



Full azimuth 4C Node Acquisition for Enhanced PP and PS imaging

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Summary

The benefits of full azimuth acquisition with sparse planted multicomponent nodes at the sea floor are numerous. Improved reservoir characterization from better imaging can be expected. The nodal positions can be located with very high vector fidelity and can be repeated very accurately. The areal sampling is done by the dense shooting. Nodes are much more practical in the presence of obstacles such as production facilities and regular coverage can be assured. Nodes provides converted waves desirable for gas occluded reservoirs, fracture detection and lithology characterization.

Introduction

Methods for marine seismic exploration and reservoir imaging have been through several stages of adjustments and improvements. The streamer technologies have gone from 2D seismic to 3D seismic and now in to 4D seismic. Frontier exploration 2D seismic is still used. For reservoir imaging 3D seismic is the popular choice. Most seismic data that has been acquired is based on pressure (scalar) sensor recording from conventional streamer surveys with a single seismic vessel with narrow azimuthal coverage.

Whatever is not illuminated cannot be imaged and wide azimuth coverage is important for imaging under complex overburden structures. In order to e.g. “see” through gas invaded zones, so-called multi-component or 4C (measures P-component + vector response of pressure and shear (S) waves) was commercially introduced in the mid nineties. True 4C-3D measurements (multi-azimuth) result in much better imaging of complex structures (e.g. multi-direction dips and fault planes) and today’s advanced directional drilling techniques and well/reservoir engineering can utilize the more accurate spatial picture provided by higher definition 3D. Time lapse-3D – or 4D represents a huge potential for reservoir management is rising and full seabed installations is immature.

The possibility to find new large field are getting smaller and it has become a common strategy for oil companies to focus on how to produce more oil from already producing

fields (“Enhanced Oil Recovery”). Big efforts are being put in research and development for technologies that can increase both the producing life and the running hydrocarbon recovery rate of these fields. This includes more efficient and accurate production technologies and also solutions for better reservoir descriptions using seismic, preferably in combination with non-seismic data.

Two techniques that achieve wide azimuth geometry offshore are multi vessel streamers plus source vessels and seabed nodes .

Wide azimuth Streamer

Conventional marine seismic is performed by towing a limited number of long hydrophone arrays (“streamers”) close to the sea surface, recording pressure wave reflections from the reservoir areas. The source for the pressure wave is usually air-guns towed from the same vessel. To achieve wide azimuths coverage various acquisition design have been developed and implemented To accurately controlling the streamer position – both in depth and laterally .especially at the far offset receivers remains a challenge One can experience lateral skew (“feather”) of several hundred meters due to near-surface sea currents. The feather and cable separation change over time due to variation in current speed and heading, cable heading and ship’s water speed. In state-of-the-art streamer the feather angle can be reduced .a few degrees by way of active



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lateral steering systems. Despite the fact that streamer cables are often an efficient way of quickly covering an unobstructed survey area, it is likely that, due to the inherent problems with positioning accuracy and repeatability, the methodology only applies to reservoirs where one can expect to observe strong 4D effects.

Ocean Bottom Seismic (OBS)

An alternative method for recording seismic data is to place the sensors on the seafloor, rather than towing them behind a vessel. Each sensor group or point receiver contains both hydrophones and geophones for recording of both pressure and shear waves. A sensor package usually includes one hydrophone and three mutually orthogonally mounted geophones. The geophones measure either velocity or acceleration and are either fixed to the sensor housing or mounted onto a gimbal. The fixed geophone solution requires determination of the vertical axis and heading to enable all 4C sensors to be numerically rotated into a common coordinate system. The gimballed solution requires only additional heading information to do the vector rotation. However, due to the low gimbal friction geophone signal distortion may be observed. Especially if the sensor package is poorly coupled to the seabed this gimbal effect will be very pronounced.

This methodology, called 4C, "multiwave" or OBS, has been in use commercially for about a decade - driven by the desire to record better and more accurate seismic data. In today's market there are two main 4C technologies available.

Cable Technology

A few contractors are using long cables with the sensor packages incorporated in cables. The sensor packages could be arranged as individual stations ("single sensor") or in groups, with a typical inter-group/station separation of 25m or 50m. The separation between neighbouring cable strings is typically 400 m. Except for a couple of exceptions the geophone response from cable-based systems is strongly influenced by the mechanical cable construction in such a way that they will mask anisotropic properties of the reservoir, due to the cable's much more pronounced, inherent "anisotropy". If the water depth is not to great, seabed cables are relatively simple to position with good accuracy in the cable's in-line direction. In the cross-line direction it is much more difficult. Without actively steering the cable's cross-line movement during deployment one will get a typical deviation between "pre-plot" and "as laid" positions of 25% of the water depth. This is a problem in a 4D context. Hence, all known seabed reservoir monitoring cables have been trenched down into the seabed. The disadvantage here is that electronics do fail

and water intrusions will happen sooner or later. It will be a challenging task to re-install a serviced or new cable into the original position. New fiber optic emerging technology is being developed to address the problem of permanence in cable installations.

