# Vibroseis or Dynamite: Investigating Source Characteristics


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## SUMMARY

A comparison of recently acquired seismic data in the Bowen Basin has highlighted inherent differences in signal content between dynamite and Vibroseis sources. This work was undertaken to assist selection of the source for proposed 2D and 3D seismic surveys in the Bowen Basin where recent drilling successes have revived interest in the hydrocarbon potential of the Permian sequence. Although comparisons between dynamite and Vibroseis sources have been made previously, the topic remains relevant because of developments in acquisition technology, the use of seismic source modelling and the area-dependency of seismic data quality.

The motivation for acquisition of further 2D and 3D seismic data in the Surat-Bowen Basin are petroleum discoveries in the Permian Tinowon Sandstone along the western flank of the Taroom Trough at Myall Creek, Churchie, Overston and Waggamba. Variable reservoir quality and extent make identification of Tinowon sands difficult and good quality, high resolution data are essential for exploration and development mapping of the prospective reservoir units. For this study, a pair of overlapping 2D seismic lines was selected, one recorded with a Vibroseis source in 1996 and the other with dynamite in 2000. Care was taken to select two modern lines with acquisition parameters that would minimise the attenuation of frequencies in the higher end of the signal spectrum, thus providing input data sets that would result in a valid Vibroseis-dynamite comparison.

Data processing was closely monitored to determine the effects of specific algorithms on signal content. Dynamite proved to have the greatest resolution in the Tinowon zone of interest, that is, around 1400 ms. Indeed, inspection of the signal spectra and particularly the bandpass filter panels on raw field records clearly showed that dynamite data contained higher frequencies and exhibited increased resolution relative to the Vibroseis data in the study area. Bandpass filtering is an effective means of evaluating seismic source characteristics.

Predictably, results showed that resolution of the dynamite and Vibroseis data converged with depth due to the natural frequency filter effect of the earth. Synthetic data produced from wavelets matching the Vibroseis and dynamite data demonstrated that the improved resolution expected from the dynamite source would improve imaging of the Permian section. Based on the results of this trial and other modelling, Origin Energy selected a dynamite source for their Myall Creek 3D survey. Mosaic Oil selected dynamite for both their 2003 2D and their 2004 3D seismic survey.



Key Words: Vibroseis, dynamite, seismic source.


## INTRODUCTION

The combination of new technology, new ideas and drilling success can lead to a resurgence of exploration activity in mature basins. The recently upgraded potential of the western Taroom Trough in the Surat-Bowen Basin (Figure 1), a mature hydrocarbon province, is fuelling a need for higher resolution and greater density seismic data. The principal Permian hydrocarbon play involves structural-stratigraphic trapping of sands of the Tinowon Formation (Figure 1). Lithologically, the Tinowon Formation consists of sand, silt and coal, with individual units less than 30 m thick. Sand thickness typically ranges between 5 and 15 m and lateral variability of reservoir development in combination with the thin beds requires seismic data of high resolution and quality.

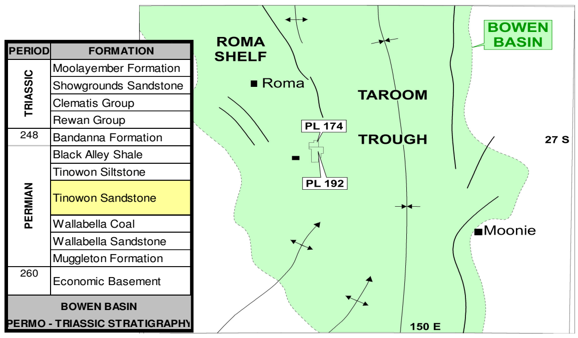


**Fig. 1. Location map and stratigraphic column**

The study takes recent Vibroseis and dynamite data sets and processes each in a consistent manner, aiming to maintain maximum frequency content in the final sections. The raw data and final processed sections are analysed for their spectra and conclusions are drawn about the inherent bandwidth and resolution of each source.

Most of the data acquired in the Surat-Bowen Basin was recorded in the early and mid 1980's. For many operators dynamite was the preferred source as the consensus was higher resolution was required for thin reservoir units.

