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# Imaging By Multiples: A Case study in the Carnarvon Basin

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## SUMMARY

Vertical Seismic Profiling (VSP) is renowned for its high resolution images of the subsurface. By and large, the images derived are beneath the well. Now a new technique allows imaging above the borehole by utilizing free surface multiples as a secondary source. A number of conditions need to be met for this technique to successfully meet its objectives. This paper presents a case study of data acquired recently in the Carnarvon basin and processed to derive an image above the well. The high-resolution, multiple-free VSP image allows verification of the shallow part of the subsurface. This information can be used to identify drilling hazards, faults and generally improve subsurface interpretation. The result can also be used to overcome the limitations of poor cementing which often causes casing ringing noise, which in itself is detrimental to VSP imaging. Subsequently, the size of the VSP image for this survey was increased by a factor of 2, thus greatly improving the value of acquisition.

**Key words:** VSP, mirror imaging, interferometry

## INTRODUCTION

Vertical Seismic Profiling (VSP) is commonly used for definitive vertical velocity, anisotropy and attenuation measurements as well as high resolution images of the reservoir. Various source receiver combinations allow a multitude of acquisition scenarios that provide specific answers. Nevertheless, commonly the coverage of VSP images is limited to the space beneath the well. In recent years seismic interferometry has been used to increase the subsurface coverage (Schuster, 2001; Yu and Schuster, 2006; Wang *et.al.*, 2010). Despite this, the computational costs for these methods are still high. A simpler, mirror imaging, approach has been developed specifically for VSP configurations (Djikpesse *et.al.*, 2010). This paper presents a case study from Australia where such approach has been applied with additional improvements.

The major advantage of the mirror imaging over the interferometric approach is the absence of the computationally costly crosscorrelograms. To compensate for this, the receivers are re-located in processing from downhole into a mirrored medium above the free-surface (Figure 1). From then onwards any common VSP imaging technique, such as migration or VSP-CDP mapping, will produce an image above the well.

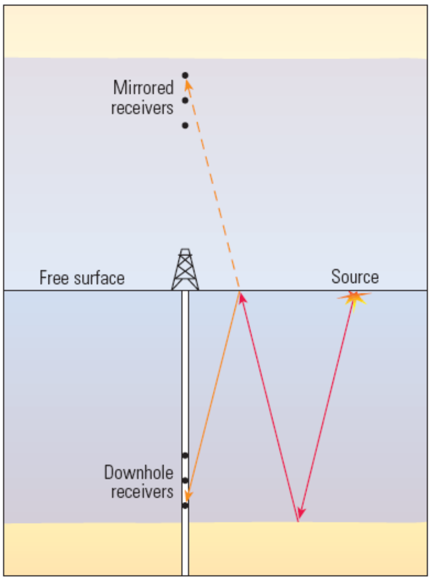


**Figure 1. Velocity model used as basis for VSP mirror imaging**

Here a modification of the processing flow is presented that results in an improvement in the mirror image by way of suppressing the various interbed multiples and imaging only the free-surface multiples.

## METHOD AND RESULTS

Common VSP imaging configurations are Offset, Walkaway, Vertical Incidence and 3D VSPs. The mirror imaging approach is suitable for these configurations (Djikpesse et. al., 2010), and in this study a Vertical Incidence VSP (VIVSP) is acquired in a deviated offshore well (Figure 2).

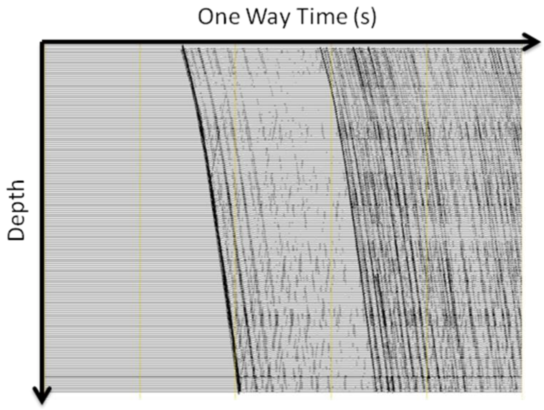


**Figure 2. Vertical Incidence VSP data used for mirror imaging**

VSP dataset comprises downgoing and upgoing wavefields due to both primary and multiply reflected energy (Figure 2). The downgoing and upgoing wavefields can be separated based on their moveouts. The multiples within the VSP wavefield originate from various interbed ray paths as well as free-surface interactions. Mirror imaging approach utilises the presence of free-surface multiples as a virtual source. The major consideration is the clear separation of 1st order interbed, here referred to as peg-leg, multiples and the free-surface multiples. Note that free-surface multiples are also 1st order multiples, where the downgoing generator is the free-surface and the upgoing generator is the seismic event above the well. Due to the shorter path of the peg-leg multiples, they can be considerably stronger in amplitude then the free-surface multiples. As a rule of thumb peg-leg multiples become very weak when the down- and up- going generators are separated by more than 500 ms. Hence the minimum water bottom depth of 380 m is required for mirror imaging to be effective. This criterion is satisfied by the VSP dataset considered here.

The processing workflow for mirror imaging utilises the downgoing component of the VSP wavefield, as opposed to the upgoing component in conventional imaging. For both approaches, the acquired downhole data are stacked, corrected for geometrical spreading and normalised to account for transmission losses. Wavefield separation into downgoing and upgoing wavefields follows. Conventionally deterministic deconvolution operator is designed on the downgoing wavefield and applied to the upgoing, prior to VSP imaging. This results in a multiple free VSP image beneath the well.