Node Technology

The second technology is the Node technology where the 4C sensor packages are deployed and planted into the seafloor, usually in a regular, grid pattern., rectangular ,or better in hexagonal geometry. However, because each unit is autonomous, inter-node separation and receiver layout envelope can easily be changed.

Even though Node type technology has been used for scientific studies for over 70 years (e.g. like regional studies at Basin scales), the birth of the commercial scale 4C Node technology happened in the beginning of the 90's. In today's market there are more contractors offering 4C Node services.

The autonomous unit is illustrated for the 3000m rated system. (Fig 1).

The following four components are recorded: Hydrophone P(pressure), vertical component Z, and horizontal components X and Y with full azimuth. As shown, in (fig 2)the spatial sampling is done by the shooting.



fig 1 : Node rated to 3000 m with sensor part planted in the seabed

Vector Fidelity

Focusing on finding high quality solution for acquiring 4C data at the seafloor testing of different type of 4C cables and Nodes resulted in a planted node for the best Vector Fidelity. It is autonomous system based on a small, low-mass sensor package, connected to a control and data acquisition unit, which contains a PC, power supply, high accuracy clock and data storage medium.



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This quality data acquisition system with a high degree of flexibility is able to acquire data with Vector Fidelity in all kinds of challenging areas. Operating a cable-less system is also advantageous in areas with a lot of infrastructure (obstructions) on the surface and on the seafloor, areas that are environmentally fragile, and in water depths from few meters to 3000 m. The Node in-situ is planted, acoustically separated from the pressure vessel that contains the complete recording system, including batteries and data storage.

Operational setup

Operations are now very efficient with the use of one DP vessel. Only one vessel is used for the complete operation

- lay out of the nodes and planting with a ROV
- handling of the nodes from the deck is completely automated with minimum human intervention
- Dual high power omni directional sources

Planting of sensors

The manipulator arm takes the Node out from its storage position on the sledge and plants it into seabed. A thin, flexible sensor cable, running between the Node and the rest of the CASE unit enable to have the sensor completely isotropic. The orientation parameters (roll, pitch and heading) are observed and recorded.

Cantarel example in Mexico

A major Node 4C-3D survey was performed by SeaBed Geophysical for Pemex in 2003/2004. This is the world's largest 4C-3D project ever performed (approx. 240km²). The acquisition was done on the Cantarell field offshore Mexico, which is the largest offshore producing field. To be able to cover the requested area, SeaBed utilized 250 CASE Units, which were deployed in 7 patches totalling in approximately 1,500 Node positions. The Cantarell field is densely populated with platforms, subsea structures and pipelines and there is lot of vessel activity in the area. These challenging conditions demonstrated the operational benefits by using a cable-less Node-based system.

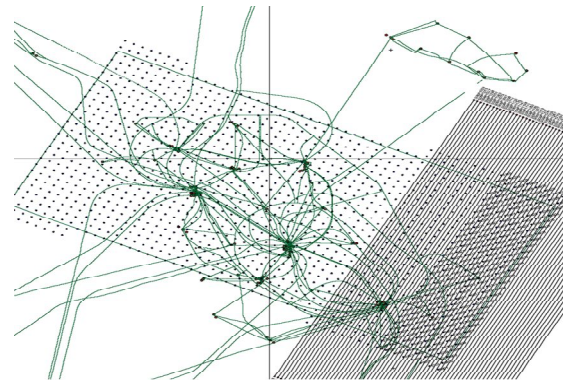


Fig 2 acquisition with sparse grid receivers. The lay out of the 250 nodes in the center of the swath is surrounded by the full dense area of the shooting, insuring a fine areal sampling.

The nodes deployed were autonomous units comprising of an instrument-housing and a node. The instrument-housing contains a CPU, A/D, data storage, clock and battery and the node contains 3 orthogonal geophones, a hydrophone and tilt meters. Each unit is deployed and positioned by crane from the support vessel and the node is planted and positioned accurately by the ROV.

Careful sensor design and controlled planting with the ROV manipulator arm provides excellent coupling and high vector fidelity; the sensors are placed at the water-seabed interface, well coupled and in a known orientation. A hydro-acoustic communication system allows data transmission to a surface vessel.

The 232 nodes per swath are deployed in a sparse grid with a 400m spacing and covers 35km² (figure 2). The total receiver area of the 7 swaths covers 230 km².

The 520 km² of shot area with a grid of 75x50m was made of 1100 km² including the overlap of swaths. The survey provided full regular azimuths and offsets up to 8000m with regular fold coverage of over 100. The shooting area is close to 160 km² for each swath. Sail line interval is 150 m with dual source shooting flip flop every 50m.



