LOW IMPACT SEISMIC REFLECTION – TRIALLING ENVIROVIBES IN THE SURAT BASIN.

Mathew Dorling[1], Randall Taylor[2], Steve Hearn[3]*

Affiliations: 1. mathew.dorling@originenergy.com.au, 2. randall.taylor@originenergy.com.au, 3. steveh@velseis.com.au

Key Words : seismic acquisition, vibroseis, envirovibe, surat, low impact seismic.

INTRODUCTION

Origin Energy has carried out a series of trial 2D seismic surveys in the Surat Basin utilising the relatively lightweight ‘Envirovibe’ Vibroseis energy source.

The purpose of the program was to determine whether environmental and community benefits can be realized through the use of smaller vibrators, whilst still fully achieving the survey’s technical objectives. These considerations are particularly relevant for the vast coal seam gas (CSG) fairway in eastern Australia, over which horticulture, grazing and cultural activities are relatively intense.

MOTIVATION FOR THE TRIAL

Motivation for the use of small vibrators stems from the potential environmental, social and technical benefits summarised in Table 1. Also listed are a number of technical risks which must be considered before any new seismic source equipment is adopted long-term.

Anticipated Benefits	Environmental • Reduce minimum width of seismic line. • Increase ability to ‘weave’ though obstacles rather than clearing them. • Reduce tyre tracks and creation of ‘ruts’, particularly after rain • Reduce fuel consumption and vehicle emissions Social • Reduced engine noise • Improved stakeholder and community relations through recognition that an operator is actively seeking to minimise exploration impact. Technical • Reduce minimum array size (shorter vehicles can be parked closer together). • Possibility of decrease in source generated noise (depending on specific equipment specifications). • Reduce running costs (fuel consumption). • Reduced transport requirements/cost during Mob/Demob.
Anticipated Technical Risks	• Signal/Noise ratio will be insufficient to achieve survey objectives, or achieving sufficient S/N ratio may require excessive source effort, increasing cost and decreasing production. • Recorded signal bandwidth may be limited by an unacceptable amount (relative to data acquired with larger vibrators).

Table 1: Potential benefits and risks associated with use of a small vibroseis source.

SEISMIC SOURCE

The seismic source used in the trial is the IVI 'Envirovibe', a low impact vibrator system designed for operating in environmentally sensitive or populated areas where larger vibrators are unsuitable.

Mounted on the IVI minibuggy, the Envirovibe is 6m long and 2m wide, with a total vehicle weight of 17,000lbs and theoretical peak force of 15,000lbs. Further specifications are listed in Table 2.

Figure 1: Envirovibe mounted on IVI Minibuggy.

Envirovibe Specifications	
Total mass	8.4 tonnes (17000lbs)
Turning Radius	4.29m
Max force	7409kgf (15,000lbs)
Reaction Mass Weight	794kgf (1,750lbs)
Baseplate Area	1.1675 m^2
Engine	John Deere Diesel 85Kw

Table 2: Key specifications of Envirovibe system

SITE SELECTION

A 6.6km line along a roadside within ATP702 was selected as the trial location (Figure 2).

The primary objective of the survey was to image the Walloon Coal Measures, as the high reflectivity of the target coals and their relatively shallow depth (usually less than 1000m) make them ideal targets for a small vibrator survey. The deeper Bowen Basin section (>1000m), with the possibility of conventional oil and gas plays was considered a desirable, but secondary objective.

EXISTING SEISMIC DATA

A recent Origin 2D survey acquired with larger Hemi44 vibrators intersects the Envirovibe trial location. This survey was acquired in 2005 using two HEMI44 truck mounted vibrators, operating at 80% of their stated 44,000lb peak force. It is used as the baseline survey against which to gauge the Envirovibe trial.

In this reference survey, a Variable sweep was employed, comprising three standing upsweeps over the ranges 10-90Hz, 50-130Hz and 30-110Hz. Recording spread consisted of 200 channels with a group interval of 12.5m. Source interval was also 12.5m, resulting in a CDP fold of 100. Receivers were 10Hz geophones in a 12 element array equispaced over 12.5m. For convenience this survey will be referred to as the 'Hemi44' survey to denote the source used.

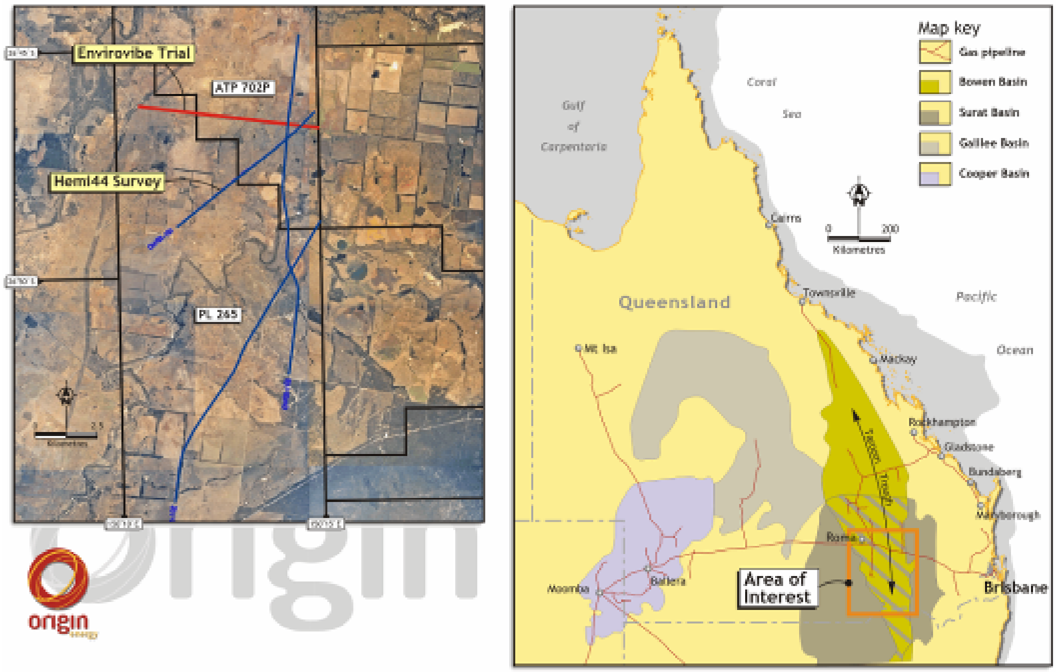

Figure 2. Location of Envirovibe trial in ATP702P (red). Hemi44 survey shown (blue).

