EAGE ANNUAL 2018
80TH CONFERENCE + EXHIBITION
COPENHAGEN | DENMARK

Th P7 02

A Method to Suppress Salt-related Converted Wave Using 3D Acoustic Modelling

J. Kumar* (Petroleum Geo-Services), M. Salem (ENI E&P), D.E. Cegani (ENI E&P)

Summary

Converted waves can be recorded in a marine environment in the presence of large velocity contrasts, like a salt body. Salt-related converted waves can significantly contaminate P-wave image. The most noteworthy converted wave recorded in a salt province is generated from the base of salt. In this paper a method has been proposed to attenuate this energy before migration to improve sub-salt imaging. A clean converted wave model is generated using 3D acoustic forward modelling. This is then adaptively subtracted from the input dataset. Application of the proposed method is demonstrated in a complex deep water salt environment data set from the Mediterranean Sea.

Introduction

Converted mode contamination of P-wave images is a well-known and pernicious problem in some geological settings. In salt provinces, the large velocity contrast between the salt and surrounding sediments generates strong conversion between P-wave and S-wave energy, which often results in recording of converted mode events. The mode conversion to S-wave is created at steeply dipping salt interfaces, and converts back to a P-wave on the upcoming wavefront (Ogilvie and Purnell, 1996; Lu et al., 2003). These usually undesired contaminants of the image can sometimes be exploited to aid in the interpretation of the base of salt, as they offer enhanced illumination due to different angular coverage (Jones and Davison 2014). However, as this energy can act as noise on P-wave migrated images, generally there is a need to suppress them to facilitate interpretation.

The converted waves examined in this paper are those which convert at the top and base of salt and travel outside the salt as P-waves. As shown in Figure 1, three possible converted modes of base salt are PSPP, PPSP and PSSP. The arrival time for symmetrical mode PSSP will be significantly larger as compared to asymmetrical mode PSPP and PPSP since S-waves travel slower than P-waves. In addition, the symmetrical mode will be recorded with much weaker amplitude due to smaller velocity contrast between S-wave salt velocity and surrounding sediments. In this paper the symmetrical mode has been ignored due to lack of evidence of its presence in the recorded field data example used here, however it can easily be incorporated in the flow if required.

Existing methods to suppress converted modes include filtering the offending energy based on normal move-out velocity (Jeff et al., 1996), or surgical muting of energy using travel time ray-tracing (Lu et al., 2003). The effectiveness of both these methods could be significantly reduced in the presence of complex salt geometries. Dual-leg 3D acoustic modelling was proposed to model converted wave (Huang et al. 2013), which then can be used to attenuate it from pre-migration or post-migration dataset. In the presence of complex salt geometries, diffractions from the top salt cover the converted mode of the base salt modelled by forward modelling. This makes it difficult to subtract prior to migration. In this paper we perform 3D acoustic modelling twice; with and without the base salt interface in the velocity model. This generates a much cleaner converted wave model that can be subtracted from pre-migration gathers more effectively.

Methodology

The ratio (r) between the salt thickness in time (Δt_{salt}) and the time interval between P-wave and converted-wave base salt (Δt_{cw}) on time migrated data can be used to identify whether the converted mode has propagated as an S-wave on one or both of the down-going and up-coming wave-fields within the salt. If we assume zero-offset raypaths, the ratio (r) can be expressed mathematically as follows (Lu et al., 2003):

$$r = \frac{\Delta t_{salt}}{\Delta t_{cw}} = \frac{\frac{2}{V_p}}{\left(\frac{1}{V_p}+\frac{1}{V_s}\right)-\frac{2}{V_p}} = 2\left(\frac{V_s}{V_p - V_s}\right) \text{ for asymmetrical modes}$$

$$r = \frac{\Delta t_{salt}}{\Delta t_{cw}} = \frac{\frac{2}{V_p}}{\frac{2}{V_s}-\frac{2}{V_p}} = \left(\frac{V_s}{V_p - V_s}\right) \quad \text{for symmetrical modes}$$

The ratio is generally between 2 and 3 for asymmetrical modes, whereas the ratio is significantly lower for symmetrical mode (between 1 and 1.5). This information aids the selection of the type of converted mode during the forward modelling process. In the dataset presented here this ratio was estimated at 2.2. This means the converted mode was recorded with only one of the up-coming or down-going wave-fields as a S-wave in the salt layer; it was either PSPP or PPSP (Figure 1). Therefore, the symmetrical mode PSSP has not been considered for forward modelling in the proposed method.

