ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15 – 18 February 2015 Perth, Western Australia

A Stable Tomographic Solution for Anisotropic Epsilon – A tool to aid in exploring for Oil in the Northern Carnarvon Basin.

Helen Debenham
ION-GXT
578-586 Murray St, West Perth
helen.debenham@iongeo.com

Shane Westlake
Finder Exploration
9 Richardson St, West Perth
s.westlake@finderexp.com

SUMMARY

AVO studies have typically been used in the search for gas on the North-West Shelf for decades, but its use for identifying oil filled reservoirs has been limited by the effective meaningful angle range obtainable from the seismic data.

We have performed tomographic updates of the anisotropic parameter epsilon to obtain flatter and cleaner gathers out to a much higher angle range than traditional anisotropic assumptions. This then gives the ability to use the data for AVO much more effectively.

Key words: Tomography, Epsilon, Anisotropy, Northern Carnarvon Basin, AVO, Oil

INTRODUCTION

Many gas reservoirs in the Northern Carnarvon Basin are significantly de-risked prior to drilling using amplitude--versus-offset (AVO) or amplitude-versus-angle (AVA) studies (Walker 2007). Fewer oil discoveries have been de-risked this way. A number of limitations exist when applying these studies and this paper is addressing the limitation of data quality in the very far angle range which is so often critical in measuring elastic properties in the search for gas but even more importantly the search for oil.

The study area (Figure 1) is located in the Northern Carnarvon Basin and lies along strike to, and within the same Lower-Middle Jurassic petroleum system that has sourced the Mutineer, Exeter, Egret and Fletcher Oil discovers (Jablonski et al 2013). Synthetic AVA modelling (Figure 2) of the Fullswing-1 well drilled by Japan Energy demonstrates that the Jurassic reservoir (in this case the O.*montgomerii* biostratigraphically aged Tithonian sandstones) sealed by Cretaceous claystones (the Forestier Claystone) has the potential to not only identify where the sandstones would be expected but also if there are fluids in place, both oil and gas. The difference between a brine and gas case could be seen across all angles as a strong amplitude increase with class 3 AVO (Rutherford and Williams 1989) and would be expected to be seen on conventional seismic. The difference between the brine and oil case is much more subtle with the major differences only being noticed in the 35-50°angle range. While there are other contributing factors as to why real data does not behave like synthetics, this study suggests that to use AVO and AVA studies in the search for oil in this part of the world, it is critical to get clean and flat gathers out to very high angles.

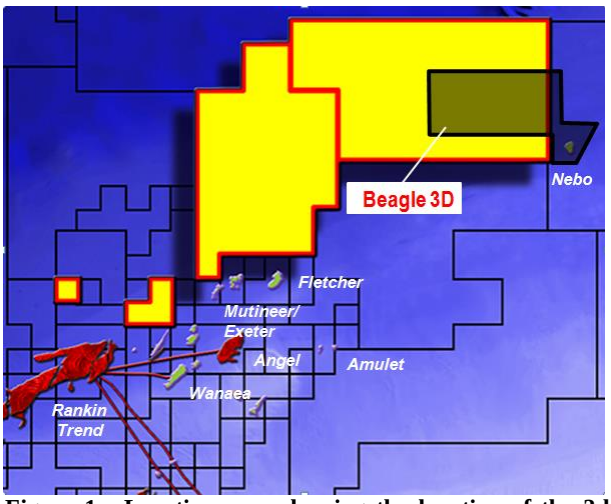

Figure 1. Location map showing the location of the 3d survey used in the tests, and showing surrounding hydrocarbon discoveries, and Finder Exploration permits.

The imaging of these high angle ranges required for successful AVA studies are very heavily dependent on correctly parameterising the seismic anisotropy. Anisotropic imaging has been commonplace in PSDM projects from the North-West Shelf for many years, and although most industry standard tomography packages have an option for inverting for epsilon, this is rarely done due to the instability of the results. Using new developments in tomographic solvers, along with improved picking algorithms and structurally oriented smoothing, a stable epsilon result can be obtained.

The traditional route for obtaining the Thomsen anisotropic parameters (Thomsen 1986), has involved using well calibration to obtain an estimate for delta (which mostly affects near offset move-out) and then making a global assumption for epsilon (which primarily affects far offset, high angle, move-out). These assumptions are often either elliptical anisotropy (epsilon = delta) or a simple mathematical relationship, the most common being epsilon =1.5*delta. These assumptions do not hold well on the Northwest Shelf, where eta, (the relationship between delta and epsilon) can be quite complex. Pre-Stack Time imaging uses the anisotropic parameter eta, and several previous projects have shown that variations in eta can be large and spatially variable.