ACQUISITION PARAMETERS AND SCHEDULE

The fixed acquisition parameters used throughout the trial Envirovibe survey are outlined in Table 3. These parameters were made consistent with the Hemi44 survey where possible. Exceptions include the use of a conventional single band sweep, and the reduction in number of geophones per group from twelve to six. Source parameters determined via in-field sweep tests included sweep bandwidth, sweep length, vertical stacking requirements, and number of vibrators (Table 3). During testing receivers were spaced at 6.25m

The acquisition schedule comprising test shots, short test lines, and a 6.6km 'production' line is outlined in Table 4.

Table 3: 2008 Envirovibe Trial – Fixed Acquisition Parameters	
Sample Rate	1ms
Record Length (correlated)	3000ms
Spread Geometry	Symmetrical Split Spread
Geophone Array	10Hz phones, 6 equispaced over 6.25m
Number channels live	220
Near Offset	6.25m
Far Offset	1368.75m
Source type	2 x Envirovibe 15,000-lb vibrator, 70% peak force
Sweep range	10-120Hz
Sweep Duration Number sweeps/VP	6000ms 1
Pad-Pad Distance	6m
CDP Fold	110

	Sweep (Hz)	Number of vibes	Number of sweeps	Group Interval (m)	Source Interval (m)	First Station	Last station	Line length (km)
Single Sweep Tests	10-160 10-120 20-120 Variable	1 & 2	1-6	n/a	n/a	n/a	n/a	n/a
Trial 1	10-120	1	3	6.25	12.5	100.0	420.0	2.0
Trial 2	20-120	2	1	6.25	12.5	100.0	420.0	2.0
Trial 3	10-120	1	1	6.25	12.5	100.0	420.0	2.0
Trial 5	10-180	2	1	12.5	12.5	938.0	1250.0	1.95
Production	10-120	2	1	12.5	12.5	200.0	1250.0	6.6

Table 4: Acquisition Schedule

IN-FIELD SWEEP TESTS

A representative test record from the Envirovibe survey is presented in Figure 3. Results were immediately encouraging with strong coherent reflections visible well below 1000ms. This is despite the peak force of both Envirovibe units operated at 70% drive level being less than one third of that generated by the larger Hemi 44 vibes.

The maximum contributing frequency from any single sweep test was found through low cut (LC) filtering to be around 110Hz regardless of source effort, so subsequent sweep end frequencies were limited to 120Hz.

Sweeping with two vibrators simultaneously produced records with superior S/N, compared with the limited noise attenuation provided by vertical stacking. An example is provided in

Figure 4a, 4b. Improvements, particularly at the deeper target (1.0 – 1.2 sec), are interpreted to result from more effective energy penetration below the base of weathering, whilst the ineffectiveness of vertical stacking suggests that random noise is a minor component of the total record.

Note that these vertical-stack tests were done with a standing vibrator. A more competitive result might be expected with moveup between sweeps. However this would be more time consuming, and hence less attractive for production use.

From these observations it was decided to acquire production data using two vibrators and a single sweep/VP, thereby ensuring data quality whilst maintaining the shortest possible cycle time.

No reduction in S/N due to the use of 6-element geophone arrays was observed. This agrees with observations made by Moriarty (1992), and Leaman and Parrott (1987). Halving the number of geophones per string significantly increases the rate at which spread can be laid and moved during acquisition.

