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Beam Migration for Imaging of Complex Geology

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Summary

Kirchhoff migration has traditionally been the leading implementation for application of depth migration to seismic data. There are many reasons for this, such as efficiency, ability to image steep and even overhanging dips, and flexibility. And in most parts of the world Kirchhoff migration produces images that are as good as, or better, than the more expensive implementations using downward continuation algorithms. However, the limitations of Kirchhoff migration are well known and its inability to image more than a single arrival is the most damaging. Downward continuation algorithms, on the other hand, handle all arrivals but their inability to image steep dips is a severe limitation.

In geological situations where there is a complex overburden and the signal to noise ratio in the regions that are the target for exploration are low, Kirchhoff migration often fails to produce good images and if the target dips are steep, downward continuation algorithms cannot be used as an alternative. Such situations occur for example where complex and rugose salt bodies mean that very little energy reaches the target, where basalt layers stops most of the energy from reaching the target, or where the targets are faults or fractures in the basement. In these situations, the single arrival imaging of Kirchhoff migration fails to give a good image. Instead, artifacts caused by the "swinging action" of the migration often obscures the real targets and it is very difficult to distinguish artifacts from geology.

An alternative to Kirchhoff or wave equation migration is the so called "beam migration" which relaxes the single arrival limitation of Kirchhoff while retaining its steep dip capability. There are a number of different types of beam migration implementations such as Hill's Gaussian Beam Migration. Our implementation of beam Migration is unique in the industry and involves a decomposition of the data into dip components using the Radon transform and a back-propagation of the dip components into the earth. The dip components can be enhanced based on various criteria before the back-propagation, thereby giving a more coherent image. The methodology inherently allows the attenuation of multiple energy, and coherent as well as non coherent noise.

Our implementation of Beam Migration has merits of simplicity, economy, flexibility, and future development possibilities. Migrated images have excellent accuracy and quality, especially in areas of poor signal to noise ratio and steep dip. The relative economy makes it an excellent velocity estimation tool to use prior to other, more compute intensive, depth migration methods.

Method

The input seismic data is assumed to have been prepared with conventional preprocessing. Thereafter BPSDM consists of three important steps, decomposition, migration, and reconstruction.

1 *Decomposition*

A multidimensional slant stack decomposes the data into a **basis** of seismic wavelets, from 100-200 msecs. in time duration, within local surface spatial superbins each being centered on a uniform Cartesian grid of CDP xline and inline co-ordinates (x,y) and S-R half offset co-ordinates (hx,hy). Each wavelet should thus have a center location (x,y,hx,hy,t) and determined dip components (dt/dx, dt/dy,

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dt/dhx, dt/dhy), these contributing to the **properties** of the wavelet. For each spatial axis the grid interval between superbin centers is typically around 200 to 400 meters, and the superbin width is chosen somewhat larger in order to have overlap.

It is significant to note that this decomposition performs a desirable uniform spatial gridding or binning of the data, the result being essentially independent of minor variations in the data acquisition geometry (minimized acquisition footprint). Also the individual wavelets should not exhibit any aliasing effects, even for very steep time dips. Thus the BPSDM procedure bypasses the aliasing issues that are a very significant problem in both Kirchhoff and downward continuation wave equation migration. Note also that the wavelet amplitude is preserved, a vital issue for any future AVO or inversion operations, and that some random noise suppression is achieved at this early stage.

2. Migration

Given a wavelet's center (x,y,hx,hy,t) and dip components (dt/dx, dt/dy, dt/dhx, dt/dhy), plus a current earth velocity model, it is possible to 3D ray trace from source and receiver locations and determine some corresponding 'best' reflector migration location (xmig,ymig,zmig), together with ancillary properties such as reflector dip, reflector azimuth, angle of incidence at reflector, S & R wave front curvatures, local interval velocity, etc. It is of paramount significance that a **point to point** mapping exists between the unmigrated and the migrated center of each seismic wavelet. This means that the seismic wavelet decomposition forms a basis in the migrated domain as well as the unmigrated domain, the mapping function being the earth velocity model.

Note that migration is applied correctly to each coherent wavelet and this bypasses the multipath traveltime problem encountered with Kirchhoff migration. Also note that BPSDM does not suffer from the severe steep dip and turning wave limitations of typical wave equation migrations. Economics often force aperture limits in Kirchhoff migration and can result in not imaging steep dips and turning waves. The BPSDM independent point to point mapping of each wavelet clearly has no migration aperture issue.