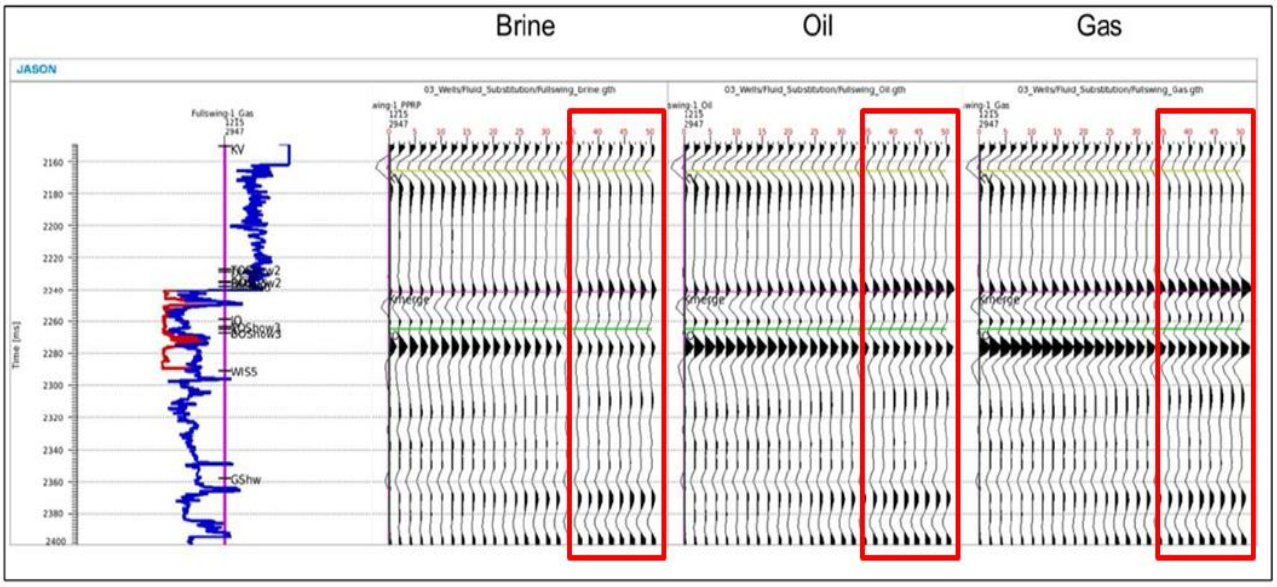

Figure 2. AVA synthetics for Fullswing-1.
The AVA synthetics for in-situ and 70% Oil and Gas saturation cases. Blue- In-situ case, Red- Gas case.
Modelled sands have a class 3 AVO response at the top. Total amplitude strength increases in the oil case, and greatly increases in the gas case. The red boxes highlight the angle range 35-50°, without which seeing the oil response would be very difficult.

EPSILON TOMOGRAPHY

Thomsen's anisotropic parameter epsilon (Thomsen 1986) is related to the ratio of vertical to horizontal P-wave velocity. Since horizontal velocities cannot be measured directly, correct parameterisation of epsilon is not simple. Epsilon primarily affects far offset move-out where more of the horizontal component of the ray paths have been sampled.

In order to use tomography to invert for epsilon, high quality picks of far offset move-out are required. The mathematics required to solve for epsilon are not a great deal different to solving for velocity, so tomographic solutions for epsilon have been possible for almost as long as those for velocity. However the matrix is very under defined and the input picks often very erratic. This can lead to a very unstable result, which explains why tomographic epsilon is not part of most standard VTI or TTI PSDM model building workflows.

To overcome the instability problems of epsilon inversion advances in several areas have needed to come together

Move-out picking

Tomography can only be as good as the picks that are put into it. Traditional picking algorithms did not provide quality picks to high angles and it has taken significant uplifts in picking technology to obtain stable enough picks to be used for epsilon tomography. Even multi-parameter move-out curves struggle to properly represent the complex far offset move-out present in areas of laterally varying epsilon, and so a non-parabolic pick is required. Non-parabolic pickers are often based on waveform trackers or plane wave destructor algorithms designed originally for tracking horizons on stack data, and hence often break down as the frequency content changes across an offset gather. This effect is worst at far offsets where the picks are most important for epsilon tomography. A picker designed to handle the changing nature of the data across offsets is required for a stable epsilon tomography. We have used ION-GXT's latest non parametric picker, which was designed with these ends in mind. (Luo *et al* 2014)

Tomographic inversion

The tomography matrices used are very underdetermined and this is not an easy problem to solve, but new generation tomographic solvers, combined with high density, high quality input picking, are helping to get past this obstacle. Increases in compute power mean that higher density input grids are able to be used in velocity model building, and a greater number of solver iterations can now be run.

