A brief comparison of the efficacy of four migration algorithms – a sub-basalt example

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Introduction

Conceptually, there are two distinct parts to migration: extrapolation and imaging. By extrapolation, we mean reconstruction of the wave field in depth using surface data. By imaging we mean obtaining the local reflection strength in the subsurface from extrapolated data using some formula or principle. This paper deals with evaluating the efficacy of four popular migration algorithms in imaging of Sub-Basalt structural play and trap geometry of Western Offshore, India. The advantage / limitations of these algorithms are discussed briefly.

Algorithms Tested

Kirchhoff migration has been a major tool over the past decade for pre-stack seismic imaging. It is efficient and can image steep dips with turning waves. While the imaging accuracy of a 'single arrival' Kirchhoff pre-stack depth migration has been sufficient for all but the most challenging structural imaging problems, accuracy comparisons with other wave field extrapolation methods have often brought out its limitations. In complicated geology, where several arrivals are required to give a good image, choosing of a single arrival Kirchhoff migration produces a degraded image as it does not preserve the amplitudes as compared to other multi- arrival migration algorithms.

One alternative to single arrival Kirchhoff techniques is the Wave Equation based Migrations. Based on the one-way wave equation or two-way wave equation, this approach automatically handles multiple paths during wave field extrapolation and hence can image all the events. It also preserves the amplitude as long as the velocity field is not too complex. However these methods generally involve 'small' dip approximations and, therefore, can have problems in imaging steep or over turned events. Their main practical drawback is their large turnaround time and cost. Although recent enhancement in computing power has made it possible to implement these methods, they still remain much more expensive than Kirchhoff migration. As a result, these methods are reserved for situations that really require multi-arrival imaging.

A bridge between Kirchhoff & Wave Equation (WE) migration is the Beam migration which solves many of the imaging accuracy problems of single arrival Kirchhoff migration and yet retains many advantages of Kirchhoff methods such as ability of imaging of steep dips with turning waves. It is capable of imaging multi-arrivals and producing accurate images in geologically complex areas. Like Kirchhoff migration, its output consists of common image gather (CIG) which makes it suitable for velocity model building. It is formulated in the common-offset, common-azimuth domain. Based on rays which are formulated into beams, it provides the kinematics & the amplitude weights of the migration. The migration itself is performed in ray parameter domain which facilitates multi-path imaging.

Another emerging migration is the Reverse Time Migration which is based on extrapolation back in time while using the stacked section or pre-stack gathers as the boundary condition at z=0. When velocity set up is complex, the Reverse Time Migration (RTM) images the subsurface by running the WE for source forward in time and by running the WE for receiver back in time, for each shot. At each depth the two extrapolated wave fields are cross-correlated and summed to obtain the partial image generated by each shot. Any diving wave or any up going wave field is therefore accounted. The important consideration is that the extrapolation step Dt in RTM must be taken quite small, usually a fraction of the input temporal sampling interval. This, then, makes the algorithm computationally intensive. In principle, RTM provides superior amplitude preserving results by virtue of its ability to handle all ray paths, phase changes associated with the caustics, high frequency variations of velocity field, step dips > 70 degrees, and even turning waves. RTM output has higher S/N compared to other migration algorithms due to lesser aliasing. RTM is not a new concept for the industry but has not been much explored as it is very compute- intensive. Its turn around time and quality of imaging are both greatly dependent on the frequency parameter. A higher frequency parameter provides superior result but at a higher cost. RTM therefore, should be used judiciously.

We now illustrate the results of each of the above migration method on one test line from Western Offshore, India with a Sub-Basalt structural play.

Discussion

In Fig-1, Kirchhoff migration shows a noise with lesser strength of signal at lower section in comparison to Beam migration for the same interval velocity and migration aperture.

