Walkaway VSP – Going beyond imaging

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SUMMARY

Simultaneous AVO inversion of seismic data is an integral part of oil and gas exploration. Traditionally this technique is applied to surface seismic data, relying on availability of various angle stacks as well as on presence of offset wells for low frequency models. This paper investigates how a Walkaway Vertical Seismic Profile (WVSP) can be utilized for localized AVO inversion. Traditionally WVSP are designed for one of the following three purposes: imaging, anisotropy and AVO/AVA analysis. This paper shows a set of conditions that allow for WVSP data to be inverted following a commonly utilized simultaneous seismic inversion technique. The advantage of performing a localized WVSP AVO inversion is that low frequency models are measured during WVSP acquisition. This significantly reduces the ambiguity of the background models for inversion. Another advantage is that the inversion input derived during WVSP migration comes from measured vertical velocities, thus allowing more accurate angle stacks, thus improving the quality of the inversion. Lastly, WVSP images are generally of higher frequency content, thus producing high frequency density, Acoustic Impedance and VpVs images in the vicinity of the wellbore. The results can assist in calibrating the surface seismic inversion once more well data are available as well as making quick drilling decisions for deepening or side tracking wells.

Key words: Walkaway, VSP AVO inversion, density.

INTRODUCTION

Simultaneous AVO inversion is commonly used to delineate acoustic impedance, P/S ratio and density during the exploration stage of the oil and gas field life cycle (Cooke and Schneider, 1983; Ma, 2001; Ma 2002). This technique is applied to the surface seismic data to help identify and classify potential reservoirs. AVO inversion of Vertical Seismic Profile (VSP) data has also been attempted (Bubshait, 2010), but relies heavily on presence of good shear data. This paper discusses the conditions required for AVO inversion of VSP data that do not rely on availability of converted shear energy.

VSP data are commonly acquired for high resolution images of the reservoir, vertical velocity, anisotropy, attenuation and AVO/AVA analyses (Hardage, 1983; Dillon and Thomson, 1984; Campbel, et al., 2005). There are a number of differing source-receiver configurations, but only Walkaway and Offset VSPs can be used for both imaging and AVO studies (Figure 1). Offset VSP (OVSP) is characterised by a single source location and receivers placed in the well from TD to loss of signal near the surface. A Walkaway VSP (WVSP) is characterised by a single tool setting within the well (tool should have multiple receivers) and varying source locations, usually at regular intervals, on the surface. Note that 3DVSPs can also be used for such studies, but will be considered as a generalisation of a Walkaway VSP in this paper.

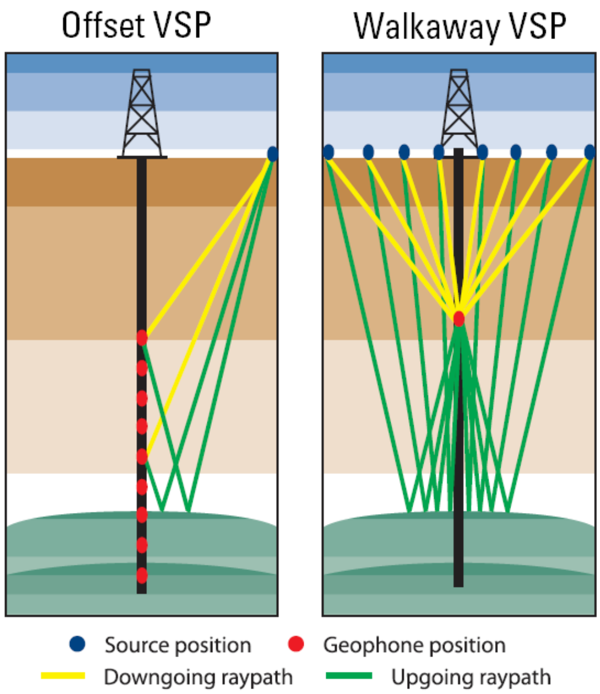

Figure 1. VSP surveys for Imaging. (After Campbel, et al., 2005)

It is also widely recognised that Offset VSP images may suffer from presence of multiples, whilst the WVSPs rely on data redundancy to overcome this problem. On the other hand WVSP acquired for imaging purposes are commonly acquired with a short tool-string (8-12 shuttles) fixed at one location, well above the target zone, in the well, resulting in limited high angle coverage near the wellbore. Conversely, a WVSP for AVO analysis is located just above the target zone, providing a wide range of angles, but no significant lateral coverage of the target.

