A Case Study Using the Beam-Derived Wavelet Attributes within Velocity Model Building

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SUMMARY

We show here a novel velocity model building approach using the Beam-derived wavelet attributes through a 3D PSDM case study in the UK northern North Sea. There are several advantages by using the Beam-derived wavelet attributes to update the velocity model compared with the conventional method. The most important experience acquired from this project is the velocity model building lifecycle is significantly shortened without compromising the quality. Additionally, this Beam approach has its unique flexibility in pre-conditioning and post-processing seismic data, e.g. demultiples, as well as resolving local velocity anomalies. It is also demonstrated how the pre-BCU challenge was tackled in this project.

Introduction

PGS has implemented a 3D PSDM project for TOTAL E&P UK in the northern North Sea (NNS). The velocity model building (VMB) process extensively utilised processing of Beam-derived wavelet attributes for data conditioning, tomography and to optimise the final structural image. The use of Beam wavelet attributes enables greater control of data selection than would be possible with a more conventional velocity model building approach which allows improved flexibility to work with selected parts of the image. Wavefield separation within the Beam domain can also be applied to remove undesirable noise when using other imaging algorithms.

Project Context

The project area is located in the UK North Sea with a water depth of 100-130m. The full-fold input area is approximately 600 square kilometres. The project comprised of a 3D VMB campaign which ran in parallel to a full integrity reprocessing effort. The VMB commenced with legacy pre-processed data but the newly re-processed data would be injected for final imaging using both Beam and Kirchhoff algorithms.

Processing data in this area of NNS brings with it various geophysical and data quality challenges that influence model building decisions. Such challenges include the following.

1. Strong water bottom and interbed multiple content that must be removed or discriminated against in order to tomographically update.
2. Shallow channels results in imaging distortion on deeper events.
3. Deeper channels in the Frigg/Lista cause more significant impact on deeper reflectors. Incorrect modelling of channel velocities causes pull-up on deeper events; the base Tertiary reflector should be flat in depth if channels are correctly modelled.
4. To the North West is a strong contrast as the East Shetland Platform rises up and strong lateral velocity variation, steeply dipping reflectors and faulting are seen.
5. Challenges associated with pre-BCU imaging, especially that of strong residual multiple content below BCU.

The VMB aspect was executed using Beam migration as this algorithm was deemed to have greater flexibility when dealing with the imaging challenges associated with this project.

Generation and processing of wavelet attributes

There are different implementations of Beam migration across the industry but this particular algorithm is based around a fast Beam implementation (Sherwood et al, 2009). As a summary reminder, the initial 3 steps of the Beam migration process are:

1. Decomposition

Step 1 consists of a multidimensional slant stack decomposition of the time processed input data into a series of seismic wavelets. The decomposition is made across a regular surface grid defined by crossline and inline coordinates (x,y) and with a regular sampling in time (t). By preserving the shot and receiver coordinates of each wavelet defined by half offset coordinates (hx,hy), the wavelet has associated dip components (dt/dx,dt/dy,dt/dhx,dt/dhy). These dip components are retained along with the amplitude thus defining a series of physical attributes for each wavelet.

2. Migration

The Beam migration itself is a point to point mapping between the unmigrated wavelet centre location and the corresponding centre in migrated space according to a supplied mapping function. The mapping function is generated by 3D ray tracing from source and receiver locations through a supplied velocity model.

It is important to note that the series of wavelets in unmigrated space have a corresponding series after migration. In addition to the physical attributes obtaining during the decomposition, new wavelet attributes are calculated such as reflector dip, reflector azimuth and angle of incidence etc.

3. Reconstruction

Reconstruction restores the series of migrated wavelets into the seismic domain and it is at this step that selection of the wavelet attributes occur. Thus, only those wavelets which are desirable to the seismic image are retained. There are many advantages and use cases of wavelet selection within the VMB process and examples of such shall form the basis of this discussion.

Data Pre-Conditioning

Prior to any velocity model update where Residual Moveout (RMO) curvature is to be analysed and updated using a tomographic approach, it is essential to first attenuate the influence of non-primary events. Assuming the velocity function is reasonable for primary reflections, a multiple reflection will retain appreciable moveout. When considering this multiple event decomposed into wavelets, the multiple wavelet would have dip in the offset dimension (dt/dhx, dt/dhy) which is far greater than a corresponding wavelet from a primary reflection which is mapped to the same image location. Therefore, removal of multiple reflections can be achieved by simply not reconstructing wavelets which have an offset dip value above a certain tolerance.