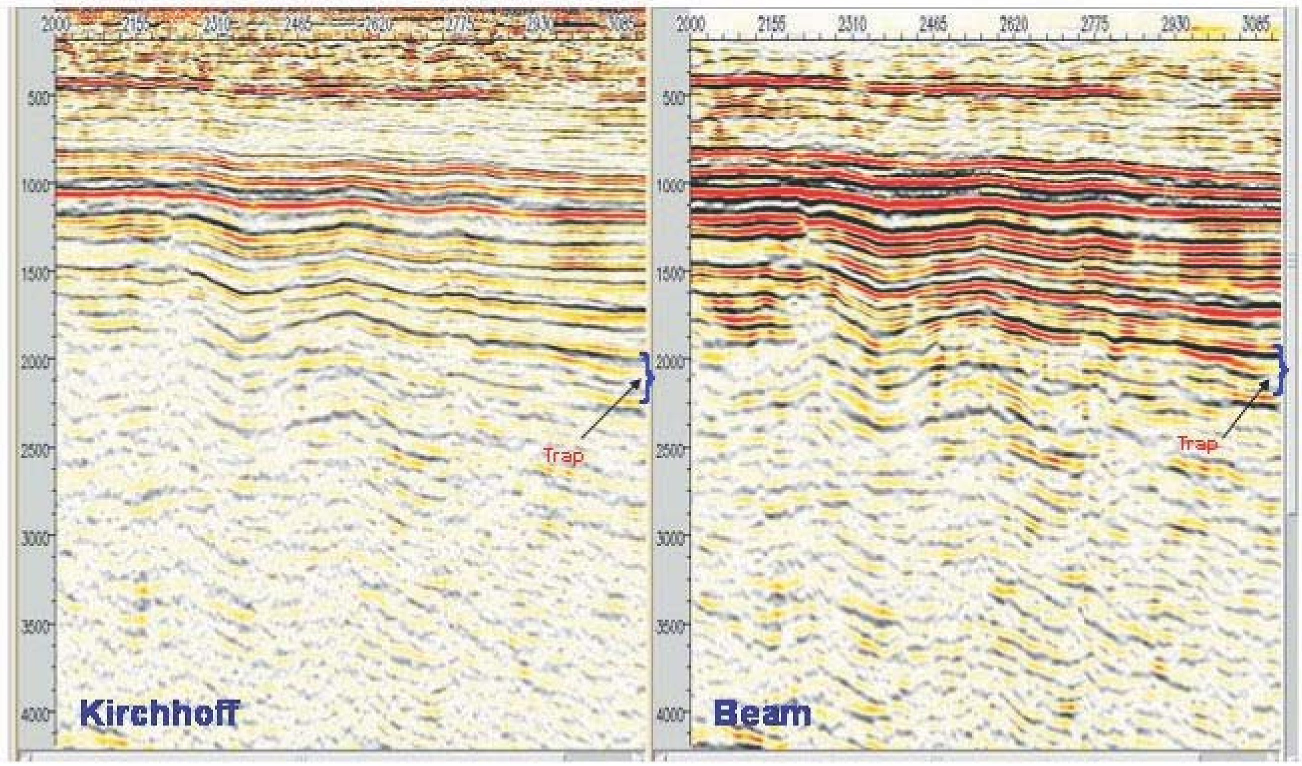

Fig. 1 Comparison of Kirchhoff and Beam Migration (PSDM)

Whereas the Wave equation migration shows better frequency preservation compared to Beam migration, migration amplitudes are better in the shallower section. Comparison of the migrated gathers of Beam and WEM (Fig. 4) shows that WEM gathers are contaminated with high frequency noise which is also visible in the stack section. RTM result (Fig. 2 & 3) show a clear imaging of the top and base of the trap with a distinct structure.

