Low-frequency data from Ocean Bottom Nodes

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Abstract

Geophones whose resonance frequency is 14 Hz can provide data with useable signal down to as low as 3 Hz. These 14 Hz geophones are available in omni-tilt versions having a far greater tilt tolerance compared to 10, 8, and 4.5 Hz phones. Geophones provide high dynamic range, low instrument noise, and lower power consumption compared to other sensor types. We therefore select 14Hz geophones for our ocean bottom nodes.

Introduction

The challenge of providing low frequencies is not new. Figure 1 is modified from a 1985 book by J.F. Claerbout. The gap between what velocity analysis provides and what reflectivity provides is an obstacle for finding a blocky earth model, and for imaging under complex, scattering, and absorbing overburden such as salt, basalt, and chalk. The motivations to acquire low frequency data and applications of such data will be elaborated in many talks in this SEG workshop on low frequencies. The subject of this talk is limited to the choice of geophones for ocean bottom nodes.

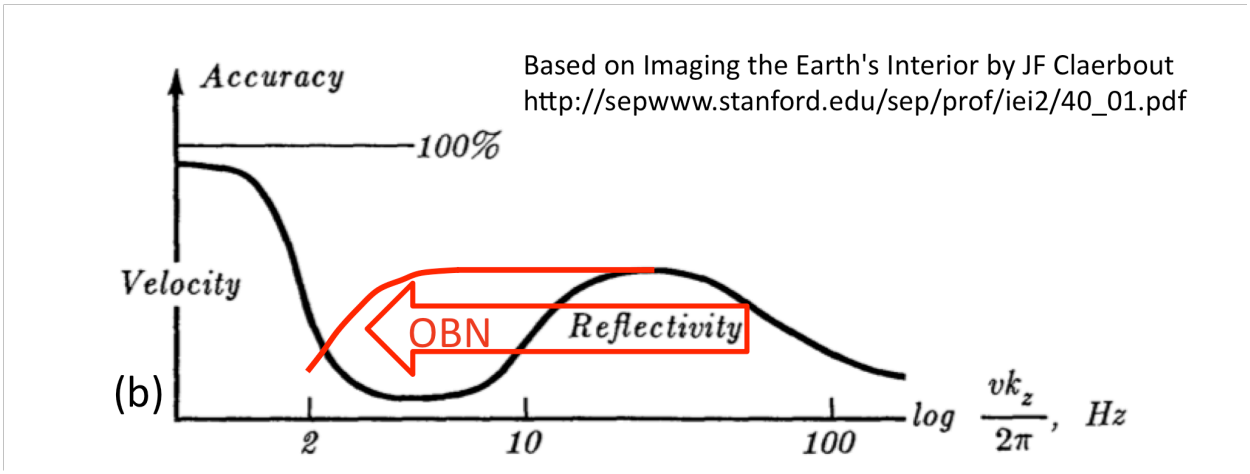

Figure 1: Reliability of information obtained from surface seismic measurements (modified from Claerbout, 1985)

The deeper we deploy surface towed streamers, the better their low frequency content. Ocean Bottom Seismometers are deployed as deep as the ocean floor. Far from weather induced noise and with a combination of hydrophone and geophones that turn the receiver ghost problem into an opportunity to image using the multiples, OBS can provide low frequency information. They can be an enabling technology to close the low frequency gap (Figure 1). This assumes that the source will emit such frequencies and that the sensors in the OBS can record low frequencies which will be demonstrated in this paper.

The choice of sensors for Ocean Bottom Nodes

The hydrophone requirements are relatively easy to accomplish; it is the particle motion sensors (geophones or accelerometers) that initially seemed to require a compromise between low-frequency response, power consumption, coupling quality, and deployment efficiency. MEMS accelerometers were never considered a practical candidate because of their added power consumption, the operating endurance of autonomous nodes being dependent on their power efficiency. We also had geophysical concerns about MEMS because of dynamic range and instrument noise. We decided to use analog geophones, and a hydrophone connected to a custom-designed digitizing unit. We still had to choose the type of geophones to use.

At first sight the low-frequency geophone response requirements can be met by choosing a low natural frequency, however, low frequency geophones exhibit features that may be contradictory to other considerations, e.g. tilt –

deployment accuracy requirement and harmonic distortion, with consequences on coupling quality and operational efficiency.

