7th International Conference & Exposition
on Petroleum Geophysics

"HYDERABAD 2008"

P - 268

Multiple Suppression and Data Quality Enhancement Using Radon Transform: A Case Study

Shashank Shekhar Singh, Uma Shankar, Kalachand Sain,
NGRI, Hyderabad

Summary

The ultimate goal of seismic exploration is to generate accurate images of the subsurface to identify the hydrocarbon bearing structure. Seismic data processing plays an important role in achieving this goal. One of the key problems in seismic data processing is to attenuate multiple reflections from seismic data. Different approaches have been investigated and applied to the multiple attenuation problem including the industry-standard Radon transformation, which has attracted the attention of explorationists during the last two decades. Here we attempt to apply the radon filter on a seismic data set in the western Indian margin with a view to improve the seismic image. Comparison of seismic sections produced with and without radon filter shows a significant improvement in subsurface image using the radon filter for both the shallow and deeper parts of the section.

Introduction

The Radon transform is a mathematical technique that has been widely used in seismic data processing and image analysis. This will typically transforms the data from the space-time domain (*x*, *t*) to the tau-p domain (t, *p*) where it is modified and then transformed back to (*x*, *t*) space. Three types of Radon transforms can be used as multiple- attenuation in seismic data processing: the slant-stack or t-*p* transform, the hyperbolic Radon transform, and the parabolic Radon transform (Trad, 2001). The slant-stack transform can be combined with predictive deconvolution to attenuate multiples in the prestack seismic data based on the periodic characteristic of multiples. In contrast to the slant-stack transform, the hyperbolic and parabolic Radon transforms are applied to multiple attenuation based on moveout discrimination between multiples and primaries. The Radon transform was first introduced by Johan Radon (1917). Deans (1983) discusses the mathematical theory, and Durrani and Bisset (1984) examine the fundamental properties of the Radon transform. Thorson and Claerbout (1985) utilized the hyperbolic Radon transform as a velocity analysis tool, and the parabolic Radon transform was applied for the first time as a multiple attenuation technique by Hampson (1986). Since then, Radon transforms have become one of the most widely used approaches in attenuating multiples (Bradshaw and Ng, 1987; Kelamis *et al*., 1990; Kostov, 1990; Foster and Mosher, 1992; Hugonnet and Canadas, 1995; Sacchi and Ulrych, 1995; Cary, 1998; Sacchi and Porsani, 1999; Trad, 2001; Oppert, 2002; Trad *et al*., 2002; Ng and Perz, 2004). Radon transform-based multiple suppression schemes are fundamentally limited by the transform's ability to resolve different events on the basis of moveout differences. This is particularly true for interbed multiples. Because seismic data consists of a finite number of discrete observation points, a least-squares solution of the transform, rather than the classical formulation, improves the resolution (Thorson and Claerbout, 1985). From a practical point of view, this approach is computationally expensive.

In this paper, we describe an approach for suppressing the multiples using a parabolic transform called the Parabola moveout time at reference offset (PRADMUS). The PRADMUS incorporates two of the discrete Radon transform methods, namely the parabolic Radon transform, designed primarily to model and subtract multiple energy, and linear Radon transform, designed primarily to attenuate the linear events from seismic records or for predictive deconvolution in the tau-p domain. The Parabolic option performs a band-limited parabolic Radon transform on input gathers that have been corrected for normal moveout. After forward transform, the program either zeros a zone of user- specified primary energy, performs an inverse transform on the remaining multiple energy, and subtracts the resulting gather from the original data to produce the signals without multiples. The linear option can be used as a filtering domain where linear events in the input gather that overlap reflection signals are mapped into a point in the tau-p domain, thus separating them from the reflection signal which makes simple filtering possible. Another application of the linear transform is for multiple predictions in the tau-p domain. Multiples in the common shot gather are periodic only in the radial direction, which in the tau-p domain is represented by a constant p trace. Common application is to apply forward transform, call a predictive decon module, then call inverse transform. Multiple calls to the program can be made to perform forward and inverse transforms separately.