Since S & R rays corresponding to a wavelet's properties normally will not intersect to give a model two way traveltime exactly equal to the wavelet center time t, it is also sensible to estimate a focussing quality factor, q. This is an additional valuable wavelet property. If the wavelet is truly a primary reflection, then q is representative of traveltime discrepancy along the composite S & R ray path and can be included in a tomography method. Alternatively, a poor focus value can be used to recognize a multiple reflection wavelet, or a converted wave event, with its NMO offset dip (dt/dhx, dt/dhy) significantly different from a corresponding primary reflection.

In summary, for a current earth velocity model, the migration operation determines and stores reflector location and associated properties along with each wavelet and its surface location and dip parameters. This stored point to point mapping between unmigrated and migrated space is very valuable and is not directly available with the Kirchhoff and wave equation methods.

3. Reconstruction

A seismic wavelet can be easily contributed to its local region in either unmigrated space or migrated space. In particular, the local nature of a wavelet and its associated migration properties enables a very limited wavefront Kirchhoff migration contribution to a 3D migrated depth volume (x,y,z) for the common offset (hx,hy). This yields certain improved signal to noise characteristics over normal full wavefront Kirchhoff migration, where data from millions of seismic traces do not necessarily cancel in an output quiet reflector area, such as salt.

Relevant ray path spreading properties enable amplitude correction of each primary reflection for its actual propagation path through the interval velocity model. This facilitates later AVO or inversion operations.

Note that any wavelet can be excluded or weighted down based upon a variety of individual or joint criteria for the wavelet properties, for example the quality of focus, thereby providing a powerful flexibility for coherent noise reduction in the unmigrated or the depth migrated data. Inline, xline or full volumes are output on appropriate grids, both for quality control and for residual moveout analysis on common reflection point depth gathers.

The residual moveout field is interpreted either manually or automatically, depending on the complexity of the data. This information is supplied to a tomography routine and enables the updating of the earth interval velocity model. The migration, reconstruction, and tomography steps are then iterated until a satisfactory velocity model is developed for which the common reflection point depth gathers are adequately flat. The final common offset volumes are reconstructed on an appropriately fine (x,y,z) grid. Since this operation is reasonably economic, it is normal to output volumes over the entire (x,y) common mid-point range of the input data.

Results

Results from the Beam migration proved to be superior to Kirchhoff and wave equation results in several respects. The quality and flexibility of the AGS implementation of BPSDM has been illustrated in many ways, such as its unique capability for handling steep and overturned dip, its demultiple options, the ability to handle extraneous coherent noise, the adaptability to anisotropic velocity earth models, its speed for iteration and the calculation of residual 3D RNMO for input to 3D tomography, the extension to multi- and wide azimuth data acquisition, and the capacity to handle both land and marine data.

Figure 1 is a comparison of Kirchhoff time migration and BPSDM applied to data from the Beaufort Sea (both plotted in time to help direct comparison). BPSDM was very successful at imaging steep dips where Kirchhoff PSTM had failed. Based on these images the structure is interpreted as an inversion anticline, not a shale diaper. Reservoir rock was identified in the core of the fold.

Figure 2 shows CRP offset gathers and stacks created using BPSDM on data from the KG-D4 basin off the east coast of India. After several iterations of migration and tomography there was still residual moveout due to unresolved local velocity anomalies associated with a rugose water bottom, slump sequences, and a strong velocity increase at the basement. After our efforts to solve the problem using velocity estimation and depth migration, further improvement was achieved using a non-hyperbolic residual moveout. The migrated offset gathers output by BPSDM allowed the flexibility required to address these data problems.

Conclusion

BPSDM does have the anticipated merits of simplicity, economy, flexibility, and future development possibilities. Migrated images have excellent accuracy and quality, especially in areas of poor signal to noise ratio and steep dip. BPSDM's relative economy makes it an excellent velocity estimation tool to use prior to other, more compute intensive, depth migration methods.

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References

1. Rieber, F., 1936, Visual presentation of elastic wave patterns under various structural conditions: Geophysics, 1, 196-218