Time to deploy is critical in node acquisition. The necessity of using ROV deployment methods inevitably carries a high cost element so that the efficient use of this equipment is essential. Time to get the first node patch deployed ready to start shooting is a prime factor impacting overall project timing and cost. Similarly, the time to rotate units for data downloading and maintenance, ready for the next deployment patch, is a prime cost/efficiency driver.

The cost of correcting for tilt during deployment is not only in increased deployment time but also and more importantly, in compromised attention to coupling. This is particularly important in locations where the seabed is sloping or irregular. With omni-tilt sensors, the ROV pilot can put full attention on coupling quality and is not concerned with keeping with tilt specification. Redeploying nodes or sensors because their tilt is out of specification is no longer necessary.

These considerations, after considerable testing, led CGGVeritas to decide on an integrated package incorporating the sensors within the node body such that only one item need to be deployed, achieving a high efficiency factor. Again, to improve efficiency we did not wish to be constrained by having to level the node, leading to the choice of a so called “omni-tilt” geophones, the lowest natural frequency available being 14Hz.

A geophysical requirement to be able to recover signal as low as 3Hz remains. The roll-off of a geophone is -12dB/octave below its natural frequency, however, this roll-off is very predictable, especially in the stable temperature environment at the seabed. Through inverse filtering that corrects for the roll-off of the geophone, it is normally possible to recover signal to 2 octaves below the natural frequency. With a 14Hz geophone this takes us to 3.5Hz (Figures 2 through 6). To achieve lower frequencies we will need to take consideration of our source array and tow depth.

One might think it is better to simply use a lower natural frequency geophone. Table 1 shows the typical tilt tolerance for different natural frequencies. In addition, low natural frequency geophones exhibit higher distortion and have wider parametric tolerances. Geophones with 4.5Hz natural frequency have essentially a zero tilt tolerance and so should be gimbaled. A compromise with 8Hz or 10Hz geophones allows for some tilt but limited by the horizontal elements and still requires inverse filtering. The use of omni-tilt 14Hz geophones allows the exact same element to be used for all three components. Use of 14Hz omni-tilt geophones mounted in the Galperin configuration places all three elements within a broad tilt range about their optimum distortion performance when the node is level, exceeding the performance of specially built Galperin orientation 10Hz geophones.

Allowing deployment at reasonable tilt angles opens available ROV deployment time to searching for a more suitable position and to achieving decent coupling. To remove uncertainty we include three-axis tilt sensors to record the node’s orientation, facilitating accurate sensor component rotation to vertical during data processing.

Alternative solutions such as gimbals to mechanically re-orientate lower frequency geophones are not considered reliable enough due to the potential failure of rotating contacts and mechanisms. Also, in our experience, energy cross-talk is inherent in gimbals. Digital sensors with their ability to measure and correct for tilt may seem attractive but unfortunately the intrinsic noise of these sensors makes them less suitable for the potentially high dynamic range requirements of deep seabed acquisition.

Conclusion

There should not be confusion between the resonance frequency of a geophone and its low frequency limit. We have shown that 14 Hz phones can provide signal down to about 3Hz.

References:

Claerbout, J.F., Imaging the Earth’s Interior, Oxford, Blackwell Science, Inc., 1985.

