Capturing Geo-Hazard and Shallow Reservoir Potential by Acquiring High-Resolution 3D Seismic Survey

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Abstract. In the era of hydrocarbon exploration and development, research to identify subsurface hazards potentials and risks need to be done first as an effort to prevent business failures due to planning errors. In the offshore hydrocarbon exploration survey, drilling hazards must be identified first. Among them are shallow gas, shallow channel, pockmark, and man-made objects buried under or lying on the seabed. Survey method with excellent record resolution is required to identify these hazards as clearly as possible. The seismic method is capable of penetrating under the seabed. However, to produce a clearer cross-section, the seismic method needs to be developed into a High-Resolution survey and uses a three-dimensional (3D) configuration to display the ability to interpret from all sides. Saka Energy Muriah Ltd through PT Mahakarya Geo Survey has successfully conducted a high-resolution 3D (HR3D) Seismic survey in the Suisen Muriah Block, ~92km NNE from Rembang coast to investigate the hydrocarbon potential and subsurface hazards that may exist. While acquiring, the data's condition and quality observed by performing QC onboard processing, we can determine the data's condition and quality when measuring so that the data will be quickly processed and more advanced in onshore-based processing.
Keywords: Geo-hazard, High Resolution 3D Seismic, QC Processing

1. Introduction

In the last few years, there has been an increasing demand for geo-hazards studies and shallow gas exploration. Particular subsurface geo-hazards include shallow hydrocarbons, shallow water flows, faulting to shallow depths, mud volcanoes, and pockmarks, all of which can lead to incompetent sediments and seabed instability [1]. This makes high-resolution seismic a solution to the problem. However, the high-resolution 3D seismic survey (HR3D) application is limited by economic and methodological reasons [2].

Geo-hazards are commonly observed in offshore geophysical surveys. Shallow gas and channel are typical geo-hazards frequently found using seismic methods. The presence of shallow gas is indicated by numerous acoustic anomalies on seismic data, including acoustic turbidity caused by the presence of free gas bubbles within the pore space of sediment, acoustic blanking caused by the absorption of acoustic energy by gas-charged sediment, and enhanced reflections due to acoustic impedance contrast with the surrounding sediment [3]. The most effective approach for a shallow hazard study is to analyze all data types and determine their suitability for application to the assessment of any particular source of hazard. One of the most significant issues with upper section drilling condition assessments is shallow gas, which may be found in the High-Resolution 3D seismic dataset and can be detected effectively. The advantages of high-resolution 3D seismic acquisition are high-frequency data and outstanding vertical resolution [4].

This acquisition uses a high-resolution 3D seismic method in which quality control is carried out by the QC processor during acquisition. The survey was acquired in Suisen Block, Java Sea from 20th –

23rd 2022 August 2022 recorded using MSX Guardian Solid™ streamer that tied up to survey vessel (Nordic Bahari). For quality control on acquisition purposes, seismic data was processed using Globe Claritas v6.6.6 with 2D and 3D processing flows.

2. Data and Methodology

2.1. Seismic Survey

Seismic method is one of the most effective methods for identifying and predicting subsurface lithology and geo-hazard. It plays a crucial role in the discovery of subsurface gas and geo-hazards. The identification marks are mainly the bottom simulating reflectors, velocity, amplitude anomaly, and variation with offset. HR3D seismic surveys utilize a difference source and receiver parameter with conventional 3D seismic survey hence the spatial resolution produced by HR3D survey will be better than conventional 3D seismic survey.

Subsurface gas or geo-hazard detection using the seismic method is seemingly straightforward. It is well known that the presence of shallow gas can be inferred from amplitude anomalies in stacked seismic data. These anomalies result from seismic reflection indicating the presence of shallow gas. However, not all anomalies in the shallow subsurface are related to gas [5].

2.2. Survey Setting

These data were collected around the North East Java Basin, located on Suisen Muriah Block (~92km of NNE Rembang) on the edge of Sundaland, where the basement is a Cretaceous to basal Tertiary melange. The area is geologically complex, and it can be grouped into five tectonic provinces from North to South are Northern slope includes the stable Rembang continental shelf and Randublatung transitional zone, Kendeng trough, the eastern extension of Bogor Trough, a labile deep sea basin, Modern Volcanic Arc Southern slope regional uplift [6].

