PSDM for improved imaging under seafloor channels - Browse Basin, Australia case study

Helen Debenham
Fugro Seismic Imaging
Perth, Australia
H.Debenham@fugro-fsi.com.au

Shane Westlake
Finder Exploration
Perth, Australia
S.Westlake@finderexp.com

SUMMARY

In the Browse Basin, as in many areas of the world, complex seafloor topography can cause problems with seismic imaging. This paper compares ways in which imaging can be improved under seafloor channels, using both time and depth domain processing.

In the time domain, to improve on the standard PSTM we applied removable seafloor statics in order to reduce the push down effect under seafloor channels prior to migration. This allows for better event continuity in the seismic imaging below. However this approach does not fully tackle the problem, still giving sub-optimal imaging, leaving amplitude shadows, and structural distortion. Only depth domain processing with a migration algorithm that honours the paths of the seismic energy as well as a detailed velocity model can provide good imaging under these seafloor channels, and give confidence in the structural components of the exploration targets in this area. We therefore performed depth velocity model building followed by PSDM, and produced a much improved result..

Key words: PSDM, channel, modelling, Browse, Australia.

INTRODUCTION

The study area is located along the boundary of the northern Browse Basin, in the Territory of Ashmore and Cartier Islands, 400-450km off the northwest coast of Western Australia. The area lies adjacent to the Permit AC/P 52 (Figure 1) and approximately 100km northwest of the giant Ichthys gas field. The area also lies 30km to the north of the Argus gas discovery. Water depths across the permit range from 400m to 1330m and Line BR98-136 traverses across 3 major northeast to southwest orientated, present day, seafloor channels.

The Browse Basin exploration has typically been inboard of the shelf break but regional geology, play fairways and prospective, structural trends are all observed to extend across the shelf edge and into the deeper water. Prospectivity of the area is dominated by what underlies the regional Middle Cretaceous, Jamieson Formation seal, typically greater than 3km below mud line. The Upper Jurassic Oxfordian sandstone overlies tilted blocks of the Lower to Middle Jurassic Plover Formation and the Upper Triassic sandstones of the Nome Formation. Overlying the prospective units is a thick Tertiary blanket of prograding carbonates and recent seafloor channels that have formed within the last 5.2Ma and are up to 700m in depth. Underneath these channels at the target zone, seismic data typically suffers from low amplitude and frequency and are poorly migrated. The lack of good imaging limits seismic interpretation, is not AVO friendly and adds significant uncertainty to the structural risk in a highly prospective basin.

Finding a solution to this imaging problem could aid in identification of new and additional multi TCF targets outboard of the Browse Basins current exploration trend.

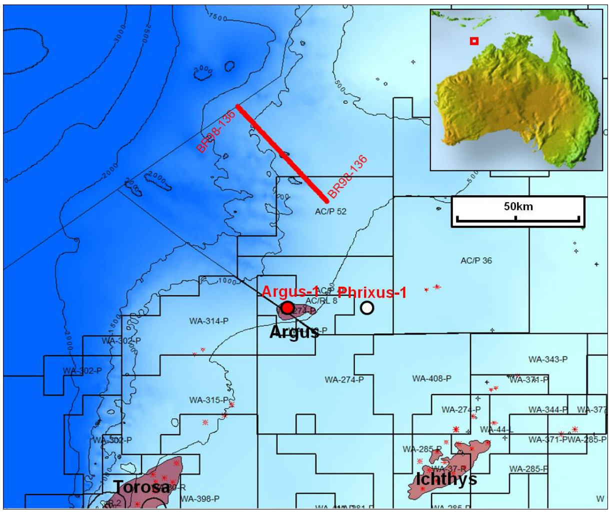

Figure 1. Location map showing the position of Line BR98-136 across the AC/P 52 Permit.

METHOD

Reprocessing work was undertaken on line BR98-136 with the aim of improving the imaging under channels. Along with a standard PSTM, two alternative solutions were tested: seafloor replacement statics followed by PSTM, and depth velocity model building followed by PSDM.

Seafloor replacement statics

The lateral velocity variations associated with seafloor channels violate the underlying assumptions of CMP stacking and Kirchhoff time migration. The calculation and application of seafloor replacement statics can reduce the influence of these lateral velocity variations.

Replacement statics calculations require information on the seafloor depth both with and without the presence of channels. First we picked the seafloor reflection on a nearoffset section that had been time migrated with a constant velocity of 1500m/s. We then interpolated this interpretation across the channels, and the two horizons (i.e., with and without channels) were converted to depth. The difference between these horizons yielded the channel depth at each source and receiver location.

Estimating a replacement velocity of 2000m/s from the interval velocity of the sediments surrounding the channels, we calculated replacement statics for each source and receiver location using the corresponding channel depth and the water-sediment velocity contrast.