Result stabilisation

Within a tomographic solver the results are stabilised between solver iterations using smoothing. Traditionally simple lateral smoothers have been used, but the smoothing lengths required to stabilise an epsilon solution have usually been so large as to destroy any detail in the solution.

Recently better methods of smoothing have become available (Hale 2009), and incorporating these into internal tomography smoothing were a natural next step. ION-GXT's structurally oriented signal enhancement (SOSE) uses a stack input to compute structure tensors. They are the smoothed outer products of image gradients. The eigenvalues of these tensors give us a measure of isotropy, linearity, and planarity for that specific sample, as well as the direction of the linear or planar features that we discovered. We compute the 3D structure oriented semblance from these eigenvalues. This semblance is then used to drive the stabilisation step in between iterations within the tomography solver. This has the effect of stabilising along structure, and within geological units, but avoiding smoothing across faults, or horizon boundaries

METHOD AND RESULTS

In order to compare traditional methods of epsilon determination with the tomographic solution, two migrations were performed. One was run using an epsilon volume where *epsilon = 1.5x delta* (figure 3a). This relationship was chosen, since that is a very common assumption used in the industry. Another migration was run using epsilon which had been derived tomographically (figure 3b). The same velocity and delta models were used in both migrations. Delta was derived based on continual well calibration performed during the velocity model building, and was propagated between well points guided by interpreted horizons.

Figure3 shows the two epsilon models used in this test. The tomographically derived epsilon shows much more variability, especially within the Tertiary progrades, where distinct sets of alternating high and low epsilon have been distinguished.

Figures 4a and 4b show the migrated gathers from both tests with angles annotated. The far offset move-out is much improved in the tomographic result, where the detailed epsilon model in the prograding units has allowed for the spatial control over the far offset move-out. In particular on the 3rd gather, at both 1900m and 2500m, the events are much flatter and less stretched.

Figure 5a and 5b show stacked results from these migrations using an angle range of 35-50 degrees. This is the angle range that is most important for identifying an oil response, and is also the range most likely to be discarded from AVO analysis due to poor quality. Key features to note are the improved focussing and clarity of the horst block just left of centre in the images at around 2.6-2.8km depth, with the reservoir sands being clearly visible on the stack produced using tomographic epsilon. This same sand unit can also be seen pinching out in the fault block on the right side of the image, but is less clear on the 5a.

Obtaining gathers flat to higher angles, not only allows for more optimum stacking, but also allows for harsher use of standard post migration demultiple tools such as Radon, as well as giving more stable AVA inversion results.

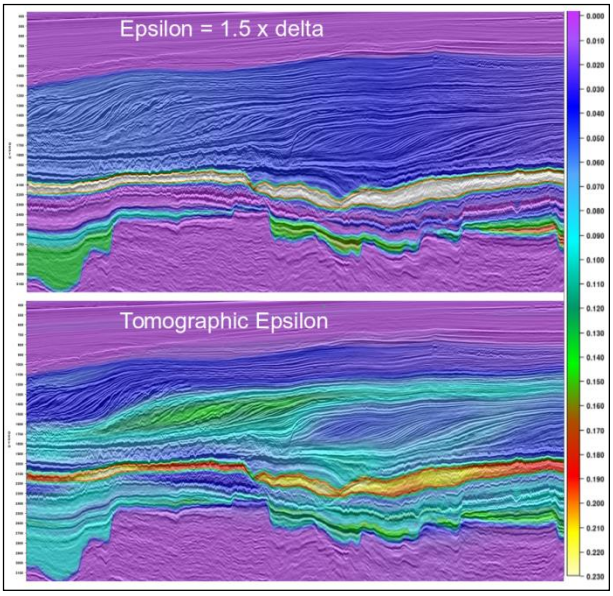

Figure 3. Epsilon= 1.5*delta above, and tomographically derived epsilon below (Seismic data courtesy of Fugro, used by permission)