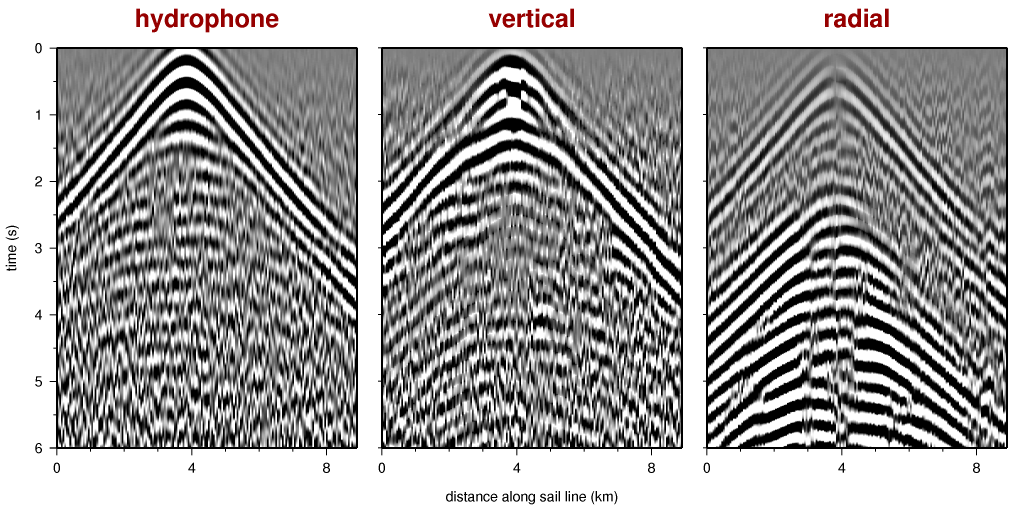

Figure 2: Narrow 1-2-3-4 Hz bandpass filtering of co-located hydrophone and 14 Hz geophones.

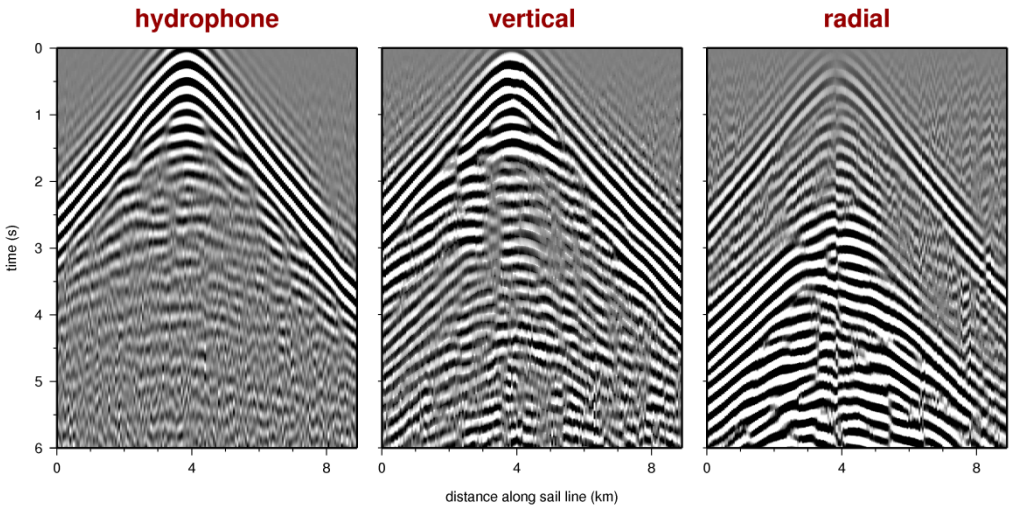

Figure 3: Narrow 2-3-4-5 Hz bandpass filtering of co-located hydrophone and 14 Hz geophones.

