Introduction

The ongoing need for improved resolution has had a profound impact on the marine seismic industry over the past decade. For both streamer and ocean bottom techniques, several innovative broadband techniques have been developed to extend the bandwidth and improve the resolution of marine seismic data through a combination of acquisition and processing technologies. Examples include BroadSeis, GeoStreamer, IsoMetrix, XArray, and OBN wavefield separation and combination techniques.

The downturn in offshore exploration and production activity since oil prices declined precipitously in 2014 has had an even more profound effect on the marine seismic industry, with the reduction of marine streamer activity being particularly concerning. Companies that are primarily focused on marine streamer data acquisition have undertaken refinancing, restructuring, and even bankruptcy protection to remain ongoing business concerns during this extended period of low activity.

Balancing the technological need for improved seismic resolution with the commercial need for sustainable profitability has proven a challenge for the marine seismic sector, and there has consequently been a continued search for cost-effective technologies that can provide the needed resolution without large capital investments. One of the simplest and most straightforward of these lower cost, high resolution technologies is the P-Cable UHR (Ultrahigh Resolution) system, which uses closely spaced, short offset streamers to collect offshore seismic data with spatial and temporal sampling characteristics more typically used for shallow geohazard surveys.

Method and/or Theory

P-Cable simply involves collecting 3D seismic data with spatial sampling, temporal sampling, and signal frequencies that support ultrahigh resolution seismic imaging. Specifically, acquisition bin sizes typically range from 1.5 to 6.25 meters, temporal sampling intervals range from ¼ to 1 millisecond, and both the streamers and sources are towed at quite shallow depths below the sea surface (2 to 4 meters) to emphasize higher frequencies. The streamers themselves are quite short (25 to 100 meters) and closely spaced (6.25 to 12.5 meters), with a correspondingly small receiver group interval (1.56 to 6.25 meters).

The configuration of the P-Cable streamer spread differs from conventional marine 3D streamer seismic where each streamer is towed from a lead-in cable connected to the acquisition vessel. In P-Cable acquisition, a single lead-in is towed along one of the paravane lines, and then connected to a cross-cable that is towed perpendicular to the vessel's direction of travel between the paravanes (the "P" in P-Cable stands for perpendicular). This cross-cable has takeouts at regular intervals to which the individual streamer cables are connected.

A complete P-Cable spread will typically have between 8 to 16 streamers with a streamer length between 25 to 100 meters, resulting in a total active streamer spread of only 200 to 1600 meters and a total channel count between 64 and 256 channels. This entire configuration is considerably less equipment and channels than a single streamer from a conventional 3D multi-streamer spread, and therefore represents a correspondingly lower capital investment.

Processing of P-Cable data is essentially identical to conventional 3D streamer processing, with the main difference being the heightened emphasis on: (1) precise navigation and positioning for horizontal positioning and binning and (2) accurate timing and statics corrections, tidal and water velocity corrections, and vertical datuming to account for any non-geologic timing variations in the recorded data. Due to the shallow tow depth of both the source and the streamers, deghosting is a critical step in the processing flow since small depth variations can lead to large phase and amplitude changes in the ghost response.

Examples

Our examples are drawn from two P-Cable surveys that were recently conducted in the Barents Sea and the US Gulf of Mexico. It is important to note that for both examples, velocities were derived from conventional, full offset 3D data since the recorded P-Cable data does not have sufficient offsets for accurate velocity estimation.

The Barents Sea survey was designed to help guide the development of a very shallow oilfield offshore Norway, with specific emphasis on achieving 4 to 6 meter vertical and horizontal resolution to help guide the horizontal drilling that will play a large part in the commercial development of this discovery. The target reservoirs in this field are upper Triassic to middle Jurassic sandstones overlain by a complexly faulted Cretaceous section beneath a regional unconformity. Figure 1 shows a comparison of P-Cable to conventional 3D streamer data, both of which have been processed with broadband techniques to achieve optimal resolution. The improvement in both horizontal and vertical resolution achieved with P-Cable is exceptionally dramatic in this comparison due to the shallow depth of the reservoir (400 meters water depth, with the target reservoir only 250 meters beneath the seafloor).