The Parabolic option of PRADMUS performs a forward parabolic Radon transform on gathers that have been corrected for normal moveout. The transform separates reflection events on the basis of moveout differences. After normal moveout correction with proper RMS velocity derived from primaries, the primary events are expected to be flattened and the multiple events may have residual moveouts. The primary and multiples events can be distinguished and separated from their moveout differences. The Linear option of PRADMUS performs linear radon transform (slant stacking) followed by least-squares inversion to condition the tau-p section such that its inverse will result in the least energy. The transform has characteristics of separating linear events that are interfering with reflection in the input gather by mapping them to a point in the tau-p domain. Then, a simple mute and inverse transform would eliminate the linear events. Linear transform can also be used for making the multiples in the prestack gather periodic. It is known that multiples are periodic in the radial trace direction in a common shot gather, which renders predictive deconvolution operations useless by transforming the input gather into the tau-p domain. The multiples are periodic in the tau direction, thus making it possible to eliminate them with simple predictive operators.

Methods

The tau-p deconvolution techniques can be used to attenuate relatively short period multiples. The time domain multiples of increasingly poorer temporal periodicity with increasing offset (the events are converging at the far offsets so they are not periodic). In the tau-p domain the multiple energy is periodic - although the period reduces with increasing slowness. By applying the deconvolution in the tau-p domain and then applying an inverse tau-p transform we get back the data into the x-t domain.

PRADMUS transforms the data into the tau-p domain. Tau and p are coefficients defining the intercept time and the curvature of parabolic curves of NMO corrected events in the input ensembles. PRADMUS first performs a least-squares forward transform. The forward transform followed by the inverse transform without any filter in between yields a least- squares approximation to the input ensembles. The forward and inverse transforms are performed in the frequency domain, independently for each frequency. Two inversion schemes have been developed for the least-squares forward transform. Assuming both the parameters in the model space and the noises in the data space have Gaussian distributions leads to a linear least-squares inversion scheme denoted as Toeplitz inversion. It is called so because the operator matrix in this inversion scheme has a Toeplitz structure. Therefore, only one column of the matrix needs to be formed and the system of linear equations can be solved with a fast recursive Levinson algorithm for the model space parameters. The Toeplitz inversion is carried out independently for each frequency. Assuming the noises in the data space has having the Gaussian distribution and the model space parameters have a Cauchy distribution yields a non-linear iterative least- squares inversion scheme. This inversion scheme is able to produce a tau-p panel where the energies of parabolic events are better focused, less smeared, compared with the tau-p panel obtained through the Toeplitz inversion. This inversion scheme is denoted as sparse inversion and is able to produce high-resolution parabolic Radon transform. Because the sparse inversion scheme requires knowledge of the model space parameters what we are looking for. It is a non- linear inversion problem, and hence the inversion has to be implemented as an iterative linear inversion problem. Within each iteration, the model space parameters obtained from previous iteration is used as the initials for the true model parameters. The inversion uses the direct transpose or adjoint forward parabolic Radon transform as initial guess of the model space parameters in the first iteration. A cost function is used to stop the iterations at its local minimum. This non-linear inversion is also carried out for each frequency independently. The sparse inversion can produce high-resolution tau-p panel. With the high-resolution transform, the collapse of parabolic events in the tau-p domain may make the primary energies and multiple energies better separated, in favor of better multiple elimination and primary preservation. The sparse inversion can be achieved by supplying hires to the parameter method. Since the sparse inversion is implemented iteratively, it is remarkably slower than the Toeplitz inversion. The processing procedure includes these steps:

Forward transform - The forward transform decomposes NMO corrected seismic data into a sum of parabolic events. The primary events may differ from other coherent energies, such as multiples and ground rolls, by the curvature (moveout) of the parabolas.

