Resolving Structural Uncertainty using DAS VSP Survey in Central Australia

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SUMMARY
Borehole seismic technology provides an efficient way to image the subsurface in high-resolution, through 3D, Walkaway or Offset VSPs. Whilst acquisition time of the conventional VSP survey is less than surface seismic, such VSP surveys can take hours or even days to acquire. With the proliferation of the fibre-optic, Distributed Acoustic Sensing technology, the acquisition time can be slashed to just a few minutes.

The Bauer field in central South Australia is the site of the major borehole seismic survey, comprising Walkaway and Offset VSPs in multiple wells, aimed at reducing structural uncertainty. The Offset VSP data presented in this paper were acquired using Schlumberger’s hDVS service. The processing results show that even at large offsets, DAS technology can be successfully applied to image the subsurface.

Key words: Offset VSP, DAS, hDVS, Imaging.

INTRODUCTION
The common use of Vertical Seismic Profiles (VSP) in the resource industry is measurement of vertical velocity, which is a critical piece of information required for surface seismic depth imaging. A variant of VSP, called Walkaway VSPs, where a source moves, whilst the receivers are fixed at a depth, is often used to measure anisotropy, which is also a parameter input into pre-stack depth migration. Such surveys, along with Offset VSP surveys, where the source is located at a significant offset from the recording wellbore, can also be used for subsurface imaging. This paper presents a recent example of such a survey, acquired with the distributed acoustic sensing (DAS) technique in South Australia’s Cooper Basin.

The DAS system used in this project was incorporated within a standard wireline hepta-cable (Varkey et al., 2008, Frignet and Hartog, 2014) and acquired at several phase-shifted frequencies (Hartog, et al., 2013). As such it is called heterodyne Distributed Vibration Sensing (hDVS). Such configuration allows acquisition of BHS measurement simultaneously with other logging runs, such as pressure measurement on the MDT* modular formation dynamics tester toolstring; downhole coring with the XL-Rock® large-volume rotary sidewall coring service (or similar tool) or conventional VSP measurements. And it is the latter that was deployed in the project area.

The Bauer field in South Australia is an established oil producing area, however its development presents challenges due to the uncertainty associated with surface seismic data. A comprehensive borehole seismic survey, comprising Zero Offset VSPs (ZVSP), Offset VSP (OVSP) and Walkaway VSPs has recently been acquired to reduce the structural uncertainty (Figure 1). The data were acquired using a 4-120 Hz linear vibroseis sweep with a single heavy vibrator provided by Terrex. The focus of this paper is the Rig Source and the Offset VSPs, acquired in the Bauer appraisal well (annotated in by the black rhomb). The choice to acquire data with both hDVS and conventional downhole seismic tools was governed by the requirement for finely sampled shallow imaging which is a forte of the hDVS system and can be acquired at a much faster rate than a conventional tool (Kimura and Galybin, 2017; Kimura et al., 2016). Nevertheless, presence of the conventional sensor was crucial in validating the hDVS response and deriving the image of the subsurface.

* Mark of Schlumberger
The ZVSP data are generally clean, although affected by low frequency noise in the double casing interval above 423 m MD. Data are processed to derive a corridor stack using conventional ZVSP workflows (Hardage, 1991), calibrate the sonic and make a 1D velocity model to perform OVSP imaging with the Offset VSP dataset, which is shown in Figure 3.

This hDVS OVSP dataset is unlike other conventional OVSP data. It took only 10 minutes to acquire, whereas a conventional dataset would have taken approximately 1 hour. This is because of the 800 m logging interval and the number of shots required to acquire the data. Moreover, this OVSP dataset contains compressional upgoing reflections and weak downgoing shear energy, but not the direct compressional energy. Presence of upgoing (vertical) shear is possible, but is not observed in this dataset. This is in line with expectation because DAS technology, of which the hDVS is a subset of, is in general less sensitive at higher incidence angles. In fact, the DAS sensitivity has been shown (Mateeva et al., 2014) to drop off as a function of \( \cos^2(\theta) \), where \( \theta \) is the incidence angle of the direct arriving energy. At 1.774 km offset the incidence angle at the base of the hDVS OVSP is estimated by ray-tracing through a 1D model to be 70°, and it is even higher at shallower levels. Nevertheless, the average incidence angle of the reflected energy at receiver from the target horizon is 38°, and therefore the reflections can still be seen in the data. Coincidently, there is a significant benefit in processing as the absence of direct compressional wavefield makes wavefield separation easier, as moveout-based methods such as velocity filters (Hardage, 1991) can be used to enhance upgoing compressional wavefields.

To validate this approach, theoretical direct transit time is computed, using the 1D model from the ZVSP and the times are shown in green in Figure 3. Several reflections are also ray-traced and can be seen to match the observed data (shown in black in Figure 3). Hence the model-based separation approach is applicable to this dataset. It is important to note that the model is 1D isotropic and appears to fit the data. In presence of dip, strong anisotropy or both, the fit of the theoretical times may...
not be as good and a calibration for anisotropy or 2D structure may be required.

The short conventional OVSP dataset has also been acquired and processed using the parametric wavefield separation technique (Leaney, 1990). The data have been merged with the hDVS data after deconvolution and are shown in Figure 4.

![Figure 4. Merged 1.7 km Offset VSP: Conventional and hDVS data](image)

There is a remarkable match between the character of the hDVS events above 811 m MD with the conventional OVSP data below 811 m MD. The transit times also match, validating the 1D model that is built for this wellbore. The offset VSP model used for wavefield separation is then used to migrate the VSP data. The result, covering 900 m laterally, is shown in Figure 5.

![Figure 5. Migrated hDVS and Conventional OVSP data (wiggle traces every 25 m), overlayed on top of the 3D surface seismic (background colour), with 40 Hz zero phase Ricker synthetic and GR at the well](image)

The match between the OVSP and 3D surface seismic datasets is excellent. The major reflectors are present in the OVSP data and confirm the imaging observed in the 3D surface seismic. Some differences do exist and these will be the foci of further investigations. This is a promising result given that the OVSP image is a single fold dataset. The Walkaway VSP data are likely to further enhance the subsurface imaging.

**CONCLUSIONS**

The combination of DAS and conventional downhole tools is highly advantageous for subsurface imaging. The DAS data offer unprecedented wellbore coverage and lightning fast speed of acquisition, whilst the conventional tools allow the processor to be guided by high quality data and validate the observed events in DAS data. The ultimate result is an accurate subsurface image, at a fraction of the acquisition cost.

**ACKNOWLEDGEMENTS**

The authors would like to thank Beach Energy Ltd for allowing publication of this work. We would like to thank the Schlumberger wireline crew on site and in Wireline HQ for the acquisition efforts and support. We also like to extend a thank you to the Terrex team for proving the vibroseis source and excellent integration in this project.
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