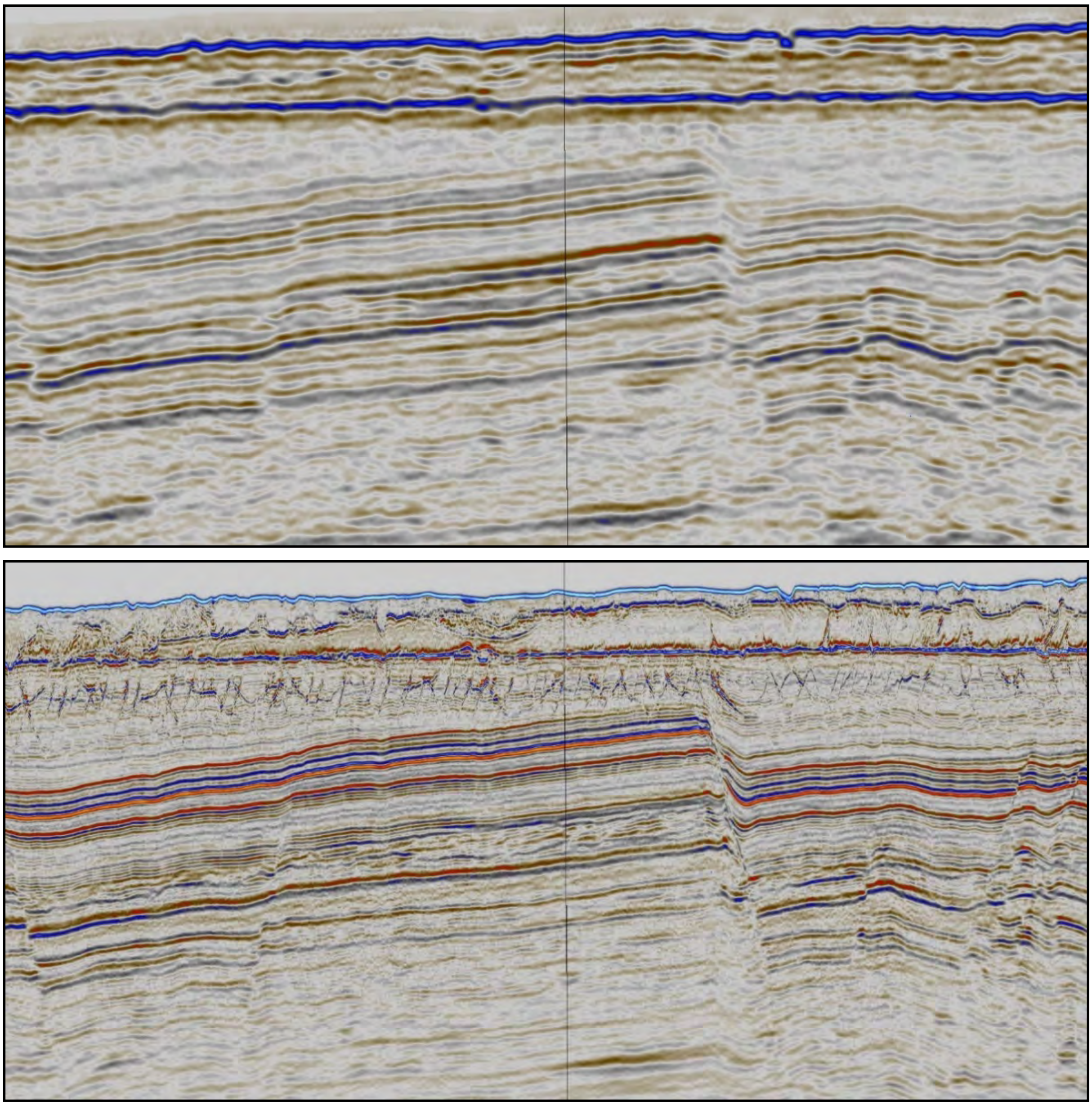

Figure 1: Vertical section comparison of convention streamer 3D seismic with broadband processing (top) and P-Cable 3D seismic with broadband processing (bottom). Image courtesy OMV.

Even more impressive is the time slice comparison shown in Figure 2, which is a slice through the complexly faulted Cretaceous formation above the target reservoirs. As seen in the vertical sections shown in Figure 1, the steeply dipping faults that can clearly be seen on the P-Cable data beneath the regional unconformity are totally absent in the convention 3D section, presumably due to aliasing associated with the coarser spatial sampling (i.e., 25 meter crossline sampling for the conventional 3D data vs. 3.25 meter crossline sampling for the P-Cable 3D).