Since 1990 the use of Vibroseis as a source in the basin has increased, mainly because its bandwidth has improved through shorter arrays, better control systems, and greater fold. In addition the introduction of heavier Vibrators, 60,000 lb, has improved the penetration of higher frequency energy. Hughes (1995) concluded that the heavier Vibrators can increase the top end frequencies by 10-15 Hz in a comparison with 38,000 lb Vibrators. However, recent shot records show that despite these advances, there remains a detectable difference in bandwidth between dynamite and Vibroseis data in the Myall Creek-Churchie area.

The validity of previous source comparisons done on older vintage data may be questionable due to the effects of arrays. In particular the combined effects of the source and receiver arrays, which were in the order of 50 metres and 30 metres, respectively, may well have restricted the resolution of the older Vibroseis data. Figure 2 shows the geophone array response for various array lengths and it demonstrates that a 55 metre array exhibits a notch at 50 Hz.

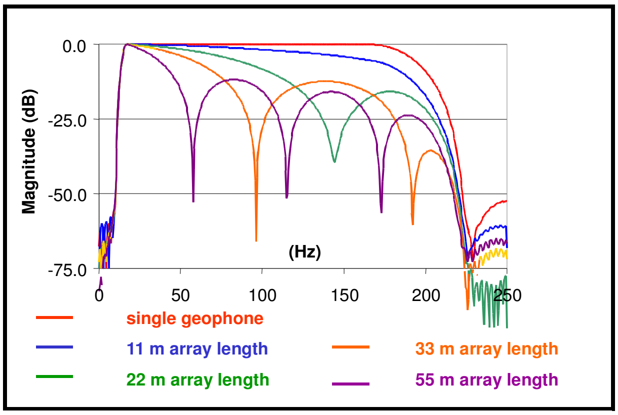


**Fig. 2. Geophone array response for a weathering profile (10 degrees of dip). Vo is 1000 m/s and Vsub is 3000 m/s.**

Optimising the source is key to obtaining the required data quality to image reservoir units. Depth of burial, surface conditions and subsurface geology all play a role in determining final data quality. This area-dependency demands a revisit of dynamite and Vibroseis source selection in the Surat-Bowen Basin.

## PREVIOUS STUDIES

Although there are few published examples, the authors are aware that various Australian companies have conducted comparisons between dynamite and Vibroseis during the 1980s and 90s. The general conclusion of these comparisons has been that the lower fold dynamite data usually contains superior frequency content, but with apparent lower signal to noise ratio when compared to a full fold Vibroseis section. The difference in frequency content is usually more pronounced in the shallow section, and while still apparent, is quoted as less pronounced for typical oil field targets below about 1 second two-way time. This observation is supported by shallow seismic field trials conducted for coal mining, (S. Hearn, pers comm.).

Data processing trials associated with a 2002 field study (Mosaic, 2002) confirm that the spectral content of seismic data is affected by the near surface sub-weathering interface, which is typical of the area. The sub-weathering in the Surat-Bowen Basin is defined by the top of the "blue shale", which exists between 12 and 36 meters below the weathered zone comprising unconsolidated sands, clays and gravels. The shale is unweathered and has a velocity in excess of 1900 metres/sec. Its competency makes it able to support explosive charges suitable for exploration purposes (0.8 - 1.6 kg).

The far field wavelet tends to be spatially consistent for dynamite shots buried in this shale medium. Such consistency is essential for high integrity processing and subsequent interpretation of the seismic data. The Vibroseis far field wavelet is less consistent due to the influence of the weathered surface layer, which varies in both velocity and thickness.

Recent field trials (Mosaic, 2002), again in 2002 were conducted to assist in survey design involved the acquisition of shot records using explosive charges of various sizes and depths of burial. An interesting outcome was the identification of a notch in the spectrum at 40 Hz for a shot discharged deep in the sub-weathering (30 m). This indicates that the acoustic contrast between the weathered layers and the shale is substantial and that a ghost is being generated at the boundary. It could be inferred therefore that this boundary affects sonic penetration from surface sources, such as Vibroseis. Another finding from this work is that unnecessarily deep shot holes can have a detrimental impact (spectral notch) on the signal/noise ratio of dynamite data.