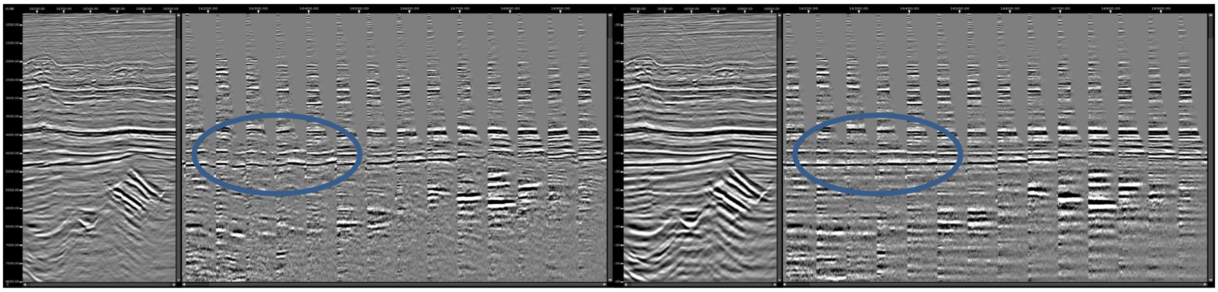
For this project, the VMB process commenced with legacy pre-processed data and progressed in parallel with a full integrity re-processing campaign. It was therefore essential that further pre-conditioning was applied to the data to enable reliable RMO estimates to be evaluated. Wavelet attributes were used for this purpose.

Velocity model updating using wavelet attributes

As discussed by Sherwood et al, (2009), the Beam migration algorithm allows calculation of a focussing quality factor, **q**. When ray tracing from the Shot and Receiver, the intersection of these two rays to give a two way travel time may not equal the centre of the wavelet in unmigrated time space. In such instance, the quality factor, **q**, is directly proportional to the residual timing discrepancy which culminates in the inaccuracy of the migration velocity model. Utilisation of this residual travel time forms the basis of velocity model update using Beam attributes.

The inversion stage is like its peer in conventional tomography using the residual moveout information. However, unlike conventional tomography where modelled curves are used to represent the observed residual moveout, in this application, the wavelet attribute describing the focussing quality factor, **q**, can be used for inversion. The residual travel time corresponds to a 3D repositioning of the wavelet centre normal to the local reflector dip that improves alignment with neighbouring migrated wavelets and is achieved using a cross-correlation method. This repositioning is a wavelet shift to an image location that improves the focussing quality factor and therefore the residual travel time to the optimal image location can be inverted to deliver an updated velocity model The tomography engine itself is very similar to the conventional approach. However since the shot and receiver location of each wavelet are known and the travel times computed during the migration stage (Step 2), there is no need for further ray trace which makes the Beam derived residual approach much faster than a conventional tomography implementation.

With Beam migration being the core of this method, there are unique ways of generating QC products during VMB. Again, it is emphasised that there are no generation of modelled moveout curves in this approach as the wavelets themselves describe the residual. For example, it is possible to apply the calculated wavelet shift prior to tomography and output these as Common Image Gathers (CIGs) and stacks. It is possible to iteratively calculate the wavelet shift before tomography until optimal CIG flatness and/or structural positioning is achieved (Figure 1). This iterative approach to residual calculation improves the robustness of the inversion and aids rapid convergence of the objective function.



(a) (b)

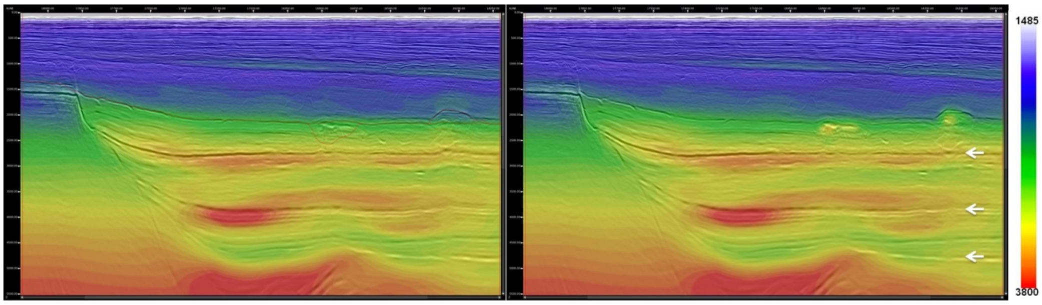
Figure 1 *Showing stacks and CIGs migrated with reference velocity model (a) and stacks and CIGs migrated with reference velocity model after 11 iterations wavelet shift calculation & application.*

However, it is also possible to produce similar QC tools as for the conventional VMB, which can be easily accessed by people who are familiar with the conventional VMB QC products. For example, it remains possible to generate a gamma attribute to quantify residual velocity error in a conventional sense.

