SEISMIC ON THE SEAFLOOR

PETER STEWART, OCEANGEO, USA, DESCRIBES THE GEOPHYSICAL BENEFITS OF OCEAN BOTTOM SEISMIC IN DEEPWATER EXPLORATION.

Historically, towed streamer has dominated deepwater seismic exploration, and for good reason, as it is relatively cheap to acquire over large open areas.

Until recently, ocean bottom seismic (OBS) surveys have generally been limited to shallower water depths, and usually where production infrastructure has limited towed streamer access.

From a geophysical perspective there is little difference between shallow water and deepwater. If OBS acquisition can successfully meet the geophysical objectives in shallow water it can also do so in deepwater. In reality, cost and the lack of suitable deepwater acquisition equipment were the limiting factors.

In recent years a new generation of OBS equipment has become available, and a growing number of surveys are being acquired in deepwater using OBS techniques. This appears to be a trend that is on the increase, the main reason being that oil companies are recognising that the improved quality

of OBS data warrants the additional acquisition cost, particularly when considered in the context of deepwater drilling costs.

So what are the geophysical benefits of shooting a seismic survey on the ocean bottom?

A quieter environment

The ocean bottom is a much quieter environment than the surface. The surface is subject to weather, waves and swells. These noises contaminate the seismic data and can be particularly problematic for deep reflections, where the recorded signal may drop below background noise levels.

Stationary sensors

Another advantage of OBS is stationary sensors. Towed sensors suffer from two main problems. The first, and most serious, is that the action of towing the streamer through the water generates noise. This noise is magnified in the presence of cross-currents and steerable bird devices.

The other problem associated with towed sensors is that they are physically moving with respect to the returned seismic reflections (deep events are spatially offset when compared to shallow events). This phenomenon usually requires a corrective processing step known as 'receiver motion correction'.

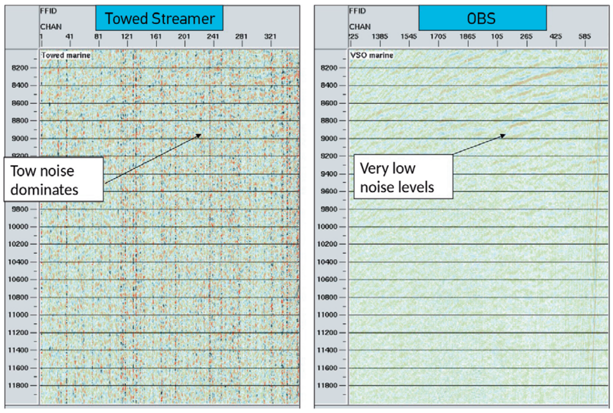

Fig. 1(a)

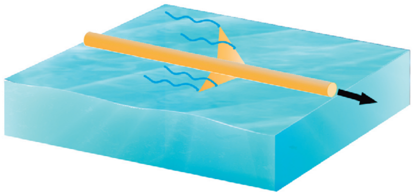

Fig. 1(b)

Figure 1. *(A) Raw shot records (time window 8 - 12 seconds) from towed streamer (left) and OBS acquisition (right). Notice vertical bands of swell noise on the streamer data which are absent on the OBS data. (B) A streamer steering bird generating drag noise as it is towed through the water.*

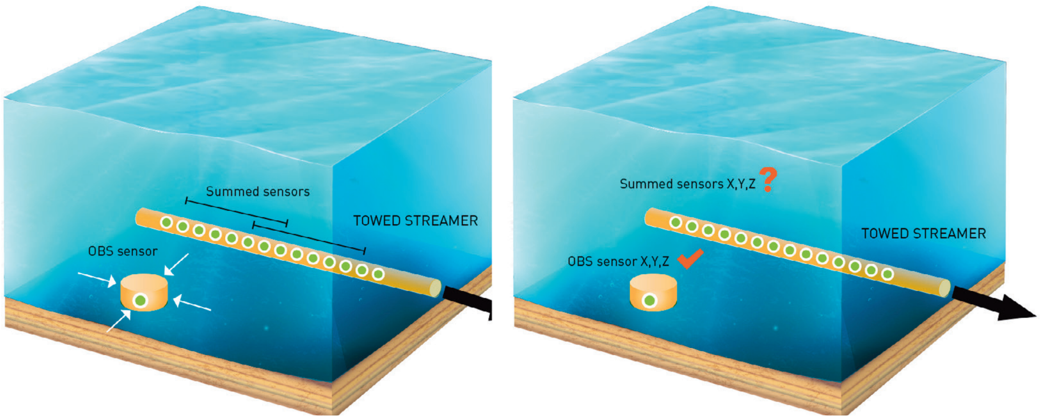

Figure 2. *Left: towed streamer hydrophones are typically summed prior to recording. This is necessary to reduce noise but results in azimuthal inconsistency when compared to node point recording. Right: OBS sensors remain in a static location that is easily calculated. Towed sensors have freedom to move in all directions. Exact location is difficult to determine accurately and not easily repeatable.*