In order to compare the signal and noise characteristics of a surface source (Vibroseis-equivalent) to a deep source (dynamite), a weathering layer shot hole record was compared to a record derived when the same charge size was detonated in a sub-weathering shot hole. The "surface" record is dominated by ground roll and Rayleigh waves and the spectral content is inferior to that of the deep shot.

In conclusion, the presence of a competent sub-weathering layer that is able to support dynamite shots results in a consistent source wavelet. However, to avoid generation of a source ghost it is crucial that the dynamite charge is not set too deep within the sub-weathering layer.

## DATA SELECTION

A valid comparison required that the selected lines were recorded with modern acquisition parameters. Data from neighbouring licences PL 174 (Vibroseis) and PL 192 (dynamite) provided the data sets and lines OS96-105 (1996, Oil Company of Australia) and MY00-07 (2000, Mosaic Oil), which overlap for 1.5 kilometres, were chosen for the comparison. Although more overlap would have been preferred, this was the best comparison that could be undertaken without going to the expensive exercise of mobilizing a crew to record the same line with both sources.

**Acquisition Parameters**

| | **Dynamite MY00-07** | **Vibroseis OS96-105** |
|---|---|---|
| **Recorded By** | Trace Terracorp | Geco-Prakla |
| **Date** | September 2000 | July 1996 |
| **Source** | Dynamite 800 gm | 3X Mertz M26<br>60,000 lb |
| **Source Array** | Single charge<br>48 m | 2 Standing sweeps<br>24 m inline array |
| **Sweep** | N/A | 2.5 – 105 Hz 5 secs |
| **Instrument** | I/O System II | I/O System I |
| **Geophone** | SM7 freq: 10 Hz | SM4 freq: 10 Hz |
| **Data Format** | SEGD | SEGD |
| **Sample Rate** | 2 milliseconds | 2 milliseconds |
| **Recording Filters** | Lo: 8.7 Hz<br>Hi:187 Hz | Lo: 3 Hz<br>Hi: 180Hz |
| **Rec. Array** | 6 over 12.5 m | 12 over 18.33 m |
| **Spread** | 480 channels | 248 channels |
| **SP/VP Int.** | 187.5 metres | 20 metres |
| **Gp. Interval** | 12.5 metres | 20 metres |
| **Near Trace** | 6.25 metres | 10 metres |
| **Far Trace** | 2993.5 metres | 2470 metres |
| **Coverage** | 16 fold | 60 fold |

**Table 1. Acquisition parameters of the 2 datasets.**

### Raw Data Quality

Shot Point 160 on the dynamite line coincides with VP 364 on the Vibroseis line. Figure 3 shows a comparison of the corresponding records. Each record is displayed without trace equalization. Shot generated noise close to the source is much stronger with the Vibroseis record but away from the shot both sources display good signal to noise around the zone of interest at 1400 ms.

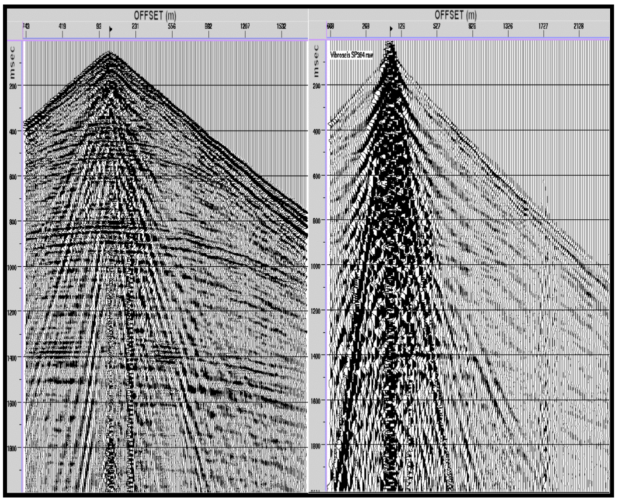


**Fig. 3. Raw record comparison. Dynamite on left, Vibroseis on the right; $T^2$ scaling only.**

The frequency spectrum in Figure 4 shows dynamite contains greater high frequency energy, with the amplitude at 80 Hz being down 10 dB from the peak amplitude as compared with the Vibroseis data whose amplitude was down 28 dB at 80 Hz. The low end of the dynamite spectrum sees a decrease in amplitude below 30 Hz. This represents the frequency characteristics of the source as neither the 10 Hz geophones or the 8.7 instrument lo-cut should be affecting the spectrum between the 10-30 Hz range. Significant notches can be observed on the Vibroseis spectra below 40 Hz, possibly due to ground roll and/or near surface ghosts.

