Offset VSP in a deviated well to get converted shear waves

Emanuel Fonseca da Costa, Rildo Marcio Oliveira, Daniel Escobar Steagall and Nier Maciel Ribeiro PETROBRAS S/A; Eduardo L. Corti(*) CONSULTANT & Fac. de Cs. Astr. y Geofísicas UNLP- Argentina, and Martín Foster(*) REPSOL-YPF, Argentina. (*) formerly SCHLUMBERGER-DCS/LAS

This paper was prepared for presentation at the 9th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

This paper presents a case history in which the main objective of the borehole seismic survey was to obtain information about converted shear waves, in order to support the evaluation of feasibility for an OBC project in a Tertiary reservoir, Offshore Brazil. The Offset VSP has shown a large degree of P to S conversion, at different layers. The well trajectory in combination with the source position allowed to get Shear velocities, and also to generate P and S images that provided an additional tool to evaluate the degree of P to S conversion.

Introduction

Borehole seismic surveys have an important role in the evaluation and design of advanced applications of surface seismic like the use of converted S waves.

In order to evaluate an OBC project, an Offset VSP survey was run in a deviated well, The well trajectory can be seen in Figures 1 and 2, with maximum inclination of 50.22 deg (Figure 1) and a TD horizontal offset from the wellhead of 1461m to the Northwest (Figure 2).

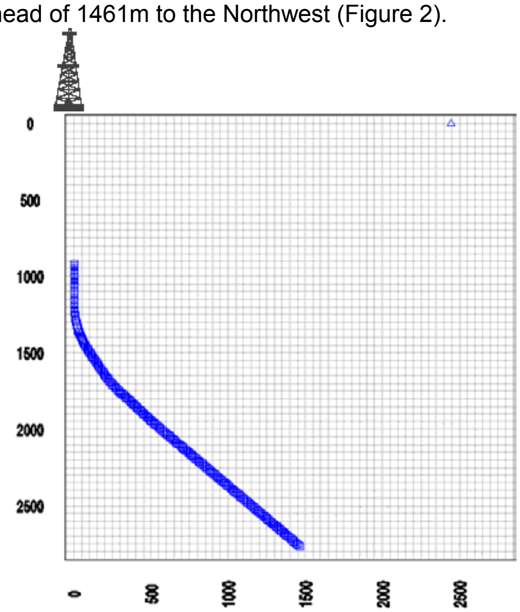

Figure 1 – Vertical section along the well trajectory.

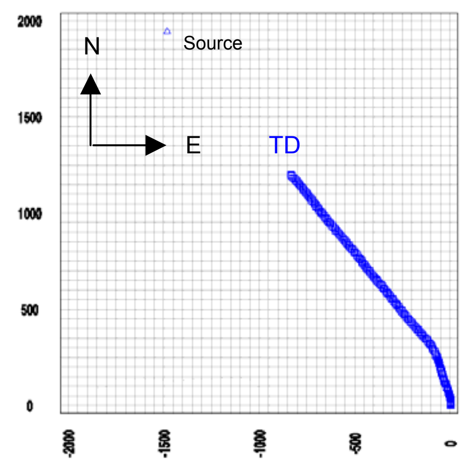

Figure 2- Map View along the well trajectory.

The level interval was selected to satisfy the Shear Wave processing, giving an optimum spacing of 12.5m. The source offset was also selected giving priority to shear wave conversion: preliminary modeling was important to define the final source position controlling the refraction paths.

The dataset has shown a large P to S conversion, showing converted downgoing and upgoing S-wave trains in the deeper survey interval, optimum to generate both P and S images.

Acquisition

The acquisition parameters were defined after simulating the survey with a 2D velocity model. This model was constructed from layers defined on a depth converted seismic line, obtained along the well direction from a 3D survey, and velocities taken from previous velocity surveys run in the field.

Many alternatives were modeled, like Offset VSP, Rig-source VSP and Walk-above VSP.

Due to technical objectives, equipment availability and budget conditions, it was decided to run an Offset VSP (Figure 3) which accomplished the objectives.

The source was an air-gun-array consisting of two GI-airguns of 250c.i. each one, controlled by the Macha TGS8 shooting system.

The tool was a CSI-B, equipped with 3 accelerometers which operate decoupled from the tool body, without gimbal system. Thus, the Z component is always parallel to the tool´s axis, the X is normal to the Z and aligned with the tool´s arm direction and the Y is normal to Z and X.