Point receivers

Towed streamers usually have sensors separated at a native spacing of 1 - 3 m but, in an attempt to reduce noise, they are summed into a single recording over a distance of 12.5 - 25 m. This 'array filtering' results in an azimuthally inconsistent response. OBS sensors are single-point recordings. As a result, they are more suitable for azimuthal analysis studies.

Sensor position, depth accuracy and 4D repeatability

Towed streamers suffer towing motion, cross currents and feather. The location of a particular sensor is a snapshot in time derived from complex navigation processing. The precise location of a sensor is difficult to repeat. The spatial location of a stationary sensor on the ocean bottom is very easy to identify. It is unambiguous; it does not change over time and is very repeatable and thus much more suitable for 4D time lapse studies.

Besides variability and ambiguity of spatial location, towed streamers may have a large variability in depth due to swells and tides. This variably can have a huge impact on 4D noise and repeatability. Recordings on the ocean bottom have effectively had the uncertainty associated with the water column removed and are overall much more suited to 4D surveys.

Higher bandwidth and lower frequencies

OBS systems inherently have the potential for broad bandwidth and lower frequencies than towed streamer systems.

A hydrophone is a pressure sensor that has no knowledge of the direction from which the pressure comes. There is no distinction between 'up-going' or 'down-going' energy. Due to the negative reflection coefficient at the sea-air interface, down-going energy from this interface is opposite in polarity to the

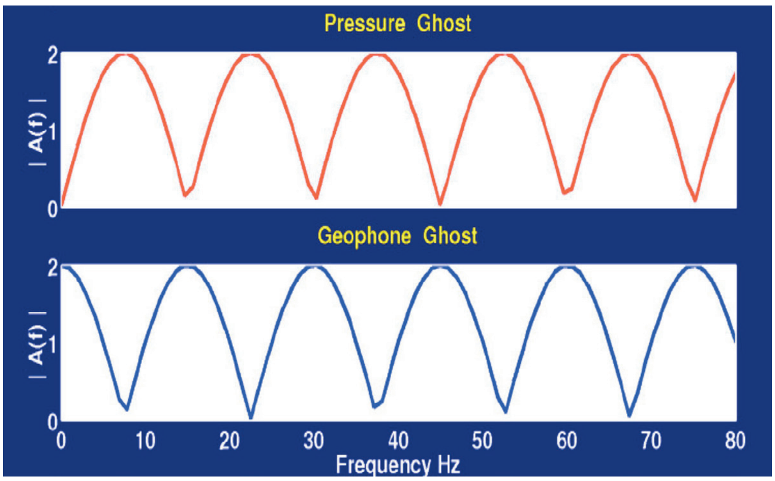

Figure 3. *Theoretical seismic ghost response for a given water depth, water velocity and assuming a vertically travelling wavefield. Note that some frequencies are attenuated to zero (the spectral notches). Note the notches are complementary (and will disappear after PZ summation). Also, note there is no notch at Zero Hertz on the geophone.*

up-going energy, resulting in notch filtering of frequencies of certain wavelengths that include Zero Hertz.

OBS recording systems include, at a minimum, a pressure sensor (hydrophone) plus a particle motion sensor (geophone or accelerometer). The beauty of a particle motion sensor is that its response is directional, and the ray paths and polarities result in the absence of the Zero Hertz notch that plagues the hydrophone. In reality, notches exist in both the hydrophone and geophone components over the entire frequency range, but they are out of phase with each other. Careful summation of the components can result in 'notch free' broadband data.

Survey design flexibility: full azimuth data

Perhaps the greatest single benefit provided by OBS recordings over towed streamers is the flexibility in survey design. Having sources and receivers completely detached from each other allows endless possibilities of offset and azimuth combination. In particular, OBS provides the ability to acquire genuine 'full azimuth' data.