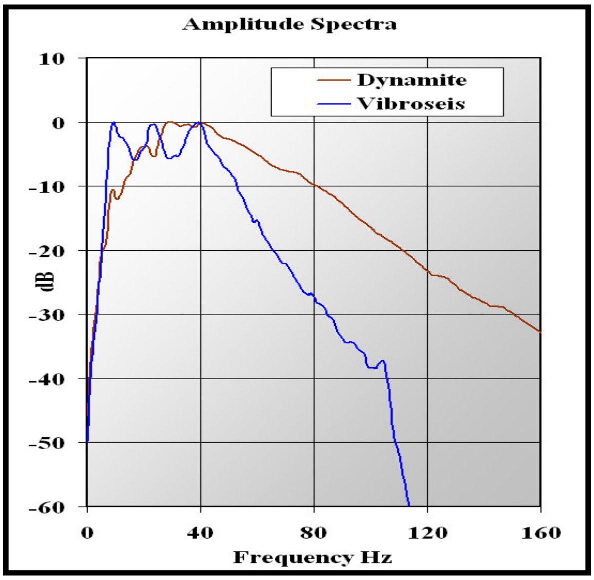


**Fig. 4. Spectrum of raw records within a window 0 to 2000 msec.**

The dynamite data clearly shows a whiter spectrum indicating that it is a superior source for generating high frequency data. However it's not possible to say with certainty how much of this energy is reflective energy and how much is ambient and linear noise. To further examine the quality and characteristics of the raw records, discrete bandpass filters were applied to the records that were then equalized by running a 500 ms AGC after filtering. This is expected to have a similar effect to deconvolution, which will allow an assessment of the potential frequency bandwidth of both sources without applying any complex processing procedures. Bandpass filters used range from 10-20 Hz to 150-180 Hz.

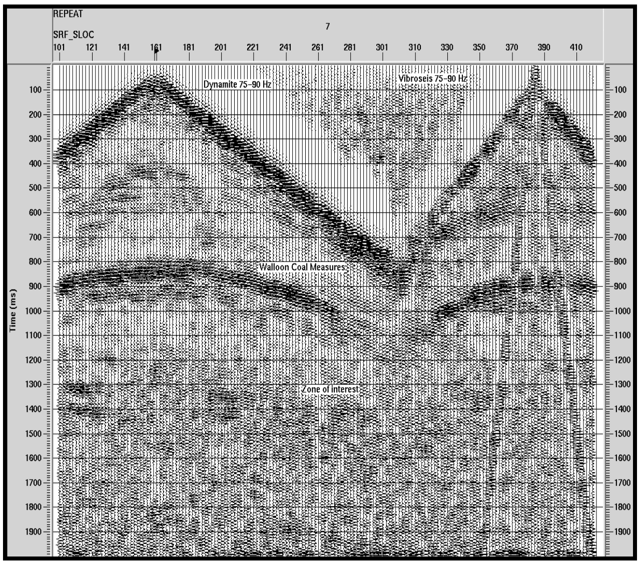


**Fig. 5. Raw records 75 - 90 Hz.**

Figure 5 shows both sources filtered with a 75-90 Hz bandpass filter. The dynamite data at the two-way time of the Permian section (1400 ms) does display some reflective energy although not continuous, while the Vibroseis data, at this time, show no reflective energy. Both sources show the reflection series of the Walloon Coal Measures. Evidently, the Walloon Coal Measures at 900 ms have absorbed and reflected a great deal of the high frequency energy but the primary energy level at these frequencies is still high enough for the dynamite signal to penetrate the coals.