The natural extension of the above-mentioned survey configurations is a WVSP with a large number of receivers. Currently the maximum number of VSP tools in one tool string varies from 40 to 100, making such large scale surveys possible.

METHOD AND RESULTS

To efficiently acquire a WVSP, and by extension a 3DVSP, survey, the location of the receivers in the well and the maximum source offsets need to be known. However due to the varying subsurface nature, it is impractical to derive a single relationship between these quantities. Pre-survey modeling consisting of ray-trace modeling and synthetics is essential for any WVSP survey. In this paper, a 1D model comprising varying compressional and shear velocities and density has been used as an example (Figure 2). A 160 level WVSP survey (corresponding to four passes of a single 40 level tool) is simulated with sources, every 25 along a 6 km line going through the well.

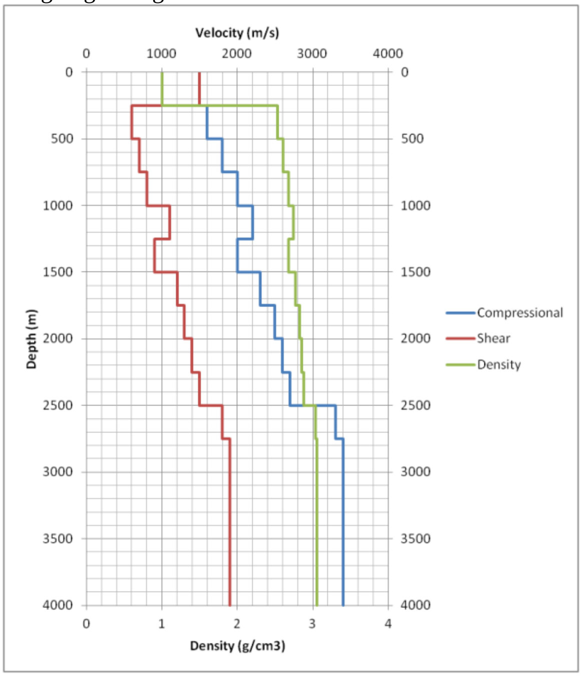

Figure 2. 1D Isotropic model for Ray trace modeling and finite difference synthetics.

The first step of modeling is to investigate the ray coverage achieved by such a survey. The bottom most layer (Figure 2) is chosen as the target. The results can be displayed as a plot of source offset, reflection point offset and receiver depth as well as being split by various angle ranges. However due to presence of refractions, as a rule of thumb once the offset exceeds 150% of the depth, then the data become un-processable. Moreover, once the distance between the target and the receiver becomes too large, the resolving power of VSP drops. Hence the results of ray tracing were also filtered to include these conditions, here maximum receiver-target separation 1500 m (Figure 3).

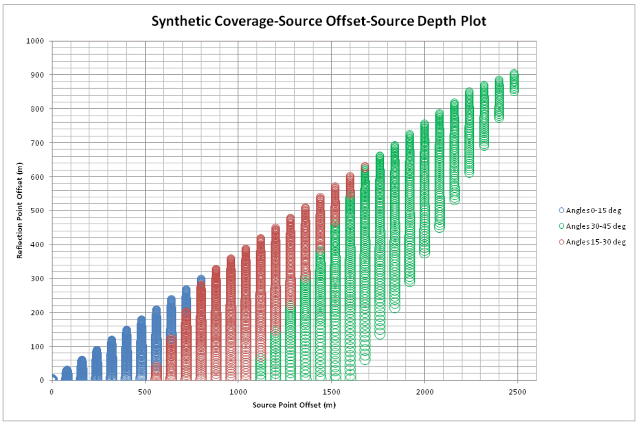

Figure 3. Ray tracing results: source offset v image point offset. The size of the circles corresponds to the depth and colours correspond to angle bands.

Figure 3 shows that such WVSP configuration will produce angle coverage of 0-45 of up to 300 m away from the well. Hence 3 angle stacks, 0-15, 15-30 and 30-45 degrees can be formed for AVO inversion. A finite difference WVSP synthetic was generated for this survey. The conditions mentioned above were also used to limit the WVSP data in processing. The main steps of processing included wavefield separation and enhancement by means of two orthogonal velocity filters and deterministic deconvolution to collapse the interbed multiples. The resulting data were then migrated using a GRT algorithm with limits placed on angles of incidence of: 0-15, 15-30 and 30-45. The resultant stack volumes are shown in Figure 4.