The acquisition parameters for the airgun and tool positions were defined as follows:

Airgun and hydrophone positions	
Airgun altitude (m)	-5 m
Airgun offset (m)	2443.2m
Airgun azimuth (degrees)	322.6 deg
Hydrophone altitude (m)	-8 m

Tool positions (measured depth)	
Interval between levels	12.5 m
From (MSL)	3421 m
To (MSL)	922 m
Number of levels	199

On one hand, the ray tracing modeling showed that refractions of the direct arrival should be expected in the interval between 1050m to 1500m depth (Figure 3)

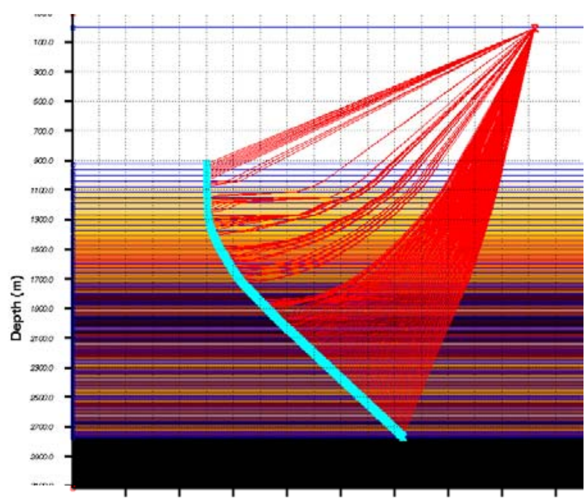

Figure 3.- Offset VSP ray tracing modeling using the selected parameters

On the other hand, it allows us to predict the lateral extension of the image simulating the reflected paths for P to S conversion and P to P wavefields. The reflection points are different for the reflected P wave and the converted S wave. The image extension is larger for the PS converted waves (Figure 4) than for the PP waves (Figure 5).

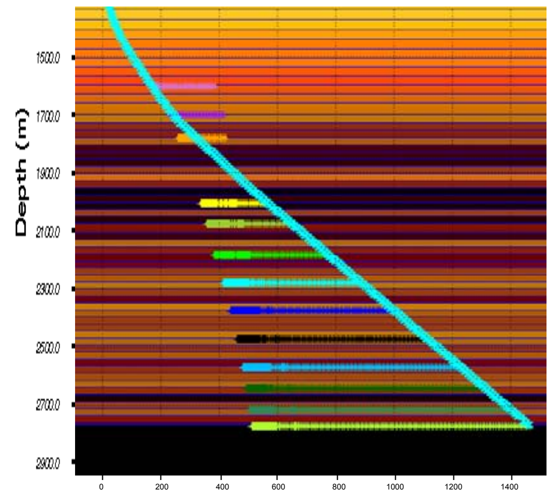

Figure 4.- Reflection points for P to S conversion

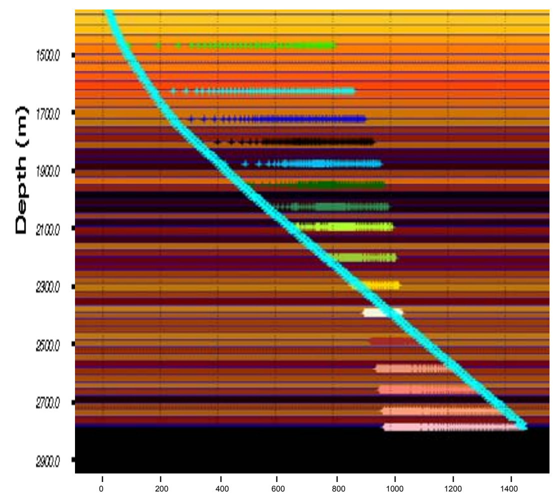

Figure 5.- Reflection points for P waves

Data

Data show good quality, containing a complex wavefield, as can be seen in the Z component of the CSI tool (Figure 6). We can observe: (i) the effect of the acquisition geometry showing larger arrival times for shallower levels with the refractions, (ii) the downgoing multiple generated on sea bottom, (iii) the converted P to S downgoing waves at intermediate levels and (iv) the reflected upgoing P and S-waves.

Processing

The first step was to adjust the model velocities to the measured transit times. Vp and Vs velocities were inverted from the transit times measured from the Offset VSP (Aminzadeh and Mendel, 1985). Once the model had been adjusted, it was used to perform a preliminary data analysis, to calibrate the sonic log, to perform the wavefield separation and GRT migration.

