Beam Pre-stack Depth Migration Algorithm in a 3D PSDM Non-exclusive Reprocessing Project, Sergipe-Alagoas Basin

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Abstract

Beam Pre-stack Depth Migration has provided a fast and reliable method of delivering a depth migrated cube for non-exclusive reprocessing projects in Brasil. The method was tested on a 3D reprocessing project in Sergipe Alagoas Basin with impressive results.

The Beam Pre-stack Depth Migration method was developed to overcome limitations in other commercial PSDM techniques and involves three main steps: decomposition, migration and reconstruction. This paper describes the process and presents results comparing pre-stack time migrated data with the beam pre-stack depth migration. The depth migrated data provides a much more accurate image of the subsurface, improving the chance of further discoveries in this new light oil province.

Introduction

Fugro's usual business in Brasil is reprocessing publicly available data from the BDEP data bank and licensing the reprocessed data to industry on a non-exclusive basis. A recent pre-stack depth migration project in the Sergipe Alagoas Basin produced impressive results, which may assist in further exploration of the Upper Cretaceous and Tertiary sequences in deeper water.

Pre-stack time migration reprocessing was applied to the 550km^2 Baixo Mosquiero 3D survey located 40 km offshore Aracaju, the capital of Sergipe, in the Sergipe-Alagoas Basin and included in Fugro's non-exclusive Brasil data library. The field data is available from BDEP and PSTM reprocessing achieved a nice result. It was noted, however, that due to the steeply dipping seafloor offshore Sergipe, that perhaps a pre-stack depth migration would produce a more valuable data set for evaluation of this area.

The most significant limitation of 3D pre-stack depth migration in multi client projects is the length of time taken to build a velocity model and then migrate the data (up to 8 months for a project of this size), together with the individuality of the velocity model used, i.e. different companies prefer to use their velocity model for the migration rather than a model created by the service company.

The Beam PSDM method was developed to remedy certain deficiencies in currently available commercial PSDM techniques and seemed suited to test on this project as migration time was expected to be less than 2 weeks! Other factors involved in selecting this dataset to test the Beam PSDM for a non-exclusive project were that the survey covers a relatively small area, has an unstable velocity field with a steeply dipping seafloor and could be used to assess potential for further hydrocarbon accumulations in a known light oil province.

The survey covers a prospective area adjacent to the SEAL-100 block (a 'blue block'), which contains the Piranema light oil discovery by Petrobras, and so the resulting PSDM cube image may assist in identifying other hydrocarbon accumulations.

Method

The basic method for Beam Pre-stack Depth Migration is applicable to conventional marine data with approximately zero shot-receiver (S-R) azimuth. It consists of three main steps applied after any relevant pre-processing such as trace editing, gain, noise-suppression, wavelet shaping, deconvolution, radon, etc:

1. Decomposition
The data is decomposed into seismic wavelets, from 100-200 ms in time duration, within local superbins each being centered on a CDP inline (y), xline (x) co-ordinate & a S-R offset (o). Each wavelet thus has a center location (x, y, o, t) and determined dip components (dt/dx, dt/dy, dt/do). Each superbin is typically about 400 meters wide in each of the three spatial axes (y, x, o), with the centers on a uniform grid with intervals around 200 meters.

It is worth noting that this decomposition performs a desirable uniform spatial gridding or binning of the data and compensates for small-scale non-uniformity in the data acquisition. Also the individual wavelets should not exhibit any aliasing effects, even for very steep time dips. Thus, this beam PSDM procedure bypasses aliasing issues which can be a significant problem in both Kirchhoff and downward continuation wave equation migration. Note also that the wavelet amplitude is preserved, which is a vital for any future AVO or inversion operations.

2. Migration
Given a wavelet's center (x, y, o, t) and dip components (dt/dx, dt/dy, dt/do), plus a current earth velocity model, it is possible to 3D ray trace from locations (x-o/2, y, z=0), (x+o/2, y, z=0) and determine some corresponding 'best' reflector migration location (xmig, ymig, zmig), together with ancilliary reflector parameters such as reflector dip, reflector azimuth, angle of incidence at reflector,

incidence ray path azimuth, S & R ray front curvatures, local interval velocity, etc.

The migration is applied correctly to each coherent wavelet and this bypasses the multipath traveltime problem encountered with Kirchhoff migration. Economics often force aperture limits in Kirchhoff migration, which can result in steep dips not being imaged correctly and in turning waves. Beam PSDM does not suffer from the severe steep dip and turning wave limitations of typical wave equation migrations, so the complete aperture of the input data is maintained.

Since S & R rays corresponding to a wavelet's parameters 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 focusing quality factor, q, which is a valuable measure.

If the wavelet is truly a primary reflection, then q is representative of travel-time 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/do significantly different from the corresponding primary reflection.

