Impacts of environmental restrictions on 3D seismic survey design, operations and signal processing: Case study from offshore Exmouth, Western Australia

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SUMMARY

Seismic acquisition in environmentally sensitive areas is governed by exacting Commonwealth and State regulatory frameworks. These are designed amongst other things to (1) minimise risks of adverse impacts to marine biota, and (2) minimise disturbance to other users of the marine environment. Seismic surveys today require an adaptive approach to survey design and operations to ensure exploration and environmental objectives are realised.

This paper describes seismic survey design, operational practices and implications on signal processing of Gazelle 3D, a shallow water marine seismic survey off the coast of Exmouth in exploration permit WA-399-P.

Survey design and operational practices were modified to meet regulatory charters. We describe the effects these had on signal processing and the techniques used to mitigate acquisition signatures on resultant seismic images.

Key words: environmental, marine biota, signal processing, seismic source, regulatory frameworks.

INTRODUCTION

Apache acquired Gazelle 3D, a shallow high resolution seismic survey in exploration permit WA-399-P. The survey lay adjacent to the Northern Boundary of the Commonwealth controlled Ningaloo Marine Park and 6km west of the State controlled Muiron Islands Marine Management Area in in Australia's north-western coast.

Survey location and timing provided for some unique environmental controls and objectives that impacted acquisition design, operations and subsequent signal processing. Timing of the survey coincided with Dugong breeding (September through April) and Whale Shark migration (March through July) periods. During the early design and approval stages it was also expected that migratory fauna such as dolphins, whales and turtles might be encountered in the survey area.

The eastern edge of the survey is adjacent to the Muiron Island Marine Management Area, where vessel traverses are prohibited. The south-western corner of the survey sees vessel tracks overlay the northern edge of the Commonwealth controlled Ningaloo Marine Park (Figure 1). No seismic sources could be discharged within the marine park. Limited seismic coverage in the southern section of the survey area results from these restrictions.

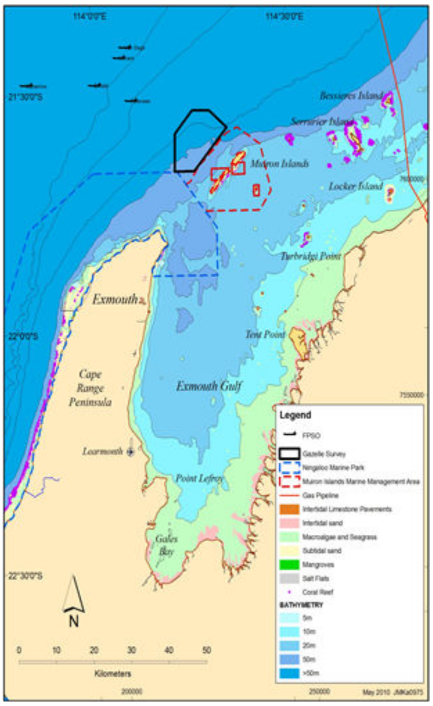

Figure 1. Gazelle 3D (black polygon) is located adjacent to the northern boundary of the Ningaloo Marine Park and 6 km west of the Muiron Islands Marine Management Area. The area is popular for dive charters, recreational fishing and is also adjacent to busy shipping lanes.

A soft-start sequence is designed that ramps the seismic source to full operational volume over a 30 minute regulatory interval. During this time the recording system is fully active. Far Field Signature modelling for each source volume removes the effects of the source-signature from the recorded wavelet. The large source-bubble inherent in the smaller volume source complicates wavelet shaping routines.

ENVIRONMENTAL COMPLIANCE

The seismic survey vessel selected for acquisition of Gazelle 3D is the R/V Geo Atlantic operated by Fugro Geoteam Pty Ltd. A full environmental audit prior to departing for the survey location is required. The objectives of this audit are:

1. To validate compliance with the proposed Environment Plan;
2. To ensure compliance with regulations, standards and policies;
3. To review operating practices; and
4. To identify areas of actual or potential contamination.

The Environmental Plan examines how, through normal vessel operations, the acquisition of the survey will (1) minimise risks of adverse impacts to marine biota, and (2) minimise disturbance to other users of the marine environment. To achieve these criteria vessel audits examine operational approaches to cetacean management, grey water/sewage disposal, bilge water, waste disposal, refuelling procedures, ballast water quarantine, general housekeeping, crew training and inductions and remedial action plans. In some cases, restrictions on certain activities are placed on the vessel when in proximity of environmentally sensitive areas.

IMPLICATIONS OF SURVEY LOCATION

The Muiron islands group is one of the most popular areas for dive charters and recreational and sport fishing from Exmouth. The area also straddles some of the busy northern shipping lanes.

