Resolving small-scale near-seabed velocity anomalies using non-parametric autopicking and hybrid tomography

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Abstract

High resolution tomographic inversion has conventionally been preceded by picking of 2nd and 4th order residual moveout of depth migrated gathers. However, this type of picking assumes that the residual moveout behaviour can adequately be characterised with a parametric fit of a simple curve to the form of moveout exhibited by the data. When we have small-scale velocity anomalies (with lateral extent a fraction of the acquisition spread length) this assumption breaks down. Unfortunately, picking the detailed non-parametric residual moveout behaviour can be very difficult, as the moveout trajectories can be obscured by residual noise (often remnant multiple), which can derail a non-parametric autopicker.

Here we demonstrate a successful implementation of non-parametric autopicking applied to two diverse data examples, and contrast the results with conventional tomographic inversion of parametrically picked moveout.

Introduction

Features with a lateral extent much shorter than the recording cable length cause highly irregular moveout behaviour on the recorded seismograms: this irregular moveout behaviour persists even after PreSDM with a smooth velocity model. If these features are only a few hundred metres wide, then it is unlikely that conventional ray-based tomography will be able to invert for them. Tomography based on non-parametric picking has a much better chance of resolving small-scale structure, as this style of picking can capture the complex moveout behaviour in the CRP gathers (Brittan and Yuan, 2005; Jones, 2010, Luo et al., 2014).

The first example considered here is from deep water offshore Sri Lanka (Stevens et al., 2014; Fruehn et al., 2014), where the sea floor is incised with deep canyons, and the sedimentary sequence below these shows clear evidence of the presence of buried paleo-canyons with significant lateral velocity variation in comparison to the surrounding sediments.

For the vast majority of the study area (perhaps 90%), parametric picking and ray-based hybrid gridded tomographic inversion worked well (Fruehn et al., 2008; Jones, 2012). High-resolution tomographic inversion was able to resolve layering within the basalt and identify trapped sediment units (of about 200m thickness) within the basal flows. Details from these results are shown in Figure 1. However, this conventional 2nd and 4th order residual moveout (RMO) picking of CRP PreSDM gathers failed to capture the short wavelength velocity variation associated with the buried canyons, thus limiting the ability of subsequent ray-based tomographic inversion to resolve the required level of complexity.

Failure of conventional parametric picking

Although the parametric approach worked well for the vast majority of the study area, in the paleo-canyon region, even after several iterations of parametric picking, the tomography was still unable to resolve rapid lateral velocity variations caused by the buried paleo-canyons. Figure 2 contrasts the conventional with the non-parametric results by comparing the remaining residual moveout error (as characterised by a 2nd order analysis for both cases, so as to facilitate direct comparison).

The CRP gathers from 3D anisotropic Kirchhoff PreSDM from the two approaches are shown in Figure 3. Overall, the CRP gather flatness is significantly improved for the deeper major reflectors by employing non-parametric picking. Gathers after conventional parametric update show sinuous RMO behaviour typical of unresolved overburden short-wavelength lateral velocity anomalies. Following non-parametric update, to a large extent the sinuosity is removed, resulting in simpler RMO behaviour. Figure 4 shows the final Kirchhoff 3D PreSDM image in the zone below the paleo-canyon complexity after several iterations of parametric picking as compared to the: corresponding image after four iterations of non-parametric (generalised) moveout picking. Overall the image is significantly improved for all deeper major reflectors.

