Advanced Borehole Seismic Acquisition challenges and Successes in Large LNG Project

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SUMMARY

In 2011, a large offshore borehole seismic program was acquired in the highly deviated GOR-3B well. It consisted of a Vertical Incidence (Walkabose) VSP and a total of four Walkaway VSP lines, out of which two deep walkaway lines were acquired for anisotropy and two shallow walkaway lines were acquired for imaging. The entire operation took 30 hours. An array of eight Versatile Seismic Imager (VSI) receivers was used as downhole sensors while a three 250 cc airgun cluster was deployed along the side of the UOS Discovery vessel at a safe distance during the entire job thus saving considerable time of changing source locations between different survey types. TRISOR was used as source controller while SWINGS was used as navigation system. Five good shots were stacked within a target circle for each Walkabose VSP station while single shot data was acquired for all four walkaway lines. Real time acquisition support was provided remotely and at the well site to monitor and guide the acquisition. The data quality was good for obtaining high quality time-depth information and for further advanced processing. Quick look processing results were produced within 48 hours followed by advanced processing of the full datasets. Based on the operational and technical success of this project, several advanced borehole seismic projects have been done on successive wells.

Key words: Borehole Seismic, Walkabose VSP, Walkaway VSP, Offshore, Imaging, Anisotropy

INTRODUCTION

The Gorgon Project is one of the world’s largest natural gas projects and the largest single resource project in Australia’s history. The Project is developing the Gorgon and Jansz-Loo gas fields, located within the Greater Gorgon area, about 130 kilometres off the north-west coast of Western Australia. It includes the construction of a nominal 15 million tonne per annum (MTPA) Liquefied Natural Gas (LNG) plant on Barrow Island and a domestic gas plant with the capacity to provide 300 tera joules per day to supply gas to Western Australia. The Gorgon Project is operated by an Australian subsidiary of Chevron and is a joint venture of the Australian subsidiaries of Chevron (47.3 percent), ExxonMobil (25 percent), Shell (25 percent), Osaka Gas (1.25 percent), Tokyo Gas (1 percent) and Chubu Electric Power (0.417 percent). Project location is shown in Figure 1 below.

Figure 1. Gorgon Project Location in WA

Borehole Seismic plays an important role in both explorations as well as in development phases of any project to better understand the reservoir structural as well as stratigraphic complexities. It helps in accurate estimation of reserves which can affect the economics of project. The major goals of acquiring borehole seismic surveys over Gorgon were to obtain a reliable true vertical time-depth relationship and high resolution images below and around the well path for better understanding of the reservoir in addition to anisotropy parameters estimation for surface seismic reprocessing. Data were acquired using an eight-shuttle 3 component VSI seismic tool down-hole and a cluster of three 250 cc airguns as source.

In this paper we will describe the operational challenges, innovative solutions and acquisition success of this large offshore borehole seismic program which paved the way for similar advanced borehole seismic surveys in other projects.

METHODOLOGY

In the following sections several key steps which lead to the successful acquisition of comprehensive borehole seismic dataset will be discussed.

Pre-job Ray Trace Modelling

Pre-job ray trace modelling is a critical step in the success of borehole seismic. It helps in the proper understanding of problems and associated challenges and hence proposing the appropriate borehole seismic acquisition solution. In this step a 3D velocity model has been generated by incorporating all horizons and fault interpretations as well as the velocity associated to each layer from available sources, generally either from sonic log from offset well or stacking velocities used in processing. Different source and receiver positions are simulated based on survey objectives and hence optimum
source/receiver positions are chosen in case of Walkabove (VIVSP) VSP and optimum source/receiver positions and line length are chosen in case of Walkaway VSP. Pre-job ray trace modelling was carried out and different survey scenarios were simulated as shown in Figure 2 below.

**Figure 2. Pre-job Ray Trace Velocity Modeling**

After review of these results Walkabove (VIVSP) geometry was chosen to obtain a reliable true vertical time-depth relationship and a high resolution image below the well path. In addition a total of four Walkaway (WVSP) lines were proposed out of which two shallow lines for imaging and two deeper lines for anisotropy.

