Impact of a tightly folded anisotropic layer on imaging in Papua New Guinea – a modelling study

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Summary:

We conducted a 2D modelling experiment to better understand the impact of a tightly folded shallow formation on the imaging of a deeper reflector. The data were modelled after a PSDM project in Papua New Guinea using a finite-difference acoustic anisotropic algorithm. The modelled data were then depth migrated to evaluate the sensitivity to dip, epsilon, delta, and ambient noise levels. The results show the sensitivity of seismic imaging to complex dips in the shallow formation. This conclusion is also supported by the results on the real data, where using the complex dip model produced a more interpretable image.

Geologic Setting:

The study area is within the East Papuan Basin in the Gulf Province of Papua New Guinea (See figure 1). The East Papua Basin has experienced multiple periods of crustal extension from the Jurassic Gondwana breakup through to the Palaeogene Tasman and Coral Sea rifting episodes. This series of extensional events was followed by a complex series of collisional events from the Oligocene through to the present day resulting in the west verging Aure Fold Belt and the South verging Papuan Fold Belt.

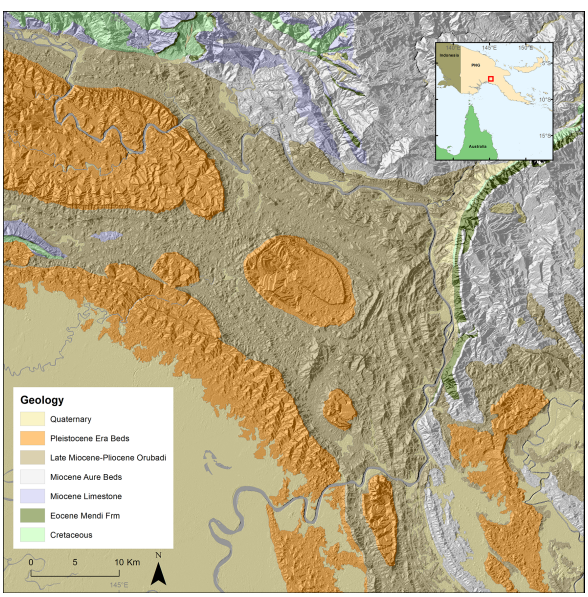

Figure 1: Geological Area map.

The reservoir interval in this study is the Miocene Kapau Limestone deposited on an irregular sea-floor inherited from the preceding Eocene Coral Sea rifting.

The Kapau Limestone is overlain by the latest Miocene-Pliocene Orubadi Formation. The Orubadi is a thick (1500-2500m) rapidly deposited sequence of bathyal mudstones and thin neritic sandstone layers deposited in the fore-deep in front of the Aure and Papuan thrust fronts. As the thrust front advanced, the Orubadi has deformed in a quasi-plastic fashion. Deformation tends to be greatest ahead of propagating thrust faults and anticline cores with tight chaotic folds exposed in outcrop whilst the formation remains relatively undeformed in the synclines.

The Orubadi is unconformably overlain by the Pleistocene Era Beds deposited as a molasse sequence in front of the Aure and Papuan fold belts. The Era Beds are dominated by sandstones with minor amounts of mudstone and conglomerate deposited in a transitional marine-non marine environment. The sandstones are often indurated and form resistant outcrop ridges.

The outcrop pattern in the study area is dominated by Orubadi cored anticlines and Era Bed cored synclines. Seismic image quality can be loosely correlated with outcropping geology, areas with outcropping Era Beds enable relatively good imaging whilst areas with outcropping Orubadi tend to exhibit poor imaging.

In areas with outcropping Orubadi, chaotic tight folds are common and seismic imaging is relatively poor in these areas. In areas with outcropping Era Beds the underlying Orubadi is relatively undeformed and seismic imaging is more coherent. This paper demonstrates how these tight folds provide a significant imaging challenge and can be mitigated if modelled correctly.

