Converted wave prestack depth migration from topography: a comparison

Saul E. Guevara *, and Gary Margrave
seguevar@ucalgary.ca

SUMMARY

- Pre-stack depth migration was applied to PP and PS waves of a synthetic dataset, obtained using 2D elastic finite difference modeling with a geological model having structural features and topography. Two methods of migration, Kirchhoff and PSPI were applied directly from the topography. Correct depths were obtained however with different character in the images, which can be related to the migration algorithm and to the wave mode used. Also, statics correction to a horizontal datum followed by migration was compared with migration directly from topography, which showed that the statics significantly degrades the images.

INTRODUCTION

Converted-waves (C-waves) have potential for lithological information, even in complex areas. However the processing methods have limitations., specially if they are in the time domain. On the other hand, methods of migration in depth , although challenging, show attractive processing and interpretation characteristics for complex areas.
It is convenient to investigate on algorithms to handle characteristics such as topography , geological structure and horizontal variation of rock properties . In this work a comparison of two methods, based on the Kirchhoff and Pspi principles, are tested for PP and C-wave, using synthetic data on a geological model of a complex geology with topography. Comparison with statics correction was also carried out.
Promising results were observed, and future investigation on amplitudes, resolution and imaging appears relevant.

THEORY

There were applied algorithms based in two robust migration methods Kirchhoff and Phase Shift plus Interpolation (PSPI) using shot-profiles. A brief explanation about the methods follows.

Kirchhoff method

The Kirchhoff method is based in a high frequency approximation to the wave equation.
According to Biondi (2006), the Kirchhoff method of prestack migration in 2D can be represented as follows:

$$I(x_\varepsilon, z_\varepsilon) = \int_\delta W(x_\varepsilon, z_\varepsilon, m, h)\psi[t = t_\psi(x_\varepsilon, z_\varepsilon, m, h), m, h]\, dm\, dh \quad (1)$$

where $I(x_\varepsilon, z_\varepsilon)$ ≡ the migrated image, x_ε , z_ε ≡ coordinates of the image point, $\psi[t, m, h]$ ≡ the input wavefield (which is a data gather that can be in the midpoint (m) offset (h) domain), $W(x_\varepsilon, z_\varepsilon, m, h)$ a weight factor, and δ represents the migration aperture.
t_ψ is the total time delay accumulated by the wave while propagating from the source to the image point and back to the receiver. An eikonal calculator, coded at CREWES, was used in this work.
For C-waves P-wave velocity is used from source to image point and S-wave from receiver to image point.

PSPI

The PSPI (Phase Shift plus Interpolation) method, (Gazdag and Sguazzero, 1984), is based on the representation of wave propagation in the Fourier domain, taking advantage of the phase shift property of the Fourier transform, which allows the extrapolation of the wavefield in depth *z*, such that:

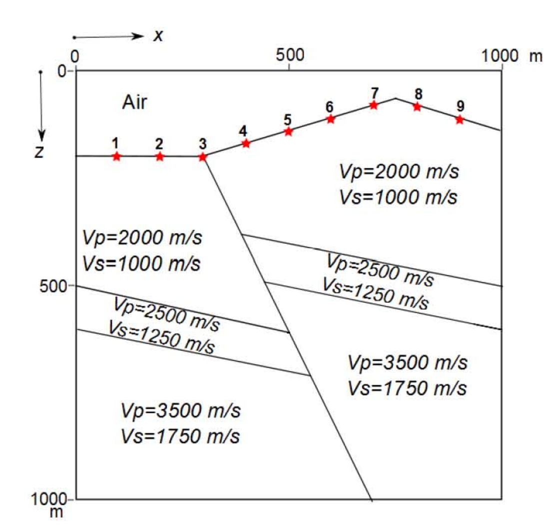
$$\varphi(k_x, f, z_0 + \Delta z) = \varphi(k_x, f, z_0)e^{2\pi ik}$$

where $\varphi(k_x, f, z_0)$ is the Fourier Transform in time and horizontal space (*x*-space) of the seismic record $\psi[t, x, z]$.