The stratigraphy in this area represented by the Rembang and Randublatung zones is dominated by stable continental shelf to basinal slope sediments. Stratigraphic and structural analyses by Yulihanto et al. (1995) show four depositional cycles within the Tertiary sediments of this area: Late Oligocene-Early Miocene extensional phase, followed by Early Miocene basin subsidence, Middle Miocene extensional phase, and Upper Miocene Pliocene basin subsidence. It is the possibility that it is composed of mid-late Miocene sedimentary rocks with the composition of the Tawun Formation, Wonocolo Formation, and Bulu Formation [7]. Meanwhile, the reservoirs of biogenic gas in NE Java Basin are from middle Miocene Tawun to early Pliocene Mundu sands and carbonates. Mixed gas occurred by depth-selective accumulation with shallow biogenic and deep thermogenic origin [8].

2.3 Energy Source

Source configuration is the dual source (port and starboard) and number of separation 50 meters (Figure 1(b)). Each source has a single array with four guns and a separation of 2.25 meters (Figure 3). Testing between two volumes was conducted to get better parameters that potentially could create good quality data; hence bubble test by picking the first-time break and bubble period of near field hydrophones attached near the gun was conducted. Gun tests were conducted before the survey using $400in^3$ and $220in^3$. The volumes of guns for $400in^3$ volume mean that each gun will have $100in^3$ volume, while $220in^3$ is distributed with different volumes of every gun (Figure 3). The gun depth for $400in^3$ at 2.5 meters and $200in^3$ at 3 meters.

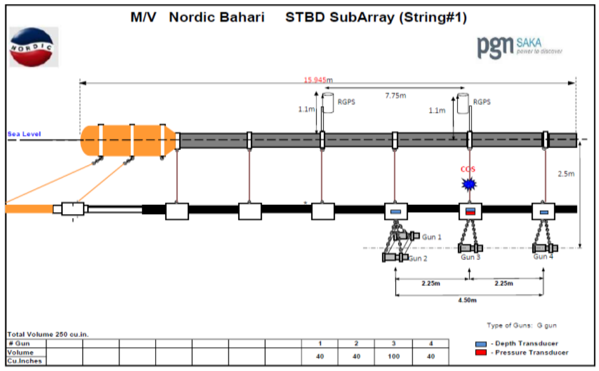


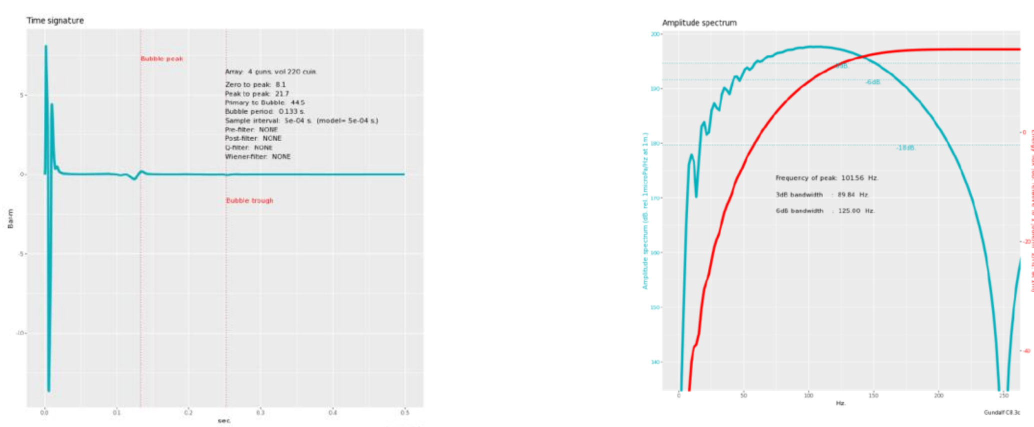
Figure 1. Gun configuration

The average errors for 400in^3 volume are -6.9% for starboard guns and -6.8% for port guns. The negative value here indicates that the calculated gun chamber volume of all guns is below the designed volume. Meanwhile, 220in^3 volume gives an average error of 0.7% for starboard guns and 3.2% for port guns. Because 220in^3 has a significantly lower error than 400in^3 volume, it is chosen for the survey conducted using 220in^3 volume of the gun at 3 meters depth.