The merits of full azimuth data have been well documented; these are improved illumination of complex structures, improved subsalt imaging, improved fault definition, improved multiple attenuation and generally improved signal to noise ratio. In addition, there is the potential to derive direct attributes associated azimuthal velocity variations. These include stress, fracture orientation and fracture magnitude. This technology is well practiced on land seismic and is starting to gain importance on OBS surveys.

Towed streamer vendors have long recognised the need for full azimuth. As a result, many exotic multi-vessel acquisition techniques have evolved that are getting wider and wider azimuths but have yet to reach full azimuth (over a reasonable range of source-receiver offsets). Dual coil towed streamer shooting comes closest to true full azimuth, but this technique is considerably slower and more expensive than conventional towed streamer methods (narrowing the gap between OBS and towed streamer) and can result in noisier data.

Survey design flexibility: ultra-long offsets

Another advantage of having sources and receiver detached is the ability to record 'ultra-long' offsets for refraction analysis, and deeper seismic reflections. Recently, 4C OBS seismic lines with offsets of over 100 km were recorded in the Gulf of Mexico. These have yielded deep Vp/Vs ratios that have improved the delineation of continental and oceanic crust, which in turn improve knowledge of oil maturation systems.

Imaging and illumination

OBS acquisition in particular offers illumination advantages over towed streamer. In conventional ocean bottom seismic processing, the reflected, up-going wavefield is recorded on the ocean bottom. However, this wavefield propagates to the sea-air interface, where it is reflected downward, and recorded at the ocean bottom again. For many years this second or 'ghost' recording was regarded as noise (similar to multiples) and eliminated by PZ summation.

In fact, the down-going wavefield contains unique information, which can usefully contribute to the subsurface image using a technique known as 'mirror imaging'. The benefits of mirror imaging stem from the larger subsurface illumination cone offered from the 'virtual' receiver location. These include improved shallow imaging, reduced acquisition footprint, improved signal to noise and improved velocities. As water depth increases the uplift from mirror imaging becomes greater.

The ability to image the down-going wave-field has been largely responsible for the acceptance of sparse node acquisition. Blind spots between the sparse nodes can be completely eliminated in deepwater using mirror imaging. Furthermore, blind spots associated with obstructions such as rigs and platforms may be healed with mirror imaging.

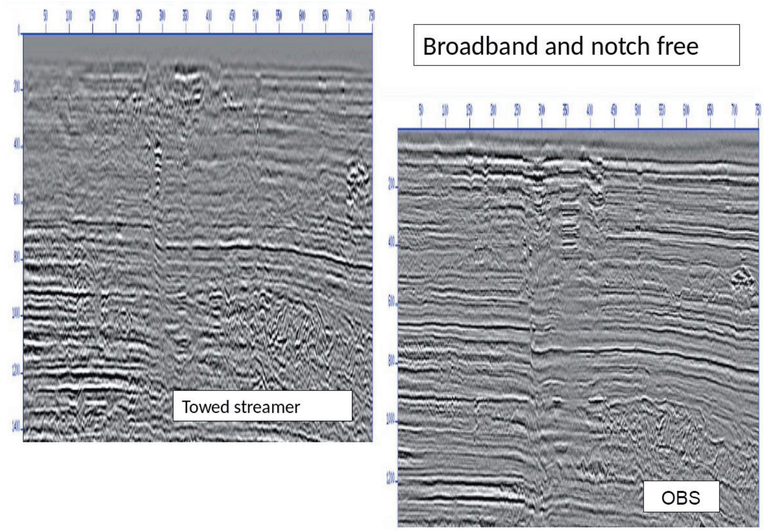

Figure 4. *OBS image (right) has considerably higher bandwidth compared to towed streamer data (left).*

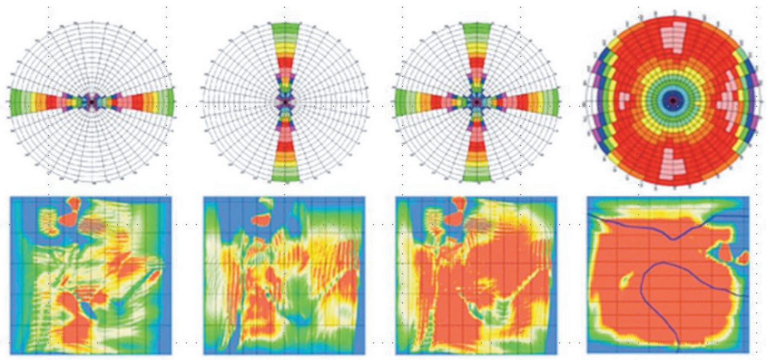

Figure 5. *Rose diagrams (top) and the associated illumination of a complex surface (bottom). The far left is a single E-W azimuth, the second left is a single N-S azimuth. The third from left is combined E-W & N-S (note improved illumination of the surface). The far right is full azimuth and offers the best overall illumination of the surface.*