Modelling Methodology:

The goal of this study was to understand the impact of the complex Orubadi formation on the imaging of the deeper Kapau carbonate. The modelling was completed in conjunction with a Kirchhoff PSDM

project. We performed several iterations of modelling as we refined the PSDM velocity, dip, epsilon, and delta models. The insights gained from the modelling results were, in turn, used to further constrain the PSDM models.

We took an interpretive approach to depth model building. Our initial PSDM model was built using well data to estimate the seismic p-wave velocities for the Era Beds (~3000m/s), Orubadi (~2500m/s), and Kapau formations (~5000m/s). The velocities also increased with depth due to lithostatic load. Our model was anisotropic with seismic velocities higher parallel to bedding, exhibiting tilted transverse isotropy or TTI (Vestrum and Lawton, 2010). We used surface geology dip measurements and interpreted horizons to build our dip field. As mentioned above, the Orubadi formation is tightly folded where it outcrops, exhibiting surface dips of up to 70 degrees. We assumed these folds decreased in amplitude with depth until the dips conform with the underlying Kapau formation. We assumed epsilon of 0.20 and delta 0.03 in the Orubadi shale, with both decreasing near the highly fractured and weathered surface. The Kapau formation is a thick carbonate with much higher velocities and lower anisotropy as shown in the model. Above the Orubadi is the Era Bed formation, a sandstone exhibiting higher velocities and lower anisotropy than the Orubadi. We completed several iterations of PSDM, updating our interpretation until we converged to our final model (see figure 2).

The data were modelled using the field acquisition geometry, with offline source and receivers projected onto the 2D line where necessary. The line was acquired using a dynamite source with a nominal shot interval of 60m and receiver interval of 15m. There were 252 shots and 982 receivers in total. All receivers were recorded for each shot, giving offsets of up to 15000m in the middle of the line.

The modelled data were generated using AxWAVE, finite-difference acoustic TTI modelling software from Acceleware. The finite-difference modeller uses a taylor series expansion to approximate the propagation of the seismic wavefield. We used the 8th order spatial and 2nd order time coefficients. The model cell sizes were automatically calculated to ensure sufficient sampling (10x10m). In this case, we used an acoustic implementation, ignoring any density contrast. The

