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Teal South 4D-4C Acquisition Phase II

(A Time Lapse Laboratory Field Study)

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Abstract

Over the last several years our understanding of repeated 3D surveys (4D/Time Lapse) has increased dramatically. Companies are presently trying to determine when and where multiple surveys are necessary and if they are economically viable. 4D is emerging as a vital technology for efficient field management however, methods used to apply this technology are not fully understood. Traditional repeated 3D surveys have already demonstrated the potential, but it is clear that significant data quality improvements can potentially be obtained with the use of permanent reservoir monitoring systems.

4C data (3 component geophone and a hydrophone) is also emerging as a key enabling technology in reservoir characterization. In areas where structural imaging is difficult, such as gas chimneys, shear wave data is able to create images not available from traditional P wave data. Even in areas where P wave data is able to create a good structural image, shear wave data offers the potential to determine valuable information about fracture orientation, reservoir permeability, and reservoir fluid content. Shear wave acquisition methods offer great potential, but current techniques are expensive and performance is not always predictable due to poorly understood influences such as sensor coupling.

The field at Teal South is currently being used to evaluate a low cost approach to permanent 4D reservoir monitoring system installation and operation. Intended as a "calibration test site", the Teal South field will also provide new information on near surface shear wave behavior, current and future 4C-sensor performance, advanced cable burial techniques, and aid in the design and development of new ocean bottom cables. In addition, Teal South provides a 4D/4C data set to allow testing of current and future processing methods and interpretation tools.

INTRODUCTION

In July 1997, Texaco EPTD acquired a four component (4C) Ocean Bottom Cable (OBC) dataset over a 9km^2 area in Eugene Island Block 354 (Phase I of a 4D-4C time lapse study of the Teal South Field). In order to minimize the cost of the permanently deployed system, it was decided to deploy a sparse receiver grid, with four lines of six (4C) receiver stations. Each receiver station was wrapped in a sandbag for satisfactory sensor coupling (ARCO licensed technology). The receiver line interval was 400 meters, and the receiver station interval was 200 meters. The recording equipment for Teal South was a standard I/O System2 RSR recording buoy in which the recorded data was retrieved on a periodic basis. In order to achieve adequate fold, a dense 25 m x 25 m grid of shots was acquired over an area extending 1,000 meters in all directions around the receiver grid. This source effort resulted in a full fold, fully migrated P-wave image over several reservoirs in the Teal South Field. The geometry configuration produced a unique receiver gather containing multiple offsets and multiple azimuths, allowing extensive examination of source, receiver, and earth anisotropy effects.

In February 1998, Western Geophysical, Input/Output, and DigiCourse returned to Teal South to locate the three cables left in place from Phase I (one cable was damaged and removed during the initial survey). The purpose of the trip was to interrogate the reliability of the acoustic transducers that were used for cable positioning. Only one of the three remaining ocean bottom cables was still in place. The two cables that were missing were most likely dragged away by shrimp trawl nets which could have easily snagged the acoustic release pop-up buoys at the end of each cable (See Figure 1.). The remaining cable appeared skewed a short distance at the location of the pop-up buoy.

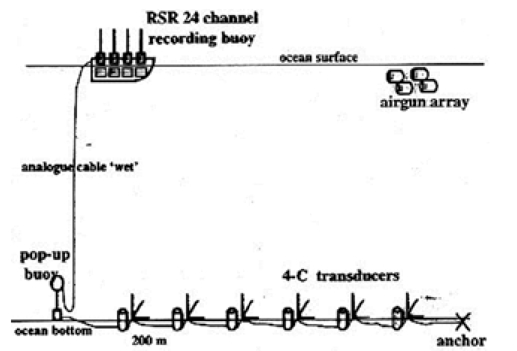

Figure 1. DigiCourse Acoustic Release Pop-Up Buoy shown extending six feet in the water column from the seafloor.