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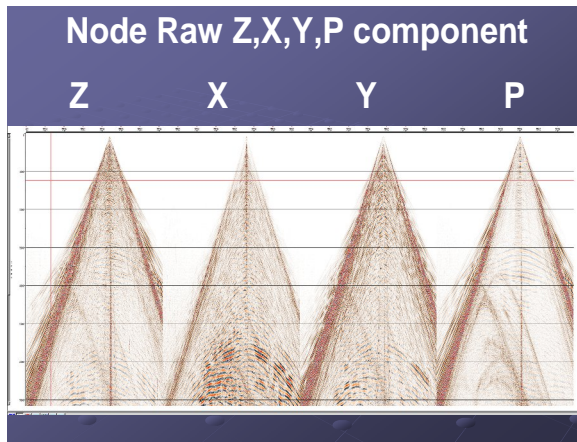


Figure 3: raw 4Cnode data

QC was done on board and the activity of the nodes was monitored. On board processing generated 2D sailing line stacks and 3D preliminary P wave stacks for QC.

The operations started on November 4th and were completed in 134 days only. Average production rate was 1,7 km² a day, with high quality records obtained (Figure 3)

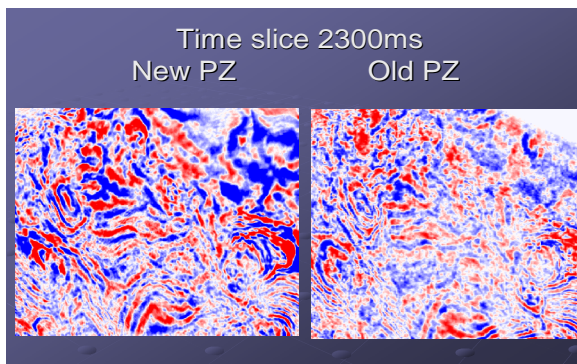


Figure 4. Time slice 2300ms New Node PZ versus Old Cable PZ

The results were quite improved in comparison with a previous 2C 3D acquire previously, mainly due to the full azimuth acquisition and excellent coupling of the nodes.

The fig 4 is a direct comparison of the same time slice at the top of the objective. This time-slice on top of the major target illustrate the gain obtain in the imaging and delineation of the blocks under the overthrust.

The converted wave was of good quality and in particular in the tertiary. The main gain obtained from the converted wave was a much better character and resolution for the shallower data and the very fine details of the geology.

The converted wave data displayed at the scale of the P data do reveal the fine details.

The interpretation from the converted wave brought also new light for the field.

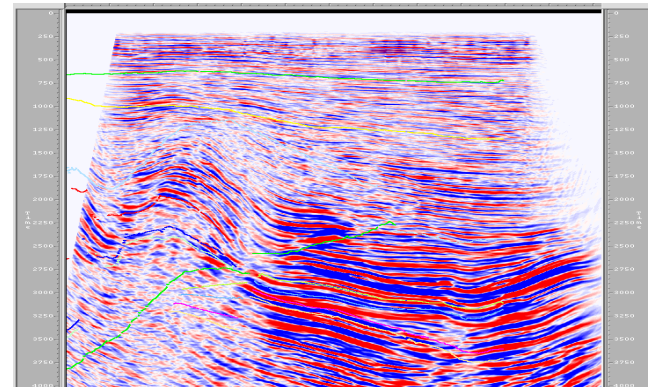


Fig 5 PP section from Node data

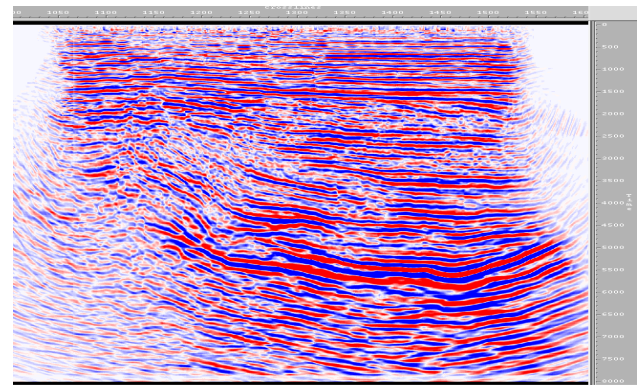


Fig 6 PS se same section from Node data

Final remarks and conclusions

The future of 4C seismic is very much formed by the oil company's strategies in development of the oil fields. The increased demand for high full azimuth quality data is expected to arise based on the need to characterize the reservoir better and producing more oil out of existing reservoirs. The trend is also to move the 4C systems towards deeper waters (3000m) with a developing market on the ultra-deep shelf as well. Finally, there is an increased focus on highly repeatable 4D seismic services, seen in conjunction with other EOR measures. Node-based 4C solutions, with the full azimuth technology seem very well suited due to its repeatable acoustic coupling, positioning accuracy and ease to service, maintain and upgrade over its 4D service life. The additional information from the shear



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waves is now recognised essentially due to the progress in processing and interpretation .

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