Gun modeling was designed using Gundalf with gun volume 220in^3 at 3 meters depth to create a far-field signature (Figure 4), and error bounds stated in Table 1:

Table 1. Error bounds modeled by Gundalf

Number of Guns	4 (220.00 in^3, 3.61 liters)
Peak to peak in bar-m	21.7 +/- 0.5 (2.17 +/- 0.1 MPa, 247 dB re 1muPa. at 1m)
Zero to peak in bar-m	8.1 (0.81 MPa, 238 dB re 1muPa. at 1m)
RMS pressure in bar-m (full window)	1.08 (0.108 MPa, 221 dB re 1muPa. at 1m)
Primary to bubble (peak to peak)	44.5 +/- 1.6
Bubble period (s)	0.133 +/- 0.004
Maximum spectral ripple (dB)	26 (10 - 70 Hz)
Maximum spectral value (dB)	196 (10 - 70 Hz)
Average spectral value (dB)	189 (10 - 70 Hz)
Total acoustic energy (Joules)	4170.2
Total acoustic efficiency (%)	8.4
Maximum model bandwidth (Hz)	0 - 1024



(a) (b)

Figure 2. (a) Far field signature of guns with 220in^3 volume at 3 meters depth; (b) The amplitude spectrum of designed far field signature.

2.4 Receiver Array, Geometry and Recording Parameters

The MSX Guardian Solid™ streamer is the fundamental component of the receiver array. The streamers were built with a group spacing of 12.5 meters and 14 hydrophones per group. The number of streamers deployed was three cables with each streamer consisting of 80 channels (total of 240 channels) with lengths of 1000 meters and 50 meters separating each cable at 3 meters and 4 meters depth as receivers (Figure 1). Line spacing was 50 meters without overlap between adjacent passes. The survey ran with two headings of 125.3° and 305.3°. This direction was considered suitable for feather matching and worked very well with the majority of the survey with a maximum feather angle was 18°, and an average feather angle was 4° to the West (Figure 2(a)).

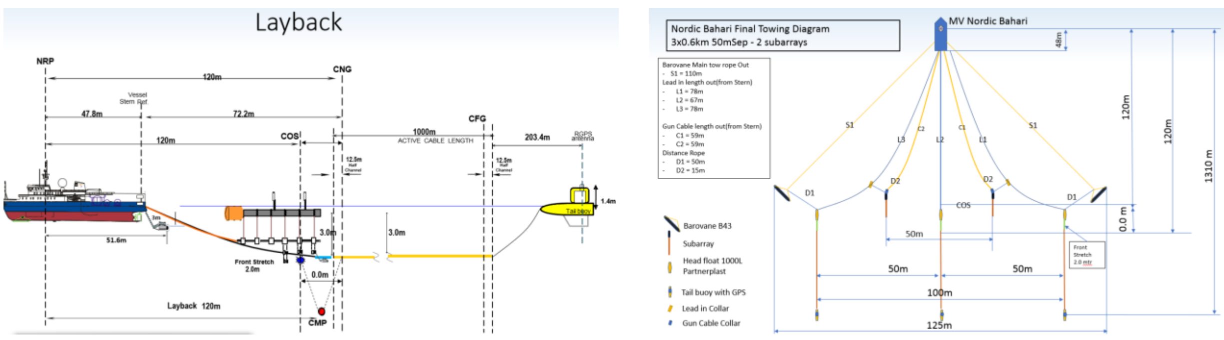


Figure 3. Vessel layout diagram (a) side view; (b) top view.

The geometry setting is not related to the seismic data, only using the existing marine geometry module by entering the seismic survey configuration information that refers to the observer log. Furthermore, the bin size is calculated using equation (1):

$$Bin\ Size\ Aquisition = \frac{Receiver\ Interval\ (RI)}{2}\ x\ \frac{Source\ Separation\ (SI)}{2} \tag{1}$$

As a result, the bin size is 6.25 meters x 25 meters, and we got a number-fold coverage of 40 (Figure 2(b)). The recording system was configured with a record length of 2.048 seconds and a sample rate of 1 millisecond. The digitizer used a low-cut analog filter (2Hz/6db/oct) and a hi-cut filter (412Hz/264db/oct) through the recording software. Target vessel speed during acquisitions was 3.2 knot over-ground. The data were recorded according to the Society of Exploration Geophysicist (SEG) with SEG-D (8058) format and normal polarity.