Wavelet attributes to constrain velocity updates

In this particular project, two different kinds of channel systems existing in the survey area: seabed channels and buried channels. For seabed channels, the velocity update was following a normal interpretation/scanning based method. However for the buried channels, the localised velocity anomaly was updated in a semi-automatic way using the channel interpretation as the only additional input. This implementation utilizes wavelet attributes to separate the wavefield to constrain and improve the tomographic update.

Using the supplied interpretation of the top of the channel, it is possible to identify wavelets that migrate through that surface. By selected wavelets with a tag, the image can be separated into data that have a raypath through the channel and data that only sample the background sediments. This approach greatly simplified the moveout behavior observed on CIGs as the velocity anomaly was separated from the background trend. Once the high frequency moveout behavior associated with the channel was removed, the background sediment velocity was updated easily. The channels were inserted by a tomographic update constrained by data that sampled channels. Figure 2 shows this effective channel velocity update by comparing the velocity model before and after updating. From the seismic sections underlying, “pull-ups” are clearly observed but are flattened directly below the channels and the imaging is much better for focussed for deeper events. This mechanism can also be applied to resolve other velocity anomalies, e.g. gas pockets etc.



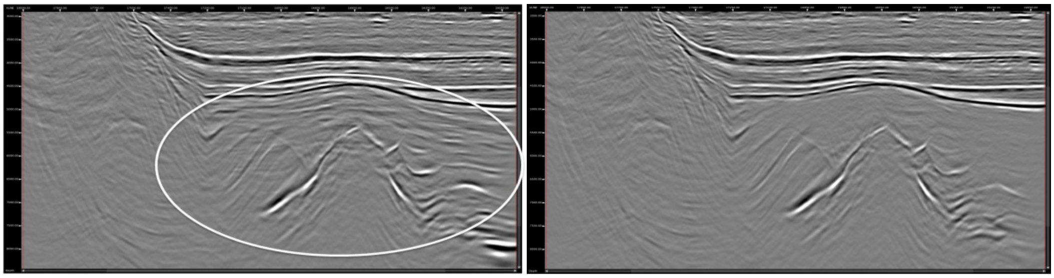
(a) (b)

Figure 2 *Buried channel update: (a) before and (b) after.*

Sub-BCU challenge

Sub-BCU (Base Cretaceous Unconformity) imaging has been a challenging problem for most, if not all, PSDM projects in the central and northern North Sea (Duquet et al. 2012). The BCU in the North Sea is mostly characterized by a big velocity inversion with very high chalk velocities in the layer above. This impacted the imaging quality below the BCU negatively in various ways, making it very challenging to resolve any structural complexity below the BCU and to eliminate any residual multiples..

Sub-BCU imaging suffers from severe residual multiple contamination even after state-of-the-art demultiple techniques have been applied. Using the Beam wavelet attributes defining inline-crossline dip (dt/dx, dt/dy) it is possible to reject wavelets which have structure similar to a supplied multiple generating surface. Figure 3 shows an example of the Beam guided demultiple applied sub-BCU. It is worth pointing out that this horizon guided beam demultiple is aggressive and that there is primary leakage however, this can be tolerated for the purpose of VMB.



(a) *(b)*

Figure 3 *Stack (a) before horizon guided beam demultiple and (b) after.*

Further work

The Beam-guided horizon demultiple is very effective at removing the sub-BCU multiples. Instead of rejecting these wavelets, it is possible to only accept the multiple reflection wavelets and generate a multiple model. Given that the point to point mapping of the migration process (Step 2) is reversible, it is theoretically possible to reverse the imaging process and output the selected wavelets in unmigrated time domain. These data could then be adaptively subtracted as a multiple model during pre-processing. Using wavelet attributes identified in the image domain but subtracted from the data pre-imaging would beneficial when imaging with other imaging algorithms such as Kirchhoff. This approach is currently being tested.

Conclusions

From the experience acquired on this project, the use of Beam-derived wavelet attributes has many uses throughout the VMB process. Although extensive use of Beam attributes is a new approach, it already offers a robust alternative to conventional methods centred around the Kirchhoff algorithm and indeed gives greater flexibility and control within VMB workflows.

Acknowledgements

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References

Duquet, B., Chavanne, E., Poupion, J.P., Rowlands M., Santos-Luis B. and Ugolini, J.M. [2013] Seismic Processing and Imaging in Central North Sea Area - Recent Advances and Remaining Challenges. *75th EAGE Conference and Exhibition Extended Abstracts*, Tu-07-11.

Sherwood, J.W.C., Sherwood, K., Tieman, H. and Schleicher, K. [2009] 3D Beam prestack depth migration with examples from around the world. *The Leading Edge*, **28**, 1120-1127.