The processed 3D P-wave seismic dataset from this survey exhibits encouragement for reservoir monitoring (See Figure 6.). Furthermore, the quality of the three component (3C) C-wave sections were better than expected, but it was apparent that much work remains to be done, particularly with the shear wave volumes. Significant migration artifacts were visible on the C wave section, due to the reduced Common Conversion Point coverage. However, the general methods used at Teal South offer potential for low cost-high quality 4D-4C datasets.

PHASE II SURVEY

The Phase II study was designed to investigate near surface shear wave behavior while evaluating various sensors and system installation improvements to refine long-term survivability of the installed ocean bottom cables. The new survey layout in Phase II, (See Figure 2.) was designed with the same spread configuration as the original four east-west (E-W) lines of six (4C) receiver stations deployed in Phase I. However, included to the east of the four E-W lines were three additional lines orientated in the north-south (N-S) direction with four (4C) receiver stations on each cable. To maintain a regular receiver grid, the station interval on the three new N-S cables was 400 meters and each cable was spaced 100 meters apart. An objective of the additional N-S lines was to evaluate sensor coupling to the ocean bottom. The westernmost N-S cable and the four E-W cables were buried to evaluate potentially improved acoustic coupling. The easternmost N-S cable was deployed on the seafloor with sandbags wrapped around each receiver station, to establish a direct comparison to the method employed in the Phase I study. The center N-S cable was laid on the seafloor without sandbags or burial.

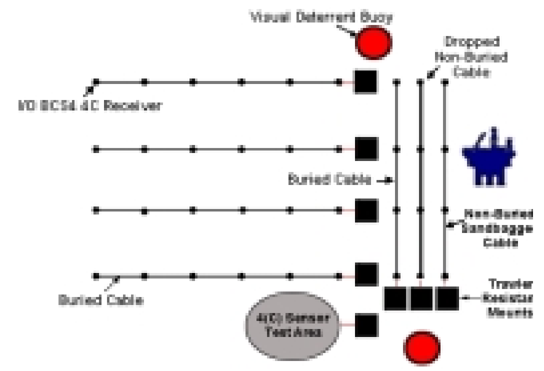

Figure 2. Survey layout for Teal South Phase II

The planned burial of the four E-W cables and the westernmost N-S cable was also a way to provide improved survivability of the cables from shrimp trawling operations. As in the Phase I cable installation, bottom-mounted acoustic release pop-up buoys were to be installed at one end of each cable to facilitate cable recovery. To provide protection to these buoys, a device known as a “trawl-resistant mount” was developed. These devices were designed to provide a protective fairing around bottom-mounted instruments and consist of a metal pyramid shape measuring 3' high, 5' wide, and weighing approximately 800 lbs. A hollow in the apex of the device provided a recess for the acoustic release pop-up buoys. A mount was placed at the location of each pop-up buoy as shown in Figure 2. As a final measure, two visual deterrent spar bouys were deployed to the North and South of the area to provide surface markers indicating a subsea obstruction to deter shrimp boats from working the area (See Figure 2.).

Another device was developed to evaluate different sensor packages and the effect of their relative orientation. The “Sensor Test Frame” shown in Figure 3, measured 25’ long, 8’ wide, and weighed approximately 1,100 lbs. At one end of the hollow metal frame, six I/O BCS4 (4C) receivers were sandbagged and mounted on 30-degree radials. The intent of this arrangement is to study the azimuthal anisotropic properties as the wavefont propagates from the source to each receiver. At the other end of the sensor test frame, ten (4C) receivers from different manufacturers were mounted on parallel axes to evaluate their relative performance. The sensor test frame was deployed just south of the Phase II survey area in the position indicated as the 4C Sensor Test Area shown in Figure 2. The test frame was actually used only as a template for lowering the sensors to the seafloor in the proper relative positions. Once the frame was laid on the ocean bottom, a Remote Operating Vehicle (ROV) activated releases allowing the sensors to fall in place on the seafloor.