**Brief Concept of Surveys/Techniques**

A: Walkabove VSP (VIVSP)

In a vertical well, a zero offset VSP (ZVSP) is acquired by positioning the source at fixed short distance from the well head and down-hole receivers move vertically inside the borehole while in a deviated well down-hole receivers move laterally and vertically with depth. If the source position is fixed (as in the case of the ZVSP) the ray paths will be largely oblique to reach the receiver position. Vertical travel-times cannot be measured accurately hence the use of the VIVSP/Walkabove technique. A Vertical Incidence VSP (VIVSP) or Walkabove VSP is a different way to acquire a zero offset VSP in a deviated well. Figure 3 shows why we do not go for the fixed source option in a case of a deviated well. A Walkabove VSP is acquired by moving both the source, deployed from a boat, and the down-hole receiver to keep the ray path between them vertical. As the well path is known the source gun is maintained right “above” the receivers, this is done by using the TRISOR navigation system. The boat will keep the source within a target circle as shown in Figure 4. The DGPS (Differential Global Positioning System) will provide the source position for each shot. The Gun position (UTM) and the time (UTC) data will be transmitted from the boat to the acquisition system on the rig and stamped on every shot.

**Figure 3. Rig Source and Walkabove (VIVSP) VSP**

B: Walkaway VSP (WVSP)

In a Walkaway VSP survey, an array of receivers is fixed down-hole in the wellbore at a particular depth depending upon the objectives, either imaging or AVO/anisotropy, and sources are moving on the surface at regular intervals along a line. Each line is acquired to be within a defined inline and cross line tolerance. At each source position, the source is fired and the resulting seismic wave field is recorded by the down-hole receivers which are clamped at a fixed depth for the duration of the lines. Depending on the survey objectives, the length of the acquisition line and the interval between shots vary. At every shot, position and time attributes will be stamped in the header of the shot in the acquisition software on the rig. Data is transmitted through a line of sight transmitter-receiver combination using the SWINGS system.

**Figure 4. Walkabove (VIVSP) VSP Target Circles**

Pre-job Planning

Pre-job planning is key to operational success. After obtaining deviation data and other well related details, a detailed Walkabove and Walkaway VSP acquisition plan and a very detailed step by step operations procedure was prepared. This was shared with all parties involved in the project. In addition, a communications protocol was discussed and agreed for better communication between all parties involved in the operation from town as well as at the well site. The Walkabove VSP acquisition plan and target circles diameter details are shown in Figure 6 below.
The Walkaway VSP (Deep and Shallow) acquisition plan source positions are shown in Figure 7 below.

Figure 6. Walkabove VSP acquisition plan and target circles diameter

Figure 7. Walkaway VSP acquisition plan

**Equipment and Setup**

Equipment for borehole seismic operations consists of down-hole tools and surface equipment. A Versatile Seismic Imager tool string with eight 3-C Shuttles configuration (VSI-8) was used as down-hole tool as shown in Figure 8.

Figure 8. VSI* Eight Shuttles Configuration

The surface equipment consisted of, two sets of three 250 cc airgun clusters (one set at the rig and other at the boat), the Maxis recording system in the wireline unit, two gun controllers, two UHF antennas (rig/boat), one GPS Antenna at the boat side, navigation data modem at the rig side and DGPS System on the boat. The system for the navigation and data transmission between the boat and the rig is called SWINGS-OFS. Surface equipment setup details are shown in Figure 9 below.

Figure 9. Surface Equipment Set-up

Guns are fired using a high pressure air supply. With the requirements of this survey, typical provision of high pressure nitrogen bottles will not suffice. A compressor was used to provide air to the guns. High pressure gas cylinders were still kept on the rig for the fixed source survey and on the boat as backup, should the compressor break down and need repair. Sufficient gas supply was arranged for 1200 shots of the survey with full backup.

The UOS Discoverer boat was used for this survey as shown in Figure 10 below. This was the only boat available that fits the requirements for deploying moving boat sources i.e. sufficient deck space, a suitable crane with enough lifting capacity and boom length.

Figure 10. UOS Discoverer boat with crane

**Challenges**

Several technical and non-technical challenges were faced during this project, which are described below.

For any moving source borehole seismic survey, the source is required to be deployed either from the back or along the side of a boat at safe distance from the hull. Finding a suitable boat with the required deck space, sufficient crane capacity and boom length for deployment of sources is one of the major challenges. There were not many vessel options available in Australia. Finally the UOS Discoverer was secured for the project but getting this boat in time for the survey was another challenge as it was being used as a supply vessel on other offshore projects.