We performed conventional stacking velocity analysis on the static-corrected data, and surface consistent residual statics analysis was used to correct for the remaining short wavelength statics variations. Finally, we migrated the data using a Kirchhoff PSTM.

Depth migration

We performed top down iterations of tomographic velocity updating on the velocity model in order to derive a final depth interval velocity model for PSDM. (Jones *et al*, 2007). The velocity model building was broken down into 10 model building units (MBUs). Tomographic updating was performed on each MBU until optimum gather flattening and imaging was achieved, before moving onto the next MBU.

Using a combination of horizon interpretation and regional well velocity information, we created an initial velocity model that was verified with seismic RMS velocities in regions away from the worst seafloor channels.

We made a seabed interpretation on the PSTM stack and inserted a fixed water velocity above this. However, when initial depth migration iterations were run in the model building process we noted that the imaging around one of the channels was not improved by as much as expected by depth migration. The shallower events, initially picked as the water bottom, on the PSTM seismic data may be artefacts related to prism rays or multiple seabed bounces that can be generated from the walls of the channel. Alternatively a channel fill of highly unconsolidated sediment could have seismic velocities very close to water velocity. Imaging of the events below was greatly improved when the seabed interpretation was altered to a deeper reflector and the velocities above this clipped back to water velocity (Figure 2).

Modelling the velocities around the seafloor channels, allowing for high frequency velocity variations was critical in building an accurate shallow velocity model. This took into account the differing overburden pressure of the water column, versus the sediment column. High resolution updates were required in the upper six MBUs in order to resolve large lateral changes in velocity. These are related to palaeo-channeling and complex variation of velocity within the prograding sediments.

Based on well ties to Argus-1 and Phrixus-1 we were able to calibrate imaging velocities with well velocities to determine parameters for VTI anisotropy. Significant anisotropy was observed in the Jamieson Formation corresponding with delta values (Thomsen 1986) of 12%, and epsilon values of 18%, determined by migration scans.

RESULTS AND DISCUSSION

The reprocessing of line BR98-136 was all carried out at the same time and with the same pre-migration processing flow. To compare the three methods as best as possible all depth to time conversions are performed using the final depth interval velocity derived for the PSDM. The amplitudes have been left as true amplitudes before any pre or post stack scaling has been applied.

Figure 3 shows some improvement of imaging in both the time and depth domain from the standard PSTM stack to the PSTM with seafloor statics stack. There was additional uplift in data quality with the PSDM solution.

The PSTM stack (Figure 3a and b) completely breaks down in imaging underneath all the seafloor channels. Event continuity is completely lost immediately underneath the channels and radiates outwards with depth to an extent several times larger than the width of the channel itself. When stretched to the depth domain the structure is completely distorted and any interpretation of the target zone at 4.5-5km (3.2-3.5sec) would be of low to very low confidence.

With the seafloor replacement static applied to the PSTM (Figure 3c and d) the results can be seen to improve event continuity below the channels with dimming zones radiating out from the seafloor channel as “shadow zones” rather than completely lost. When stretched to depth you can see that the target zone structures are better illuminated and first hints of rotated tilted fault blocks are imaged to be sub-cropping. The imaging, however, still suffers from distortion and significant amplitude loss.

The calculation and application of seafloor replacement statics is straightforward and computationally inexpensive. However, this method assumes vertical ray paths, constant replacement velocity, and time-invariant static shifts. In reality, the static shifts are neither surface-consistent nor time-invariant (see, e.g, discussion in Blackburn 1981). Wave-equation datuming might instead be used to remove channels prior to time migration, although the determination of a replacement velocity remains somewhat subjective (Berryhill 1986). Pre-stack depth migration is not subject to the above limitations, and can be used in conjunction with depth velocity model building.

The PSDM results (Figure 3e and f) show greatly improved event continuity under the channels along with better amplitude preservation laterally. This is best exemplified under the smaller channel features on the left of the image whereas the imaging under the larger seafloor channel on the right still suffers from some amplitude loss. This channel cuts the line obliquely causing some of the energy to be lost offline and never recorded in acquisition. The biggest improvement is seen at the target depth as the channel “shadow zones” are very well resolved and high reflectivity is preserved. In the depth domain the channel velocity effects are removed from the data, shown by well defined flat horizons between 1.5 and 2km. At 2.7km deeper channels are apparent, not as an artefact of the seafloor, but as Oligocene aged channels underlying the present day seafloor scours. Through the improvement of velocity modelling in the shallow section the Oligocene channels could be tomographically resolved as demonstrated by underlying laterally continuous events at 4km. This cascade effect of improvements could not be resolved using the other techniques.

