Comparative analysis of One Way Wave equation and Two Way Wave equation migration with Kirchoff's method: A case study from Cambay Basin

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Key words

Depth imaging, Kirchhoff, PSDM, Wave Equation Migration (WEM), RTM

Abstract

Seismic imaging is based on numerical solutions to wave equations, which can be classified into ray-based integral and wave field based differential solutions. Kirchhoff migration is a typical ray-based imaging procedure that is efficient computationally but often fails in areas of complex geology, such as subsalt, because the wave field is distorted severely by lateral velocity variations, leading to complex multipathing. Wave field imaging works better for complex geology but is compute intensive than Kirchhoff migration. Depending on computational time constraints and available resources, different levels of approximation are applied to accelerate imaging, e.g., one way versus two way, acoustic versus elastic, isotropic versus anisotropic. In this study, a small portion of an area was chosen to do the comparative study of the three imaging methods, *vis-a-vis* time & quality of image outputs.

Introduction

Kirchhoff migration is being widely used in industry due to its economical and easy to implement nature. Advances in computing power made wave equation type algorithms economically feasible as alternative methods for pre stack depth migrations to image in complex geological areas. A small portion of the Nandej-Nawagam area was chosen from Cambay basin to make a qualitative & quantitative evaluation of the different imaging algorithms and the time analysis of the same. The area is characterized by strong lateral velocity variation as well as steep dips. The Selection of proper imaging methods is essential to map structural closures at Kalol level and step fault closures at syn rift sequences. Figure - 1 & 2 shows tectonic map of Cambay basin and fold map of the area respectively.

Methodology

Seismic imaging is mainly classified into ray-based integral and wavefield based differential solutions. Kirchhoff's migration is based on integral approach and one way wave equation (WEM) and Reverse time migration (RTM) are based on differential approach to wave equation.

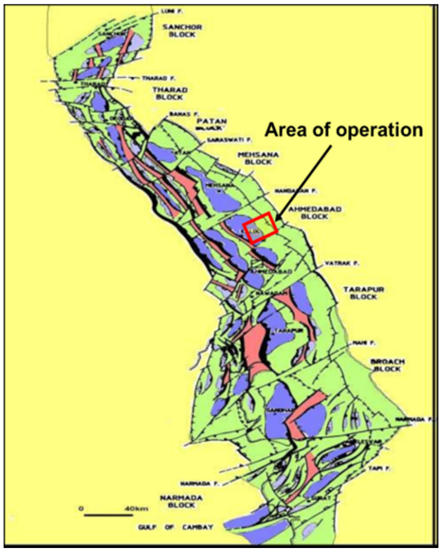

Figure - 1: Tectonic map of Cambay basin

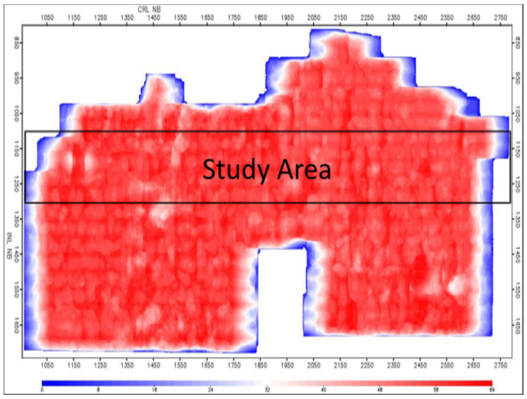

Figure - 2: Fold map of input data of study area

Kirchhoff pre stack depth migration uses the actual ray path from every source to every receiver. This ray path is used to construct the diffraction surface. The migration of a seismic section is achieved by collapsing each diffraction trajectory to its origin (apex). The advantage of this method is its good performance in case of steep-dip structures. The method performs poorly when the signal-to-noise ratio is low & multi pathing due to severe complexities of structure and velocity.

One-way wave equation-based migration methods utilize the paraxial approximation to the wave equation to extrapolate the wave fields from one depth to another for each frequency component. These methods work well for waves propagating in directions within certain angle limits from the main direction usually the vertical direction, but they fail to handle waves propagating at wider angles, especially those near or beyond 90°. Thus, a typical one-way wave equation-based migration method cannot image steeply dipping reflectors, salt overhangs etc., where a down going path may dive and locally turn upwards and an up going wave may locally turn downwards due to complex velocity and structure.