Filtering - The program designs and applies a filter to the transformed data in the tau-p domain to reconstruct a selected part of the data. The range of curvature p to selectively filter out part of the data is supplied by the user. In practice, the region occupied by primary energy in the transform domain is usually removed, that leaves only the non-primary energy and only non-primary events will be modeled in the inverse transform.

Inverse transform - This transforms the data from tau-p back into the original x-t domain. The new data contains either primaries or multiples, depending on the filter specifications. This data then can be either substituted for the original data or subtracted from it. Processing flow chart is given in fig. 1.

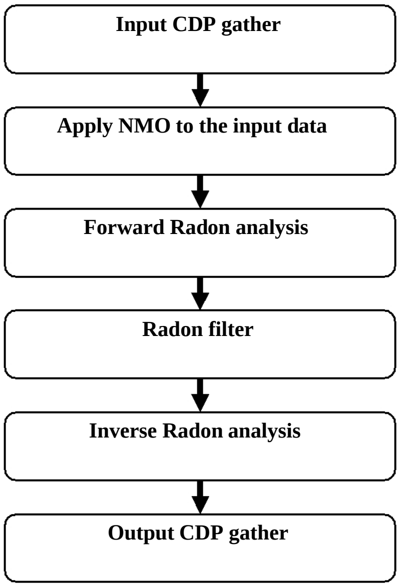


Figure 1 A flowchart for the Radon transforms

Examples

We present seismic sections with and without multiple attenuation technique on multi-channel seismic data of the western continental margin of India (WCMI). Multi-channel seismic data were collected over the western continental margins of India in the early 1990s for the exploration of hydrocarbons. The data was made available to our institute by the Gas Authority of India (GAIL) to reprocess with suitable parameters and identify possible locations of gas hydrate-bearing horizons in this area. The air-gun array source for the data acquisition was a tuned array with a total volume of 1650 cubic inches. The data were recorded on 96 channels giving a full foldage of 48, with a maximum offset of 2575 m. The shot and geo-phone group intervals were both 25 m. The data quality was fair and shallow reflectors were identifiable on the records. Data processing was carried out with band pass filter in the range of 8-10-60-70 Hz and true amplitude recovery was done at 6 db/sec. Velocity analyses were carried out at every 250 m and spiking deconvolution was also applied to data so as to increase resolution.

Figure 2 contains a NMO corrected CDP gather of edited data of the western margin of India and Figure 3 contains the same NMO corrected CDP gather after applying the Radon filter to the data. This illustrates a marked improvement in the signal with respect to the edited NMO corrected CDP gather without Radon filter. We see that there are many missing traces in the raw CDP gather making the velocity analysis difficult. As we apply the radon analysis to the data, it interpolates the missing traces.