Underneath the regional seal at 4.5km, several horizons can now be defined with at least two major unconformities. Seismically visible onlap on the upper unconformity (the JO Oxfordian unconformity), and angular subcrop at the lower unconformity (the JH base Jurassic unconformity) are interpreted to define the top and base Plover Formation that is a primary reservoir target of the Browse Basin (Jablonski and Saitta, 2004). This level of detail provides the interpreter with key seismic picking criteria improving confidence in long distance well ties and direct analogues to nearby fields. This positively impacts the exploration potential of the Northern Browse Basin along the shelf edge.

CONCLUSIONS

While seafloor replacement statics provides good imaging uplift over the standard PSTM results, it is not adequate for properly resolving the structure and preserving amplitudes below the seafloor channels. With both the complex shallow overburden correctly modelled, and the VTI anisotropy correctly determined, both the imaging and the structural validity of the PSDM result was a step change above either PSTM route.

The ability to image the unconformities and define the prospective zone, high grades this area for further hydrocarbon exploration, despite the work being conducted on 2D seismic only connected to the well data by a series of tie lines. With PSDM processing, geological play fairways can be mapped under the shelf break in the vicinity of AC/P 52. The improved structural picture and better velocity control will significantly de-risk the structural component of the exploration targets in this area.

ACKNOWLEDGMENTS

Thanks to Fugro Seismic Imaging for permission to present this work, to Finder Exploration Pty Ltd and Sasol Petroleum Australia Limited for permission to show the data. Thanks also to Narcisa Lazarescu for her work on the replacement statics solution amongst other things.

REFERENCES

Berryhill, J.R., 1979, Wave equation datuming: Geophysics, 44, 1329-1344.

Blackburn, G.J., 1981, Seismic static corrections in irregular or steeply dipping water-bottom environments: Exploration Geophysics 12(4), 93-100.

Jablonski, D. and Saitta, A.J., 2004, Permian to Lower Cretaceous plate tectonics and its impact on the tectono-stratigraphic development of the Western Australian margin: APPEA Journal, 44(1), 287-327.

Jones, I.F., Sugrue, M.J., and Hardy, P.B., 2007, Hybrid grid tomography: First Break, 25(4), 35-41.

Thomsen, L.,1986a, Weak elastic anisotropy: Geophysics, 51, 1954-1966.

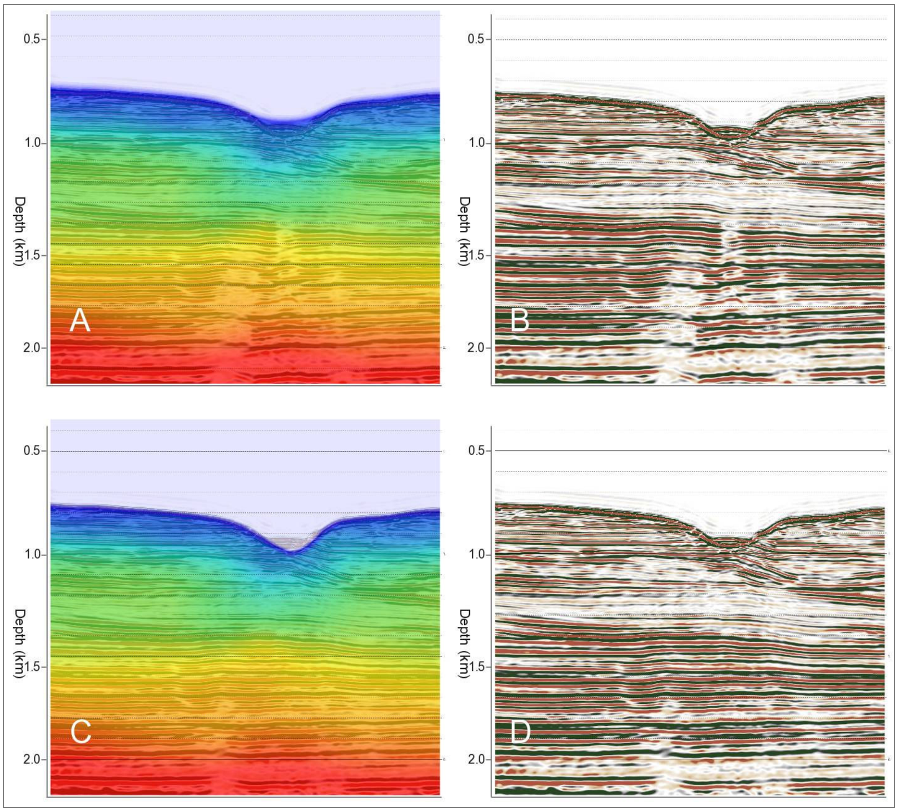

Figure 2. Examples of the difference to the PSDM imaging that small changes to the water-bottom interpretation can make. A - Original velocities. B - PSDM stack from model shown in (A). C - Velocities as shown in (A) but with water velocity replacing the sediment velocity in the centre of the channel. D - PSDM stack from model shown in (C) showing improved event continuity.