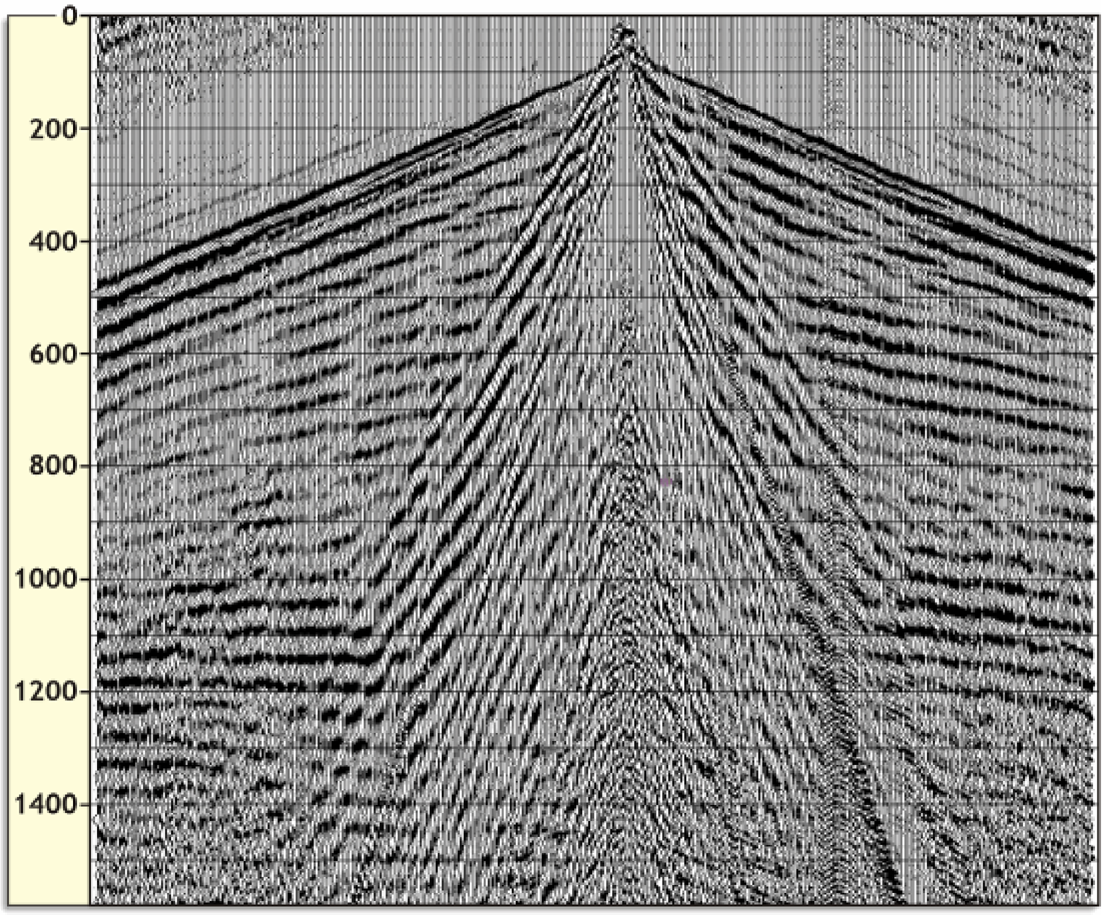

Figure 3: Test record – 2 Vibes, Single, 10-120Hz Linear upsweep, 6 second sweep.

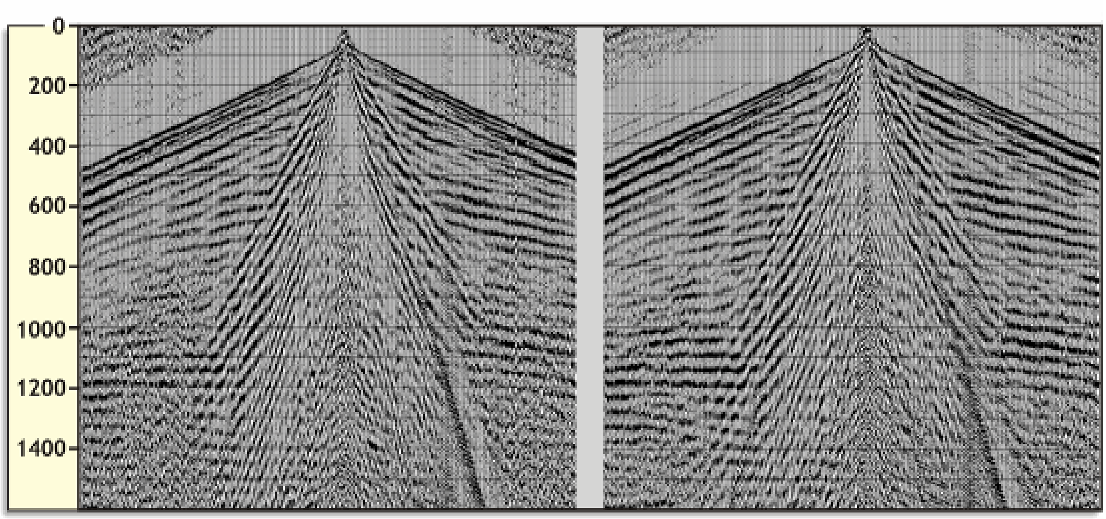

Figure 4a: Envirovibe test records. 1 vibe, 6 vertically stacked sweeps (left). 2 vibes, single sweep (right).

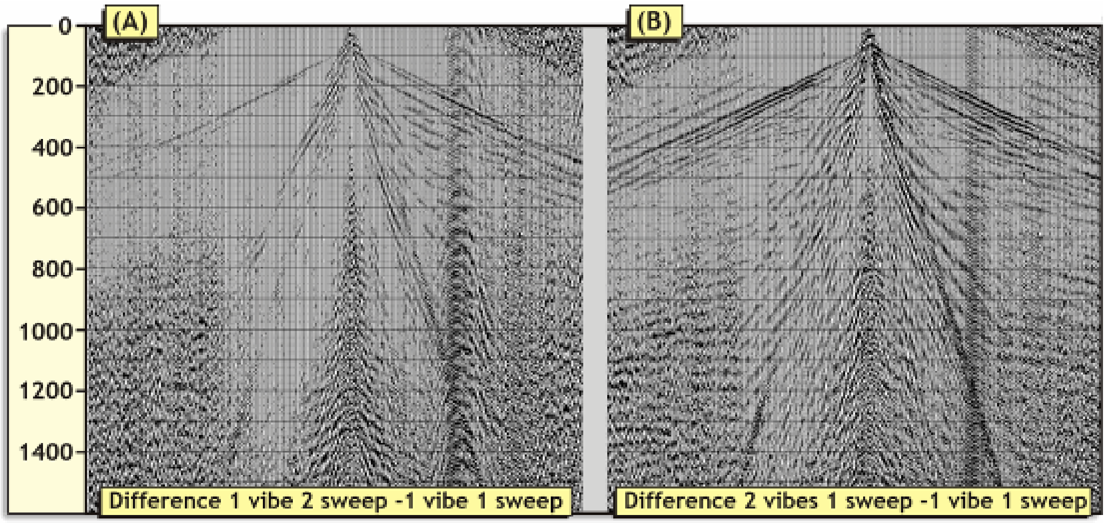

Figure 4b: Additional energy recorded employing an additional sweep versus an additional vibrator. Differencing was performed after normalising the amplitudes of each input record.

The character of the Envirovibe gathers is quite distinct from that of the Hemi44 gathers (Figure 5). The most striking difference is the apparently higher dominant frequency of the Hemi44 data due to the use of a variable sweep. Analysis of the amplitude spectra of each record (Figure 6b) reveals that frequency bands which overlap in the variable sweep design have been amplified, producing this high-frequency character. However filtering suggests that in the deeper section, much of this additional energy is noise. (Compare the spectra in Figure 6b to the records in Figure 5e and 5f.)

The first breaks of the Envirovibe record are noticeably cleaner and lack the 'ringy' appearance of the Hemi44 record. There are a number of possible contributors to this. It may relate to the smaller, circular pad used on the Envirovibe, or the use of a linear, rather than variable sweep. Seriff and Kim (1970) have noted that oscillatory forerunners to the correlated signal can also result from harmonic distortion introduced by decoupling, inadequacy of the feedback system, or nonlinear effects within the Vibrator.