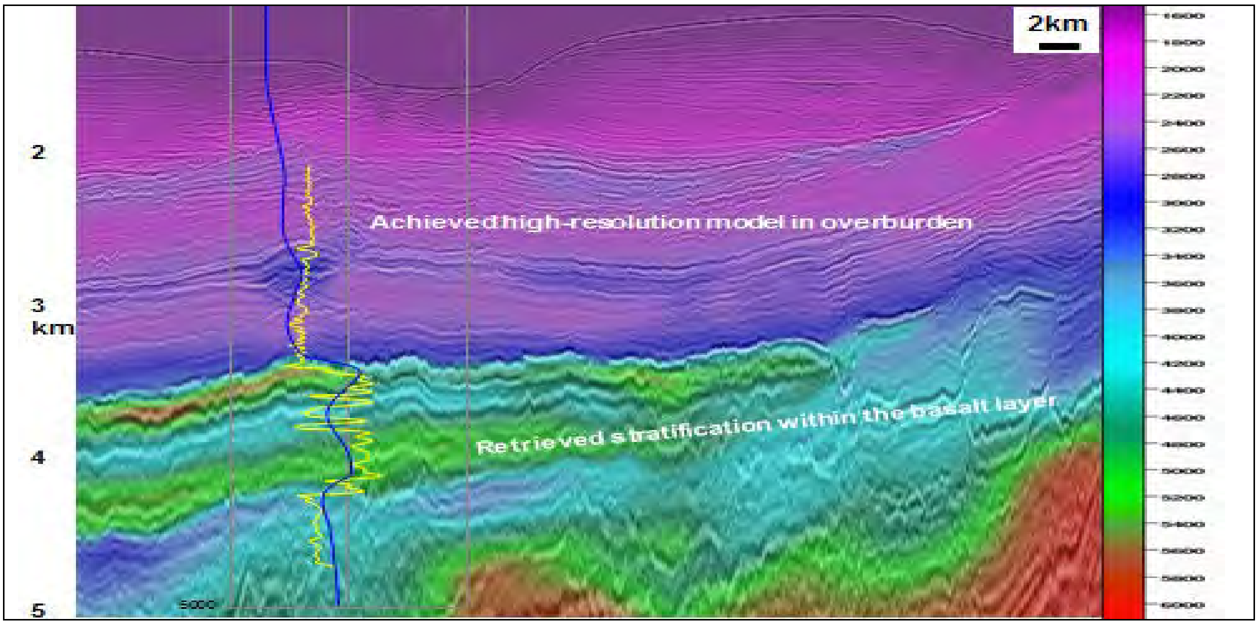

Figure 1 *For the vast majority of the study area, parametric picking and inversion worked well. Hi-resolution tomographic inversion was able to resolve layering within the basalt and identify trapped sediment units in the basal flows.*

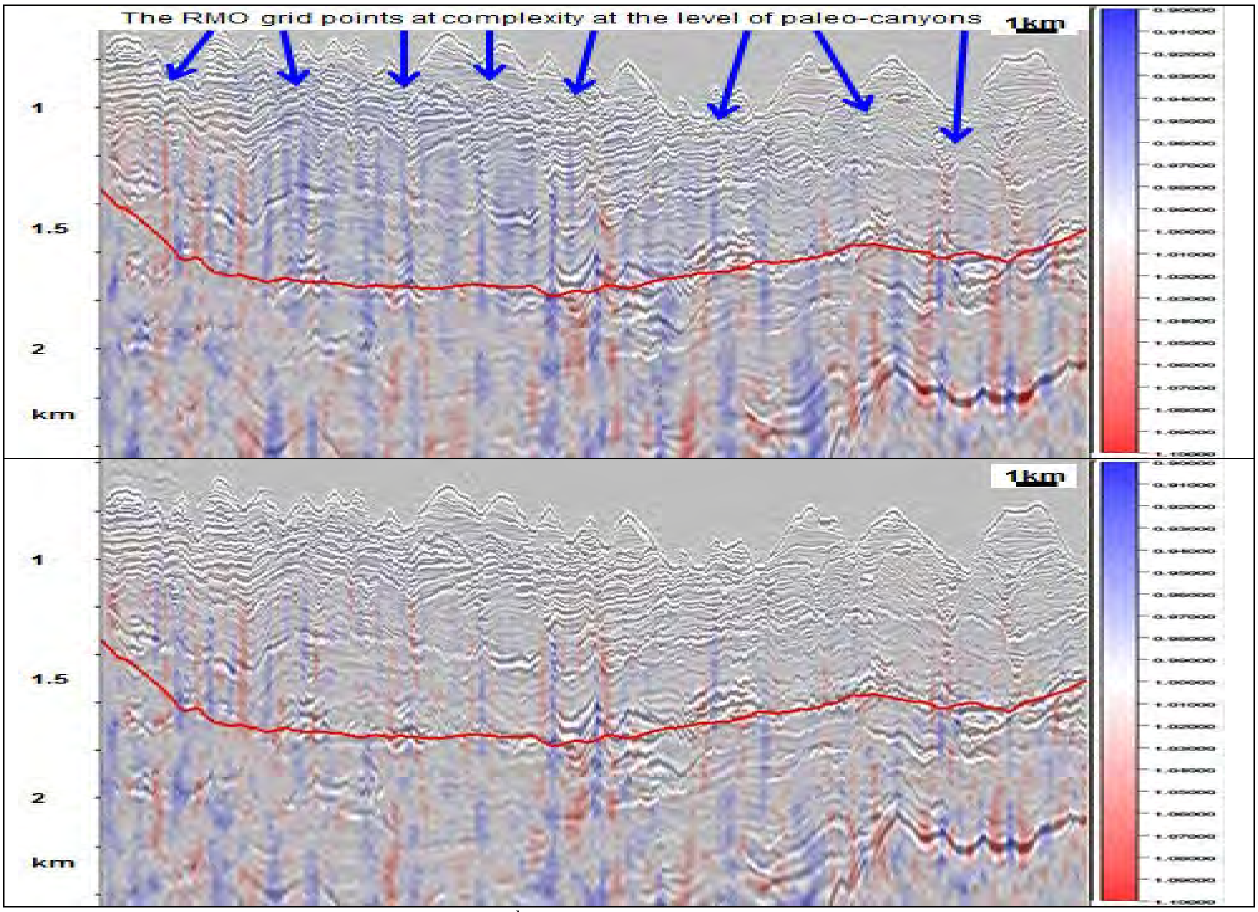

Figure 2 *Top: After several iterations of 2^{nd} order parametric picking, the tomography was still unable to resolve rapid lateral velocity variation caused by the buried paleo-canyons. The colour overlay indicates the RMO error (expressed as a percentage ratio to the input and updated velocities), here ranging from +- 10%. Bottom: After two iterations of non-parametric moveout picking, the result is improved. For direct comparison, the colour overlay is again the result from a 2^{nd} order parametric fit to the observed RMO behaviour in the CRP gathers.*