The RTM technique uses the two way wave equation without any approximation and assumptions. Each shot gather of the input will be migrated independently and the output of RTM in the migration mode is a volume of migrated common shot gathers. RTM works in three phases: first, the forward extrapolation of a modelled source wavefield for *each* shot location through a gridded velocity model is performed, and the wavefield at *each* time step is saved (for later application of the "imaging condition"). Second, the receiver wavefield for each shot (as recorded in the field) is backward propagated in time through the same velocity model. During the third stage, corresponding to each time step, the source and receiver wave fields are cross-correlated by applying the imaging condition. The image is formed accounting all possible arrivals, including caustic and prismatic waves (Figure - 3). Thus, the *final* wavefield in the source propagation scheme is correlated with the *initial* wavefield in the receiver propagation scheme, and so on backwards through the receiver propagation. The results are summed to form a partial image volume for each shot, and the image volumes for consecutive shot gathers are spatially summed to produce the final pre-stack depth image.

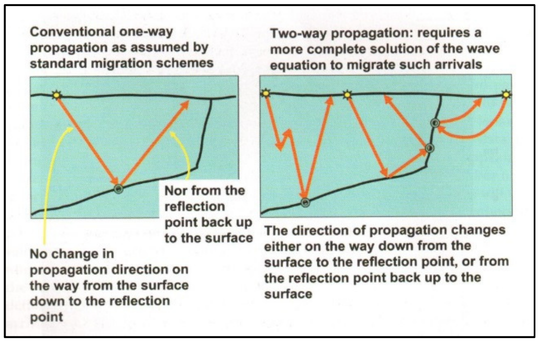

Figure - 3: Wave propagation in One Way (left) and Two Way (right) wave methods (Jones, 2010)

Its superiority becomes more important as exploration for hydrocarbons encounters more and more complex geological settings, such as structures with steep dips or salt overhangs, which are beyond the limits of one-way wave equation-based migration algorithms. Nevertheless, complex structures are often accompanied by strong lateral velocity variations, which result in significant multi pathing, limiting the effectiveness of ray-based Kirchhoff migration. RTM outperforms all of these methods in imaging such complicated structures.

RTM may suffer from artefacts originated from diving, head and backscattered waves. It is customary to apply Laplacian type of filtering to RTM derived images to minimize very low frequency and DC bias.

Processing Sequence

Processing sequence of depth imaging includes two steps, first one interval velocity model building and second implementation of depth migrations. RMS velocity was used as input to build interval velocity model. Signal conditioned gathers were used as input to migration.

(a) Building the initial Interval velocity model

Smoothed RMS velocity volume was converted into interval velocity in depth using Dix method. Smoothed RMS velocity and Smoothed interval velocity volume are shown in Figure - 4 & 5 respectively. Velocity model refinement was not attempted in this study. For this order accuracy of the velocity model, the efficacy of the migration approaches were only attempted.

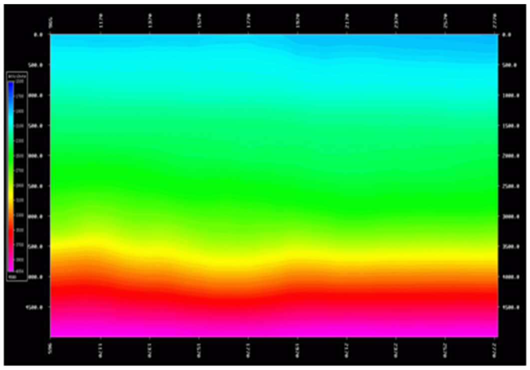

Figure - 4: Smoothed Vrms in time

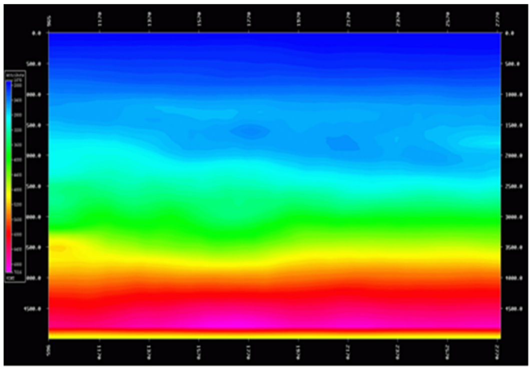

Figure - 5: Interval velocity in depth

(b) Final Depth migration

Kirchhoff's PSDM was implemented in two steps, first travel time computation using interval velocity model in depth then depth migration using travel time so computed. Travel time was computed using a ray tracing algorithm with uniform 3D grids. In travel time computation, the following parameters play important role such as ray step, ray propagation direction, and variable depth sampling. Depth migration was implemented using computed travel time with conditioned input seismic data.