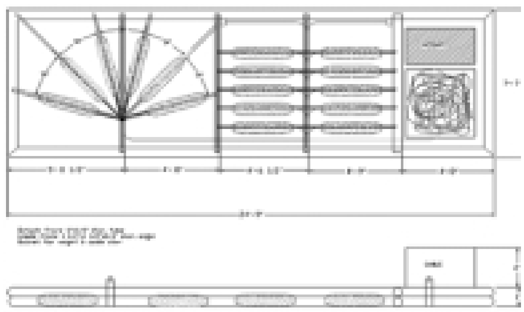

Figure 3. Sensor Test Frame

EQUIPMENT DEPLOYMENT

The original cables used in Phase I were deployed under ideal conditions. With the aid of a Dynamic Positioning (DP) vessel and with sea conditions of 1-2 feet, the crew was able to deploy the cables by hand. However, sea conditions were not as favorable and a DP vessel was not available for the cable laying operations in Phase II. Since the objective for Phase II was to deploy the receivers as close as possible to the original locations in Phase I, other measures were taken to improve the ability to reoccupy the same positions. A pneumatic-tire cable engine (Squirter) was used in Phase II to apply a higher laying tension as the cables were being deployed. This measure helped improve the “straightness” of the cable lay. In addition, prior to cable deployment, acoustic transponders were installed at the ends of each cable near the last receiver location. The purpose of the transponders was to determine cable positions, measure the installed cable track to establish deployment accuracy, and to get a fixed position of each cable for future burial work and retrieval. After each cable was deployed, they were then pinged to determine accuracy relative to Phase I pre-plot positions.

Poor weather conditions and lack of DP support made it difficult to accurately deploy the trawler resistant mounts at their pre-plot positions. As the cables were deployed, a floatation buoy was tied to the end of each cable. Once all the cables were deployed, the cable lay vessel retrieved each floatation buoy and attached a pigtail connection to the cable’s associated trawler resistant mount. As the mounts were lowered to the seafloor, an acoustic signal was transmitted at various intervals to verify equipment reliability and positioning accuracy. Once on the seafloor, each acoustic release

was pinged to validate that a response signal was received prior to leaving the Teal South Field.

The planned deployment method of the sensors from the Sensor Test Frame had to be re-engineered due to poor visibility at the seafloor. The intent was to lower the frame down to the seafloor and a ROV would remove the sensor test cable and associated clump weight from a cage (See Figure 3.) approximately 100’ from the frame location. The ROV would then plant two spiked receivers by pushing them down from poles attached to the frame. The ROV would then cut rope that supported the sensor test receivers to the frame. Afterwards, the frame would be lifted back to the surface leaving the receivers on the seafloor in the configuration of the frame. Due to poor visibility in the zone from 0’-40’ above the seafloor, the ROV was unable to perform the task originally intended. The sensor test cable had to be let down from the main deck of the vessel as the frame was being lowered to the seafloor. The poles to drive down the spiked receivers had to be permanently mounted beneath the frame so that the receivers would be planted as the frame was being set onto the ocean bottom. Special “ginsu” blades that surrounded each rope to be cut were fabricated and tied to a 50’ rope that was attached along the crane cable lowering the frame. Once the frame was lowered to the ocean bottom, the spiked receivers were automatically planted and the ROV was able to cut the ropes supporting the other sensors by pulling a 50’ tether attached to the cutting blades. The frame was lifted back to the surface and the remaining cable on deck was attached to a trawler resistant mount that was then deployed.

CABLE BURIAL

The deployment of a permanent reservoir monitoring system in shallow waters may require it to be buried into the seafloor sediments. This protection may be necessary since 4D time-lapse requires a long-term deployment in a fixed location. If left on the surface of the seafloor, or even buried in weak surface layers of sediments, ocean bottom cables may be vulnerable to damage from trawler fishing activity. This risk has expanded as technology and demand has pushed trawling operations into waters as deep as 1,500 meters. Some of the latest telecommunications installations now specify burial of cables in water depths less than 2,000 meters to address future range of trawling depth extensions.