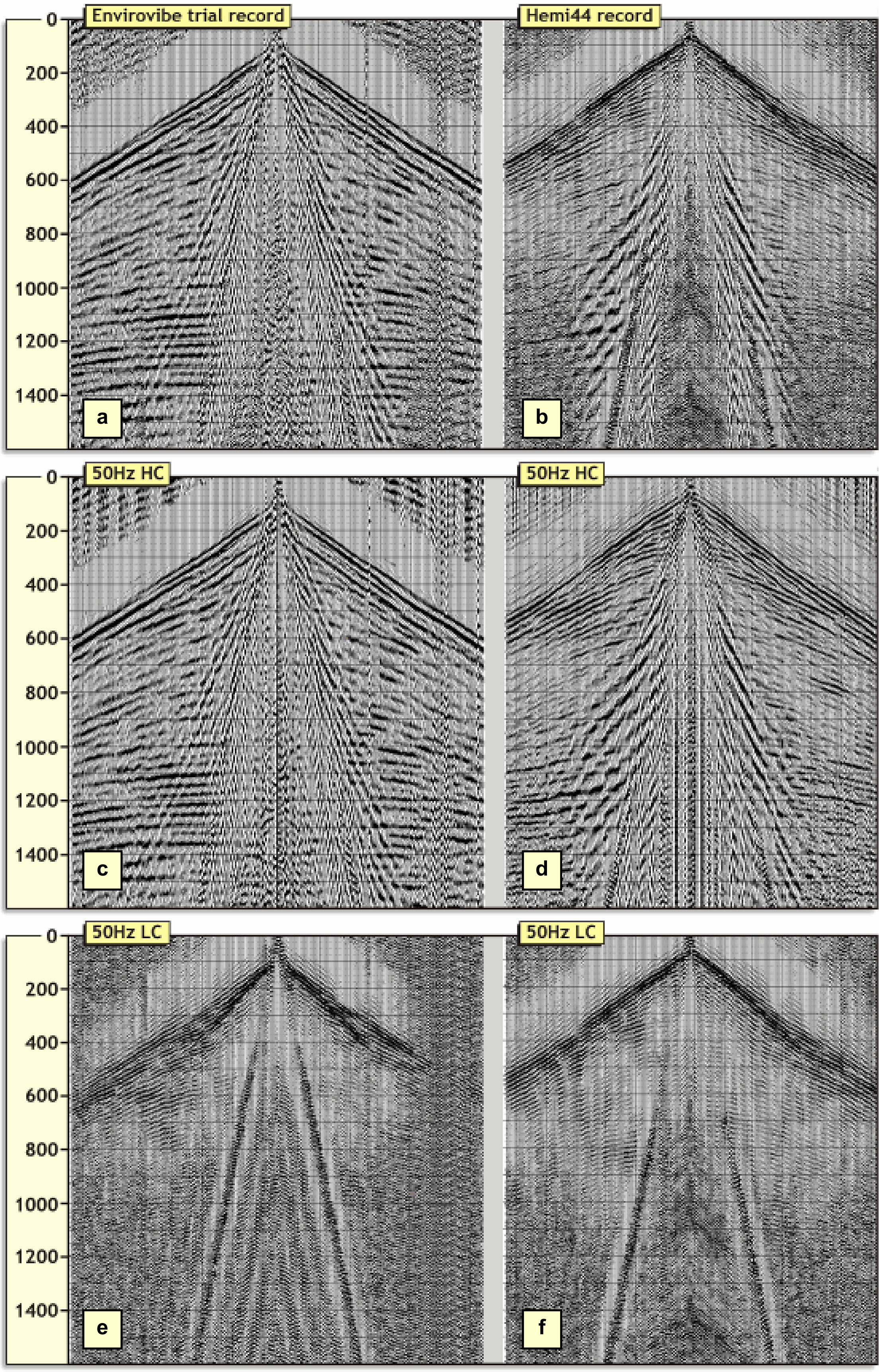

Figure 5: Production shots from Envirovibe trial (left column) and Hemi44 survey (right column).

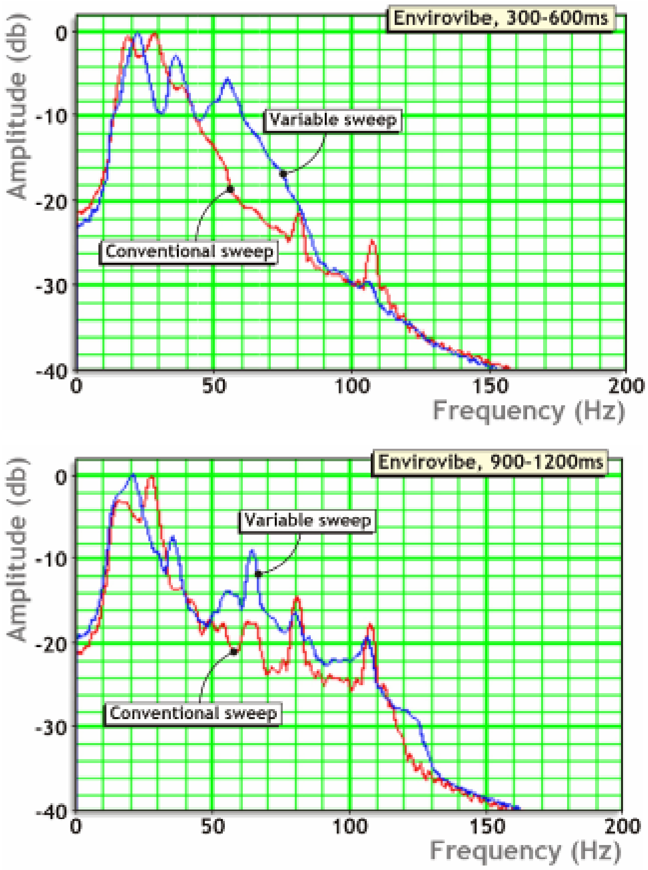

Figure 6a: Envirovibe amplitude spectrum, conventional and variable sweep records.