One way wave equation migration was implemented in the following processing steps. Input traces were transformed into shot recorded frequency planes and input interval velocity traces were transformed into velocity planes. In the next step, migration operators were computed using velocity planes and finally one way wave equation migration was performed.

Reverse time migration needs to implement in shot domain. The input gathers were sorted into shot order prior to perform RTM. Subsequently RTM was performed in shot by shot order.

Performance evaluation

Table-1 shows the execution time comparison of three types of depth migration methods. Similar parameters were used in all three depth migration methods. Reference of 100 CPU cores as taken for comparison.

Kirchhoff migration was implemented with maximum energy criteria. It took about 20 hours with 40 CPU cores. Wave equation based methods are implemented in shot domain. One way wave equation migration took about 648 hours with 100 CPU cores and RTM took about 1711 hours with 132 CPU cores. Identical type of CPU cores were used in all these migration methods.

	Kirchhoff	***WEM***	***RTM***
Runtime (hrs)	20	648	1711
Cores used	40	100	132
Runtime after normalization to 100 cores (hrs)	8	648	2249
Ratio of Run time	1	81	281

Table – 1: Run time comparison of three depth migration methods with frequency of 50 Hz

Discussions

The amplitudes of dipping reflectors are better preserved by one way wave equation migration in comparison to Kirchhoff migration with better imaging at Kalol level (1500m). Figure - 6 shows the comparison between Kirchhoff and WEM.

In addition to amplitude preservation of dipping reflectors, RTM improved the fault definitions when compared to the Kirchhoff and WEM. Figure - 7 shows the comparison between Kirchhoff's and RTM and Figure - 8 shows the comparison between the WEM & RTM.

