[GC]Vertical Wave Testing*

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*Adapted from the Geophysical Corner column, prepared by the author, in AAPG Explorer, January, 2010, and entitled "Vertical Wave Testing: Part 2". Editor of Geophysical Corner is Bob A. Hardage (bob.hardage@beg.utexas.edu). Managing Editor of AAPG Explorer is Vern Stefanic; Larry Nation is Communications Director. Please refer to closely related article by Bob Hardage, 2010, Horizontal Wave Testing, Search and Discovery article #40502.

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General Statement

Vertical wave testing is done by deploying seismic receivers downhole and recording the downgoing wavelet generated by each energy source being considered for surface seismic data acquisition across the area local to the receiver well. The objectives of a vertical wave test are to determine the frequency bandwidth of the downgoing wavelet that illuminates subsurface geology, and to observe how the energy and frequency content of that wavelet diminishes as the wavelet propagates through stratigraphic intervals that need to be imaged with surface-based seismic data. *Vertical wave testing is a rigorous technique that allows geophysicists to decide which seismic source is optimal for imaging specific sub-surface geology.*

One limitation is that the data provide information that helps only in selecting the seismic source that will be used across a prospect. The technique does *not* provide information that helps in designing surface-based receiver arrays. Horizontal wave testing, described in Search and Discovery Article #40502, has to be done to determine appropriate surface-receiver array dimensions.

Vertical Wave Test Methodology

The source-receiver geometry used for vertical wave testing is identical to that used for vertical seismic profiling. A downhole receiver is positioned at selected depths by wireline, and the surface sources that are to be tested are stationed at selected distances from the wellhead (Figure 1). The downgoing wavelet generated by each source option proposed for use across a prospect should be recorded at depth intervals of 600 to 1,200 feet (200 to 400 meters), starting close to the Earth's surface and extending to the deepest interval of interest.

A vertical wave test can compare different sources, such as explosives, weight droppers and vibrators, or it can evaluate the relative merits of only one type of source, say a vibrator, when that source is operated under different conditions. In either type of wave test, the objective is to determine what source, operated in what manner, will generate a downgoing illumination wavelet that detects geology with a targeted thickness at a specified depth.

Example

An example of wave-test data comparing vibrator-source wavelets against explosive-source wavelets is illustrated as Figure 2. In this source test, wavelets generated by a 40,000-pound vibrator are compared against wavelets produced by small 10-ounce (280-gram) directional charges buried at a depth of 10 feet (3 meters). At this prospect, both source options create high-frequency wavelets, and either source would provide the desired illumination of the targeted geology.

The small directional-charge source option was selected for acquiring 3-D seismic data across this prospect because a significant part of the survey area was covered by dense timber that made vibrator operations difficult and expensive (due to timber clearing). However, small drill rigs could wend through the trees and drill shallow holes for deploying explosives without the necessity of clearing any timber for vehicle movement, resulting in more affordable data acquisition.

The frequency content of the explosive-source and vibrator-source test data is exhibited as Figure 3. The frequency spectrum of the explosive source wavelet measured at a depth of 2,000 feet (600 meters) extends to 200 Hz – and at a depth of 5,000 feet (1,500 meters) there is still appreciable energy at frequencies as high as 180 Hz (Figure 3a). The vibrator sweep of 6 to 160 Hz results in a frequency spectrum that exhibits an abrupt onset of energy near 8 Hz and an abrupt energy decrease at 160 Hz at all receiver depths (Figure 3b). These data supported the decision to use small directional explosives as the seismic source at this prospect. To increase the signal-to-noise ratio of the surface-recorded data, three shot holes, each having a 10-ounce (280-gram) directional charge, were shot simultaneously to increase the amplitude of the downgoing wavelet.

Results from a second vertical wave test at a different prospect are illustrated on Figure 4. At this prospect there were numerous buried data communication cables (some of them connected to intercontinental missile silos!). Because of these buried cables, the option of drilling shot holes for explosive charges could not be allowed; the source had to be vibrators. Consequently, the objective of this wave test was to determine what vibrator sweep parameters would create a robust wavelet at a depth of 5,000 feet (1,500 meters) that had frequencies up to – and we hope above – 100 Hz. As illustrated by the frequency spectra of the recorded vibrator wavelets, a non-linear sweep rate of 3 dB/octave produced a greater amount of energy above 100 Hz than did a linear sweep rate. With these test data, a decision to operate vibrators using a 10-120 Hz, 3 dB/octave sweep was made with confidence. Good quality data were acquired; no buried communication cables were damaged as the production data were recorded; no missiles were launched.