So, for a current earth velocity model, the migration operation determines and stores reflector location and associated information along with each wavelet and its surface location and dip parameters. This stored 'point to point' mapping between unmigrated and migrated space can be valuable and is not directly available with the Kirchhoff and finite difference methods.

3. Reconstruction
The wavelets and their associated migration information facilitate a very limited wavefront Kirchhoff migration which outputs a 3D migrated depth volume for each common offset, at any desired increments in x, y, z. 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 information enables correct amplitude correction of each primary reflection for its actual propagation path through the interval velocity model, which facilitates later AVO or inversion operations.

Any wavelet can be excluded from output based upon a variety of criteria, particularly quality of focus, thereby providing significant flexibility for coherent noise reduction in 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 and reconstruction 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 typical to output complete volumes over the entire (x, y) common mid-point range of the input data.

Results

The data examples below compare the Pre-stack Time Migrated section with the Beam Pre-stack Depth Migrated section. The depth migrated cube provides a much more accurate image of the subsurface, as travel time effects can often be forgotten when looking at time sections. The PSDM shows syn-rift sediments do not have monoclinal dip as they appear in the PSTM section. The depth migration shows structure in the syn-rift section, providing potential hydrocarbon migration pathways to an unconformity, overlain by a possible basin floor fan feature.

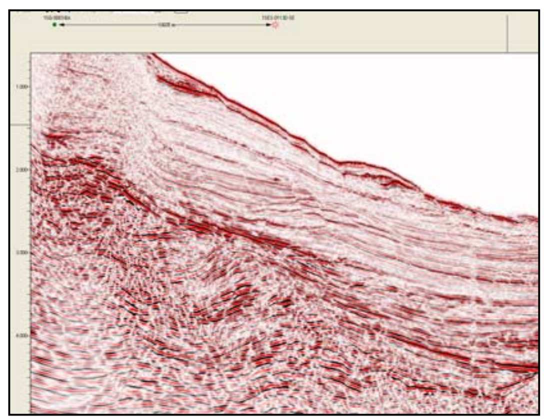

Figure 1 – Pre-stack Time Migration

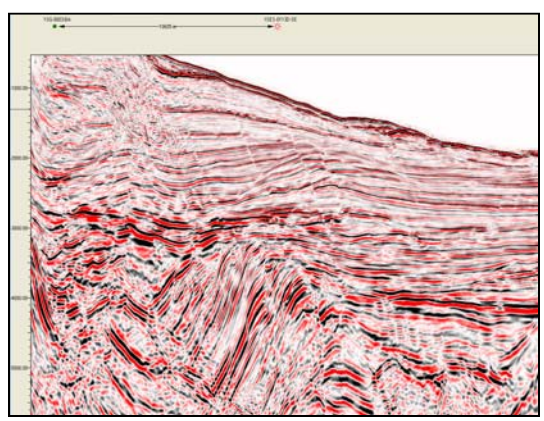

Figure 2 – Beam Pre-stack Depth Migration, note the significant structural differences in the syn-rift section.

The nearby Piranema discovery was made by Petrobras in SEAL-100 block and contains 41 to 43º API oil. Estimated reserves are 76MM barrels in water depths of 1200 to 1600m. The survey lies immediately to the south of this discovery and the data examples below show two wells, which missed an anomaly when drill locations are determined from time data. The depth migration has clearly imaged an amplitude-supported structure north of the previous well locations, just outside the SEAL-100 block.

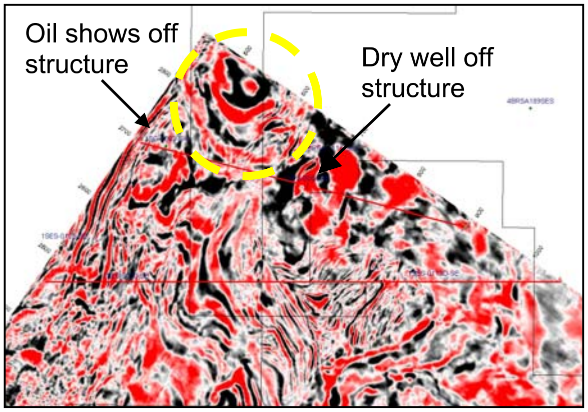

Figure 3 – Depth slice (3,250m) showing amplitude supported structure missed by previous wells.

Conclusions

Beam PSDM provides a fast and reliable method of creating a depth migrated cube, which easily lends itself to non-exclusive projects as the quick turnaround allows a reliable depth cube to be delivered with a PSTM cube. As the velocity model has been created in the non-exclusive depth migration, and can be accessed by licensees of the data for further iterations to suit a particular interpretation of the area, it provides a fast, convenient and reliable way to include depth migration in an area's database.

Depth migration in an area of velocity instability, or a steeply dipping seafloor can dramatically change the subsurface time image, providing a better earth model and so greater opportunity for successful exploration.

References

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