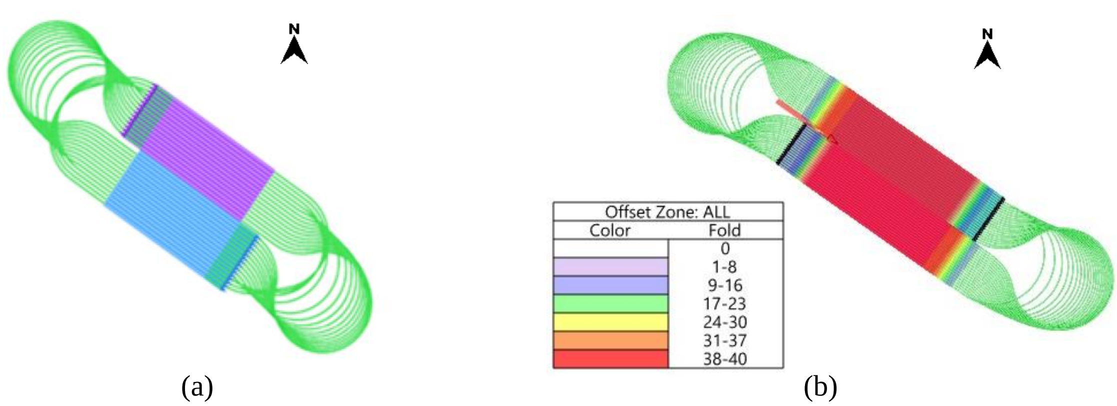


Figure 4. (a) Estimated shooting plan. The blue line has a heading 125.3˚ and the purple line heading is 305.3˚; (b) Fold coverage map

2.5 Environmental constraints

Sea conditions during the survey were determined by the wind and swell predominantly coming from the East / East South East. Wind speed on average was 10 knots. Wave height increased gradually to 1.6m averaging at approximately 1m. Strong currents were experienced upon arrival on site decreasing during deployment, and increasing again towards the completion of the survey. Sea conditions continued to build during the survey. Currents were influenced by lunar cycles. The direction followed generally came from the SE traveling to the NW. Between 0.3 to 1 knot. This caused predominately slow speeds traveling in the Southeast Easterly direction at 125°. Feather angle varied depending on the velocity of the currents.

3. Results and Discussion

QC onboard processing is done along acquiring the data using Globe Claritas software. Processing flow was divided into two parts, such as 2D and 3D processing (Figure 5). Processing is generally aimed not at attenuating noise but at showing the data either as recorded or as it would be presented to an onshore-based processing center. All acquired seismic sequences were processed through basic processing flows to assess data quality, and confirm acquisition geometry and parameters.