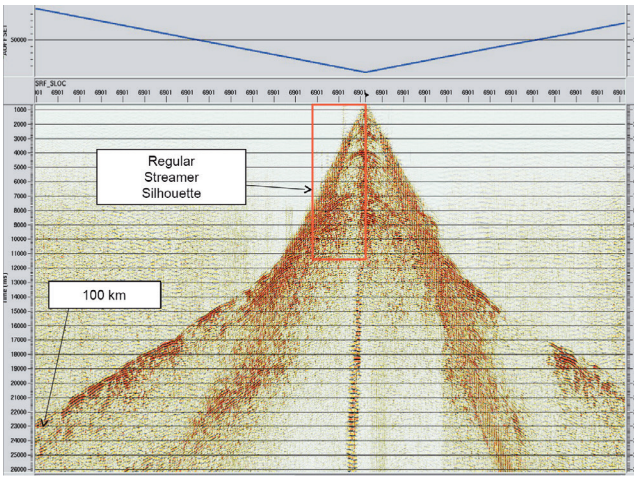

Figure 6. *Example Common Receiver Gather recorded to 40 seconds and 100 km offset. The red inset box shows for reference the amount of data typically recorded with towed streamer.*

Converted waves

Shear waves do not propagate in fluids (the shear modulus of a fluid = 0). As a consequence, having sensors attached to the ocean bottom is the only way shear waves may be recorded in a marine environment.

Shear waves have a unique and increasingly useful place in seismic interpretation. Historically, the most successful have been in subsurface regimes that are saturated with gas. Gas accumulations absorb and distort P-waves, which in turn obscure subsurface structures that delineate reservoirs. Shear waves propagate through the rock matrix and are not affected by the pore fluids.

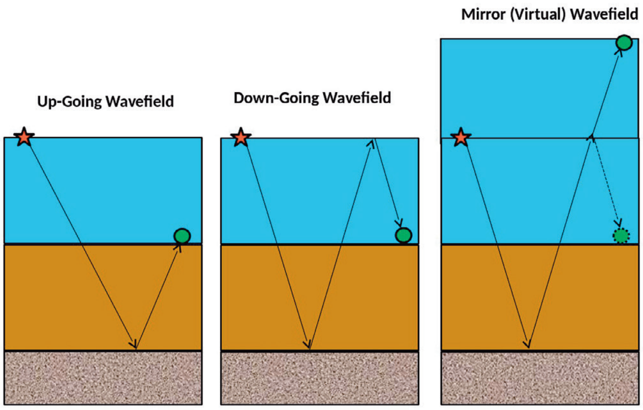

Fig. 7(a)

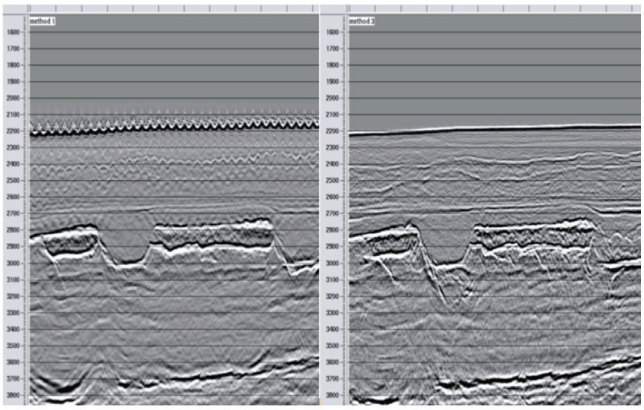

Fig. 7(b)

Figure 7. *(A) Raypaths commonly used for OBS imaging. Star = seismic source, circle = ocean bottom receiver. Conventional 'up-going' wavefield (left). The mirror wavefield (right) is derived from the down-going wavefield (centre). It simulates an acquisition where the receiver is located at the sea surface and at double the water depth. (B) Sparse node data imaged with up-going waves (left) and down-going waves (right). Notice improved reflector continuity, lack of footprint and general improvement in resolution associated with the down-going waves.*