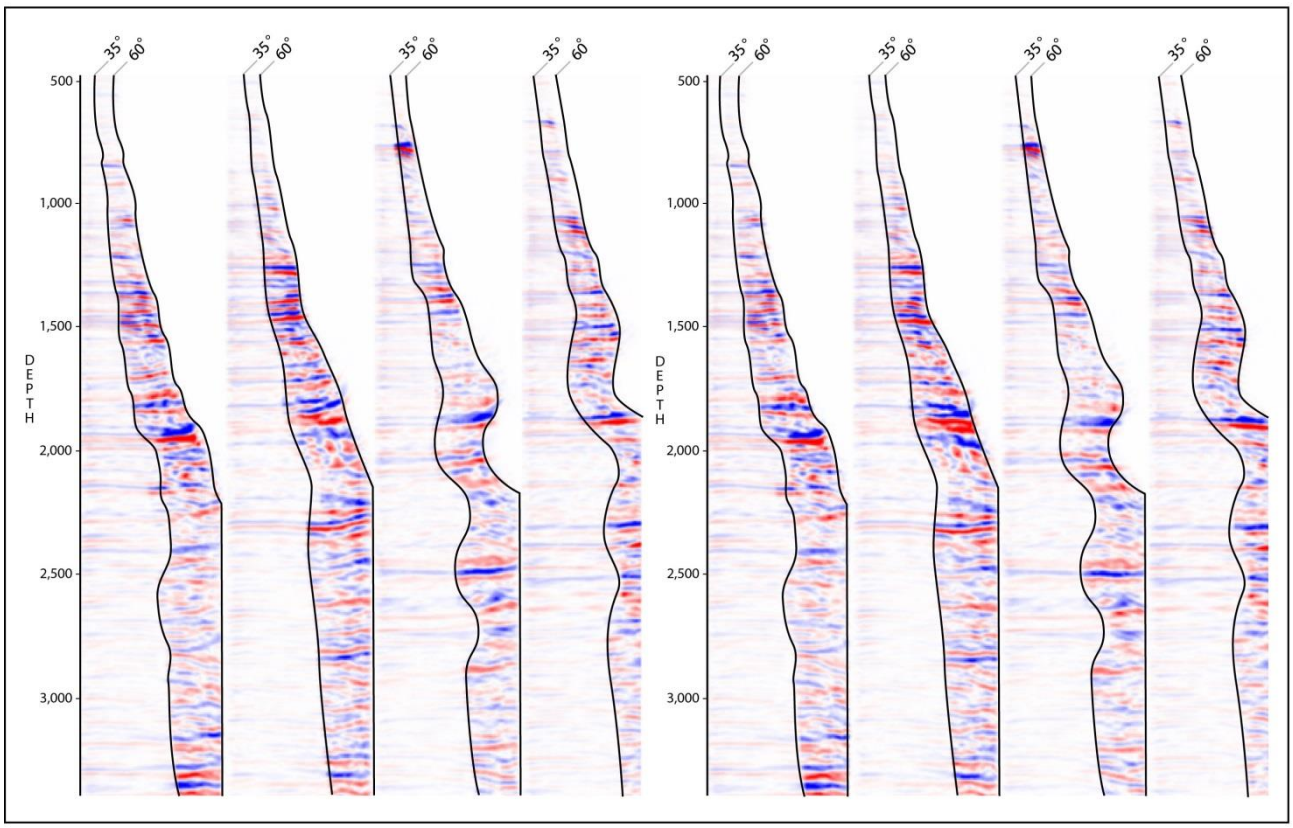

Figure 4: Gathers migrated with epsilon derived in the standard way on the left, and tomographically on the right. With the angle range 35-60° indicated. (Seismic data courtesy of Fugro, used by permission)