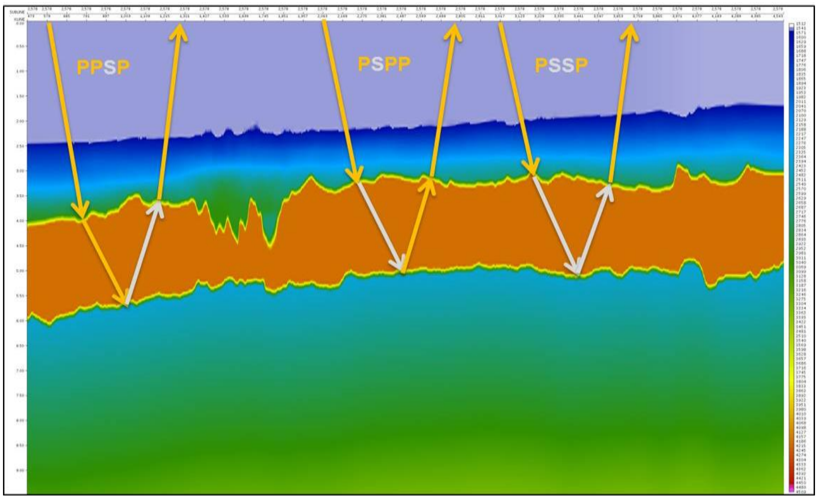

Figure 1. *Three possible converted wave ray path from salt layers. Symmetrical mode PSSP has been ignored due to lack of evidence of its presence in the recorded field data.*

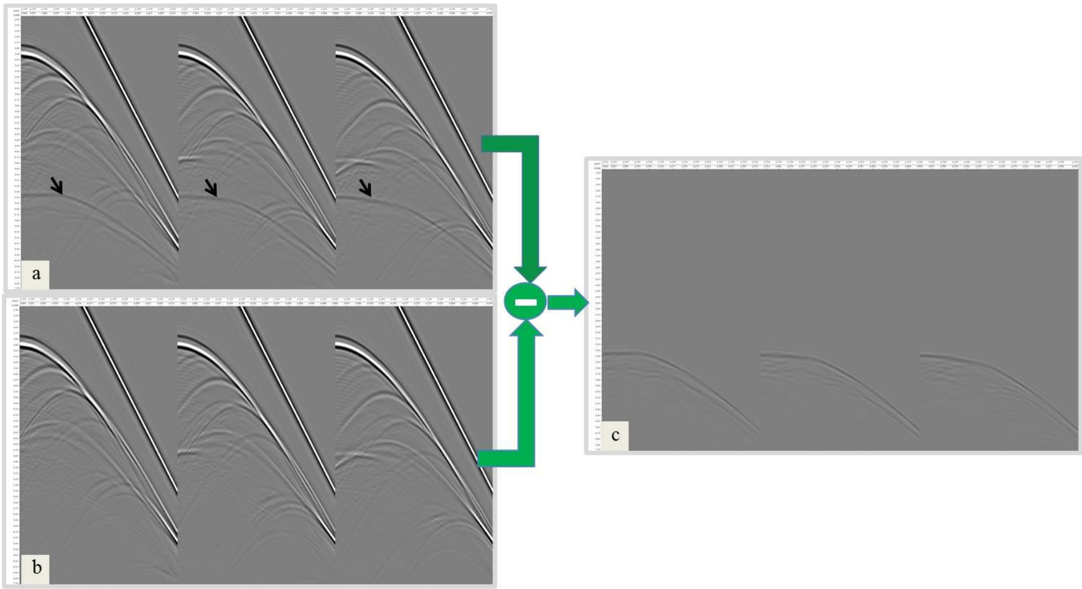

Figure 2. *Different stages of modelling: 3D acoustic forward modelling with base salt reflector included in the modelling (a); forward modelling without base salt reflector in the model (b); subtraction of the previous two models to generate clean converted wave model (c).*