Conclusions

The message: Always execute a vertical wave test if there is any desire to compare the relative merits of seismic sources – and if a well is available for depth deployment of receivers.

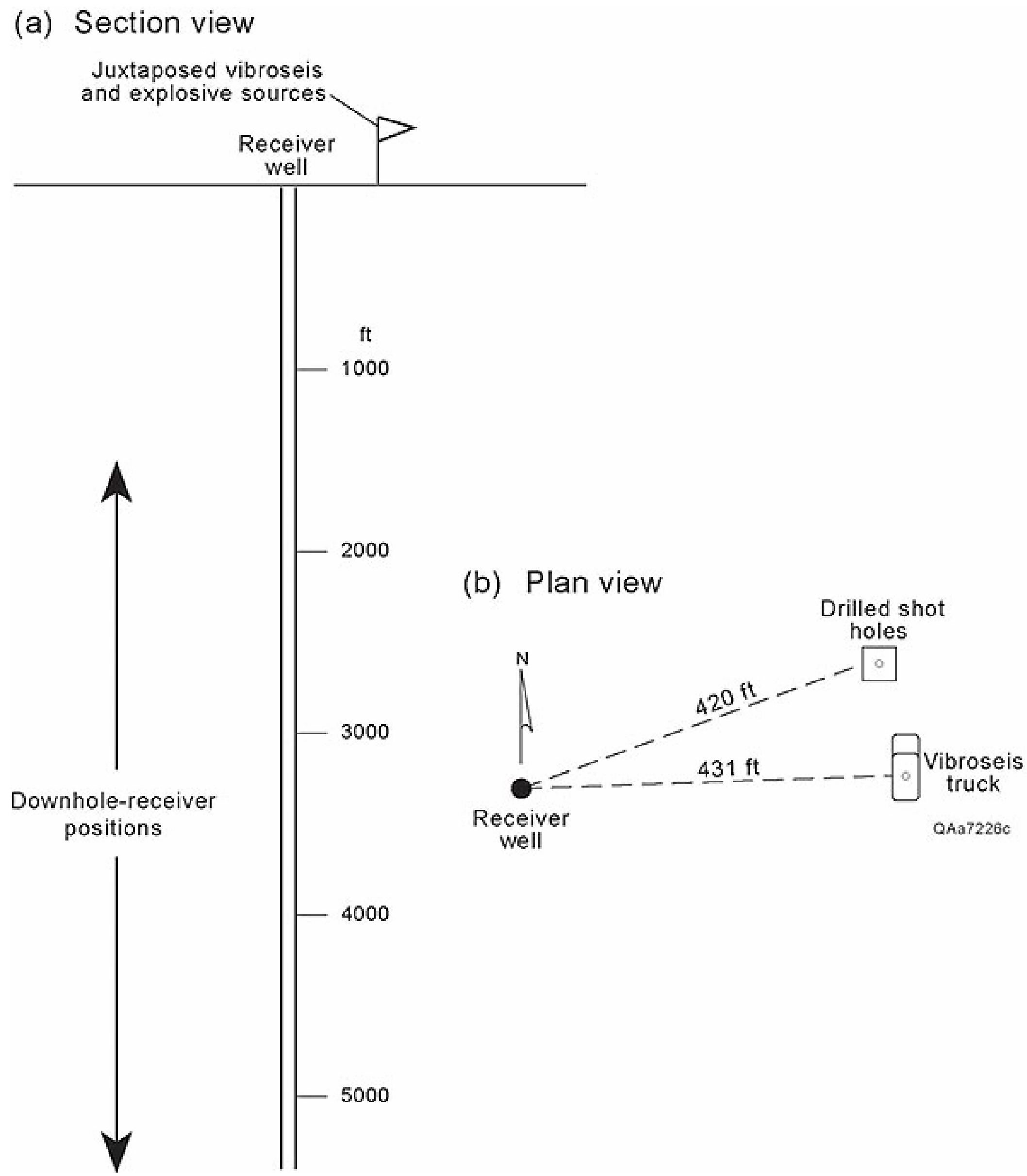

Figure 1. Source-receiver geometry used in a vertical wave test. In this example, the objective is to compare the merits of vibrator and explosive sources. (a) Section view of geometry; (b) map view of geometry.