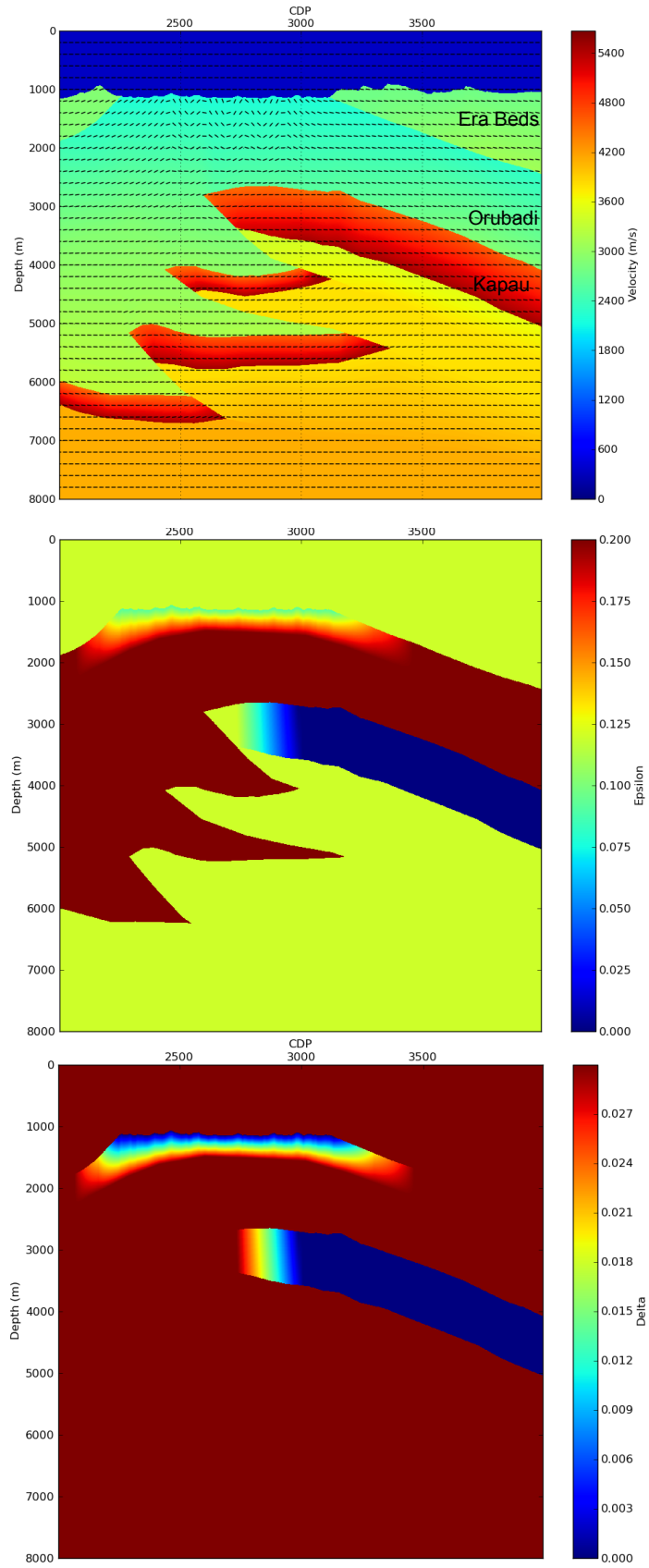

Figure 2: Velocity model with dips overlaid (top), Epsilon (middle), and delta (bottom) models used for modelling.

The data were modelled up to 60 Hz using a 25 Hz Ricker source wavelet.

Results:

The modelled shot in Figure 3 clearly show the impact of the tightly folded Orubadi on the top Kapau reflector. As expected, the reflector is distorted in the region below the folds, enough to significantly impact the quality of the stack or migrated image if the dips are not properly handled. To evaluate the magnitude of the image degradation, we conducted a series of Kirchhoff PSDM tests.

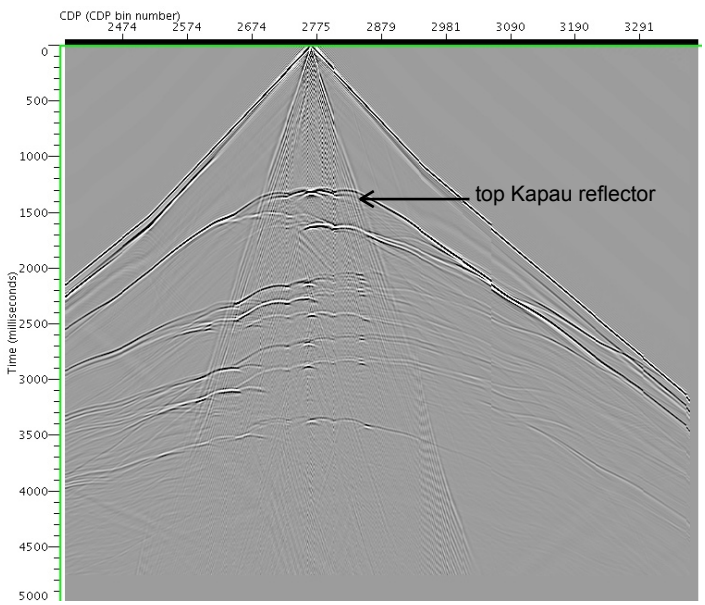

Figure 3: Modelled shot record

We first migrated with the exact models we used for the modelling as a benchmark. As you can see in figure 4, the PSDM produces a good image. The top Kapau reflector is very well imaged. The subsequent repeats of the Kapau have some lack of clarity in the image, particularly in locations below the complex dips of the Orubadi and strong velocity contrast with the Kapau. This is not unexpected given that Kirchhoff migration has challenges with such complex velocities.