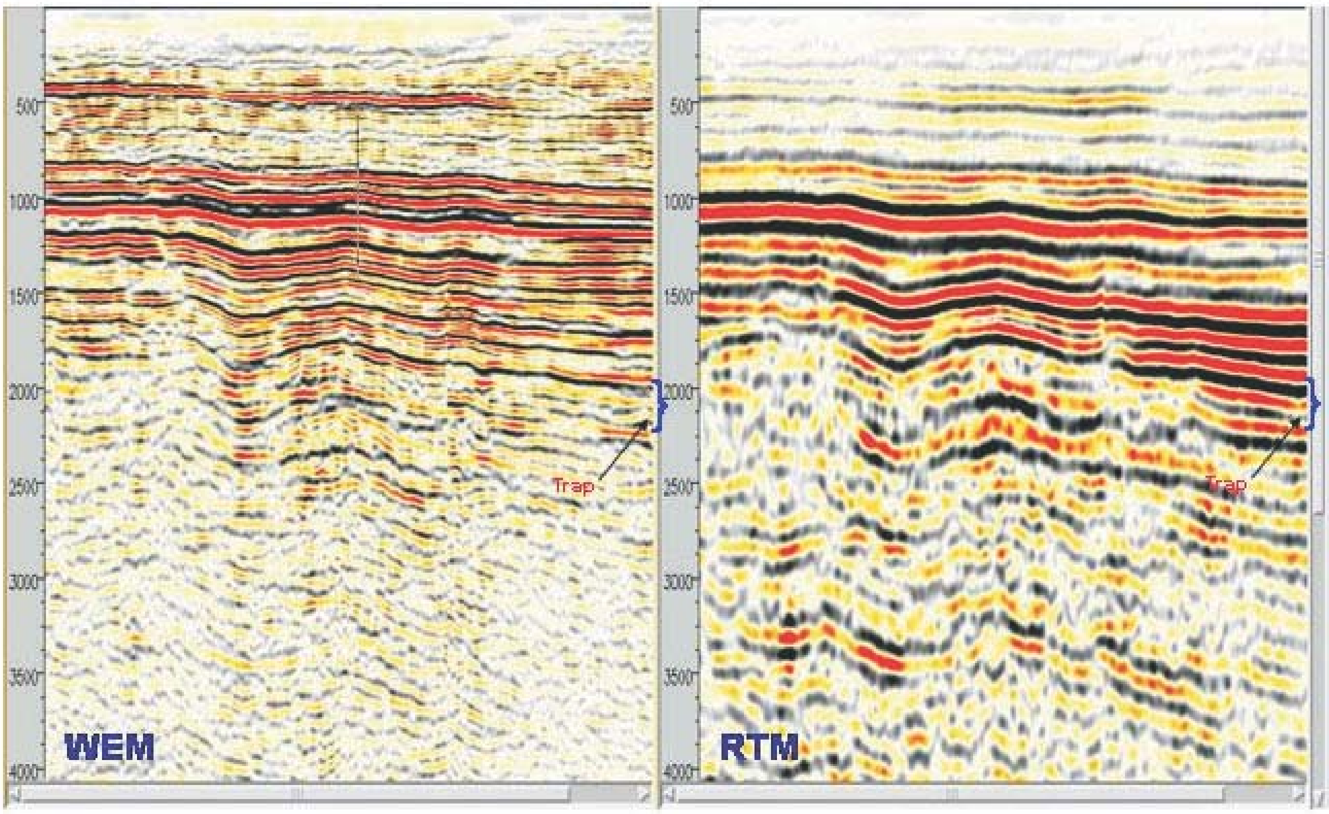

Fig. 2 Comparison of Wave Equation Migration (WEM) and Reverse Time Migration (RTM)

Because RTM elapse time and cost are directly proportional to the max frequency of migration output, the frequency parameter was kept relatively low (17 Hz) which has resulted in higher amplitude strength and a lower frequency from top to bottom in comparison to the other migrations. Unfortunately, the RTM software used for this analysis does not generate the PSDM gathers for a full comparison with other migration algorithms. A low frequency Kirchhoff image has been generated to match with RTM imaging (Fig-3) but RTM is still superior in terms of imaging, signal strength and fault resolution.