Examining all the bandpass filtered outputs showed some interesting results. At 500 ms the reflected energy has a bandwidth of 20-135 Hz for dynamite and 20-90 Hz for the Vibroseis. Even though the vibrators were sweeping to 105 Hz, little energy above 90 Hz could be seen in the shallow section. The Vibroseis source spectrum is shaped by the near surface geology in conjunction with the sweep frequencies. At the top of the Permian sequence (2000 m, 1400 ms) the dynamite data has a bandwidth of 10-90 Hz while the Vibroseis data has a bandwidth of 10-75 Hz. Interestingly, the signal to noise at the lower end of the spectrum, 10-20 Hz was higher for the dynamite data despite the fact that the raw dynamite spectrum shows attenuation below 30 Hz. The Vibroseis source, being at the surface, generated more ground roll in this frequency bandwidth than the buried shot. Consequently, dynamite data has higher signal to noise and by virtue of its greater bandwidth, will theoretically be capable of resolving thinner beds than a Vibroseis source. As Vibroseis data can be economically recorded at higher fold, it was necessary to produce stack sections to see if greater fold can reduce the bandwidth difference between the Vibroseis and dynamite sources. In a concurrent investigation, Beresford and Taylor (2004) use elastic modelling to show that in the Myall Creek area Vibroseis sources will generate more shear wave energy and Rayleigh waves compared to dynamite sources. This energy particularly contaminates reflected signal at offsets greater than about 1km. This noise contributes to a degradation of the signal to noise ratio unless it can be removed.

## Data Processing

Care was taken with data processing to ensure frequency-limiting algorithms were not used and parameters were selected keeping in mind that we were trying to achieve maximum resolution from both datasets. Extensive testing was run independently on both datasets with parameters selected to be similar on both datasets without compromising the fact that we wanted to get the maximum resolution out of each.

**Processing sequence**

Convert to ProMAX and apply geometry
Calculate statics
Gain recovery
Radial filter to attenuate linear noise
SC 2 window spiking deconvolution
TV spectral whitening 10-140 Hz (both datasets)
1st pass velocity and residual statics
2nd pass velocities and residuals
DMO and additional velocity analysis
Trim statics
Stack
Spectral whitening and noise attenuation
Migration
Time variant filter

Frequency ranges for the final post stack whitening were selected to ensure that no signal was present outside the range of the whitening frequencies used.

## RESULTS

Unfiltered migrated stacks VP 334-384 of line 0S96-105 and SP 160-210 of line MY00-07 were concatenated together. VP 384 was joined to SP 160. Figure 6 is a display of this section along with the FX spectrum. Events on the trace data shows a sharper wavelet on the dynamite section while the FX spectrum taken over the time range displayed, shows the Vibroseis data has little energy above 70 Hz while the dynamite data shows energy up to 85 Hz. Filter panels indicate energy in this range is reflected signal. This result is similar to what we saw on the raw records with discrete bandpass filtering. Note that the spectra of both sources have energy down to 10 Hz. These frequencies are preserved in the dynamite data even though its initial spectrum tapered off below 30 Hz.

The same traces where redisplayed with an FX spectrum (Figure 7) but this time a window centred over the Walloon Coal Measures, that occurs between 800 – 900 ms, was selected. Note at this level the spectra of both the dynamite and Vibroseis data are wider with higher frequencies present.