Figures

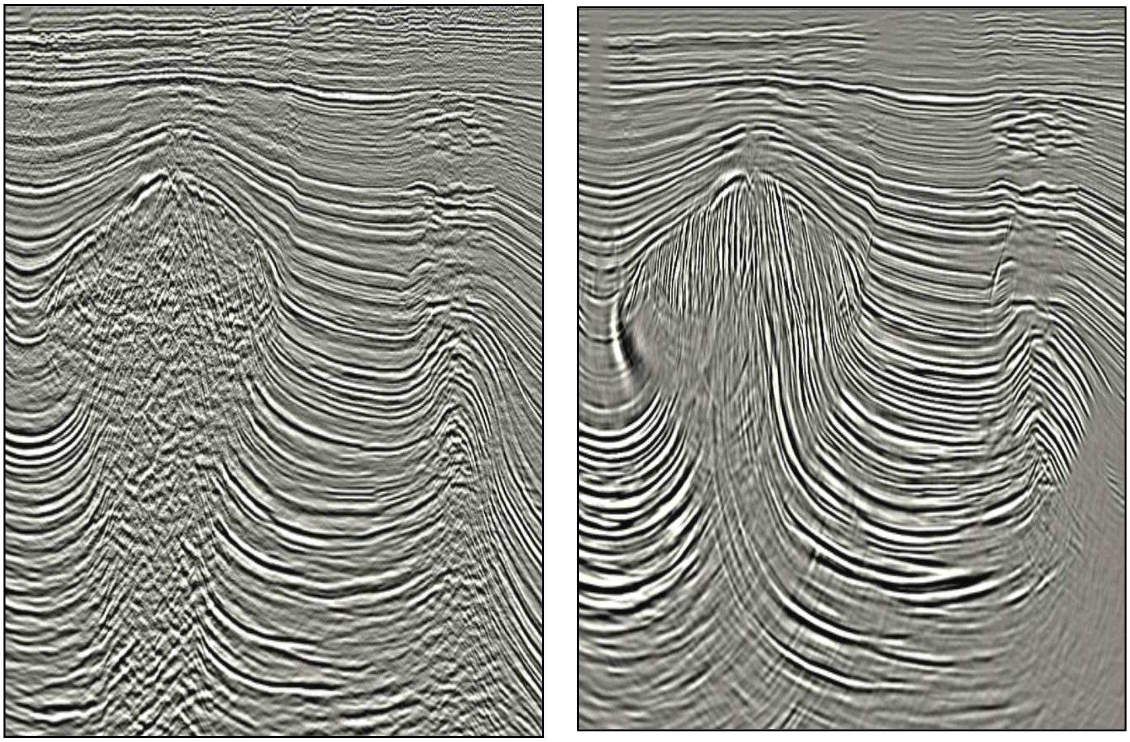

Figure 1: Kirchhoff prestack time migration (left) and BPSDM (right) on Beaufort Sea data. The beam migration imaged steep and overturned events.

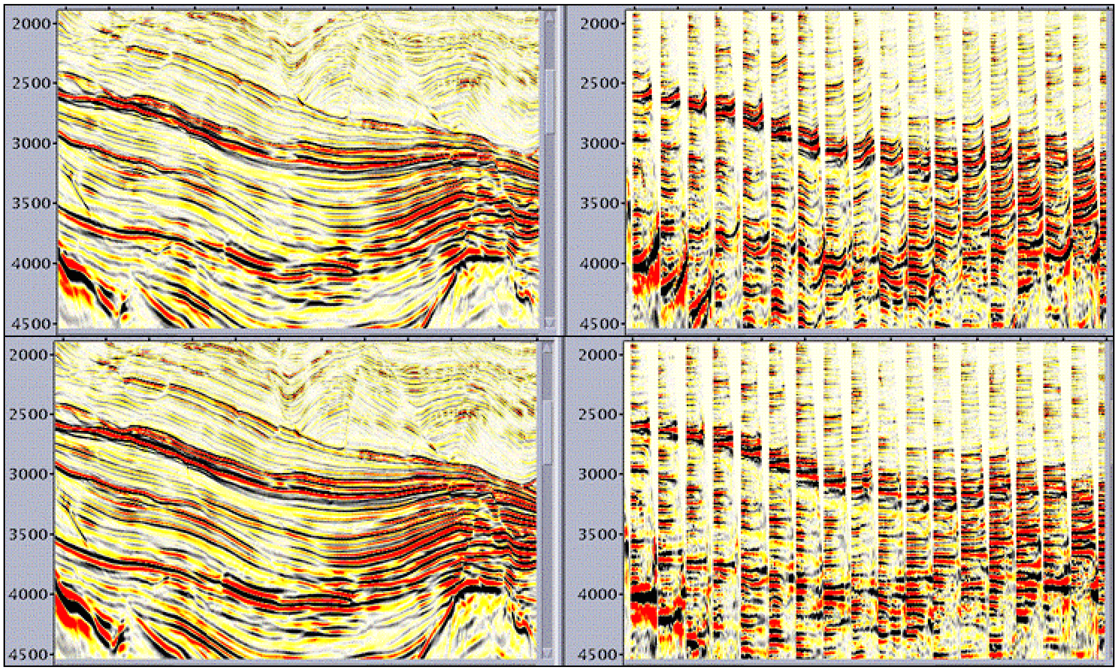

Figure 2. BPSDM from the KG-D4 basin, East of India. The stack and migrated gathers show residual moveout due to local unresolved velocity anomalies associated with a rugose water bottom and slump sequences. Residual moveout can be used to flatten the gathers and improve the stack.