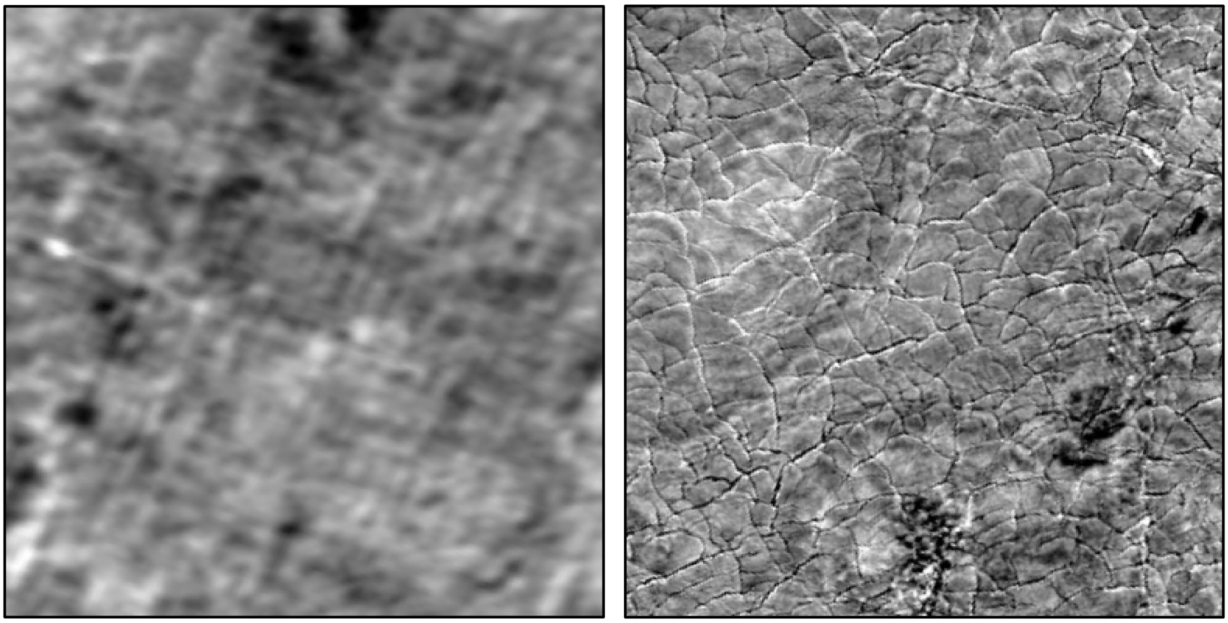

Figure 2: Time slice comparison of convention streamer 3D seismic with broadband processing (left) and P-Cable 3D seismic with broadband processing (right). Image courtesy OMV.

The US Gulf of Mexico surveys were conducted as part of a 4D (time-lapse) reservoir management program aimed at monitoring the progress of fluid movements as the reservoir is produced using water injection. For these surveys, which are in relatively deep water (1000 and 3000 meters), the objective was not improved resolution, but rather reduced survey costs compared to higher fold OBN (Ocean Bottom Node) surveys, which had been previously used for field development and reservoir management.

The initial baseline surveys demonstrated that P-Cable can provide data of sufficient quality for time-lapse monitoring of the intervals of interest. An example is shown in Figure 3. which shows a side-by-side comparison of the OBN and P-Cable datasets processed using pre-stack depth migration. In additional to the much lower fold of coverage, the P-Cable data were acquired with a much smaller energy source (300 in^3 airgun array) than the OBN data (2900 in^3 airgun array).

Processing of the first set of repeat surveys, conducted approximately one year after the baseline surveys, has confirmed that the P-Cable surveys are repeatable enough to recover reliable 4D signals, which for these reservoirs is an amplitude increase associated with hardening as hydrocarbons are replaced with water pumped from the injector wells. 4D signals have been recovered from reservoir intervals as deep as 2800 meters below seafloor with a relatively modest energy source and this level of performance indicates that P-Cable technology is suitable for relatively frequent, low-cost time-lapse seismic monitoring of reservoirs.