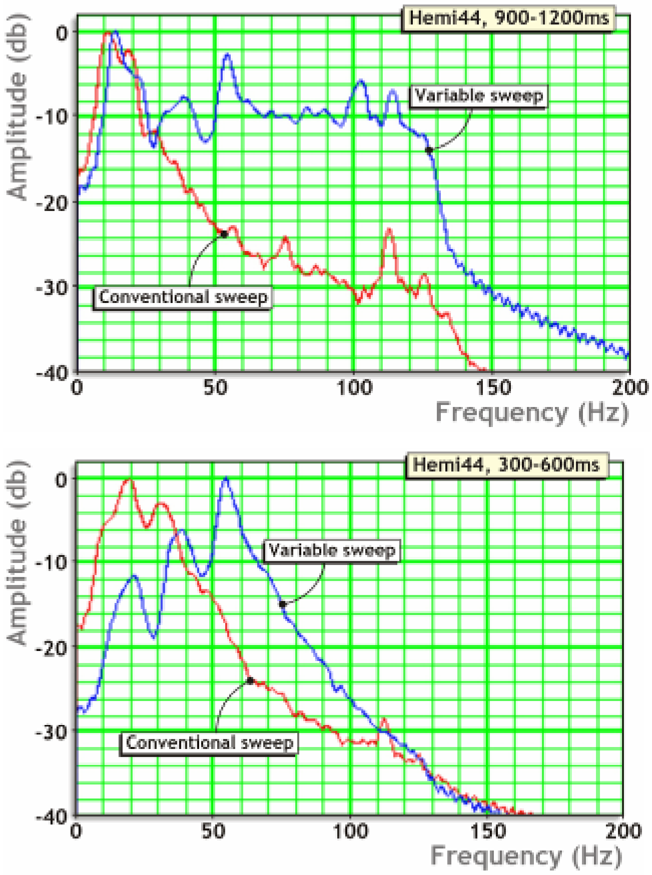

Figure 6b: Hemi44 amplitude spectrum, conventional and variable sweep records.

ENVIROVIBE VARIABLE SWEEP TRIALS

A variable sweep record was produced with the Envirovibe, with sweep bands matching the Hemi44 data (Figure 6a). High frequency reflection energy is more visible in the first 800ms of the Envirovibe record (compared with the conventional upsweep), however still lacks the 'ringy' energy preceding the first arrivals (Figure 7b).

This lends further support to the conclusion that distortion has been reduced, either through the reduction in drive force, improved phase and amplitude control, or through differences in baseplate size and shape or vibrator mechanics. A conventional test sweep (5-140Hz linear upsweep) acquired with the same Hemi44 does not exhibit this ringy character (Figure 7b), suggesting the variable sweep frequencies selected were not well suited to the larger vibrators. One possibility is that the sub sweeps with higher start frequencies are not handled as well by the larger vibrator.

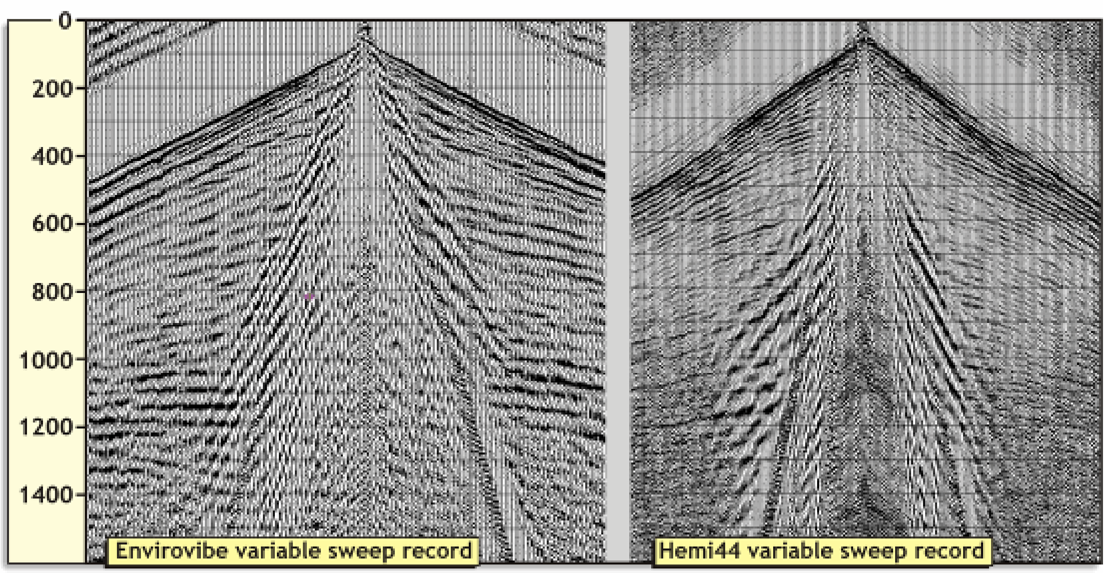

Figure 7a: Comparison of records recorded with variable sweep Parameters. Sweep sequence 10-90Hz, 50-130Hz, 30-110Hz.