The method proposed to suppress the converted mode consists of the following steps:

1. Obtain a suitable interval velocity model for the P-wave data with an accurate salt layer geometry.
2. Create a version of the velocity model which contains the shear velocity within the salt body. The shear velocity can be obtained by scanning for the velocity which flattens the converted mode energy at the same depth as the interpreted base salt.
3. 3D Finite Difference shot modelling is then performed using a single scattering approximation, to produce modelled shot gathers corresponding to the PSPP and PPSP wave fields resulting from conversion at the top salt and reflection from the base of salt reflectors (Figure 2a).
4. An additional 3D finite difference modelling step is performed to model P-waves without any reflection from the base salt reflectors (Figure 2b).
5. A difference is produced of the model obtained in step 3 and 4 producing a clean converted mode model (Figure 2c).

6. The model is then adaptively subtracted from the input shot gather suppressing the recorded PSPP and PPSP converted mode energy.

Field Example

We demonstrate a successful application of the above described method in a complex deep water salt environment from the Mediterranean Sea. Figure 3 shows the stack data of one subsurface line before and after application of the converted wave attenuation. Marked by red arrows in the left-hand image (Figure 3a), one can clearly see the recorded converted wave as a shadow of the base salt event on the stack. The right image (Figure 3b) clearly shows that the recorded converted wave energy has been attenuated effectively with the proposed method.

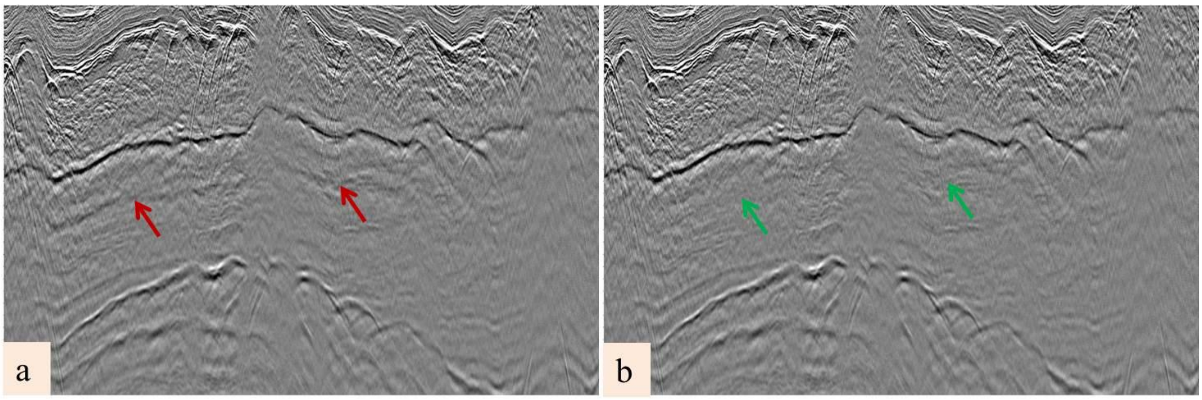

Figure 3. *Stack output in the data domain without converted wave attenuation flow applied (a) and with converted wave attenuation flow applied (b)*