The Teal South installation was also designed to evaluate the impact of burial on the receiver performance. It is thought that burial will improve the receiver acoustic coupling to the seafloor strata. Most of the receiver stations were buried, but two of the north-south sensor cables installed were left unburied for comparison (See Figure 2.). A benefit of the ROV post-lay burial was the establishment of the as-built cable tracking positions. The ROV position was tracked acoustically and tied to the ship positioning gear. This allowed the actual installed cable track to be plotted on the cable laying pre-plots of the planned positions as shown in Figure 4.

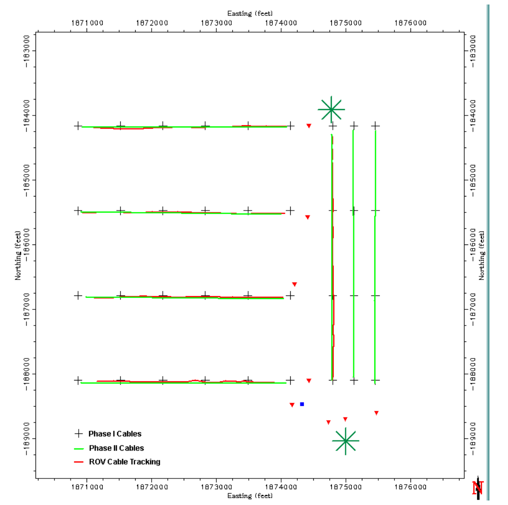

Figure 4. As-Built of Cable Pre-Plot and ROV Tracking Positions

As a member of the Teal South Field study, Oceaneering International Inc., provided the surface vessel, equipment, and personnel to deploy the 4D-4C test bed and to perform post-lay burial of the sensor cables. Oceaneering’s Telecommunications division which routinely provides services to support the installation, inspection, and burial of submarine communications cables assisted in the planning and project management support for the Phase II cable burial operations. The **Oceaneering Intervention 1** (OI-1), a 74 meter DP multi-service vessel was selected to support the burial operations. The DP capability combined with the moonpool launched **Millenium III** ROV system on the OI-1 provided the ideal platform for Teal South. A water-jetting skid for cable burial was added to the 150 HP ROV. An Innovatum cable tracking system on the ROV allowed the cable to be located, followed during burial, and depth of burial measured. This device usually tracks cable using an injected signal tone. However, this experiment used a chain that was magnetically coded by Innovatum, then attached to the array cable to provide the signal passively.

SEISMIC ACQUISITION

In order to minimize repeatability variables, Phase II was acquired using a similar source array and configuration as Phase I. In Phase II, a 12km^2 source grid (25 m x 25 m shot spacing) was shot in the north-south direction into four stationary 1,000 meter ocean bottom cables oriented in the east-west direction and three stationary 1,200 meter ocean bottom cables oriented in the north-south direction (See Figure 5.). The increase of 1km to the east of the survey added an additional 40 source lines and 4,800 source point locations to the Phase II survey. One thing unique about the acquisition at Teal South is the source direction relative to the receiver orientation is unlike conventional acquisition methods.

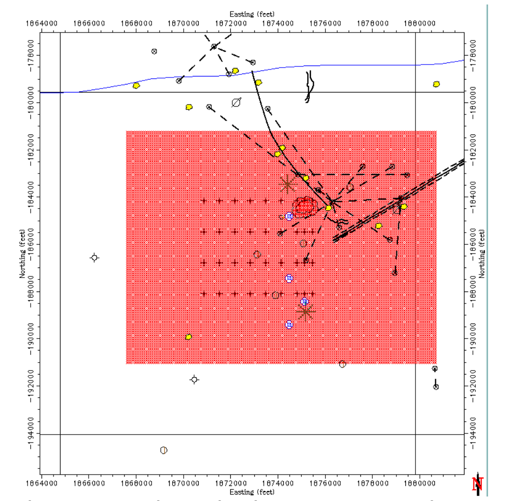

Figure 5. Teal South Phase II Survey Plot

The source and receiver effort was also extended by 1km to the east of the Phase II survey to reduce the migration artifacts within the field that were visible on the C wave section in Phase I. Consequently, by adding the forty additional source lines and three additional receiver lines to the east of the survey, the nominal fold was increased significantly over

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several of the predominate reservoirs in the field. To take full advantage of the three additional receiver lines to the east of the survey, the coupling of the receiver stations to the seafloor for each line was modified for sensor coupling comparison.