Environmental sensitivities particular to the region and the mitigation measures and management strategies to minimise environmental impact are assessed early in the survey design stages. Specific operational conditions applied to acquisition of Gazelle 3D as part of the Commonwealth Environmental Protection and Biodiversity Act 1999 include the following:

1. Seismic acquisition not to be undertaken prior to 15 February 2011 or after 1 July 2011;
2. Interaction between offshore seismic exploration and whales using the 2km low power zone to be implemented;
3. Lighting to be kept to the minimum required for safety and navigational requirements;
4. No refuelling of the seismic vessel and any support vessels within 12 nautical miles of the outer boundary of the Ningaloo Marine Park and the Muiron Island Marine Management Area; and
5. The survey vessel is not to discharge the acoustic source within the Ningaloo Marine Park.

Adverse weather conditions prior to survey start and the onset of the Australian International Billfish Tournament from the 14th to 17th March 2011, reduced the acquisition window to 26 days. At the time issues were anticipated between the 67 competing recreational fishing vessels and the R/V Geo Atlantic (Australian International Billfish Tournament, 2011). Minimisation of vessel noise and interference with survey equipment soon become a priority.

Interaction with whales under a state of minimal lighting is a conflict for after-dark sail- line starts where additional vessel lighting can assist with spotting marine mammals. Best practices were observed at all times to satisfy these requirements. Refuelling is a non-issue for such a small survey. Not discharging the acoustic source within the Ningaloo Marine Park did have impacts on survey design.

Acoustic source discharge

Two acquisition swaths are required for full fold coverage at Gazelle 3D (shown as blue and purple polygons respectively in Figure 2). Selected sail lines in the south western part of the survey area steered through the northern sections of the Ningaloo Marine Park. Since no sources could be discharged within the park boundary, a soft-start procedure is implemented at the permit boundary. The source volume is progressively ramped up to full power by switching on guns in a pre-determined sequence over a 30 minute regulatory timeframe. To maintain spread and steering control while simultaneously minimising the distance the vessel travels into the permit during this interval, a constant 4 knot speed is maintained.

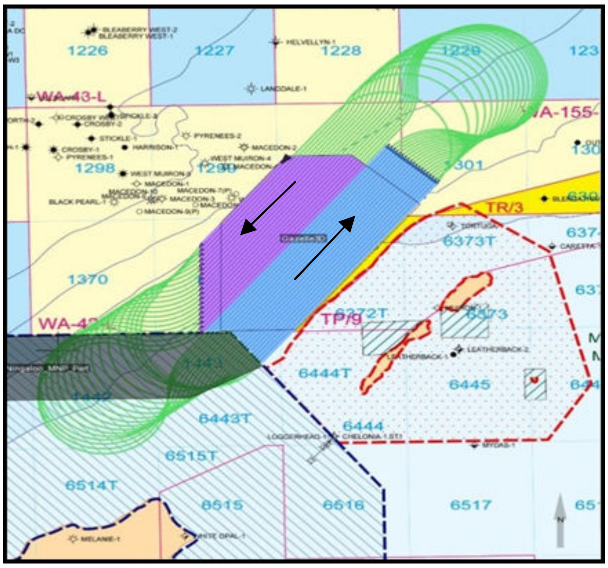

Figure 2. Seismic sources for in the south western part of the survey area are ramped up to full power using a predetermined soft-start sequence. The gun volume is progressively increased to full power by switching on guns in a pre-determined sequence over a 30 minute regulatory timeframe.

Survey design on Gazelle 3D tested and evaluated numerous scenarios in order to optimise goals of survey time and cost (Fleming, 2009). Figure 2 highlights the SurvOPT solution (a survey design, optimization and simulation package), although this is not the only solution package used in this case.

Soft-start sequence

Different combinations of source array soft start volumes are designed. Government regulations state that the energy source must be ramped up over a 30 minute window with no indication of how the power can be ramped up during this time. We evaluated the relative power of the array as gun combinations became active and settled on a sequence that linearized the array power over the 30-minute interval.

SOURCE SIGNATURE MODELLING

Modelled source signatures for a 60 and 2700 cubic inch seismic source are shown in Figure 3. The main difference and point of concern is the large bubble inherent in the 60 cubic inch gun compared to the 2700 cubic inch source. The bubble in the 60 cubic inch gun signature creates a notch effect in the low frequency amplitude response curve (Figure 3a) (Sargent, *et al*, 2011). Preservation of low frequencies is essential for bandwidth extension in preparation for subsequent acoustic impedance inversion.

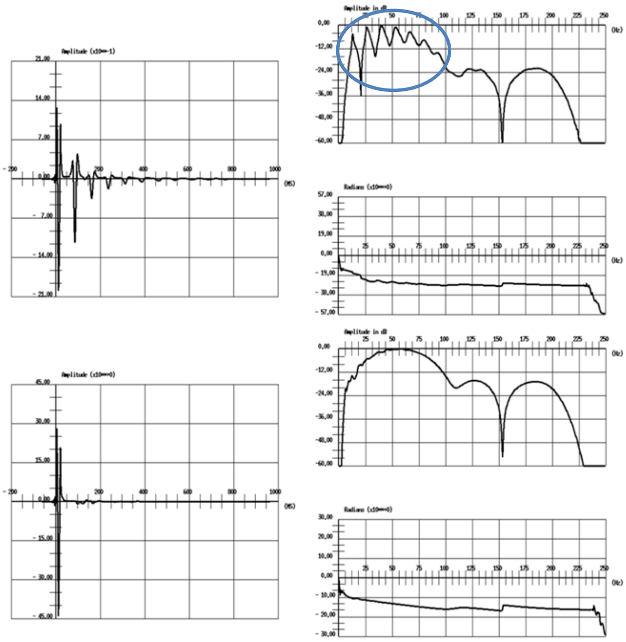

Figure 3. (a) Source signature and corresponding amplitude-phase response for the 60 cubic inch gun, and (b) corresponding signature for the 2700 cubic inch source array. Note the large bubble inherent in the 60 cubic inch gun when compared to the 2700 cubic inch array. The bubble creates a notch effect in the low frequency amplitude response (blue circle).