Once the three volumes were derived, wavelets for each individual volume were extracted, compared to the stack angle volumes (Figure 4a-c) and simultaneous AVO inversion in ISIS© (as part of a Petrel plug-in) followed. The results are shown in Figure 5. For more information on ISIS see Barclay et al., 2008.

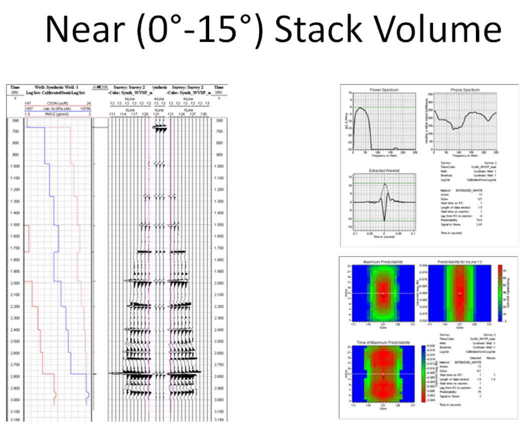

Figure 4a. Wavelet extraction for near stack data

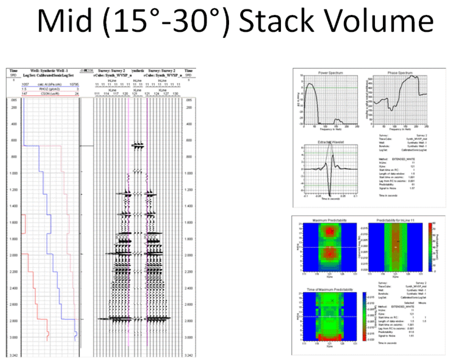

Figure 4b. Wavelet extraction for mid stack data

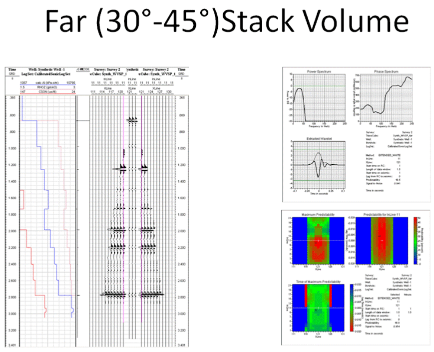

Figure 4c. Wavelet extraction for far stack data

The inversion parameters were optimised for a sparse inversion, so the minimum reflectivity was set to 0.0015. Note that in real life, this reflectivity value should be considerably less. The low frequency model (LFM) was derived by converting the depth model (Figure 2) to TWT and filtering it to 0-5 Hz.

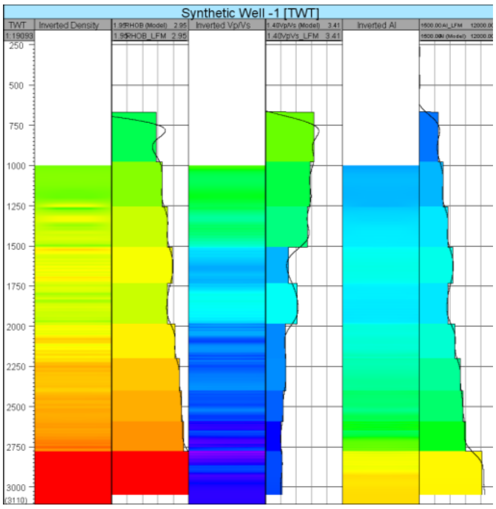

Figure 5. Inversion QC at the well location: The input model, the LFM and the inverted result.

The initial model, comprising Vp, Vs and Density has been recovered by the inversion. This shows that theoretically, it is possible to derive such parameters as Vp/Vs, Acoustic Impedance and Density away from the well for up to 300 m.

CONCLUSIONS

Simultaneous AVO inversion of Walkaway VSP data can be performed to significantly extend the suite of petrophysical data laterally away from the well. Major recommendations for acquisition of WVSP data suitable for AVO inversion are summarised below:

- VSP logging interval (array length) needs to be maximised from TD to near surface
- Source offsets are adequate to achieve the required angle coverage (150 % of target depth)
- Ray trace modeling is performed to investigate ray coverage
- Finite difference synthetics are generated to understand various wave modes within the data

Given that these recommendations are met, it is likely that AVO inversion results can be obtained. Moreover, if these conditions are met for a 3DVSP survey, the AVO inversion would derive 3D property volumes around the wellbore, thus greatly enhancing the knowledge of the reservoir.

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