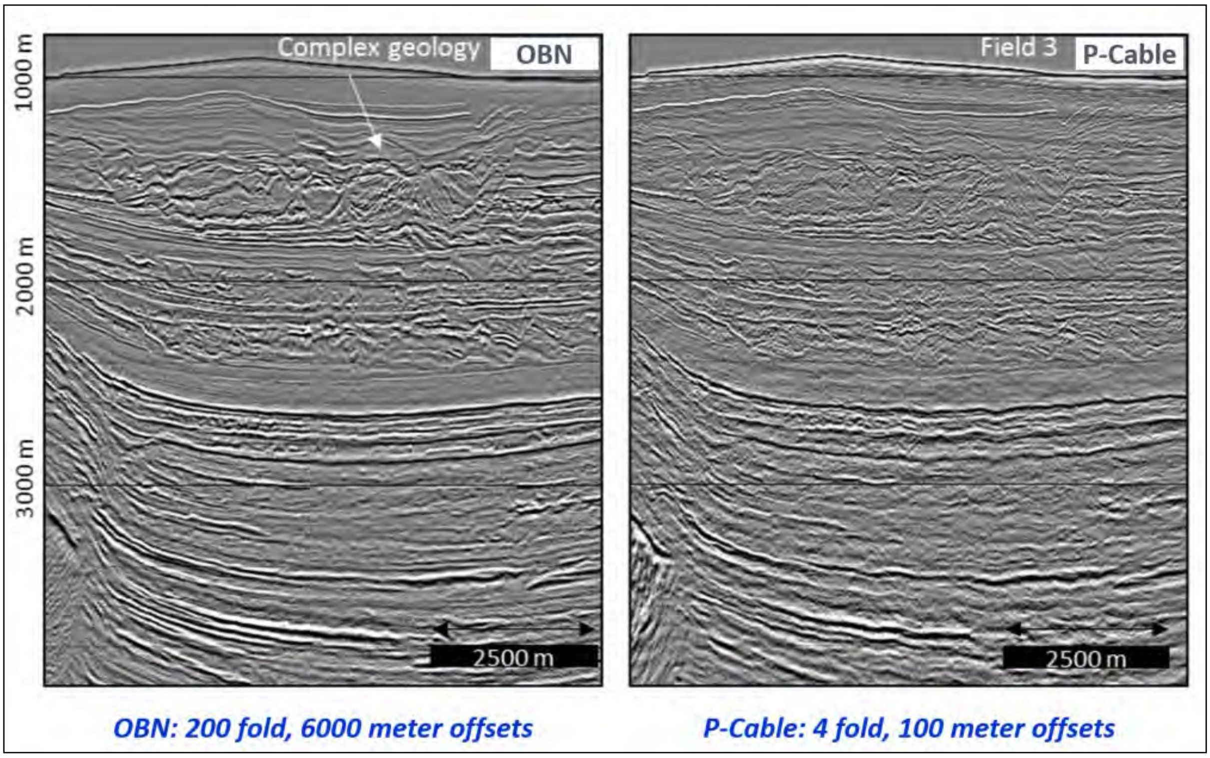

Figure 3: Vertical section comparison of full offset, rich azimuth OBN 3D seismic with broadband processing (left) and P-Cable 3D seismic with broadband processing (right). Both datasets were pre-stack depth migrated using the same velocity field. Image courtesy Shell.

Conclusions

The P-Cable marine seismic streamer technique produces extremely detailed, high resolution seismic images using densely sampled, short offset streamer arrays. Despite the low fold of this acquisition technique, data quality is excellent and sets a new benchmark for ultrahigh resolution marine seismic data. The limited, short offset characteristics of this type of data has both advantages and disadvantages.

Advantages include excellent zero offset data with minimal frequency loss due to NMO stretch, accurate well ties and acoustic inversions, and excellent 4D repeatability due to the reduced impact of streamer feathering with short streamer cables. Disadvantages include inability to support AVO/AVA analysis or elastic inversion and rock property studies due to the limited offset range. The limited, short offset nature of P-Cable data may also make it inappropriate for imaging in the presence of complex velocity structures, where a broader range of offsets and azimuth is required to achieve acceptable subsurface illumination.

Although by no means a replacement for conventional marine streamer or OBN seismic, P-Cable can play an important role as a complementary tool in target areas that require exceptionally detailed and repeatable imaging or where the limited size of the project makes P-Cable a financially attractive option for cost-effective surveying.

References

Brookshire, B.N., Lippus, C., Parish, A., Mattox, B., and Burks, A., Dense arrays of short streamers for ultrahigh-resolution 3D seismic imaging, The Leading Edge, 35, No.7, 594-599