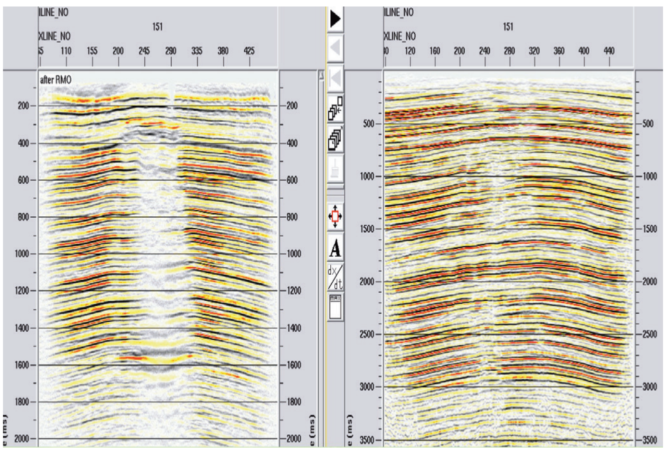

Figure 8. *PP imaging though a gas cloud (left). Notice dimming, frequency loss and 'pull-down' of reflectors on the crest of the anticline. PS imaging (right) suffers much less distortion.*

Another (growing) area of usefulness for converted waves is the improved estimation of rock properties. Density is a particularly important property from which many other secondary attributes can be derived. Density may be estimated from the AVO properties of P-waves, but these estimates can be unreliable. Combining P-wave and C-wave data and performing joint inversion techniques can yield a much more reliable estimate of density.

In addition, converted waves combined with full azimuth acquisition can utilise the birefringence properties of shear waves to estimate azimuthal properties. At the interface of an anisotropic layer, shear waves polarise into fast and slow wave fronts. With careful processing these can be separated and measured, which in turn yields stress and fracture characteristics of the anisotropic layer.

So what are the drawbacks to OBS? Geophysical, there is no obvious downside, but the cost to acquire is relatively high. However, lower manufacturing cost, higher channel counts and efficient survey designs are all bringing costs down.

Acquisition methods

There are two main methods used to acquire ocean bottom seismic, cable based and node based systems. Cable based systems were the first to gain popularity, and in the early days these were simply waterproofed land systems and had limited deepwater viability.

Nodes can be split into two further categories. The first are autonomous and un-connected. These are the type used commonly in deepwater exploration. These nodes are usually deployed and retrieved with ROVs. Due to their high cost, limited numbers and slow deployment speed, they are usually deployed very sparsely. Grids of 300 - 500 m spacing are not uncommon. To compensate for this sparsity of receivers, a high density of shots is required, typically a 50 x 50 m grid. High shot density solves the sampling problem for P-waves, but not for C-waves, and can create environmental concerns in some areas.

The other category of OBS acquisition is 'tethered nodes', i.e., the nodes are connected in some way with ropes or wires. Essentially these nodes offer deployment and recovery options similar to cable systems, which enjoy higher deployment speeds and higher density sampling. Tethered nodes are mainly used in shallow water. They are not really suited to deepwater due to low deployment speed through the water column and lack of placement accuracy.

Today there are number of purpose built cable based systems such as ION's Calypso™ system. These are designed to handle a large range of water depths (0 - 2200 m) quickly, accurately and with good sampling, making them well suited for full azimuth, 4D, C-wave surveys.

The future

So what does the future hold for OBS acquisition? Historically, the majority of OBS acquisition has been performed in production environments, and that is unlikely to change. The high level of production related infrastructure often precludes towed streamers, and it is in these production environments that 4D surveys are required.

As the geophysical benefits are becoming better understood and OBS acquisition costs decline, OBS acquisition will continue to become more attractive, particularly in areas with complex geology. Are the geophysical benefits worth the extra cost? Giants like Shell, BP, Chevron, Exxon and Total have published extensively in support of the method. National oil companies such as Petrobras, Pemex, Petronas and ADNOC have followed suit. All have spent hundreds of millions of dollars on multiple surveys over the last few years.

Statistics show that OBS acquisition (as a percent of the dollars spent on seismic acquisition) has grown steadily at a rate of about 1%/year over the last decade, and currently represents about 13% of marine data acquisition. This could grow to 25% by 2025.