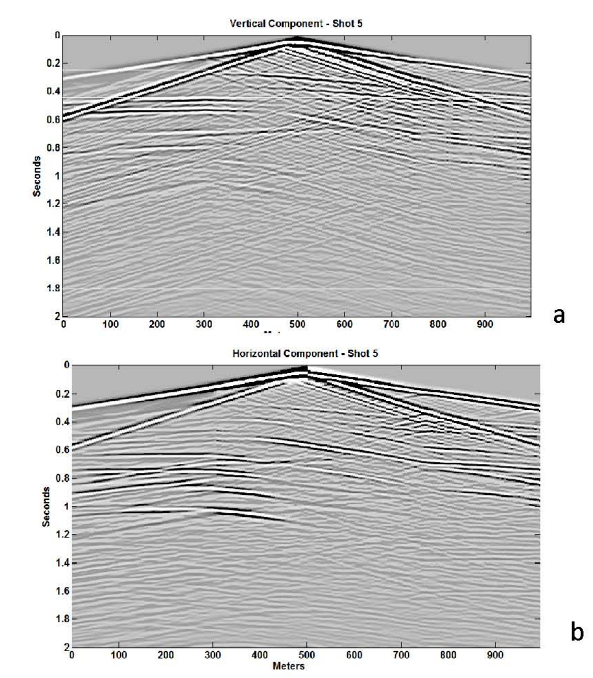
However the Fourier transformed data in the horizontal space domain prevents for property variations in this direction. Margrave and Ferguson, (1999) developed a method to address this issue using non-stationary phase shift. It allows variations in the horizontal direction such as velocity and topography. The PSPI code used here is described in Ferguson and Margrave (2005) and implemented in the MATLAB codes pspi_shot and pspi_cwave. These codes were applied to topography as described Al-Saleh et al. (2009). This theory is applied in this work.

DATA GENERATION: MODELING

Finite difference (FD) was the method used to generate the synthetic data. An FD code 2D, elastic and isotropic, was used. It uses a staggered grid scheme, second order in time and fourth order in space, and allows implementing an irregular surface.



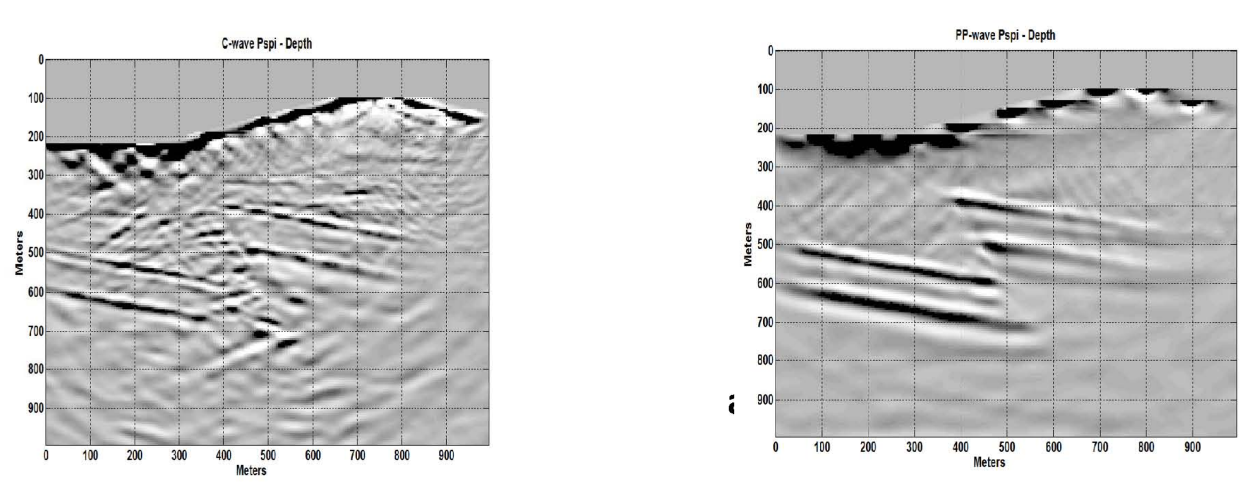
Geological Model. The left and right hand sides are separated by an inverse fault. The surface shows a hill with 135 m high. The shot points are indicated by stars on the surface and identified with numbers. The target is the dipping layer with Vp 2500 m/s separated by the inverse fault.



Shot gather resulting from modeling corresponding to the shot location number 5. a) Vertical component and b). Horizontal component It can be observed strong energy in the first linear events. The Horizontal component shows later events compared to the vertical. These events most probably correspond to S-waves. Many events can also be observed simultaneously in both components.