Next, to evaluate the importance of having the correct dips in the overburden we migrated the modelled data using a much simpler dip model (see figure 5) while keeping the same models for velocity, epsilon, and delta. The results show a significant degradation in image in the regions of the complex dips.

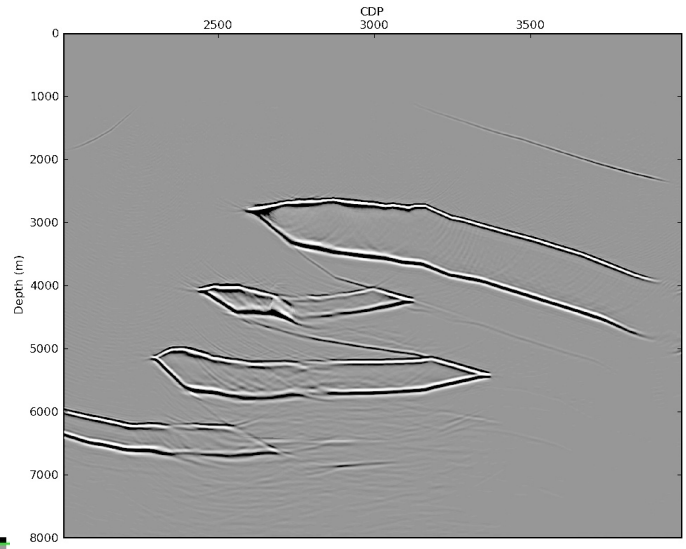

Figure 4: PSDM of modelled data using exact model

To better understand the impact of the dips on real data, we repeated the PSDM after adding ambient noise of a similar level to what we see in the field data to the modelled data. The results are shown in figure 6. The migration with the correct dip model still clearly images the Kapau limestone, while the migration with the simple dips does not. There is now ambiguity as to how far the Kapau protrudes to the southwest, making for an uncertain interpretation.

A final set of tests were run to evaluate the importance of understanding how quickly the dips reduce with depth as well as how sensitive the results are to differing anisotropy.

Conclusion:

This modelling study demonstrates the importance of using an appropriate dip model for a TTI PSDM. In this case we had no seismic evidence for the strong dips in the shallow section. However, surface geology measurements showed there were steep dips in the Orubadi Formation and incorporating them into our model improved the imaging. How quickly the dips diminish with depth as well as the shallow delta and epsilon values also impact the quality of the image. Our interpretative approach to PSDM model building allowed us to test various scenarios for dip and anisotropy parameters using what we learned in the modelling study to improve the imaging results on the real data.