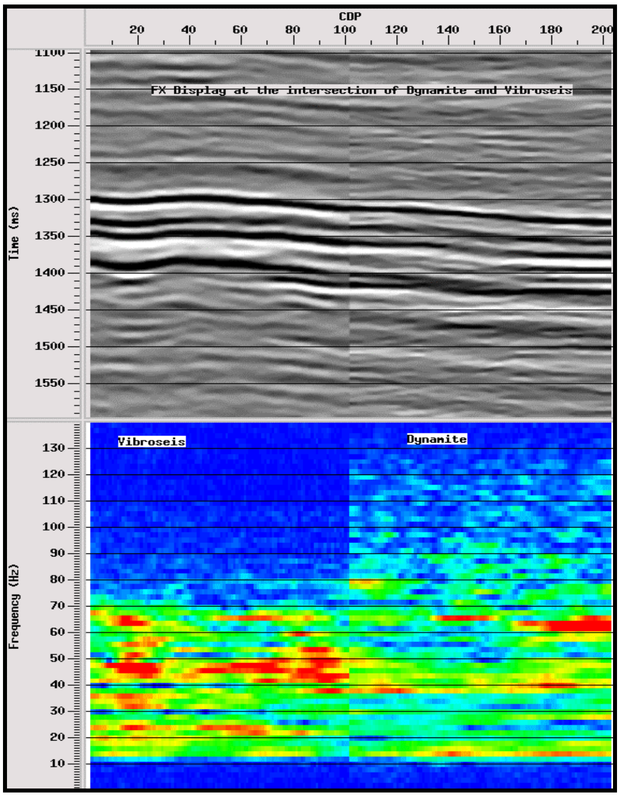


**Fig. 6. Trace and FX display Permian (1100-1600 ms).**

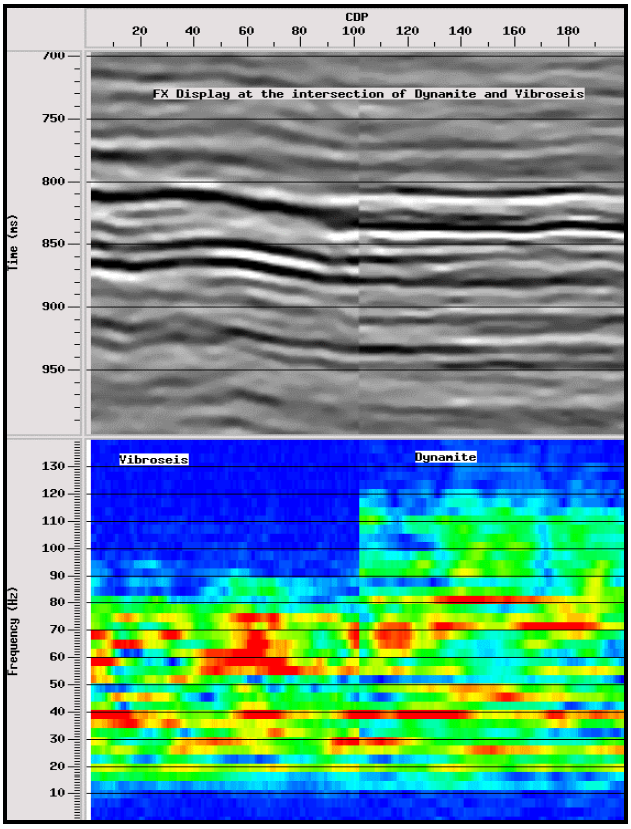


**Fig. 7. Trace and FX display Walloon Coal (700-1000 ms).**

Figure 8 shows spatially equivalent sections from the dynamite and Vibroseis data next to each other for comparison. We have also produced an enlarged comparison, Figure 10 that is placed at the end of the abstract. Four features are pointed out on both sections. At the top end of the spectra, dynamite data ranges up to 120 Hz while the Vibroseis data now extends to 90 Hz. The difference between the maximum frequency of the dynamite data and the Vibroseis data is now 30 Hz, which is greater than the difference of 15 Hz in the deeper section. Hence the frequency spectra of the dynamite and Vibroseis data are converging with depth.

The blue arrow points to a possible seam split where the Wallabella Coal (1400 ms) splits into two distinct seams at the base of the Permian section. It is clearly better defined on the dynamite data. The orange arrow points to a fault that can be tracked up through the section. The fault or series of small faults stand out on the dynamite through the Permian coals while it cannot be seen on the Vibroseis section. The only hint of faulting on the Vibroseis data is a reduction in amplitude. The red arrow shows an increase in the number of reflectors at the base of the Permian coal section on the dynamite data. The green arrow near the base of the Walloon Coal sequence at 900 ms also shows finer stratigraphic detail than can be interpreted from the dynamite section.

Figures 6-8 and 10 clearly show that the section character of dynamite and Vibroseis data match quite closely. Most of the strong reflector sequences are similarly continuous and amplitude variations are roughly compatible throughout the investigated time interval. It is noted that a 180 degree phase rotation of the dynamite data provided an optimum character match.

