

Seismic on the edge – a 3D transition zone seismic survey from concept to final volume

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SUMMARY

The Speculant 3D Transition Zone (3DTZ) Seismic Survey was acquired by Origin Energy in the Otway Basin, approximately 30km east of Warrnambool, Victoria during November and December 2010. The objective of the survey was to fill a data gap between an existing Marine 3D Seismic Survey (3DMSS) and Land 3DSS, with the target located offshore in the shallow waters of the coastal zone. Although the survey covered a small surface area, the coastal location combined with the economic and environmental significance of the region dictated numerous exclusion zones.

To achieve coverage of the target under these exclusion zones, the survey was designed to simultaneously use two independent recording systems; a cable free system on land and an Ocean Bottom Cable (OBC) system offshore, two different sources (GI air gun offshore and Vibroseis on land) and three different receiver types.

The final survey design was an orthogonal geometry with a high density of marine shots and a high density of land receivers, with large holes due to access restrictions. The field data were a collection of six different source - receiver combinations, each with unique noise characteristics and statics, covering separate but overlapping CMP's. Combining these disparate data sets was the key challenge of the processing. The lessons learnt during planning, acquisition and processing are shared in this paper along with examples of the effect that survey design, field conditions and equipment use and limitations can have on field records and processed data.

Key words: Transition Zone, 3D Seismic Survey, OBC, acquisition.

covered a small area, it required access to numerous dairy farming properties, The Bay of Islands Coastal Park and the waters administered by the State of Victoria, which is a prime fishing location for the Southern Rock Lobster and the migration route of the endangered Southern Right Whale. The survey was conceived to fill a data gap between an existing marine 3D Seismic Survey (3DMSS) and land 3DSS, with the target located offshore in the shallow waters of the coastal zone. As the operator of this shallow marine offshore block, Origin Energy contracted Geokinetics to acquire the survey during November and December 2010. The challenge was to obtain the desired coverage through numerous exclusion zones caused by the physical landscape while not causing environmental damage and to minimise inconvenience to stakeholders. This was achieved by designing a survey using:

- Two independent recording systems
- Two different sources
- Three different receiver types.

The final survey design was an orthogonal geometry with an average near offset gap of 600 m along the surf zone due to access restrictions.

This paper is a summary of lessons learnt, which may be applied to other 3D land and 3DTZ surveys, especially those in sensitive environments. The first section is a brief overview of the how the approvals, regulatory requirements, stakeholder issues and operational challenges influenced the survey design. This is followed by how these challenges were addressed in the field, including a discussion of the advantages and disadvantages of equipment chosen. Some field examples are provided. The paper finishes with a review of the processing challenges, including noise removal and merging the data acquired from the combinations of and sources and receivers.

INTRODUCTION

Sheer limestone cliffs eroded by the pounding Southern Ocean swell provide a scenic backdrop to pristine national parks, high productivity dairy farms and a sea brimming with life. This is an excellent place to experience the raw beauty of nature and friendly western Victorian towns, but it makes an extremely challenging location to acquire a seismic survey. The Speculant 3DTZ Seismic Survey was named after a nearby shipwreck which founded in 1911. The survey covered a surface area of approximately 35 km², about 30km east of Warrnambool, Victoria. The site was located just off the Great Ocean Road and extended beyond the 60 m sea cliffs, approximately 3 km offshore. Although the survey only



Figure 1: View from within the survey area

DESIGNING AROUND THE APPROVALS AND STAKEHOLDERS AND LANDSCAPE

As simultaneous activities were planned for both onshore and offshore, the survey triggered two separate Petroleum Acts, requiring submission of documentation and approval under both Acts. In addition, the Bay of Islands Coastal Park required a ministerial consent under the National Parks Act of 1975. This required the submission of a request to the Victorian Minister for the Environment for their consent, which was then tabled in both houses of the Victorian parliament for fourteen sitting days; the whole process took eleven months. Table 1 provides an overview of the approvals required.

Table 1: Summary of legislation and approvals required for the survey.

Regulator	Legislation	Trigger	Requirement
Vic DPI	Petroleum (Submerged Lands) Act 1982	Activity Offshore	Environmental Plan
Vic DPI	Petroleum Act 1998 (Vic)	Activity Onshore	Environmental Plan
Vic DSE	National Parks Act 1975	Activity in the Bay of Islands Coastal Park	Ministerial consent through Parliament
SEWPAC	Environment Protection and Biodiversity Conservation Act 1999 (EPBC)	Offshore seismic activity and Whales	EPBC referral

Obtaining each approval involved making commitments to protecting the environment and stakeholder interests, which required regular interaction with regulators through the submission and re-submission of environmental plans as well as accepting or challenging conditions. These commitments and conditions increased exclusion zones in the survey area, or required specialized field roles, such as botanists to map vegetation in the Coastal Park.