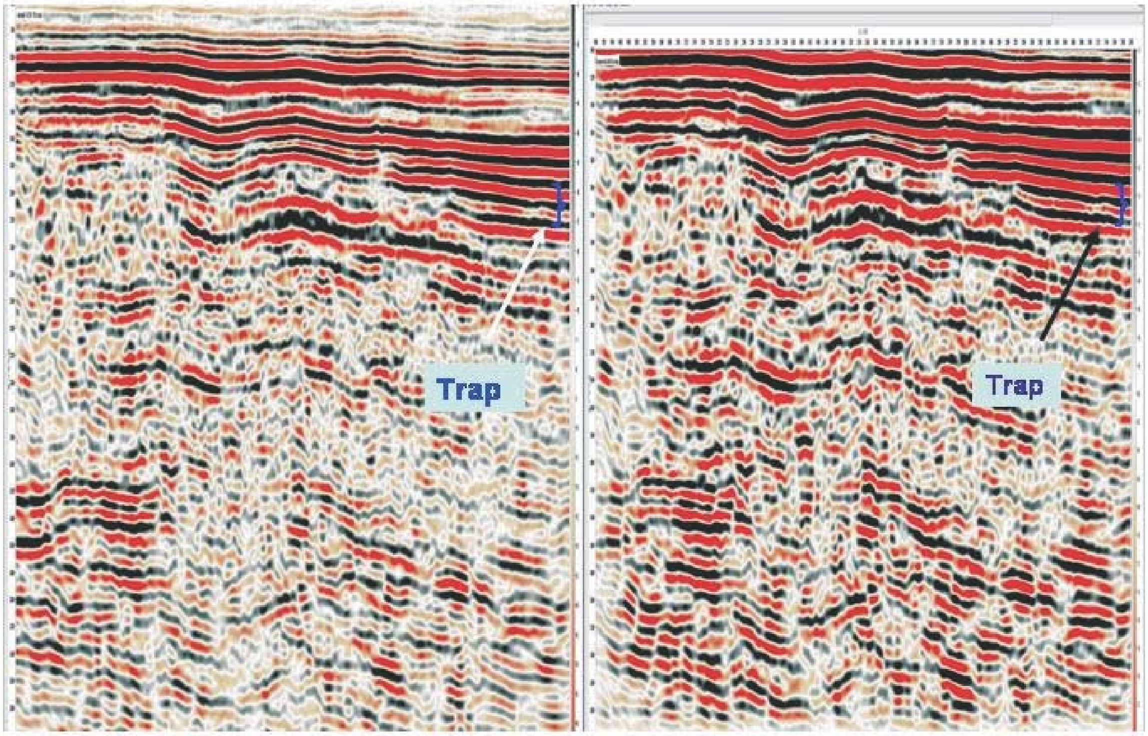

Fig.3 Comparison of Kirchhoff PSDM, on left (17 Hz) v/s RTM PSDM (17 Hz)

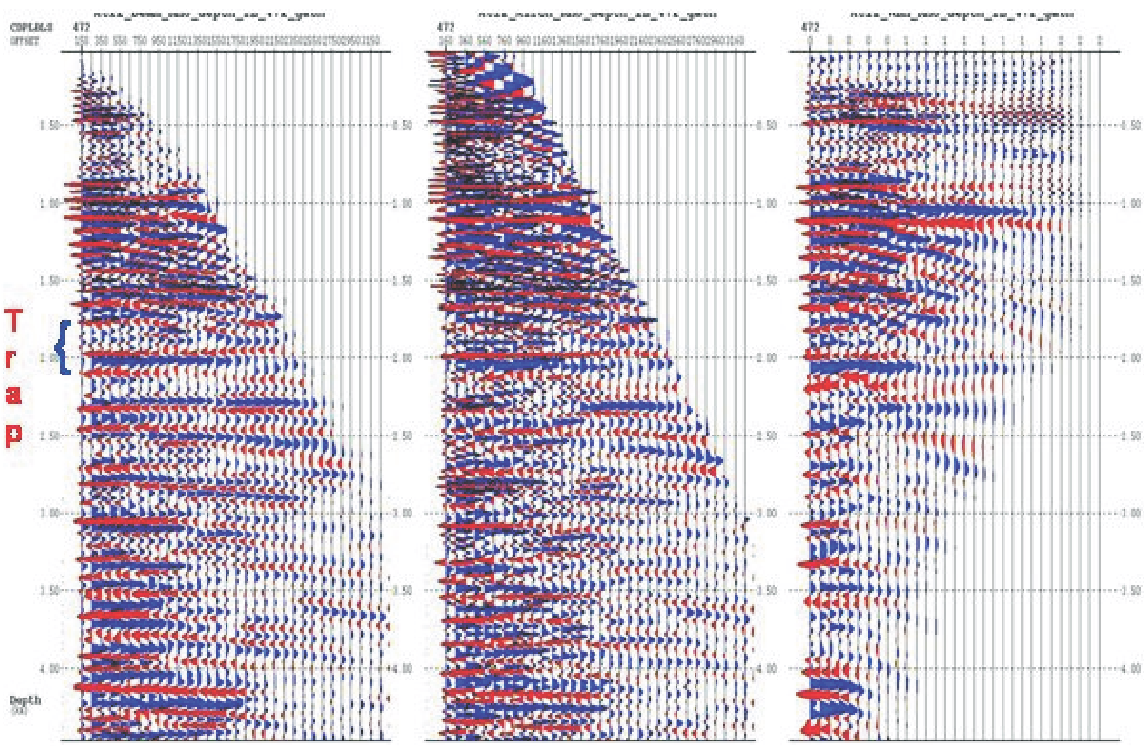

Fig.4 Comparison of PSDM gathers (left to right) Beam, Kirchhoff and Wave Equation Migrations, respectively.

Conclusions

Signal strength and quality of imaging in the Kirchhoff image is not adequate for mapping basalt top and bottom.

Wave Equation Migration image is better than beam migration and Kirchhoff migration, but contains considerable noise in the deeper section. Further, the migrated gathers are contaminated with the high frequency noise (Fig-4). Also, it is more expensive in terms of time & cost compared to Beam migration.

RTM image shows better signal strength and clear mapping of trap top and base in the section. Turn-around time & costs associated with RTM impose practical limitations on the frequency parameters which resulted in an overall low frequency output. Hence Beam migrated output is preferred over other algorithms in the present scenario.

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Recommended Reading

"Practical issues in reverse time migration: true amplitude gathers, noise removal and harmonic source encoding" by Yu Zhang and James Sun, First Break, Jan 2009, Vol. 27, Page 53.