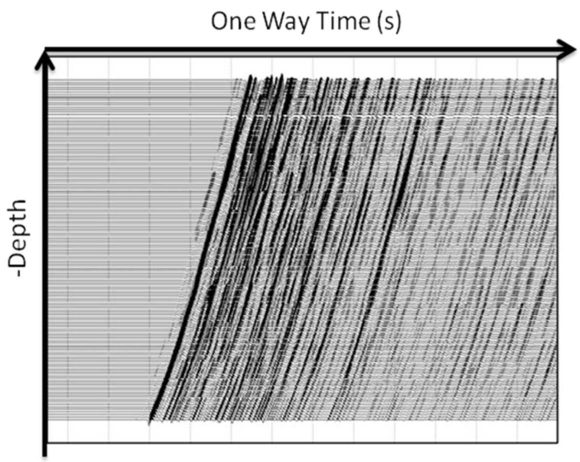


**Figure 3. Basic mirror imaging input comprising free-surface multiples, gun bubble effects as well as 2nd order interbed multiples.**

A common mirror imaging approach uses the downgoing wavefield, muted before the arrival of the first free-surface multiple, as input into a VSP imaging algorithm (Figure 3). The velocity model is mirrored above the free surface, and so are the receivers (Figure 1). At this stage, the polarity of the downgoing wavefield is reversed to match the polarity of the upgoing wavefield. As a result the second order interbed multiples and source signature effects are migrated/mapped together with the free-surface multiples, resulting in a mirror VSP image that contains multiples. The modification applied to the data at hand consists of designing a deterministic deconvolution operator on the downgoing wavefield before the first free-surface multiple arrival time. Hence the interbed multiples generated by the primary wavefield are collapsed into a controlled zero phase wavelet. However, because the operator is designed not to include free-surface multiples, its application to the remainder of the downgoing wavefield collapses the second order multiples, but maintains the free-surface ones. The additional benefit is that the resulting wavefield is zero phase as opposed to minimum phase (Figure 4).

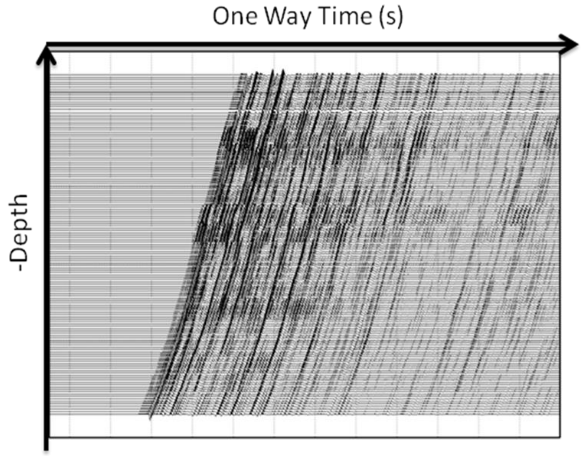


**Figure 3. New mirror imaging input comprising only free-surface multiples.**

At this stage a VSP-CDP mapping is applied to the zero-phased downgoing wavefield resulting in an image above the well (Figure 5). The match between the VSP mirror image and the available surface seismic data through the well is conclusive (Figure 5).

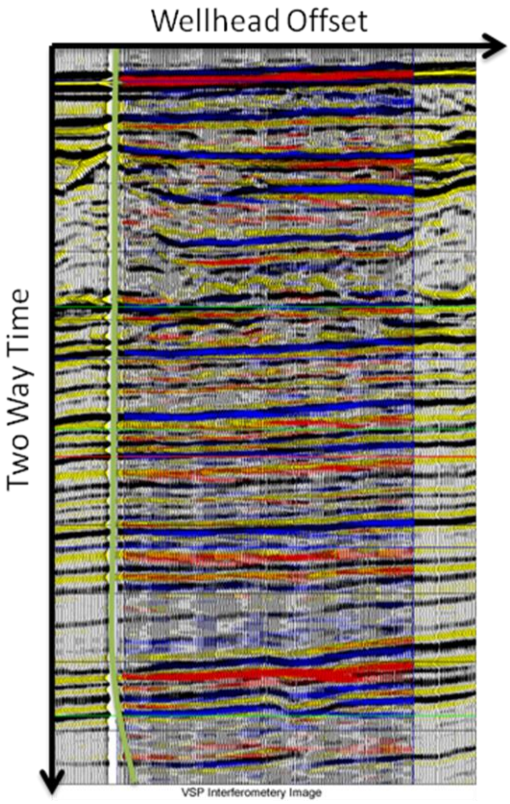


**Figure 5. Surface Seismic and VSP Mirror Image (well path is shown in green)**

## CONCLUSIONS

This paper builds on the common VSP mirror imaging workflow and presents an improved result from a well in Australia. An improved match between the surface seismic and the VSP mirror image is achieved. The extent of the VSP image is doubled. This technique can be applied to any type of imaging VSP, such as Walkaway, Offset, Vertical Incidence or even 3DVSP, given a presence of a strong free-surface multiple (Ruiqing *et.al.*, 2006). The main requirement is a clear separation of 1$^{st}$ order peg-leg multiples and the free-surface multiples. This technique is advantageous in terms of computing power because it utilises common VSP imaging techniques such as VSP-CDP mapping or VSP migration without the need for time-consuming crosscorrelograms. The results can be used to verify shallow imaging, interpretation and hazard identification.

## ACKNOWLEDGMENTS

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