The variety of stakeholders and their concerns were as diverse as the approvals. The main stakeholder groups were cray fishermen, dairy farmers, the community and environmental groups. A summary of stakeholder and access issues and the solutions adopted is given in Table 2

Table 2: Summary of concerns and requirements from stakeholders and regulators and their solutions.

	Concern	Solution
Farmers	Disturbance of cattle by restricting grazing areas and fence cutting.	Cable free equipment, multiple vibs allowed moves through gates without compromising production.
	Cutting crops with survey equipment in the way	Survey flexibility to move around crops, cable free receiver was flagged with a high stake for visibility in a crop

	Spreading of animal disease and weeds	Wash downs between properties, single entry and exit points and sign in. Access restricted to required personnel only
Fishermen	Reduction in fishing area due to exclusion	No exclusion zone placed on fishing
	Loss of catch	Allowing fishing during operations resulted in no reported loss of catch.
Community	Concerns for whales from airgun source noise	2xMMO, on source vessel and cliff; Timing survey to avoid migrations; Daylight operations only for increased whale detectability.
	Movement of OBC cables damaging reefs	Divers were deployed to monitor OBC and assist removing any snagged
	Concerns of vegetation damage.	No vegetation cutting, no line preparation as lines are bent around obstacles
	Access restrictions to public areas	Small operation did not require restricting public access
	Increased local traffic	Small land operation only required 5 non source vehicles
Coastal Park	Damage to endangered flora	Botanist mapped flora with Survey and Layout crew to identify avoidance areas
	Fire hazard	Water and pumps on standby, doubled as wash down units
Safety	Connection between onshore and offshore recording systems over 60m cliffs and rough surf	No physical connection between onshore and offshore required by using cable free recording system onshore and radio link for source time break
	Shallow Water & Rough seas	Shallow draft boats scouted ahead of larger vessels. Proximity to shoreline of OBC equipment was based on conditions at the time.

Many of the issues were resolved by selecting equipment that easily allowed a flexible survey design and by designing the survey to fill in the gaps while working within the principles of symmetric sampling (e.g Vermeer, 2002). After numerous iterations, this resulted in the pre-plot survey design (Figure 2) with access to the Bay of islands Coastal Park restricted to receivers only.

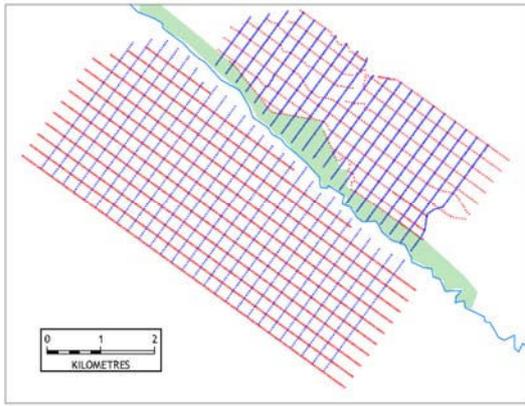


Figure 2: Pre-plot location of sources (red) and receivers (blue), avoiding known exclusion areas, around the coastline (blue line) and restrictions in the coastal park (shaded green). There is approximately 600 m offset between onshore receivers and offshore sources.

As is often the case, the real effects of field conditions and access restrictions only become apparent during operations, and as a result, some modifications to the design were required in the field. These were:

- compensating for missing or skipped land shots by increasing the number of marine shots.
- Off-setting land sources and receivers to avoid obstacles, while maintaining smooth lines where possible.

The final survey design is illustrated in Figure 3.

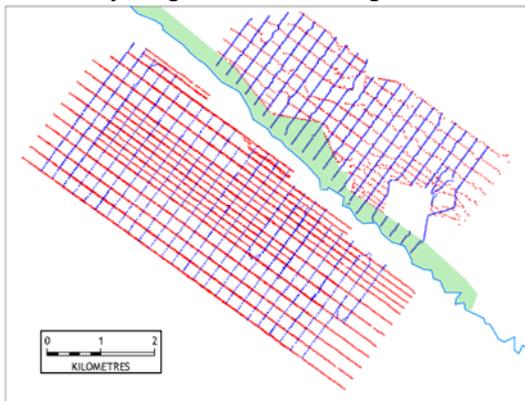


Figure 3: Post production plot of receiver and source locations.