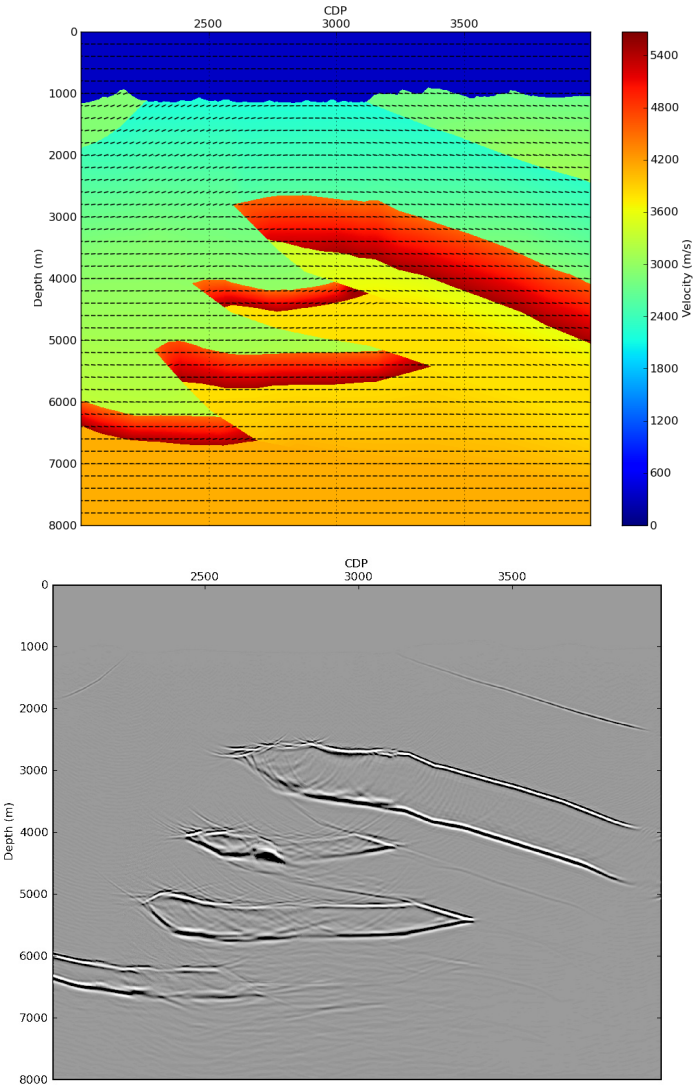

Figure 5: Velocity model with simple dips overlaid (top), PSDM of modelled data using simple dips (bottom)

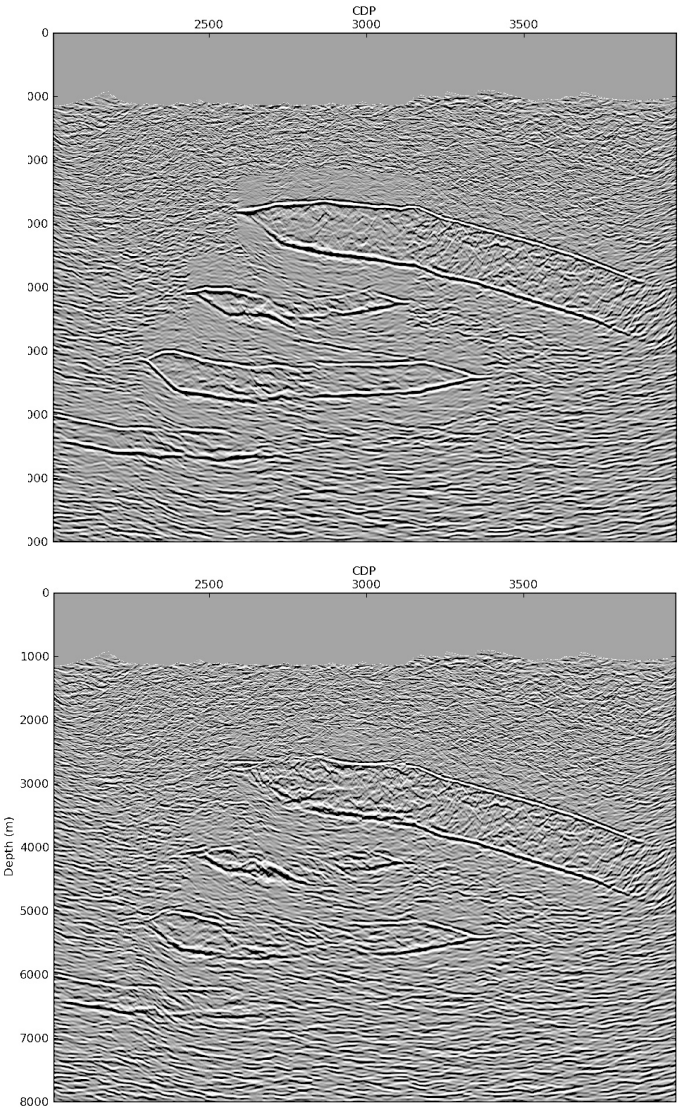

Figure 6: PSDM with exact model with noise added (top), PSDM with simple dip model with noise added (bottom)

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