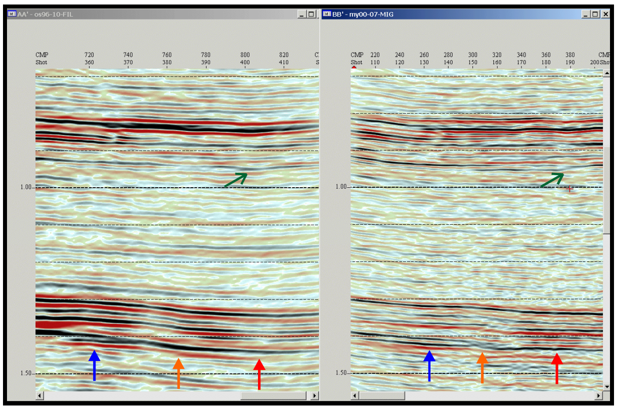

**Fig. 8. Spatial comparison showing differences in resolution of reflections and tectonic elements (see arrows) with the dynamite section on the right.**

### SYNTHETIC MODELLING

The comparison of the two sections demonstrates that the greater bandwidth of the dynamite data has produced a section that appears to resolve a larger number of stratigraphic boundaries. Synthetic seismograms have been generated to help determine whether this result is real or if data processing steps such as spectral whitening have created side lobes of the strong coal reflectors with an apparent increase in resolution.

A synthetic was generated for the Riverside 1 well, which lies 75 m southwest of VP 195 on Vibroseis line OS96-105 (Figure 9). A wavelet from the Vibroseis data was extracted and used for synthetic generation. A wavelet was also extracted from the dynamite data set, which was used to create an additional synthetic trace. Wavelets for the dynamite and Vibroseis synthetics were extracted over a window centred on the Permian section. Real seismic data is displayed on the left hand side of the plots. A third synthetic was generated with an Ormsby wavelet of 20 –100 Hz. This represents an even higher bandwidth scenario than was achieved with the dynamite data.

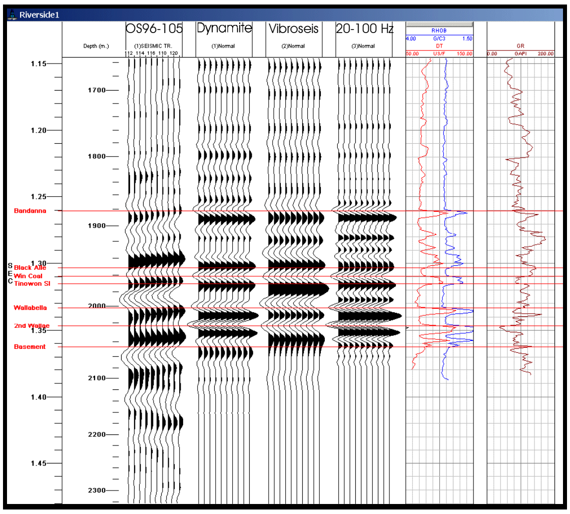


**Fig. 9. Synthetics produced at Riverside 1.**

The synthetics produced at Riverside 1 show the trace produced from the dynamite wavelet have sharper reflectors, particularly at the boundaries of the thicker coal seams. There is an extra peak at the time of the second Wallabella Coal seam showing the dynamite data has resolved this seam split as seen in Figure 8 (blue arrow). The 20-100 Hz synthetic shows even better definition and more legs are present.

The synthetic data supports the fact that the higher frequency dynamite data is bringing out real events related to stratigraphy.

## CONCLUSIONS

Vibroseis and dynamite data selected for this study are modern vintage, overlap and are parallel, thus allowing a valid comparison of seismic source systems. Results obtained in this investigation are area-dependent and have been influenced by source/receiver coupling, depth of target and geologic section.

The evidence provided by field trials indicates that the highly variable layers may have some considerable effect on the transmitted Vibroseis source wavelet. The presence of a consolidated homogeneous layer beneath the weathering appears to be ideal for the transmission of a consistent source wavelet from a small dynamite source. This consistency is crucial for a reliable interpretation of the thin sands in the Tinowon Formation.

Examination of raw shot records gave an initial indication that potential bandwidth of dynamite data was superior to

Vibroseis data. Comparison of stacked data and their associated spectra confirmed the broader frequency characteristics of the dynamite data. Consequently, dynamite is able to better resolve finer stratigraphy, a requirement for exploration of Tinowon sandstones.

A comparison of stacked data demonstrates the general similarity of section character that can arise from dynamite and Vibroseis seismic acquisition.