OPERATIONS

Equipment

A cable free autonomous recording unit, the OYO Geospace Seismic Recorder (GSR), connected to a string of six grouped geophones was used as the land recording system. This system provided logistical and operational advantages over cabled systems. Most significantly it allowed each unit to be placed freely, to avoid obstacles without the restriction of a cable system. This allowed receiver 'lines' to be relatively continuous to avoid discontinuities in shot gathers. Another major advantage was its ease to protect from cattle using a light wire mesh to cover it, this prevented temporary fence construction which splits up farm land and was a serious concern of landowners. It also significantly reduced equipment volume, man power and number of vehicles required. The main disadvantage was no live check of incoming records, which meant there was no way to determine the amount of noise on the spread. Another disadvantage of

this particular operation was that the geophones had to be grouped so they could be protected from cattle. Each of the GSR units broadcasts a health status, which required regular monitoring by the line crew to ensure the units were live.

AHV IV 60,000 lbs Vibrator trucks were used as the land source. A single vibrator per source point was used, allowing flexibility for each vibrator to operate in a different paddock, reducing overall down time when wash downs were required. The presence of sink holes and boggy ground in the area caused phase and distortion errors at some shot locations. Shots were moved on-the-fly by the vibroseis operators to drier areas or further away from sink holes to improve the vibroseis signal quality, slowing down acquisition.

The marine recording system was an ARAM Aries SPM 458 using Ocean Bottom Cable (OBC). Two types of sensors were used per station on the OBC, a single hydrophone and two gimbaled geophones. The cable was weighted to sit on the sea floor and reduce movement. To determine the position of the deployed cable, an acoustic ranging system was used. Acoustic transponders were attached to two out of four hydrophones (either side of the take out), these were then 'pinged' by a transceiver on a vessel. This was done following initial deployment of the cable and throughout the day. Cables left out overnight were checked in the morning prior to recording and throughout the day.

The marine source was an array of six, 150 cubic inch Generator-Injector (GI) airguns. Each airgun was set to have a 45 cubic inch generator volume (the primary source) and a 105 cubic inch injector volume, (to control the bubble collapse), meaning that the effective source volume was 270 cubic inches. This smaller airgun volume than conventional marine acquisition sources meant that noise was attenuated faster in the ocean, allowing a smaller 'low power zone' under the Australian EPBC Act policy statement 2.1. All recording operations were controlled from an offshore 'Dog box'. Extensive timing tests were undertaken prior to production to ensure the time break for the vibrator and the airgun was accurate and recorded. Testing was also done to ensure both the ARAM and GSR system had a synchronized time zero. The onshore recording system worked autonomously and was checked regularly through the day by the line crew, while the OBC was continuously monitored from the dog box, line breaks or faulty receivers were changed as required.

Patch acquisition

As is often the case with land surveys, there was not enough equipment to deploy to cover the whole area. The acquisition strategy was to ensure adequate in-line and cross-line fold, while moving equipment in an efficient manner. Using a 'roll along' approach for spread movement (where receivers from the back are brought to the front as the source effort is concentrated in the middle of the spread) would not work efficiently in this scenario. This was because single or even multi line rolling of OBC spread would take longer to move than the number of shots for the airgun to take. Given that it was easier to take more shots at sea, but lay more receivers on land, a 'patch' acquisition strategy was employed for the OBC while the land spread was rolled along. This involved a set number of OBC lines being deployed and a larger number of GSR lines planted. These were all recorded into by vibroseis and airguns, with all the OBC picked up and moved to their next position while the GSR lines were moved from the back to the front. This approach was used as it minimized the repetition of land shots, which were slow and required entry on to multiple properties, while also giving time for the GSR to be downloaded and recharged.

Balancing the acquisition between time spent on land sources and marine sources was often dependent on weather and therefore could vary on a day to day basis. If the ground was wet, then the airgun could be used while the paddocks dried. It also allowed operational flexibility if there was a technical problem with the one of the sources. An example of a day when weather permitted swapping between sources for efficiency is outline in Table 3.

Table 3: Summary of daily activity, taken from the observers log.