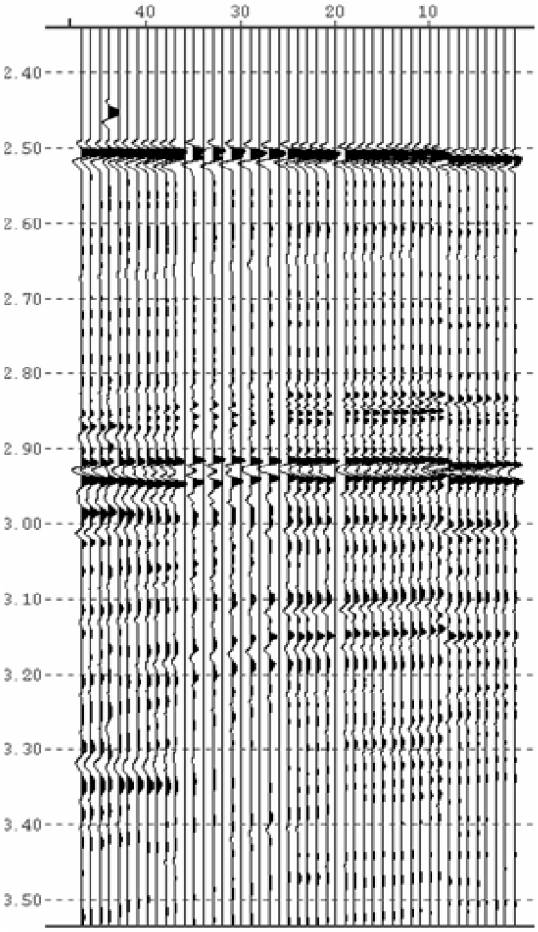
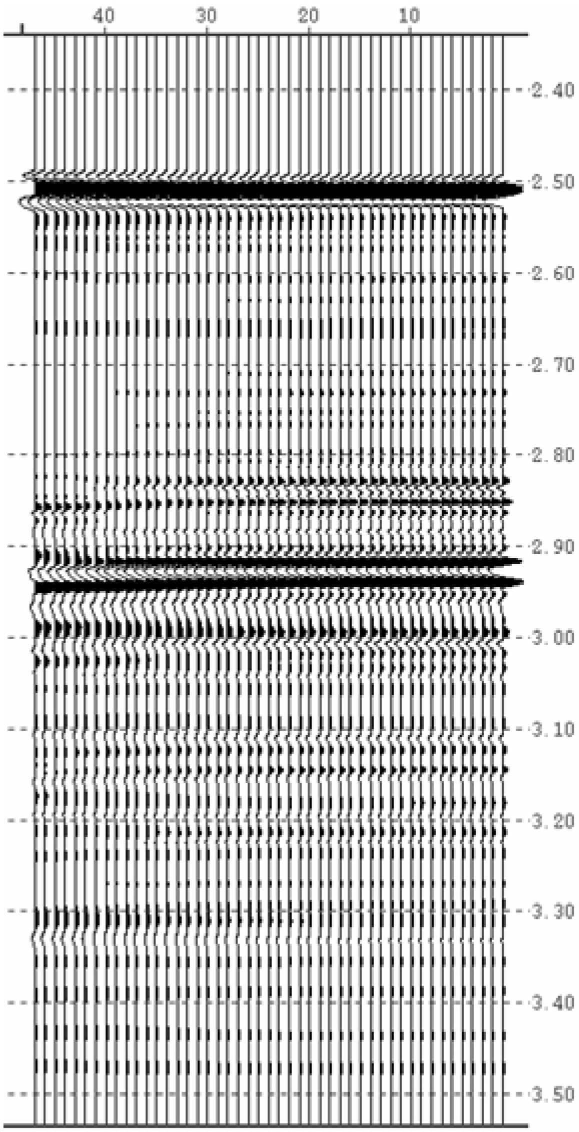


Figure 2 NMO corrected single CDP gather edited

Figure 4 shows a stack section before the radon application whereas Figure 5 displays the stack section after the radon application, and we observe an improved seismic image of the subsurface earth, and this demonstrates the potential of applying radon transform in improving the seismic image.