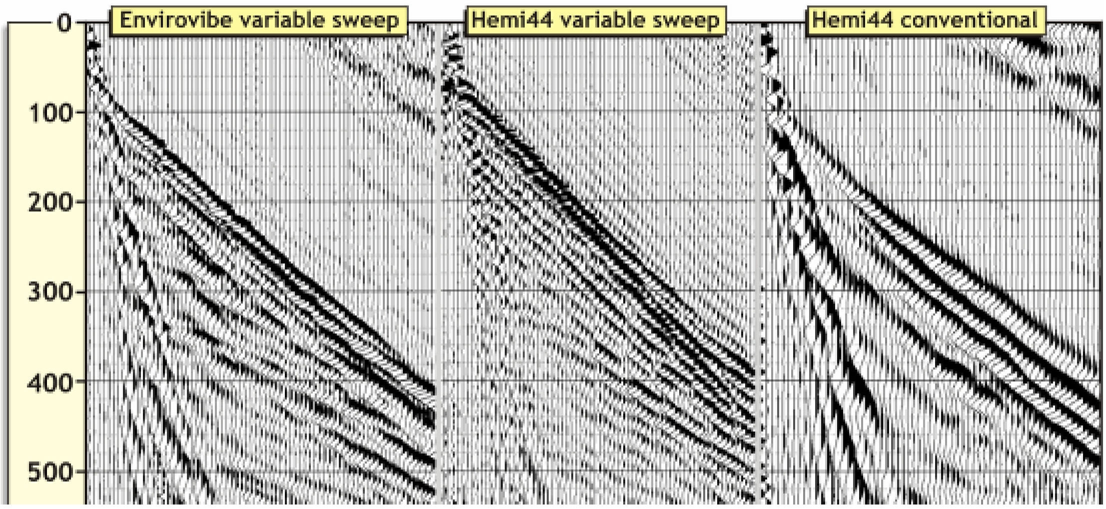

Figure 7b: Variable sweep records zoomed to emphasise first breaks. Sweep sequence (10-90Hz, 50-130Hz, 30-110Hz). Conventional sweep (5-140Hz linear upsweep).

Autocorrelations were calculated and compared for the conventional and variable sweeps (Figure 8). In raw form, the variable-sweep wavelet arguably achieves better cancellation beyond the first side-lobe. However, after application of a 50Hz high-cut filter, the conventional sweep (10-120Hz linear upsweep) yields a higher peak amplitude to side-lobe ratio compared with the variable sweep wavelet. This suggests that the standard 10-120Hz upsweep was a better choice for imaging the deeper target.

REDUCTION IN VIBRATOR DRIVE LEVELS

Test were recorded where drive level was reduced in order to determine at what point source energy became insufficient (Figure 9). S/N remained remarkably similar even at 30% drive level, although as expected an increase in random noise was observed. Since no signal degradation due to harmonic distortion or decoupling was observed at the 70% drive level, this was deemed an appropriate drive level for the local ground conditions.

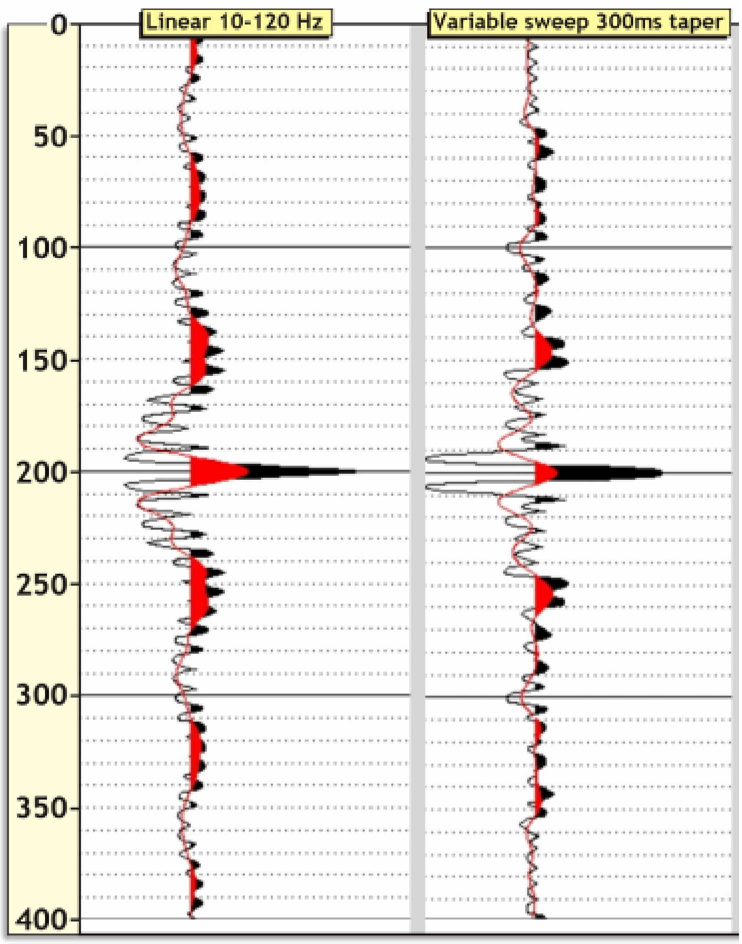

Figure 8: Correlated pilot sweeps. Linear upsweep 10-120Hz (Left), Variable sweep 10-90/50-130/30-110Hz (right). Red curve represents 50Hz HC filtered wavelet.