Time	Activity
0555	Leave Warrnambool
0800	Commence soft start
0835	Start production – Airguns
0913	Switch to Vibroseis
0948	Passing rain and squall, standby for weather
1011	Restart with vibes
1107	Rain starting, ground conditions getting slippery, stand by Vibes
1150	Light rain continuing, commence airgun soft start
1221	Acquisition commence with airgun
1334	Gunboat problem, switch to vibe
1516	Severe weather warning issued by BOM, lighting observed in approaching storm. Stop work, and head to port.
1640	Vessels arrive in port

DATA EXAMPLES

The multi-source, multi-receiver operation resulted in six sets of field records:

1	Airgun into Hydrophone
2	Airgun into Marine Geophone
3	Airgun into GSR
4	Vibroseis into GSR
5	Vibroseis into Hydrophone
6	Vibroseis into Marine Geophone

In practice the marine geophone data (from both sources) has a very low signal to noise ratio and has not been used in the processing to date. A brief investigation of shot records show how different noise impacted the data recorded on land or at sea (Figure 4 and Figure 6). The difference in frequency content by receiver type for the same shot can be seen in the frequency spectrum in Figure 5.

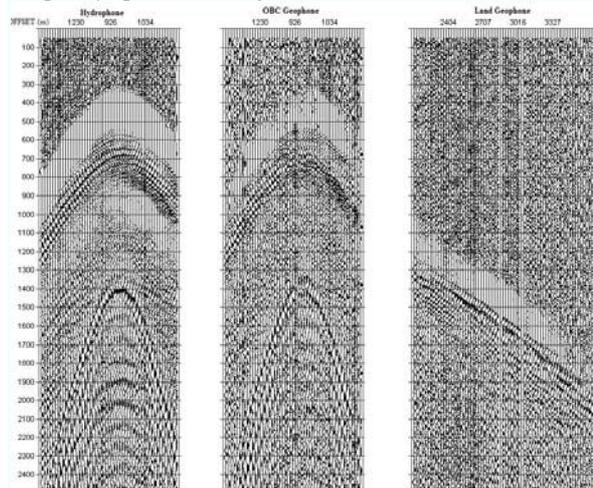


Figure 4: Shot record for an airgun shot into hydrophones (left), OBC geophones (centre) and land geophones (right). AGC applied

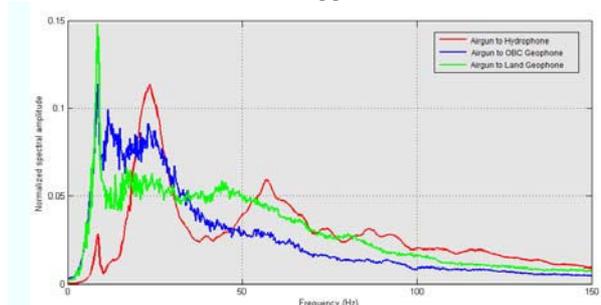


Figure 5: Frequency spectrum from the same airgun shot into the three receiver types, OBC hydrophone (red), OBC geophone (blue) and land geophone (green).

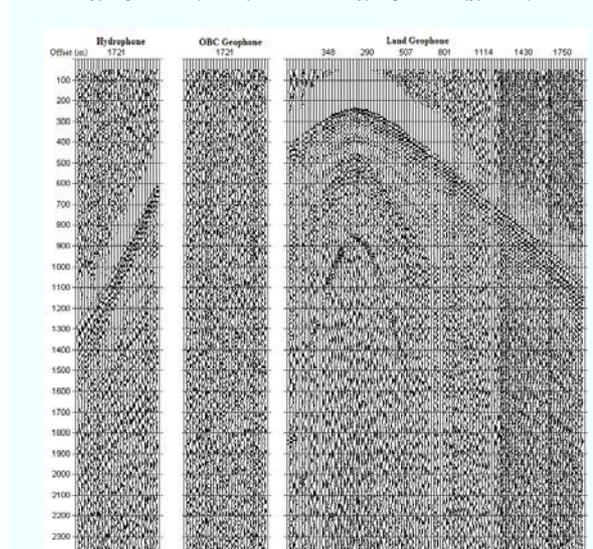


Figure 6: Shot record for a vibe shot into hydrophone (left), OBC geophone (centre) and land geophone (right). Offset is given at the top of the record. AGC applied.