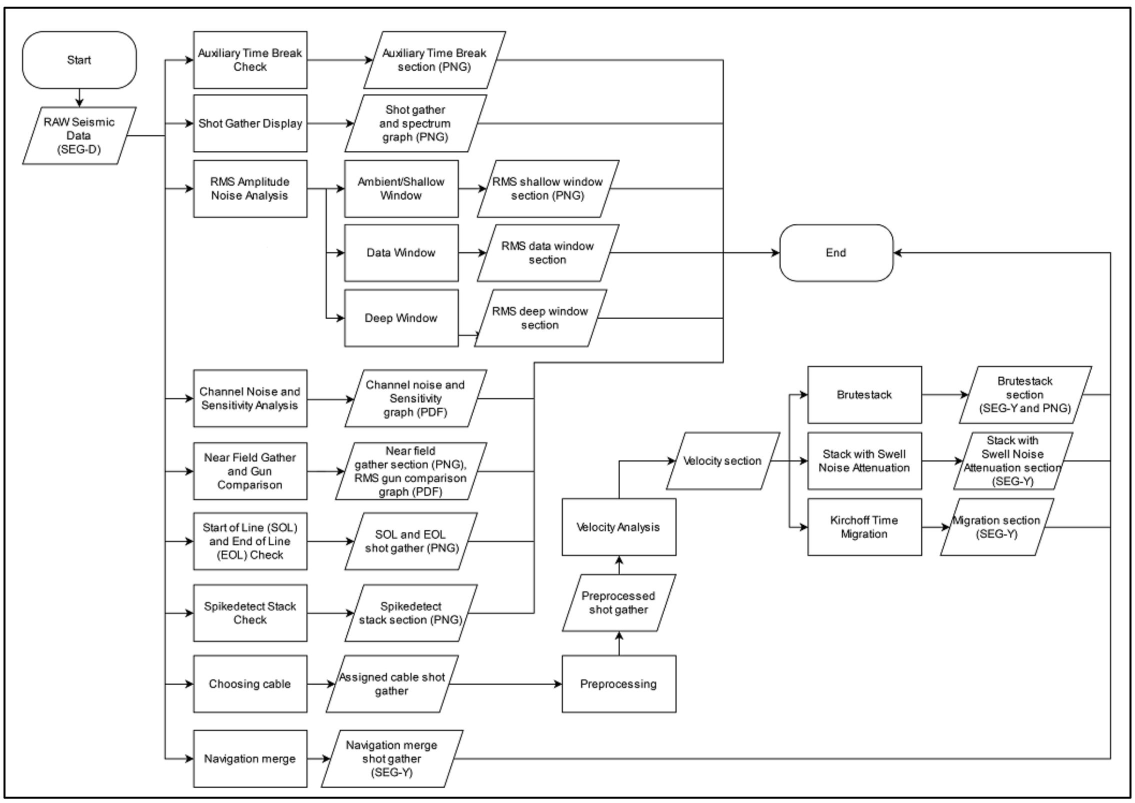
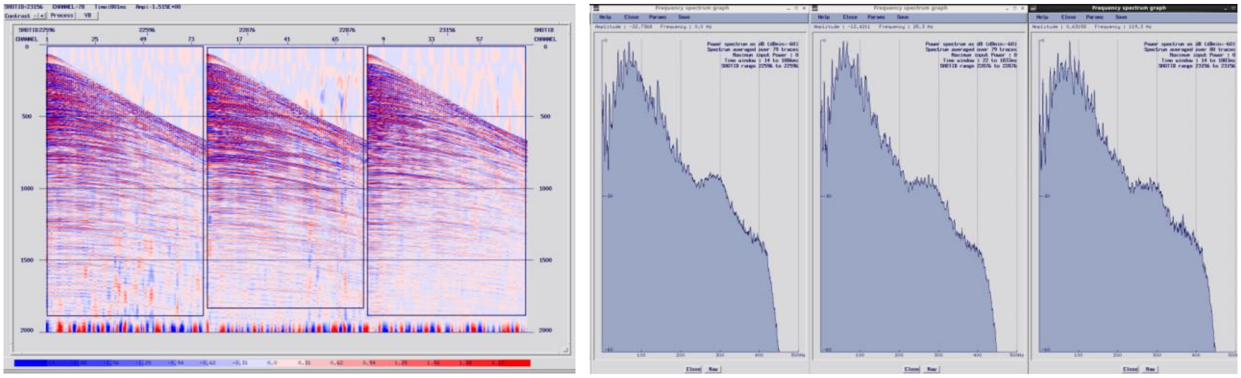


Figure 5. QC processing workflow

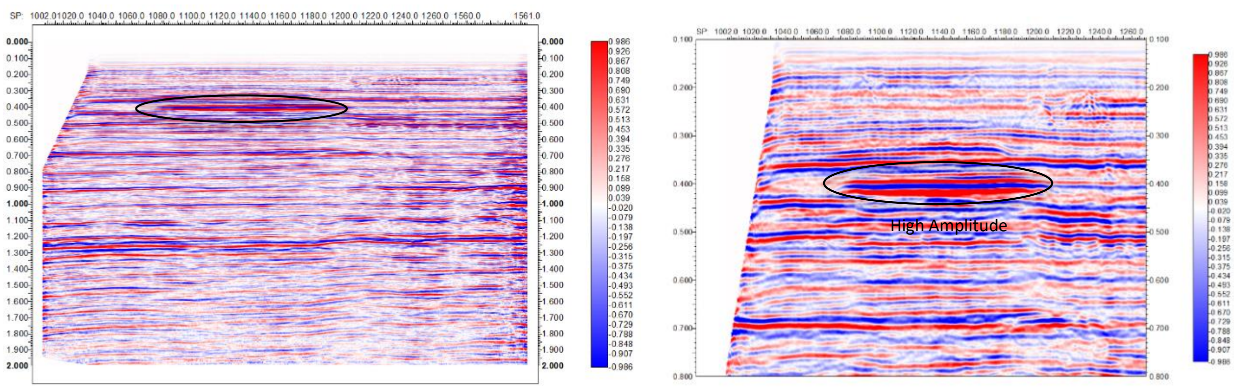
Figure 6 illustrates the frequency spectrum from 0 seconds to ±1.9 seconds TWT. The average result of the dominant frequency is 100Hz for the three streamers. The data also seems to be affected by noise from climatic conditions described in section 2.5, which results in low-frequency noise (swell noise) and affects the data from light to moderate intensity. This noise was removed adequately using a low-cut filter on the brute stack. In most cases swell noise was generated by current and tidal oscillation, which were the general source of the noise throughout the project. Although swell noise affected the data, the seismic data itself qualitatively produced a clear enough image of subsurface layers.