In addition, the project entailed a combination of Walkabove VSP and Walkaway VSP, which added more complexity to the acquisition sequence by switching between different surveys types with different acquisition parameters. The project details were discussed and explained to all parties involved to make sure that all are on the same page.
In moving source surveys, it is critical to know the actual position of the source at the time of firing the guns and the correct position coordinates should be electronically transmitted to the seismic waveform headers to avoid any human mistakes, which could be unrecoverable. For that purpose a well-trained navigator is required on the boat to make sure that this is happening in real time and securing properly trained navigators in the industry is quite challenging and requires advance notice.

Rig time is a main concern for all offshore jobs. Minimising rig time is always preferred by optimizing the survey parameters and maximising the efficiency of operations. This was achieved with good pre-job planning, excellent communications and survey optimization without compromising data quality and survey objectives.

During data acquisition, external coherent noise was observed on two components of the data. Detailed analysis was done and this noise was successfully attenuated in subsequent processing. The data was confidently processed for the stated objectives.

**Operations and Quick look processing**

Because of the complex nature of the project, it was subdivided into seven sub-surveys as described below to facilitate the operation for flawless data acquisition and to minimise the rig time. A total of 39 stations with VSI-8 (Eight shuttles VSI down-hole tool) were acquired for the walkabove VSP. A boat (moving) source was used for stations 1 to 33 and a rig source was used for stations 34 to 39. A total of 280 shot points were acquired for the deep walkaway lines and a total of 640 shot points were acquired for the shallow walkaway lines. Five good shots were stacked within the target circle for each walkaway station while single shots were acquired for all four walkaway lines.

Survey-1: Walkabove VSP was acquired from 4905 m MD to 4554.48 m MD along well track from NW to SE from station 1 to 3.

Survey-2 and 3: Deep Walkaway lines, 7000 m long each were acquired with tool depth of 4657.94 m MD (mid-point of geophone array) at 50 m shot point interval.

Survey-4: Walkabove VSP was acquired from 4539.24 m MD to 3701.04 m MD along well track from NW to SE from station 4 to 10.

Survey-5: Shallow Walkaway line-1 with tool depth of 3748.47 m MD (mid-point of geophone array) started 1000 m ESE from well in x-line direction and ended 7000 m WNW from well track in x-line direction with 25 m shot points increment. Total length of line was 8000 m.

Survey-6: Shallow Walkaway line-2 with tool depth of 3748.47 m MD (mid-point of geophone array) stared 7000 m away from WH on well track NW and ended 1000 m SE beyond WH with 25 m shot points increments. Total length of line was 8000 m.

Survey-7: Walkabove VSP was acquired from 3685.80 m MD to mud line from station 11 to 39.

The entire operation took 30 hours. Real time acquisition support was provided by Borehole Seismic domain Champion in addition to Chevron’s expert witness at the well site. Data quality was good for establishing a good quality T-D relation and for further advanced VSP processing as shown in Figure-11 below. Quick look results and reports were generated within 48 hours, which helped to proceed with advanced processing.

**Figure 11. Walkabove and Walkaway VSP data**

**CONCLUSIONS**

This project shows that for success in advanced borehole seismic surveys, pre-job ray trace modelling and proper pre-job survey planning are essential.

Based on ray trace modelling results, the length and number of Walkaway VSP survey lines were optimized to minimise the rig time, which is one of the major cost factors in borehole seismic acquisition for offshore projects.

Noise which was observed during acquisition has been successfully attenuated during processing and the acquired data sets were used with confidence to achieve the desired objectives.

Good pre-job modelling and pre-job planning contributed towards the successful acquisition of comprehensive Walkabove and Walkaways data sets, which after integration with surface seismic helped in better understanding of the reservoir and this increases the value of each of the data elements.

Reliable true vertical time-depth and velocity information was achieved from the Walkabove VSP data set in 42 degrees deviated well, which helped in fine tuning the depth prognosis of the successor wells/projects.

Data from Walkaway VSP can be used not only for anisotropy estimation and imaging but also for validating the existing velocity model. Thus, structural depth uncertainty is reduced and the confidence of reserves calculations is improved.

Based on the lessons learnt during this project, several recommendations have been implemented for other projects which improved overall efficiency and helped in minimising the cost of these projects.

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Advanced BHS Acquisition Challenges and Successes

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