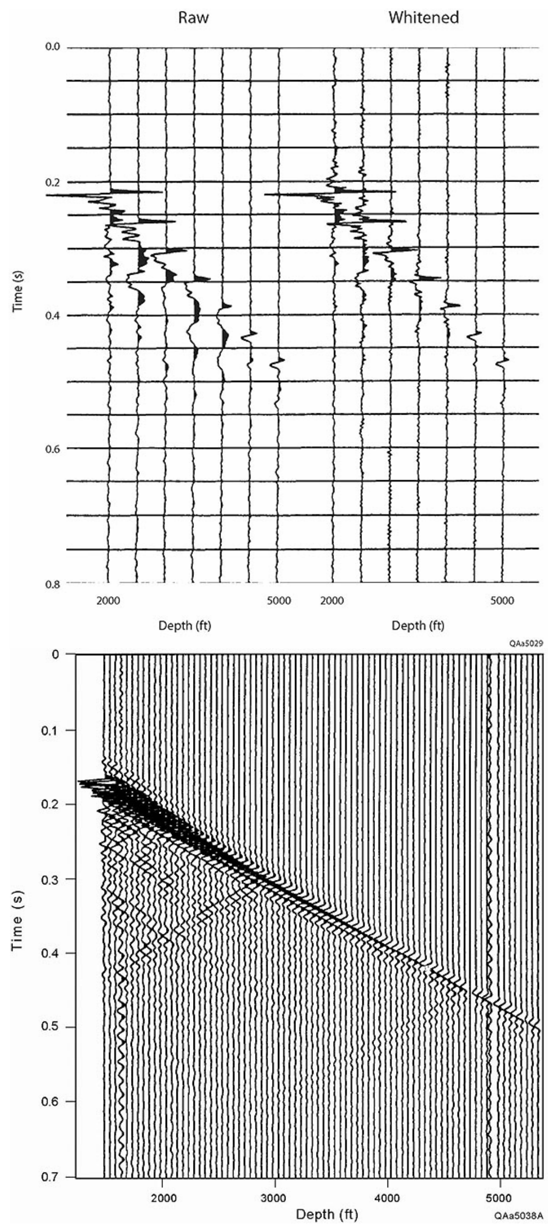

Figure 2. Vertical wave test data acquired with the geometry exhibited on Figure 1. (a) Downhole wavelets generated by small 10-ounce (280 grams) directional charges detonated in shallow 10-foot (three-meter) shot holes and recorded at depth intervals of 500 feet (150 meters). (b) Downgoing wavelets produced by a 40,000-pound vibrator and recorded at depth intervals of 50 feet (15 meters).

