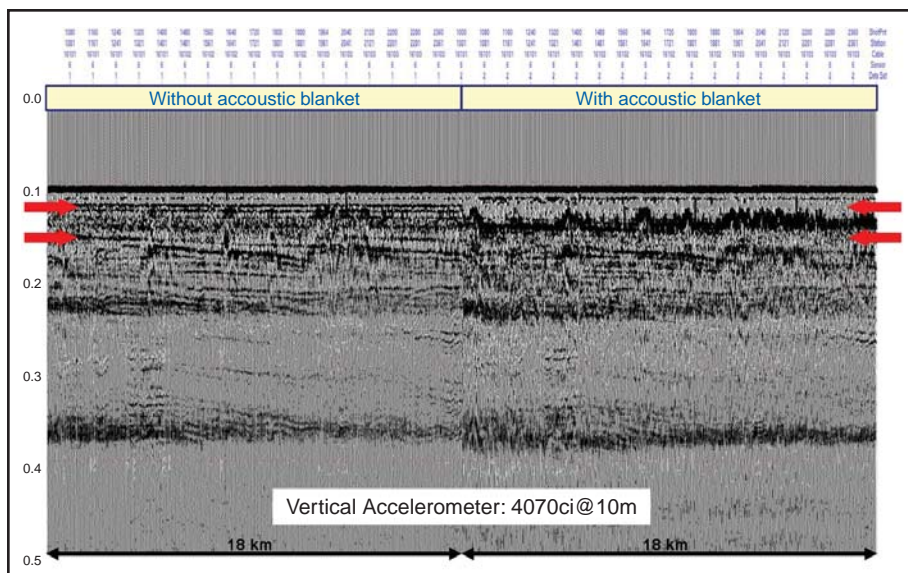
The noise generated by a towed streamer is larger in amplitude and temporally less uniform than the noises observed on OBC acquisition systems. These lower noise levels, along with less attenuation by the acquisition system filters, increases the ability to recover low-frequency content.

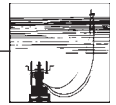
With improved system filters and less sensor noise, conventional air gun arrays were observed to provide recoverable energy down to at least 6.0 Hertz. The limit to which low-frequency energy is recoverable will be dictated by the ambient noise environment. During this test, large-amplitude, low-frequency noise was observed. The amplitude and low-end frequency characteristics of this noise appear to be a function of the sea and wind state.

Acoustic blanket technology appears to provide a means to modify conventional air gun signatures in a useful manner. The interaction of the air gun’s energy with an acoustic blanket requires

FIGURE 9

Comparison of 4,070-Cubic Inch Air Gun Array With/Without Acoustic Blanket





additional study.

The MEMS-based OBC system provided significant improvement in the recoverability of low-frequency content. The improvement in low-frequency content improved the continuity and signal-

to-noise ratio of deeper targets. □

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