PROCESSING

The challenges in processing this data were many and varied. They included: land statics, surface scattering of vibroses data proximal to the cliffs, ground-roll, mud-roll, low signal to noise ratio and phase and static differences between data sets. The biggest hurdle was obtaining adequate noise removal to generate a set of CMP gathers that could be reliably pre-stack migrated. Most effort was spent on coherent noise removal, such as mud-roll shown in Figure 7. Each pass of noise attenuation was followed by an iteration of residual statics and velocity re-picking to optimize the data for the next pass. As can be seen from the shot records, the different source-receiver combinations had unique characteristics. It was decided to process each set separately and regularly combine the sets into stacks to gauge improvement. A summary of the main processing steps is listed in Table 4. After applying de-noise and then phase matching the stack shown in Figure 8 resulted.

Table 4: Overview of the main processing flow.

1	Separation of records into 6 Source-Receiver sets & Nav Merge
2	Land statics: Refraction Method QCed against upholes
3	Swell Noise/Random Noise – Despiking
4	LN (Linear Noise Attenuation) Receiver Domain
5	LN in Shot Domain
6	LN in CMP Domain
7	LN in Offset Domain for airgun to land geophone
8	Separate deconvolution on land and marine records
8	Phase matching between land and marine
10	Stack and post stack Migration for QC
11	Pre-stack random noise
12	PSTM
14	Variable Mute; Final Stack and Scaling

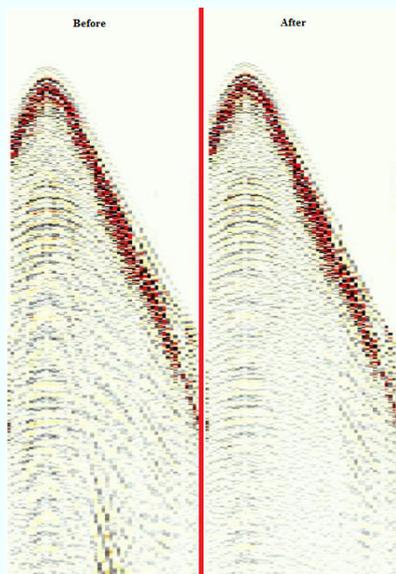


Figure 7: Airgun to hydrophone shot record, before mud roll removal (left) and after (right).

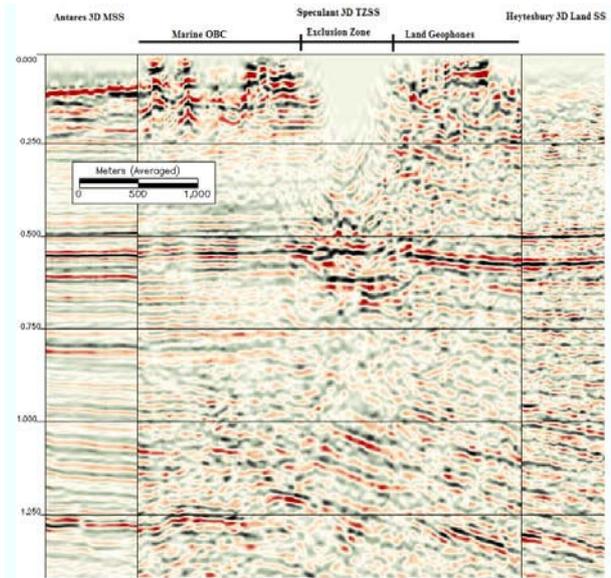


Figure 8: Post stack migrated volume of the Speculant 3D TZSS showing the infill between existing marine 3DSS (left) and land 3DSS (right). The effect of the exclusion zone caused by the surf zone and the cliff can be seen, this represents a minimum near offset of approximate 500m.

CONCLUSIONS

Even with the large exclusion zone along the shoreline and a high noise environment, the Speculant 3DTZ survey successfully imaged the coastal transition zone between the existing land and marine 3D seismic surveys, using smaller source sizes than traditionally used in the region. This result was achieved by many individuals from a variety of disciplines working more than 18 months to solve the many and varied challenges, from initial stakeholder engagement through the technical complexities of making disparate equipment communicate, to the challenging processing task of squeezing data out of low S/N records. However as may be expected in such an undertaking, many lessons were learnt. Suggestions or future surveys would include:

- closer spatial sampling through smaller receiver and source intervals to improve noise attenuation efforts
- allowance for more down time (in this environment).
- allow significant lead time in dealing with regulators
- listen carefully to stakeholders concerns so that the most mutually beneficial solution is found.

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