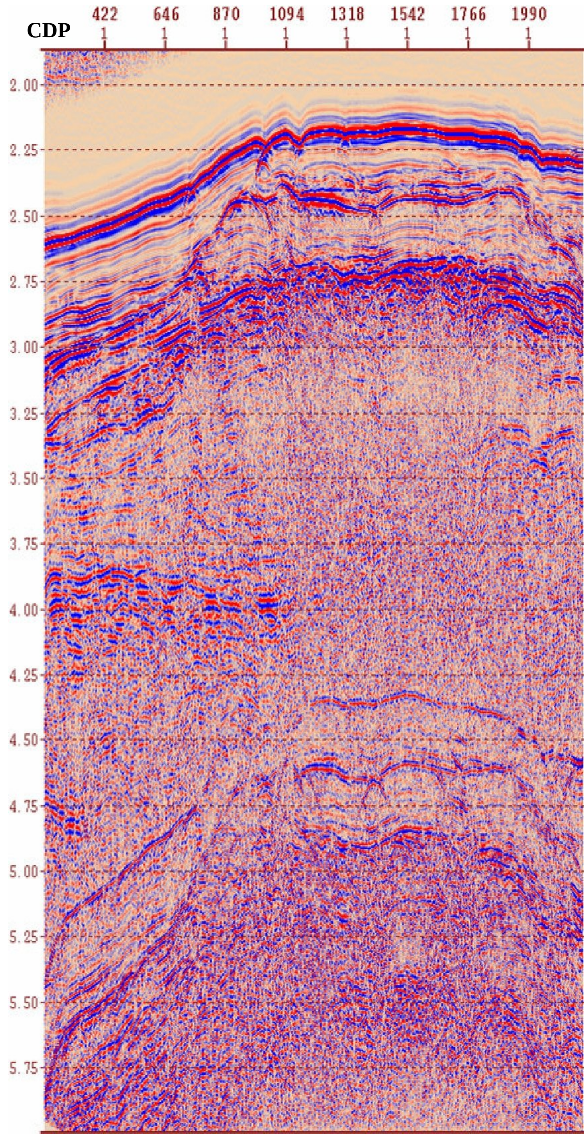


Figure 4 Stack section wthout radon filter

Figure 3 Output of NMO corrected single CDP gather data with radon filter

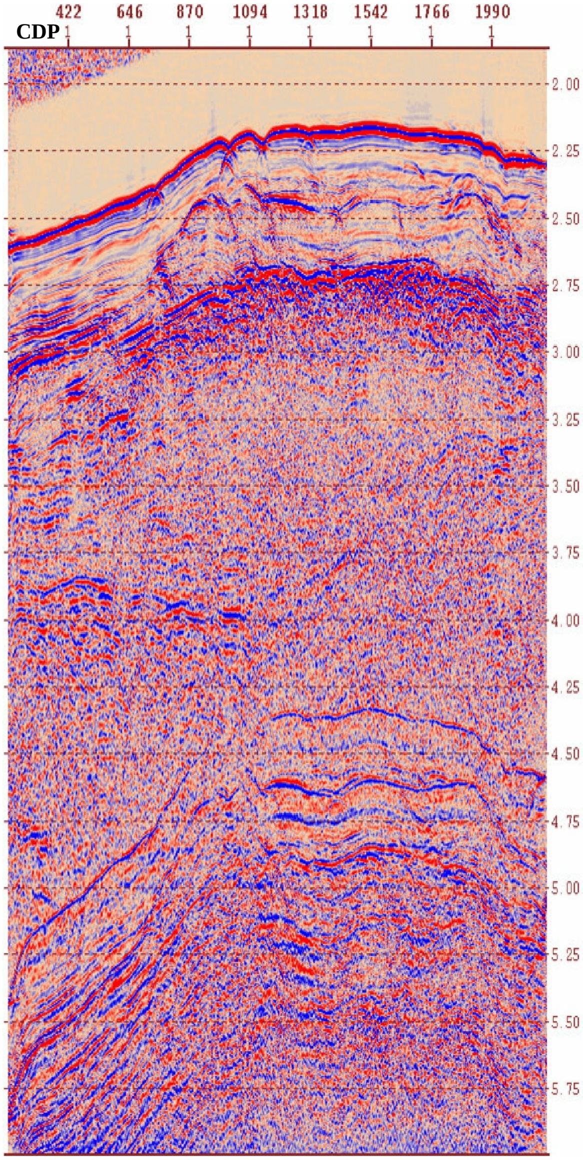


Figure 5 PRADMUS output Stack section.

Conclusions

Application of Radon analysis on a data set in the western continental margin of India shows remarkable improvement in seismic image. The Radon transform is an important tool to gain an insight into the complex geology to bring out meaningful features, and thus can be used for the exploration of hydrocarbons including the gas-hydrates and understanding the geologic and tectonic evolution of an area.

Acknowledgements

The authors wish to thanks Dr. V. P. Dimri, Director, National Geophysical Research Institute, Hyderabad, for his kind permission to publish this paper and Gas Authority of India Ltd. (GAIL) for making data available to us.

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