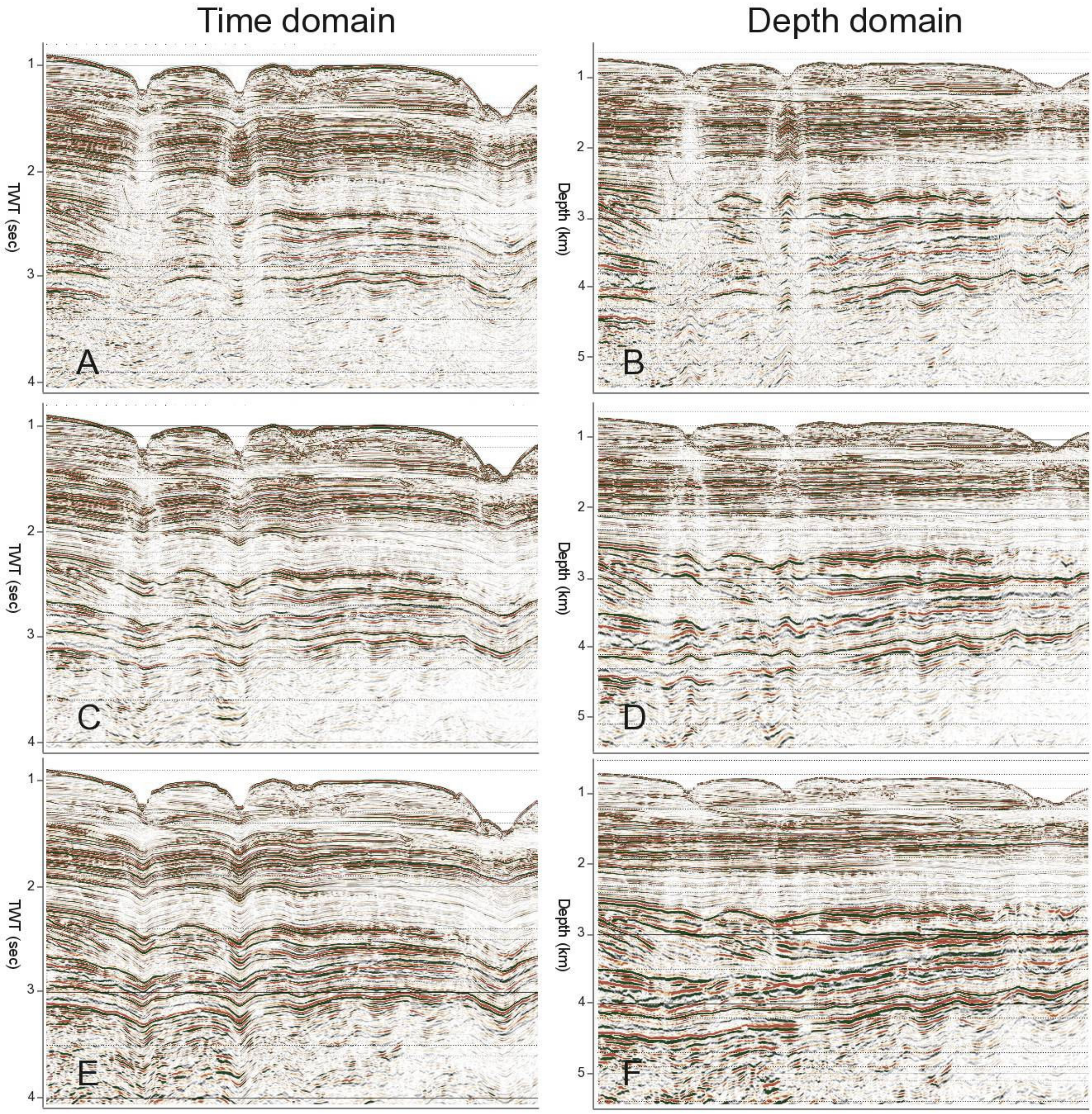

Figure 3. Stack comparisons showing stacks generated by each of the methods tested, clearly showing the effects on both structure and imaging that the choice of solution produces.
A - Standard PSTM - time domain
B - Standard PSTM - depth domain
C - Seafloor statics followed by PSTM – time domain
D - Seafloor statics followed by PSTM – depth domain
E - PSDM – time domain
F - PSDM – depth domain
All conversions between time and depth, and depth and time were performed using the PSDM migration velocities. No AGC has been applied, all stacks are shown at true amplitude.