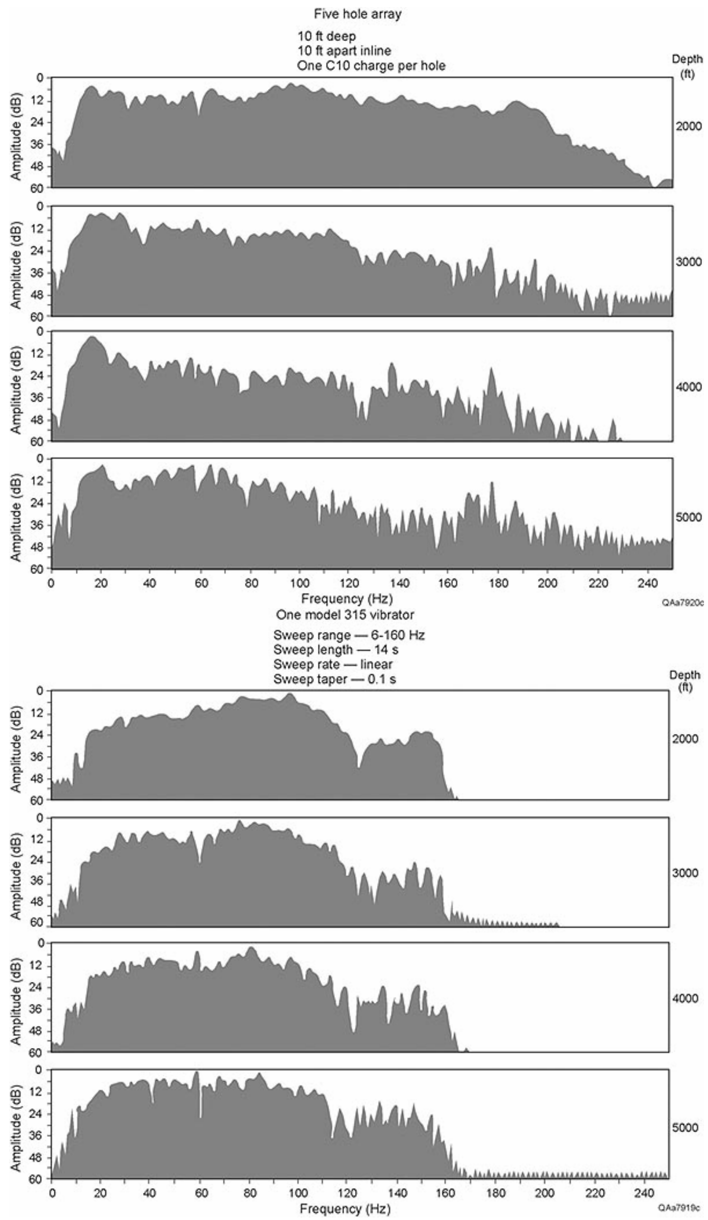

Figure 3. (a) Frequency spectra of explosive-source wavelets selected from the data exhibited as Figure 2a. (b) Frequency spectra of vibrator-source wavelets selected from the wave test date of Figure 2b.

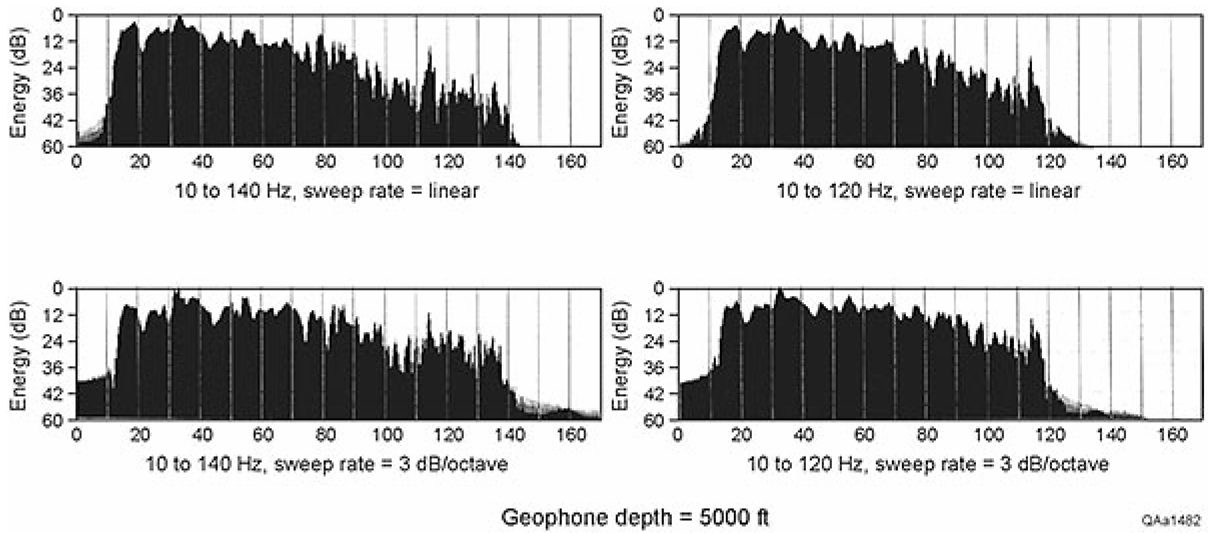

Figure 4. Vertical wave test spectra comparing the merits of vibrator wavelets generated with different sweep parameters. The wavelets that were analyzed were recorded at a depth of 5,000 feet (1,500 meters), immediately above a targeted reservoir interval. The comment sweep rate = 3 dB/octave means that when the vibrator sweep advanced into a new octave of frequencies, the vibrator dwelled two times longer on each frequency component than it did in the preceding octave band. The intent of this test was to determine if this vibrator operation caused more high-frequency energy to remain in the wavelet when it reached target depth. In this instance, the optimal sweep parameters were judged to be a sweep of 10 to 120 Hz at a sweep rate of 3 dB/octave (lower right spectrum).