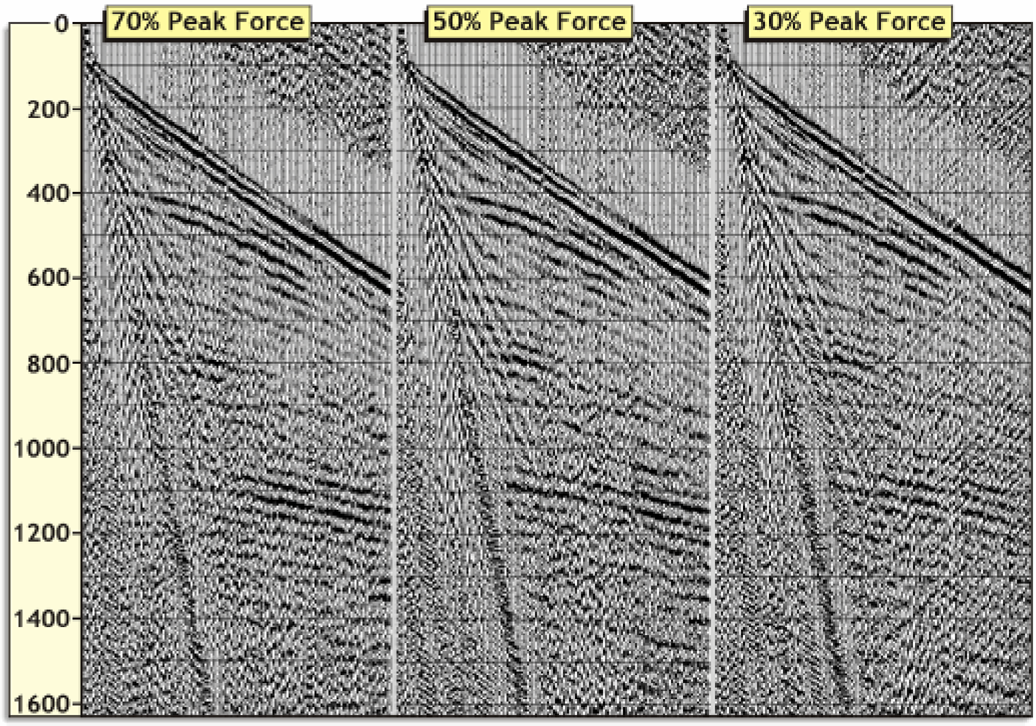

Figure 9: Envirovibe test records acquired with drive level at 70%, 50% and 30% of the 15,000lb peak force. Each record produced by a single vibe, sweeping once from 10-120Hz over 6 seconds.

PROCESSED TEST LINE ANALYSIS

Four short test lines were acquired prior to final production recording and processed by Velseis Processing Pty Ltd. The purpose of these short lines was to determine the effect of several vibrator and sweep combinations after processing.

These sections revealed that stacked data quality was satisfactory even when using a single Envirovibe source and a single sweep/VP (Figure 10a). An improvement in S/N was achieved by vertically stacking sweeps (10b), and by the use of multiple vibes (10c). However the improvement was minor.

The ability to achieve acceptable data quality with a single 6-second sweep resulted in cycle time being significantly reduced compared to previous surveys. Pre-stack decimation testing performed by Velseis Processing on these lines found that halving the CDP fold by removing every second source point had very little effect on stack quality, although additional random noise was discernible.

PRODUCTION LINE ANALYSIS

The final 6.6km Envirovibe trial data were processed by Velseis Processing Pty Ltd using parameters consistent with the Hemi44 survey. Figure 11 is a composite line with migrated, filtered Envirovibe stack on the left, and the similarly processed Hemi44 line on the right. Envirovibe data quality is on par with seismic acquired in the area with much larger vibrators. The strong reflection events between 250-500ms TWT correspond to the Walloon coal measures (the primary CSG target of the trial). Small scale faults and seam splitting are easily interpreted at this level, with the maximum contributing frequency within this interval being around 100Hz.

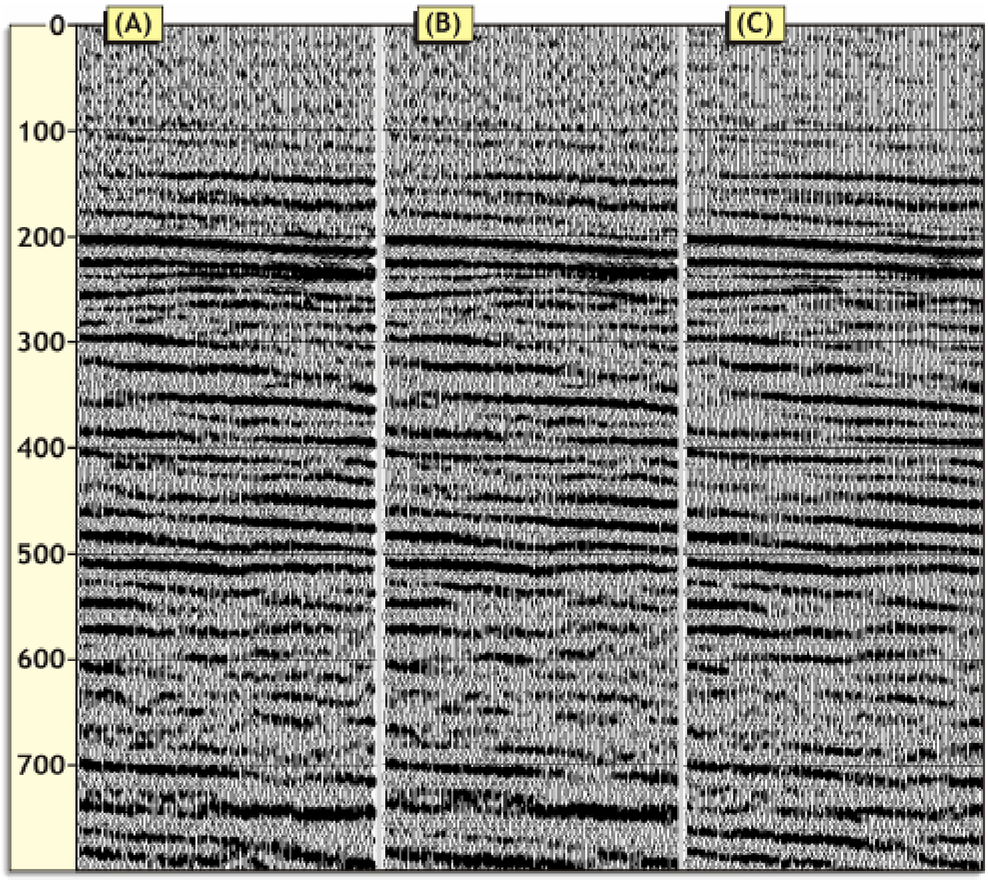

Figure 10: Subsets of stacked Envirovibe trial data (a) Single vibe, single sweep test line, (b) Single vibe, 3 sweep test line, (c) Production line, 2 vibes, single sweep.

The basal Jurassic unconformity has also been imaged at around 750ms, along with a number of folded Permian horizons below this. The maximum contributing frequency for this interval (750ms – 1250ms) is around 55Hz.

The Envirovibe and Hemi44 sections are remarkably similar in data quality and character, despite the significant character difference in the field records. Signal Bandwidth is similar, although the larger Hemi44 vibes did recover slightly higher signal frequencies in the Permian section, with a maximum contributing frequency around 60Hz. This increase in bandwidth at the high-frequency end is similar to that reported by Hughes and Fitzgerald (1995).