This adjusted model has helped us to confirm the interpretation of the complex wavefield described in Figure 6.

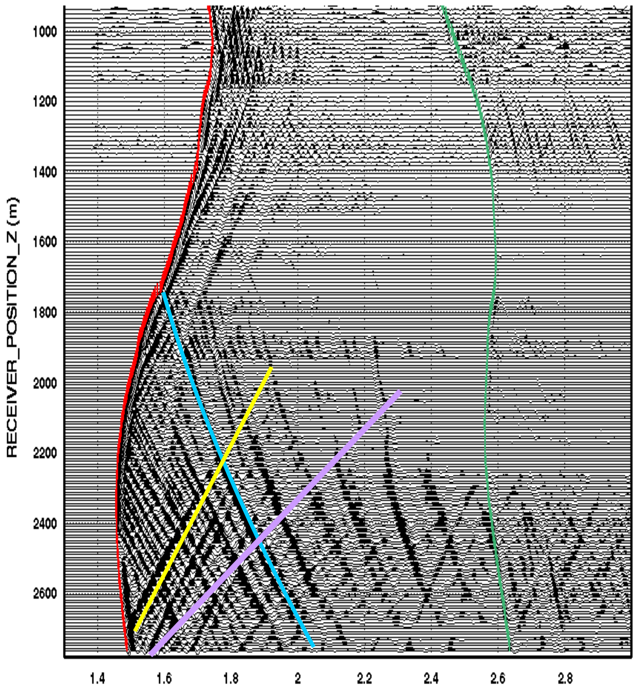

Figure 6.- Model response compared with the observed data: P first arrival (red), downgoinig P sea bottom multiple (green), converted downgoing S (blue), upgoing P (yellow) and S (violet).

In order to perform a good time matching with surface seismic, a walk-above VSP was simulated to compute vertical transit times for calibrating the verticalized sonic.
The interval with refractions was not used for the GRT migration.
The three components (Z,X,Y) were rotated to get two components contained in the Incidence plane (Z parallel to the well trajectory, and HMX normal to it) and one normal to the plane of incidence (HMN). Then, P and SV waves will be found in Z and HMX components (Figures 7a and 7b, and 8a and 8b, respectively) while the SH component will only be present in the HMN component (Figure 8c).