(a) (b)

Figure 6. (a) Raw shot gather; (b) Frequency spectrum graph measured over 0 – 1.9 seconds.

Figure 7(a) shows a representative illustration of the penetration that can be generated from the survey. The good results are also shown from 0.1 seconds as the seabed and abnormal amplitude exist at 0.4 seconds, which could be considered an anomaly (Figure 7(b)). Further processing needs to be undergone to identify any potential of shallow reservoir or probability of geo-hazard. One of QC's priorities was to produce brute stacks for every sequence. These QC’s products were used to identify noise and acquisition related problems. Brute stack was examined for bad shots (telemetry errors etc.) as well as for checking that the correct range of shots/CDP's was present. The brute stacks also contributed to take the final decision about the quality of acquired seismic data.



(a) (b)

Figure 7. (a) Example of processed brute stack; (b) Brute stack zoomed in up to 0.8s

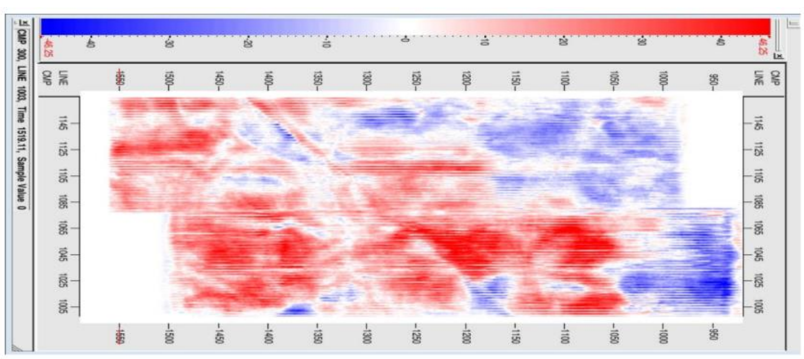


Figure 8. Time Slice at 300 ms

The results of the brute stack cross-section show high and low amplitude contrasts at several times, such as 0.2 seconds, 0.4 seconds, and 0.7 seconds (Figure 7(b)). So, the quality of the data from the high-resolution 3D seismic survey results is very good for showing subsurface structures shown by a time slice of near trace cube produced at 300ms (Figure 8). Several possible anomalies exist on the data with low to high amplitude characteristics, like an anomaly on 0.4 seconds (Figure 7(b)) which shows a significant amplitude contrast. Hence this could prove that using the quality of acquired seismic data is good enough because it can create a quite good image of the subsurface layer or structure.

4. Conclusions

High-Resolution 3D (HR3D) seismic survey is proven to be applied for critical assessment to minimize drilling risk by spotting geo-hazards. HR3D seismic survey has conducted in Suisen prospect ~92 km NNE from Rembang coast using in order to identified shallow gas, pockmarks, surface channels and obstruction lying on seafloor. Survey ran with two headings 125.3° and 305.3°. The headings were considered suitable for feather matching and worked well for the majority of the survey with a maximum angle feather of 18° and an average angle feather of 4° to the West.

Source used four air guns (G Gun 1™) clustered into two sub-arrays with 2000 psi pressure, 220in^3 volume of gun, separated 50 meters from each subarray and towed at 3 meters depth based on bubble test result. The receivers use MSX Guardian Solid™ streamer with three cables, 80 channels, 1000 meters length, 12.5 meters group intervals, separated 50 meters each cable, and towed at 3 to 4 meters depth. The acquisition bin size for this survey is 6.25 meters x 25 meters based on source and receiver parameters.

From the parameters set up, the acquired seismic data quality is excellent. It could create a clear subsurface structure from near trace cube time slice and the probability of anomalies with a quiet amplitude contrast exist. The acquisition plan and design are proven to be optimal.

Acknowledgments

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