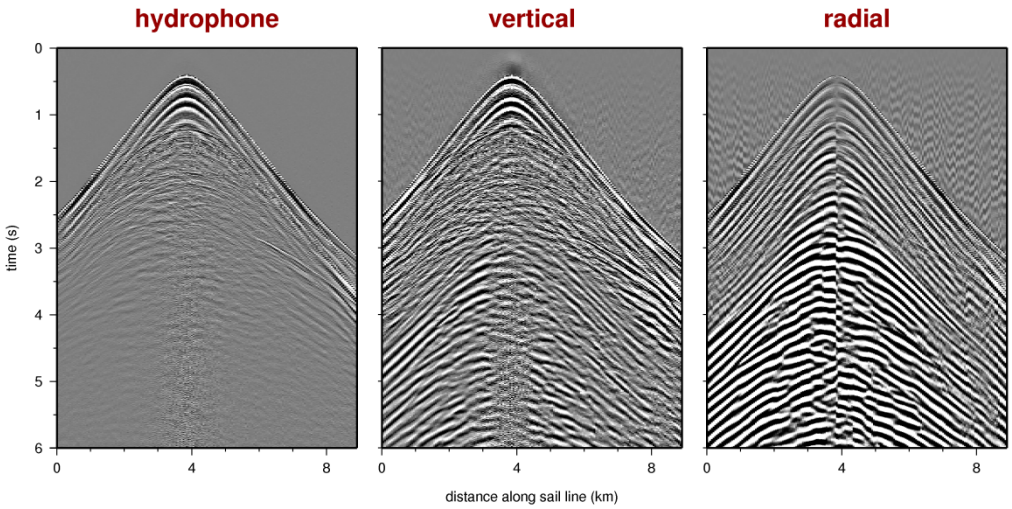

Figure 4: Broad band 2-3-100-150 Hz. As in Figs 2 and 3, the data shown are three components of a common receiver gather with a single shot line. The data have been gained with spherical divergence.

Fn	Tilt V	Tilt H
14Hz omni-tilt	+/-180	
10Hz (not high spec.)	+/- 25	+/- 7
10Hz (special Galperin)	+15 to -40	
8Hz	+/- 20	+/- 5
4.5Hz	0	0

Table 1. Tilt tolerance for a range of geophone natural frequencies. The darker boxes indicate the limiting specification and component.

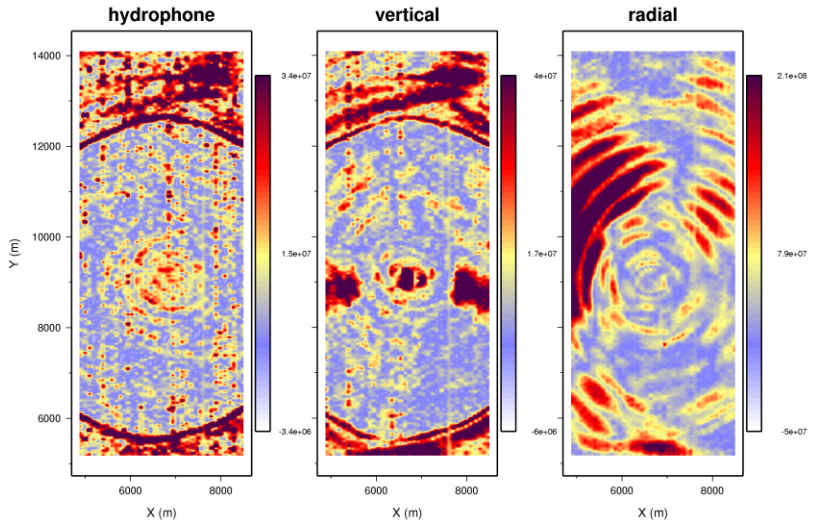

*Figure 5: Frequency slice at **2** Hz from co-located hydrophone and 14 Hz geophones.*

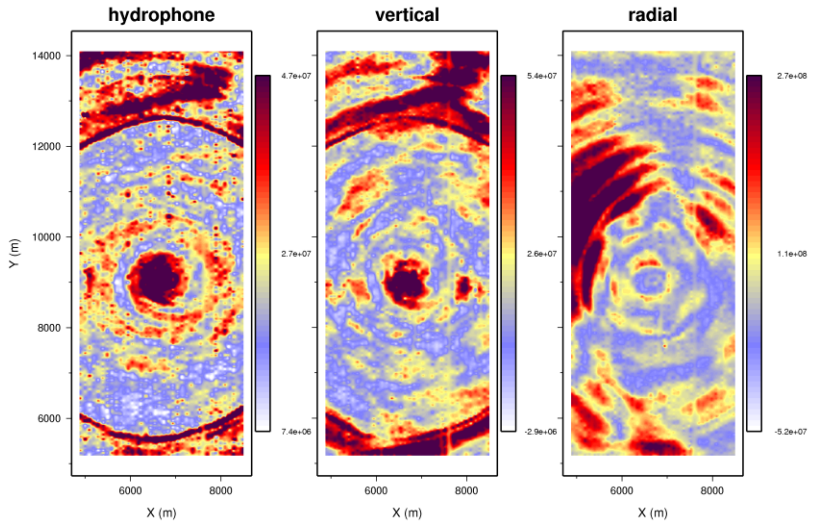

*Figure 6: Frequency slice at **3** Hz. As in Fig 5, all shots, one common receiver gather.*