OTHER ENVIROVIBE TRIALS

Following the initial Envirovibe trial in ATP702P, two further trial surveys were conducted by Origin Energy in the Surat/Bowen basin to determine the applicability of small vibrators in a range of geologic settings.

These two surveys were acquired consecutively in April/May 2008 and comprised one 4.2km line across a CSG prospect in ATP973P (Bogandilla 2D), and two lines totalling 11.6km over a producing Surat Basin oil field (Emu Apple 2D).

The first of these surveys, Bogandilla 2D, successfully imaged deeper CSG targets, as well as horizons to the base of the Taroom Trough below 3000ms, whilst at Emu Apple the Boxvale sandstone was imaged at 1400m depth with data quality comparable to seismic acquired previously in that area.

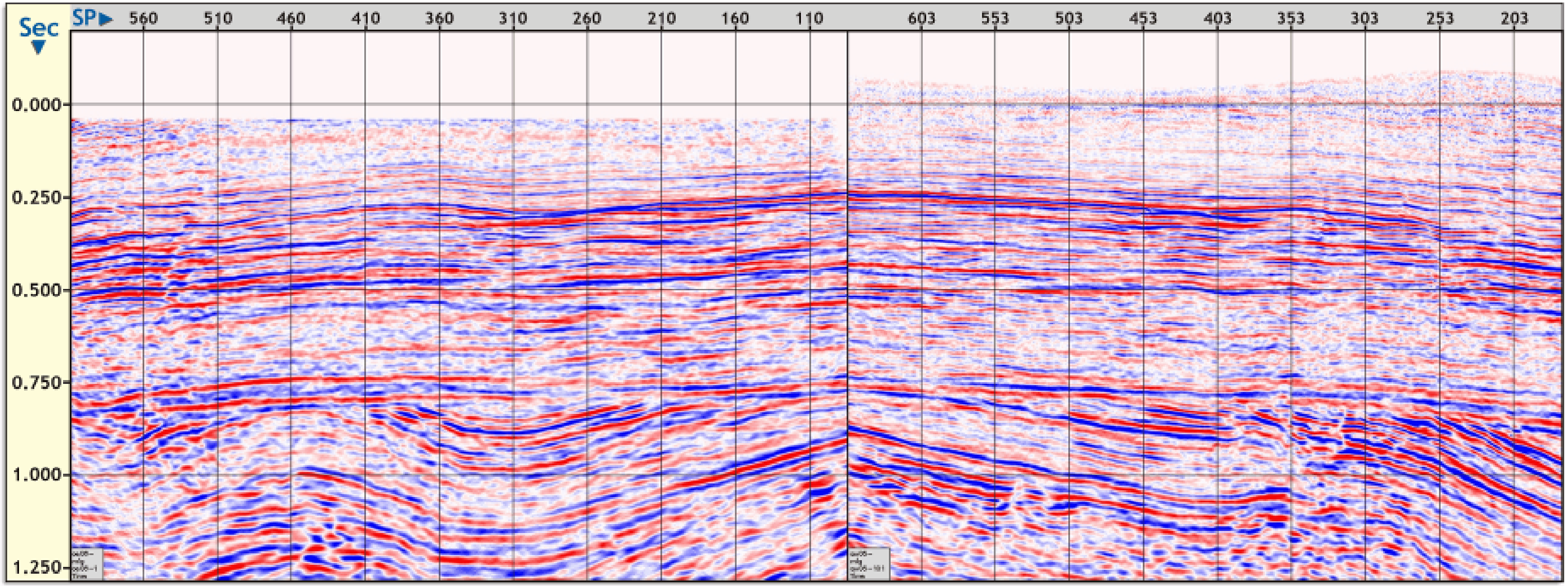

Figure 11: Composite 2D Seismic section, Envirovibe trial line (left), Hemi44 line (right).

CONCLUSIONS

The Envirovibe trial survey in ATP702P, along with the follow-up surveys described above successfully imaged both CSG and conventional targets in three geographically diverse areas within the Surat/Bowen basins. This result validates the use of smaller vibrator sources in this region. Stacked images were almost indistinguishable from those acquired previously with much larger vibrators, and further decimation in processing suggested that field effort could be reduced further still, without affecting data competency.

Following are some key observations made following the Envirovibe trial surveys:

- Envirovibe produces sufficient penetration of acoustic energy to adequately image all target horizons in the trial location with equivalent clarity to heavier vibrators

- Useful records were produced with drive level as low as 30%, demonstrating that the energy imparted by the Envirovibe was well above any 'minimum requirement' to image these targets. Larger vibes could presumably be operated at even lower drive levels, reducing noise and mechanical wear without sacrificing data quality.

- The Envirovibes produced well-defined first breaks without the precursory ringing often seen on conventional Vibroseis data. Smaller vibrators may produce less distortion, particularly when higher start frequencies are required (as in the variable sweep technique). This may relate primarily to the size and shape of the Envirovibe pad. On the other hand it may relate to other mechanical factors, in which case reducing the drive level of larger vibrators may have a similarly positive effect.

- One apparent benefit of using the heavier vibrators was a slight high-frequency increase in bandwidth (5-10 Hz) in the deeper part of the section (> 750 ms). Further trials are needed to explore whether thus is intrinsically related to vibrator mass, or whether it resulted from the variable sweep used in the Hemi44 survey.

- Standing vertical stacking provided minimal noise attenuation and is very time consuming. Recording a single sweep with two vibes simultaneously was the preferred technique to ensure high data quality and recording efficiency.

- Reducing the number of geophones/group from 12 to 6 had no observable effect on S/N.

For imaging conventional targets of moderate depth, and especially for the highly reflective and often shallow coal seams targeted by CSG exploration, small vibrators such as the Envirovibe are demonstrably competitive with much larger and heavier vibrators. With appropriate parameter optimisation, seismic data in the Surat/Bowen Basin can be acquired with improved efficiency, with reduced environmental impact, and without jeopardising data quality.

ACKNOWLEDGEMENTS

The authors thank Origin Energy Ltd for permission to publish the data examples used in the paper.

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