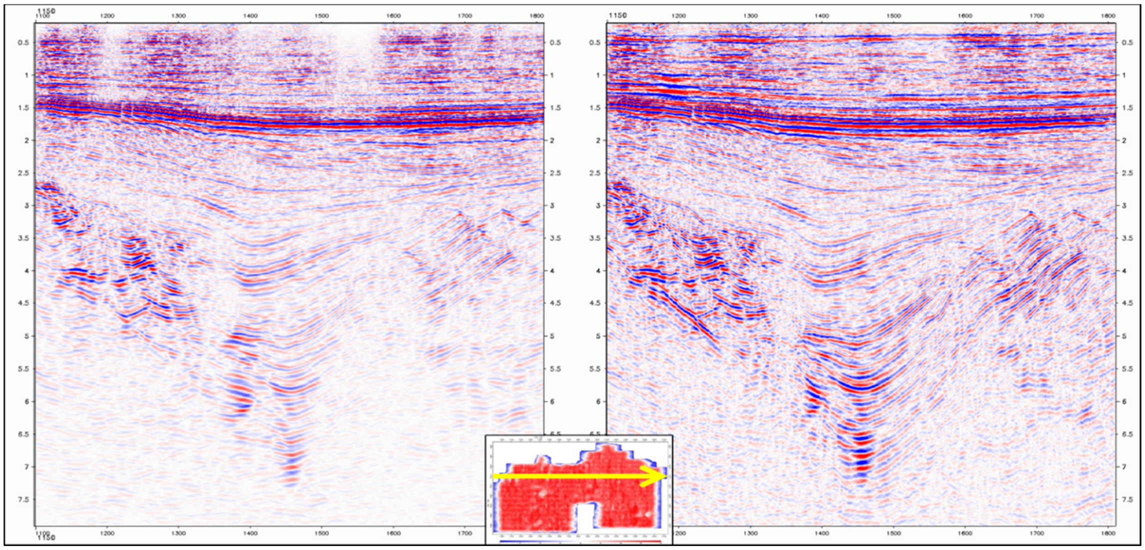

Figure - 6: Comparison of Kirchhoff and WEM depth migration

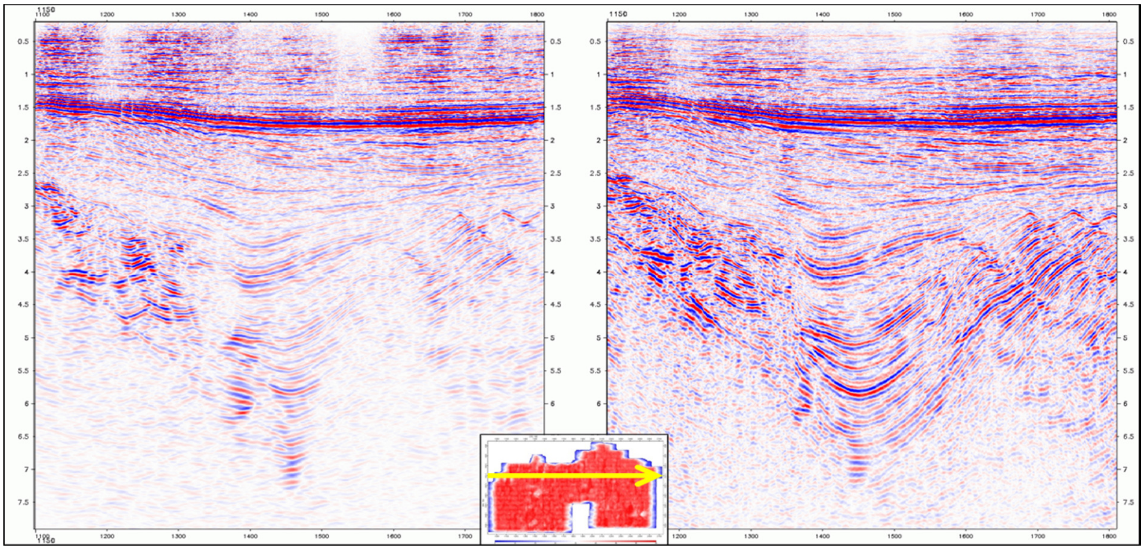

Figure - 7: Comparison of Kirchhoff and RTM depth migration

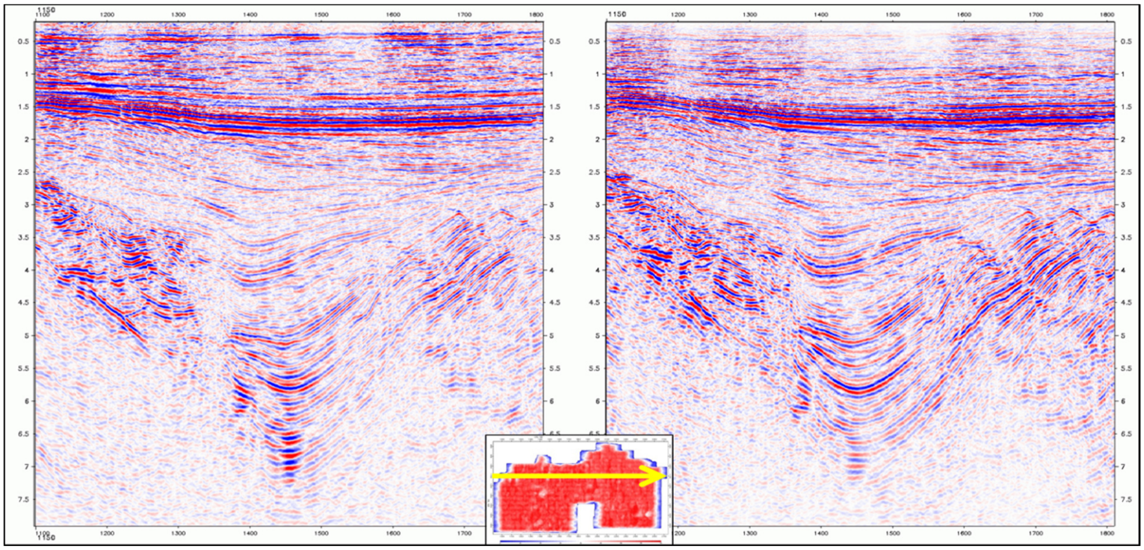

Figure - 8: Comparison of WEM and RTM depth migration

Conclusions

An attempt was made to compare the relative strengths of three different depth imaging algorithms for a land 3D dataset pertaining to Nandej-nawagam area in Western onland basin, India. The objective was to image the syn-rift sequences. Signal strength and quality of imaging from the Kirchhoff image was found to be inadequate for mapping of fault closures at syn rift sequences. WEM showed better image at Kalol level and dipping reflectors. Improvements were seen in the axial parts of the syncline, raising flanks on the either side of syncline, fault definition on the eastern side rotated blocks and overall image quality in RTM outputs compared to other methods. However, the compute times are very high for WEM and RTM. Table -1 compares the compute time for imaging the same data volume. In this case study, it was observed that RTM provides the best imaging in the area of complex geology, provided the time and resources are affordable.

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