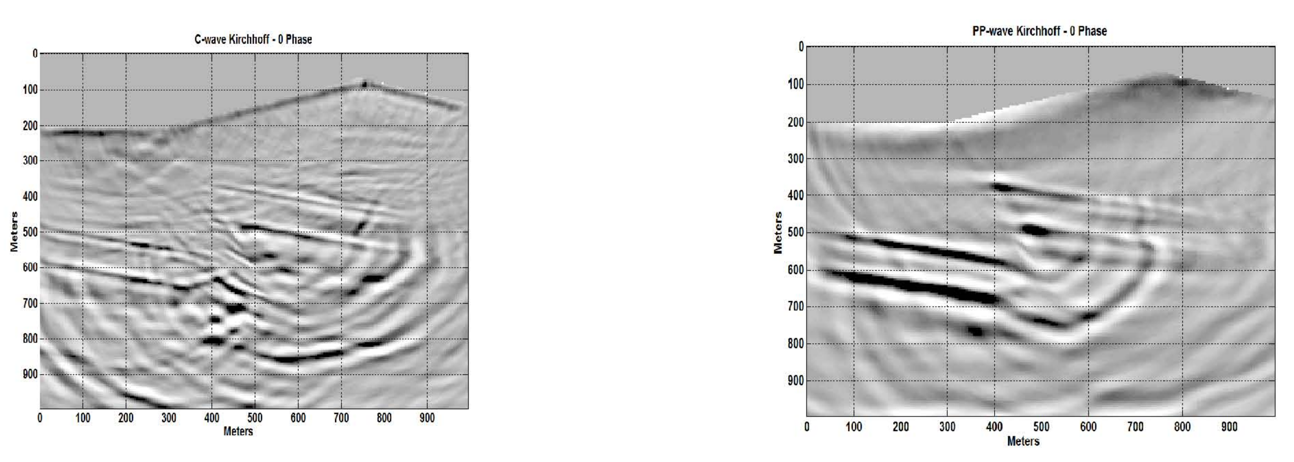
MIGRATION RESULT: PSPI

The migration methods are applied to the data resulting of modeling, assuming that the vertical component corresponds to P-waves and the horizontal component to C-waves.



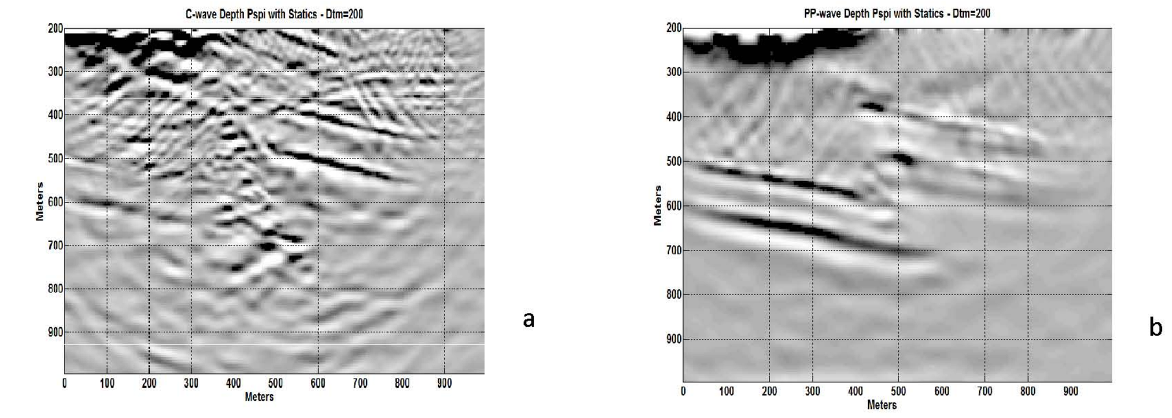
Depth PSPI migration results (a) C-wave (b) P-wave. The top of the target at the distance of 600 m, is close to 420 m as expected according to the geological model. The geometry corresponds to the geologic model.

KIRCHHOFF RESULT



Kirchhoff migration (a) C-wave. (b) P-wave. Notice the artifacts for later times.

MIGRATION PSPI WITH STATICS CORRECTION



Migration stack after conventional statics application. (a) C-wave. (b) P-wave. Notice the strong noise, specially for the C-wave. The depth has also error, as can be noticed by the top of the target at x=600, whose depth should be 420 m.

DISCUSSION AND CONCLUSIONS

•Real data are affected for factors not considered here, such as attenuation, noise and heterogeneity, however this experiment illustrates the application of these technologies to complex areas.
•Although no any filtering or noise attenuation, neither wave mode separation, were applied, both migration methods were applied successfully for P- and C-waves. Both depth migration methods from the topography gave correct reflector depths.
•Both wave modes show the same structure, however with difference in the amplitudes and other attributes.
•Amplitude differences can arise because of the differing PP and PS reflection coefficients and potentially allow an elastic inversion.
•C-wave looks noisier and its resolution is higher.
•The Kirchhoff migration has generated more artifacts at later time.
•Statics causes a systematic error in the depth location for depth migration with rough surface. It could also affect the velocity analysis in real data.

ACKNOWLEDGEMENTS

We thank Ecopetrol SA, who allowed the use of the modeling software for the data generation and we also thank the CREWES sponsors for their support.

REFERENCES

•Biondi, B., 2006, 3D seismic imaging: SEG Investigations in Geophysics No. 14.
•Ferguson, R. J., and Margrave, G. F., 2005, Planned seismic imaging using explicit one-way operators: Geophysics, Vol. 70, No. 5, pp S101-S109.
•Gazdag and Sguazzero, 1984, Migration of seismic data by phase shift plus interpolation: Geophysics, 49, 124-131
•Margrave, G. F., and Ferguson, R. J., 1999, Wavefield extrapolation by non-stationary phase shift: Geophysics 6, 1067-1078.
•Al-Saleh, S. M., Margrave, G. F., and Gray, S. H., 2009, Direct downward continuation from topography using explicit wavefield extrapolation: Geophysics, Vol. 74, No. 6, pp S105-S112.
•Schneider W. A., 1978, Integral formulation for migration in two and three dimensions: Geophysics, 43, 49-76.