SEISMIC PROCESSING

Changes in fluid saturation, pressure, and temperature that occur during production induce changes in the reservoir density and compressibility that may be detected by differencing repeated seismic data. The data acquired in the Phase I survey were processed and the pre-stack 3D depth migrated data was compared against the 3D streamer legacy data that was shot in late 1995. The resulting 3D pre-stack depth migration difference cube (See Figure 6.) clearly shows significant amplitude changes in the 4,500' sand over time. The 4,500' sand was one of several target sands in the Teal South time lapse survey.

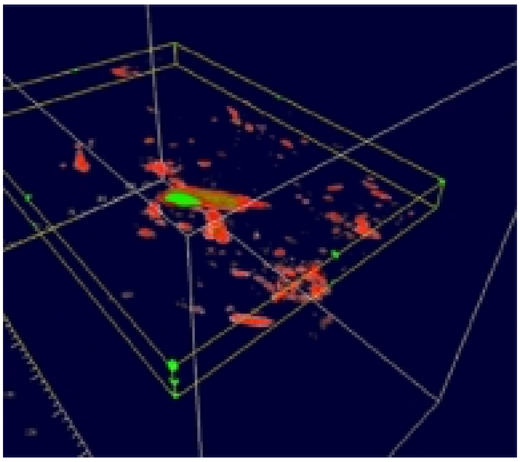

Figure 6. 3D Pre-Stack Depth Migrated Difference Cube (Legacy Streamer Data versus Phase I OBC Data).

This reservoir has been a major producer at Teal South since going onstream in November 1996. At the time of the OBC survey (July 1997), the 4,500' sand had been in production for only 8 months. Current production data show a rapid depletion rate in nearly all the reservoirs in the Teal South Field. This gives industry an excellent opportunity to review time lapse effects in a short period unlike large low permeability reservoirs, with long production lifespans.

Teal South was chosen as a useful time-lapse test site because the high flow rates and small reservoir volumes shorten the production lifespan of Teal South reservoirs to a couple of years. The seismic data from this field will be used to help monitor and predict reservoir fluid movement, locating bypass oil, avoiding premature breakthrough, optimizing infill well locations, and evaluating enhanced oil recovery pilots prior to full field implementation.

CONCLUSIONS

Although recent studies suggest that the potential economic impact is great, the acceptance of 4D seismic data remains limited in our industry, similar to 3D seismic data over a decade ago. Proven results through the development of new technology can aid in the acceptance process by increasing understanding of how 3C converted shear wave data can optimize reservoir monitoring. Most published seismic reservoir monitoring examples have been demonstration projects and the impact of new technology on reservoir profitability has not been well established.

New field developments require planning of 4D-4C acquisition to have the greatest impact on field economics. The ongoing laboratory field study at Teal South is intended to increase industry understanding of time-lapse reservoir monitoring and characterization. Based on current industry gaps, scientists working in the Teal South project are studying issues that should result in increased economic value of a field. The Teal South field was chosen to evaluate industry needs and concerns; in particular, permanent 4D reservoir monitoring system installation and operation, cable burial benefits, sensor coupling and behavior, cable protection and development, converted shear waves, azumthal anisotropy properties, 3D seismic processing routines, and developing interpretation tools. A major objective at Teal South is to understand when and where to apply these technologies and how they can be made to be more cost effective.

Seismic monitoring is a maturing technology and its impact on reservoir management is far from proven. The improvements as well as pitfalls gained through laboratory and field experiences at Teal South will help industry in the development and restructuring of new and existing technology. Also, as industry begins to focus their efforts away from the Gulf of Mexico shelf and into more structurally complex areas, the information and knowledge gained at Teal South will enable companies to face the challenges ahead. Project focus at Teal South was driven by industry consortium members, therefore reflecting industry needs. As with the development of 3D seismic technology, industry experience through case studies will establish the costs and benefits of 4D-4C technology.

REFERENCES

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