During signal processing, separate Far-Field Signatures are modelled for each of the 14 separate gun volumes used. The signatures are used to remove instrument response from the field data (Ziolkowski, 2000) using a deterministic filter approach (Sargent, *et al*, 2011). Differences in source strength during soft-start will allow for some shot gathers to have significantly more energy than others. To preserve amplitude variation with offset and amplitude variation within individual traces we balance shot amplitudes using a similar method to Takougang et al 2011.

WAVELET PROCESSING

During wavelet processing a unique inverse filter for each of the 14 separate source signatures is designed to (1) convert the data to its zero phase equivalent, and (2) remove the effects of the bubble (referred to as de-bubble) from recorded signal. Zero phase data is preferred for seismic interpretation (Simm *et al*. 2002) and a prerequisite for pre-stack imaging. The output wavelet after convolution of the derived filter with the modelled far-field signatures is shown in Figure 4 for the 60 and 2700 cubic inch sources. As expected, the output wavelet does appear zero-phase. The large bubble pulses in Figure 3a are mostly removed with only minimal evidence in the equivalent zero phase time series wavelet of Figure 4a. The deep notches in the corresponding amplitude spectra are also reduced. The minimal bubble energy in the 2700 cubic inch array that are causing slight low frequency perturbations in the amplitude spectra of Figure 3b are removed in Figure 4b.

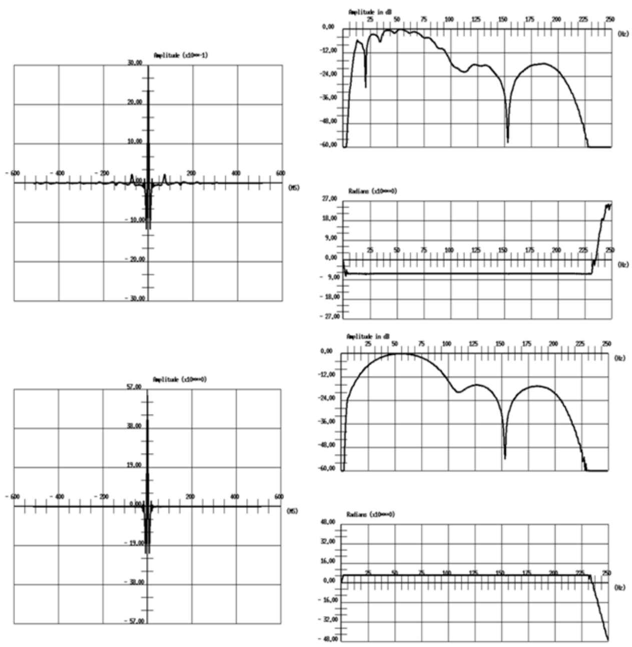

Figure 4. (a) The output wavelet and corresponding amplitude-phase response for the 60 cubic inch gun and (b) 2700 cubic inch source array. The output wavelet is produced after convolution of the Far-Field signature with the corresponding unique inverse filter.

In order to ensure the stability of the inverse filter, the degree of de-bubble processing was varied for each separate source volume (Table 1). We attribute the reduction in de-bubble power for the 380 cubic inch gun to be related to the interaction of the energy pulses for the particular source geometry. Guns are placed in different physical locations within the array. The peak strength of an air-gun's signature is proportional to the cube-root of the gun's volume (Dragoset, 1990). The soft-start sequence is chosen in a way that linearizes the relative peak strengths, but this may have adverse effects of the superposition of the source pulses from energy originating in different geometrical gun locations. This is because gun signature peak strength also depends on a host of factors such as number of guns, their positions, volumes and firing times (Dragoset, 1990).

Source Volume (cu. in.)	De-bubble (%)
60	40
140	50
280	85
380	70
880	100
960	100
1100	100

1160	100
1460	100
2060	100
2200	100
2400	100
2600	100
2700	100

Table 1. The degree of de-bubble processing is varied for each separate source volume during wavelet processing. This was tested on an individual basis to ensure the stability of the inverse filter.

CONCLUSIONS

Survey design and operational practices in environmentally sensitive areas are not a hindrance to producing useable seismic data. Acquisition induced complications of soft-start sequencing are overcome during signal processing at Gazelle 3D to produce a high quality 3D seismic volume. Additional effort during signal processing ensures desired wavelet shaping operations are correctly applied.

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