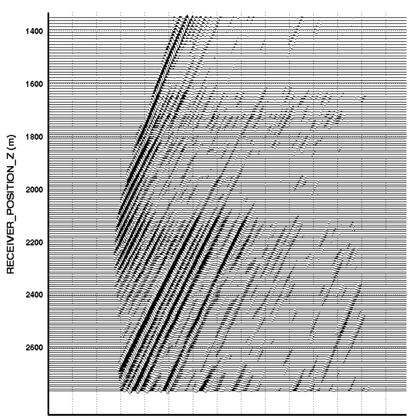

Figure 7 a.- P-wave from Z component

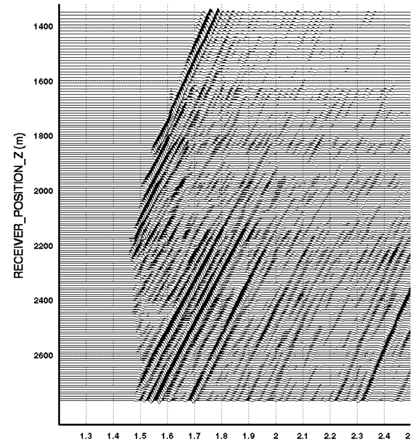

Figure 7 b.- P-wave from HMX component

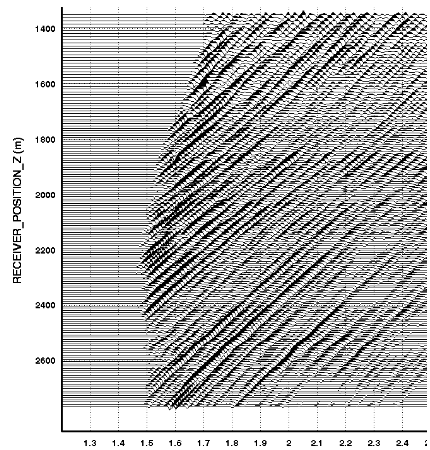

Figure 8 a.- SV-wave from Z component

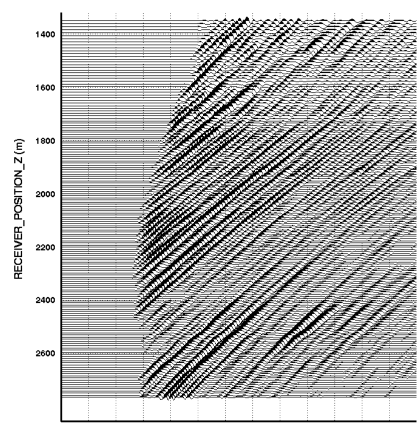

Figure 8 b.- SV-wave from HMX component

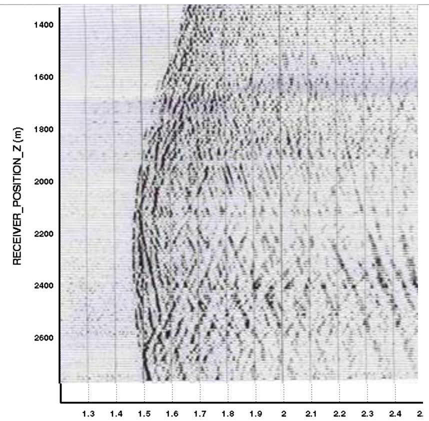

Figure 8 c.- SH-wave from HMN component

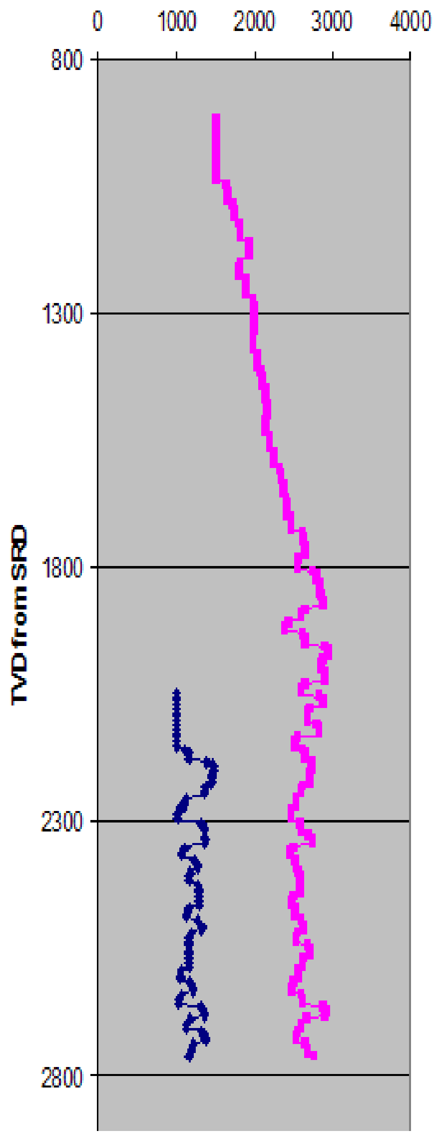

Figure 9.- Interval Vp and Vs velocities

Results

a- Vp/Vs relation

The separation of downgoing P and S-waves with high signal to noise ratio allowed us to obtain reliable interval velocities Vp and Vs (Figure 9), and to compute the Vp/Vs relation along the common interval (Figure 10).

The actual Vp/Vs relation is a fundamental input on the CCP (Common Conversion Point) definition of converted reflections on the OBC survey (Leaney et al., 2001; Giroldi et al., 2002).

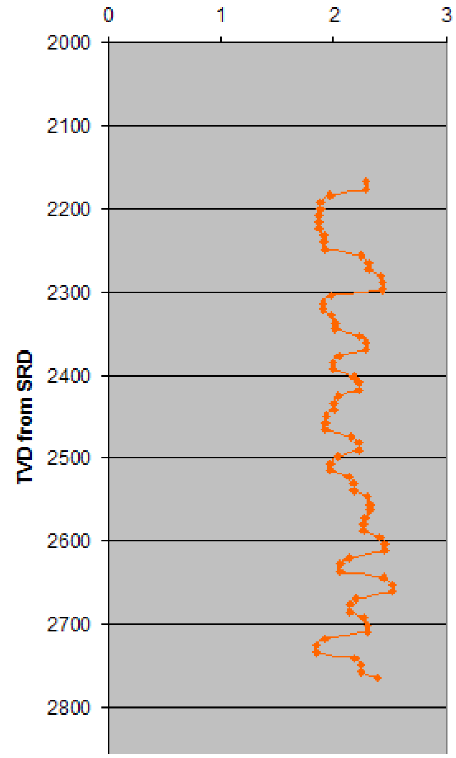

Figure 10.- Vp/Vs relation

b.- Migration

The GRT time migration was performed on the reflected P-wave and SV-wave. The HMN component was discarded provided that the SH-wave presents low S/N ratio.