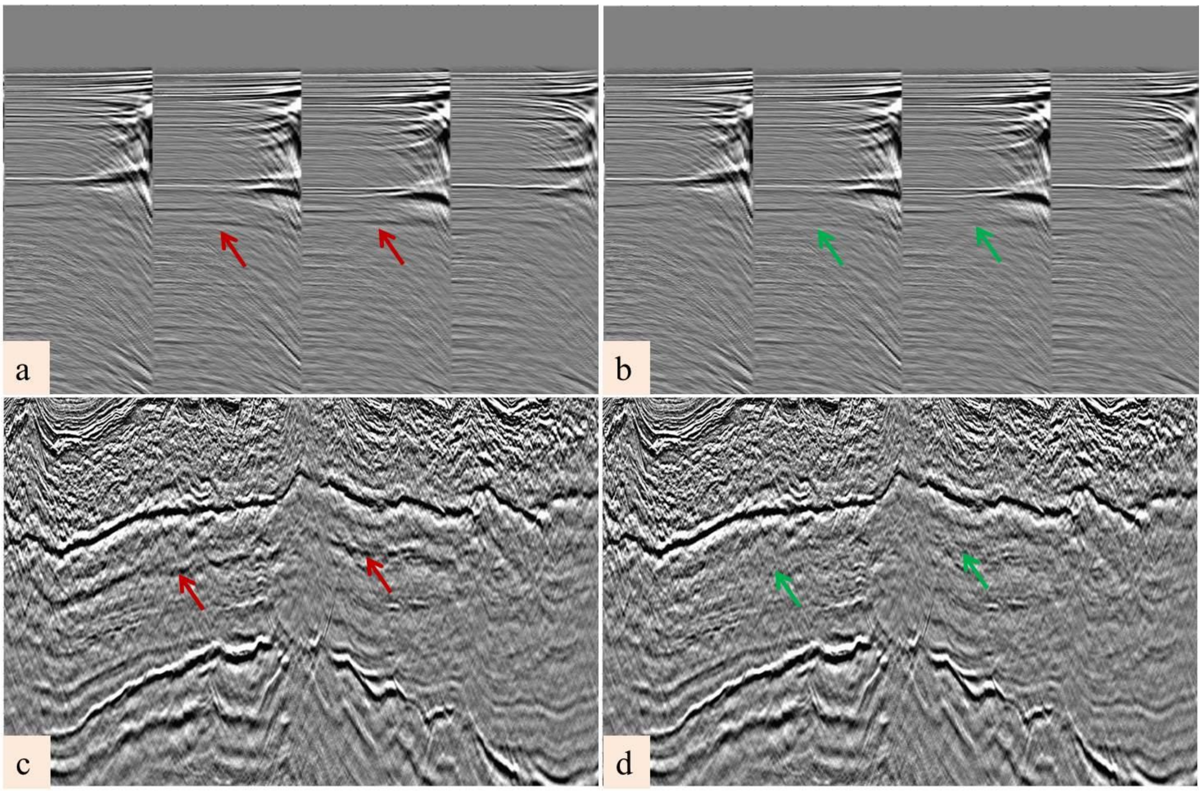

Figure 4. *Image domain gathers (a and b) and stacks (c and d) using input dataset without converted wave attenuation flow applied (a and c) and with converted wave attenuation flow applied (b and d). The image in this example has been produced using Kirchhoff migration.*

Figure 4 shows the result of the proposed flow in the image domain obtained by migrating data using Kirchhoff algorithm. Figure 4a and 4b show the result on migrated CIP gathers, where the converted wave has been marked with arrows. Please note the move-out of this energy is quite small (approximately 100ms at 8 km offset), which makes it difficult to filter using normal move out based methods. Figure 4c and 4d show the same data after stacking. These clearly show the effectiveness of the flow in attenuating recorded converted wave which acts as noise in the P-wave image.

Conclusion

In this paper we proposed a method to attenuate converted wave energy which is very often recorded in geological settings with large velocity contrasts such as a salt body in a sediment background. The application of the method to a Mediterranean Sea dataset clearly demonstrates the effectiveness of the approach. Suppressing converted wave is important in facilitating sub-salt interpretation, especially when target formations are very close to the base salt.

Acknowledgements

The authors would like to thank IEOC for the permission to present the data. We also like to thank all geophysicists from PGS who helped us in producing the results.

References

Huang, Y., W. Gou, O. Leblanc, S. Ji, and Y. Huang, 2013, Salt-related converted-wave modeling and imaging study: 75th Annual EAGE Conference and Exhibition, Tu 01 13.

Jones, I. F., and I. Davison, 2014, Seismic imaging in and around salt bodies: Interpretation, 2, 4, SL1–SL20.

Lu, R. S., D. E. Willen, and I. A. Watson, 2003, Identifying, removing and imaging P-S-conversions at salt-sediment interfaces: Geophysics, 68, 3, 1052–1059.

Ogilvie, J. S., and G. W. Purnell, 1996, Effects of salt-related mode conversions on subsalt prospecting: Geophysics, 61, 2, 331–348.