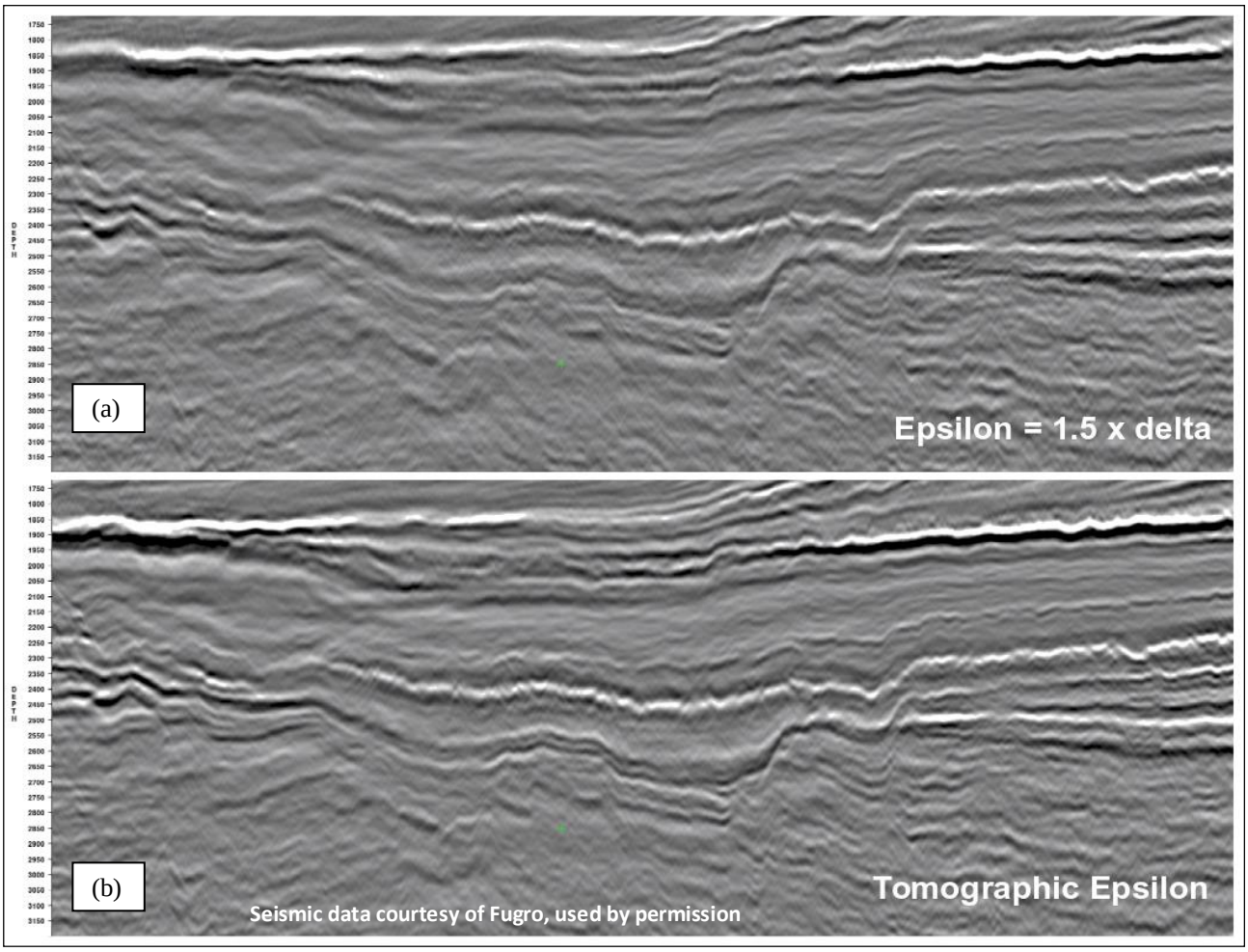

Figure 5: stacks from the two methods over angle ranges 35-60° (a) from a migration performed using epsilon =1.5 x delta, (b) using tomographic epsilon. Note the increased focussing and event definition on the lower stack. (Seismic data courtesy of Fugro, used by permission)

CONCLUSIONS

Several advantages are taken away from using a stable tomographic epsilon inversion as part of velocity model building.

- Velocity and anisotropy models can be produced with a much higher degree of detail and accuracy.
- By using model parameters closer to those of the real earth, better focusing in the migration is possible.
- The migrated gathers are flatter, and hence stack quality and frequency content is not degraded with stretch.
- Better post migration demultiple flows can be applied, in turn giving even cleaner far angle stacks.

Improvements in seismic imaging out on the furthest angles will have a positive impact on future AVA inversion studies. In the Northern Carnarvon Basin and Beagle Sub Basin this technology will aid in using AVA inversion techniques to explore for oil within the Lower to Middle Jurassic petroleum

ACKNOWLEDGMENTS

Thanks to Fugro Multi-Client for permission to show the seismic data, and to Japan Energy Australia for the well synthetic study.

REFERENCES

Hale, D., 2009, Structure-oriented smoothing and semblance: CWP Report 635, Colorado School of Mines, 261-270.

Jablonski, D., Preston, J., Westlake, S., Gumley, C., 2013, Unlocking the Origin of Hydrocarbons in the Central Part of the Rankin Trend, Northern Carnarvon Basin, Australia: West Australian Basins symposium. F 1-31.

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

Rutherford, S. R., Williams, R. H., 1989 Amplitude-versus-offset variations in gas sands: Geophysics, vol54no6, 680-688.

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

Luo, Z., Brittan, J., Fan, D., Mecham, B., Farmer, P. and Martin, G., 2014. Imaging complexity in the earth – Case studies with optimized ray tomography. The Leading Edge. 936-94

Walker, T. R., 2007, Deepwater and frontier exploration in Australia – Historical perspectives, present environment and unlikely future trends. APPEA journal, Vol 47 p15-38.