The velocity model was used for the computation, after adjusting its Vp and Vs velocities with the transit times observed in the Offset VSP (Esmersoy, 1990) Both images (P and SV GRT migrations) were generated with same vertical scales corresponding to Vp (P-wave TWT), in order to be comparable (Figure 11).

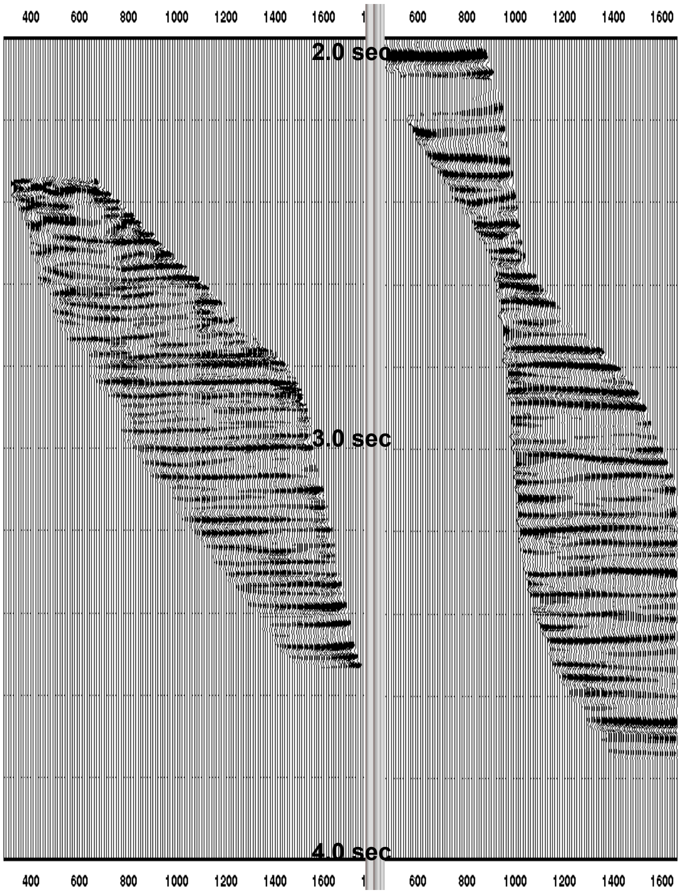

Figure 11.- SV and P migration in PP time scale

Conclusions

The survey has provided more information than expected:

Firstly, we got an actual seismic Vp/ Vs relation.

Secondly, it was possible to identify different layers as generators of Z converted S waves.

Thirdly, the high degree of P to S conversion was verified with the separation of S wavefields which allowed us to generate a high quality PS Offset VSP image.

These results confirm that the area is a good candidate for the use of converted waves on surface seismic. They are also a good example of a specific application of BHS that supports early stages of a Surface Seismic project, like the survey evaluation and design, and allows a well driven processing.

Acknowledgments

The authors would like to thank PETROBRAS for the authorization to present this case history, and for their support in preparing this paper.

We also want to thank Oscar Montenegro (Schlumberger-DCS Argentina) for his cooperation during the processing.

References

Aminzadeh, F. and Mendel J. M.,.1985, Synthetic Vertical Seismic Profile for non-normal incidence plane waves. Geophysics, Vol 50, N1, p 127-141

Esmersoy, C., 1990, Inversion of P and SV waves from multicomponent offset vertical seismic profiles. Geophysics, Vol 55, N1, p 39-50

Giroldi, L., Oviedo, E., Corti, E., Moyano, B., Gaiser, J. and Omana, J., 2002, Well Driven seismic: the role of the VSP on a 3C-3D seismic survey in Co. Dragón (Golfo San Jorge, Argentina). 5th Hydrocarbon E&D Congress, Mar del Plata, Argentina. Abstracts.

Leaney, S., Bale, R., Wheeler, M. and Tcherkashnev, S., 2001, Borehole-integrated anisotropic processing of converted modes, TLE, Vol 20, p 996-1020