Finally, there is good correspondence between the dynamite and Vibroseis synthetics and the stacked section data. Synthetic modelling showed that the dynamite source provides a higher resolution trace that is capable of resolving finer geological detail.

The results obtained in this study vindicate the decisions made in the 1980's regarding the selection of explosive source in the Surat Basin. However as acquisition, processing and interpretation technologies evolve, with a consequent improvement in resolution, it will be necessary to continually evaluate and compare seismic sources.

## ACKNOWLEDGEMENTS

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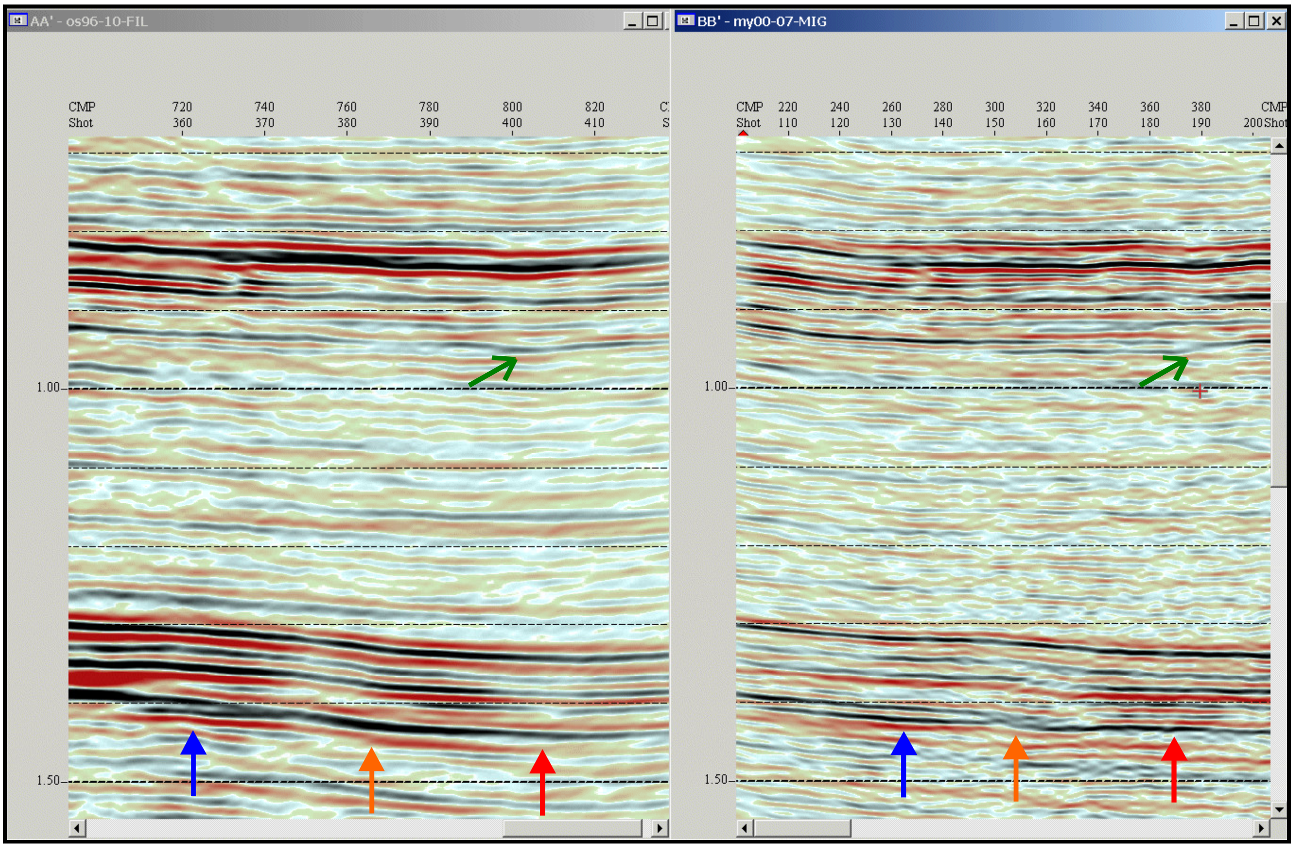


**Fig. 10. Spatial comparison showing differences in resolution of reflections and tectonic elements (see arrows) with the dynamite section on the right. (Enlarged)**