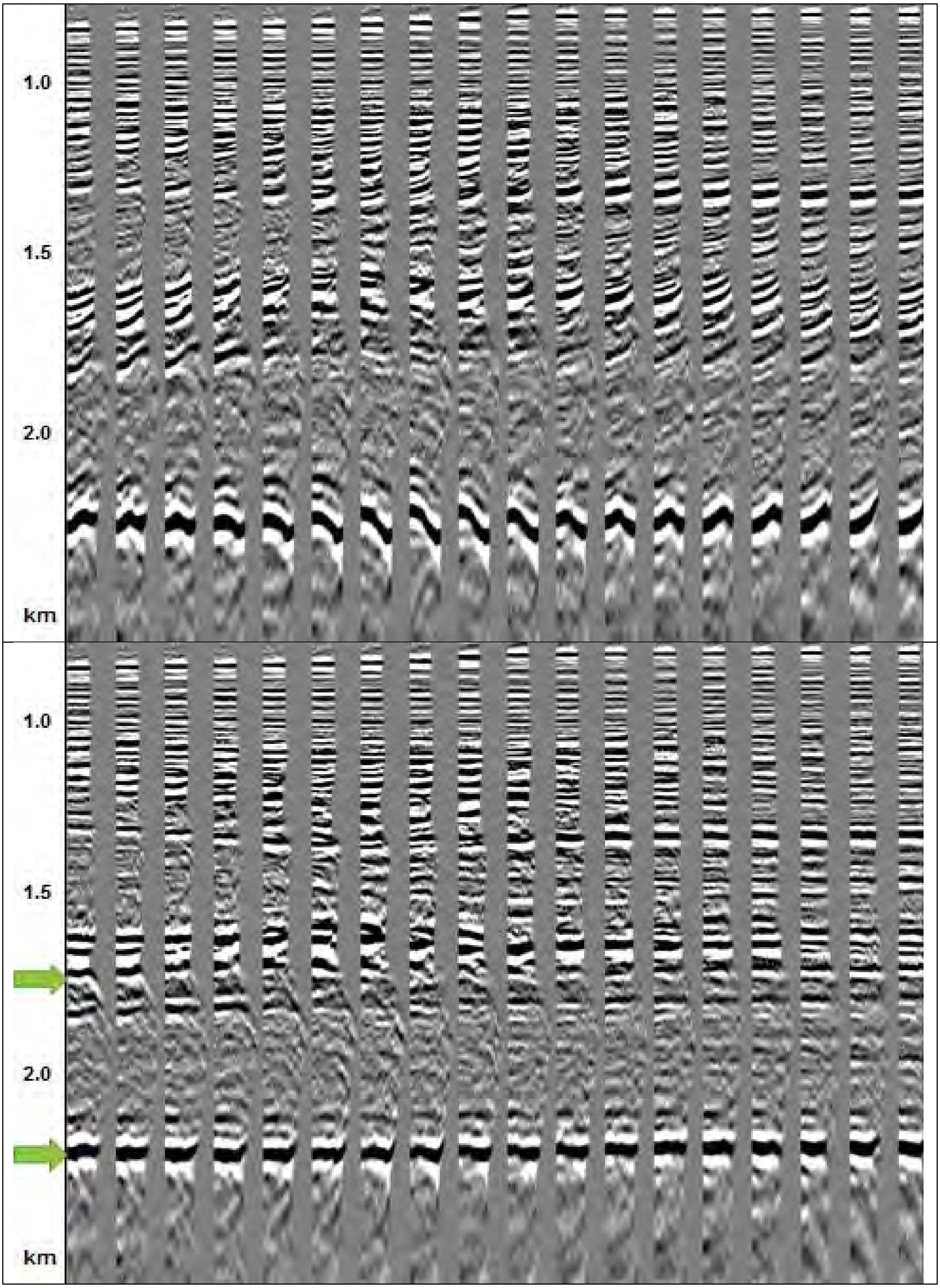

Figure 3 *Top: 3D PreSDM CRP gathers in the zone below the paleo-canyon complexity after several iterations of parametric picking (5km maximum offset). Bottom: After four iterations of non-parametric moveout picking, the result is improved. Overall CRP gather flatness is significantly improved for these deeper major reflectors.*

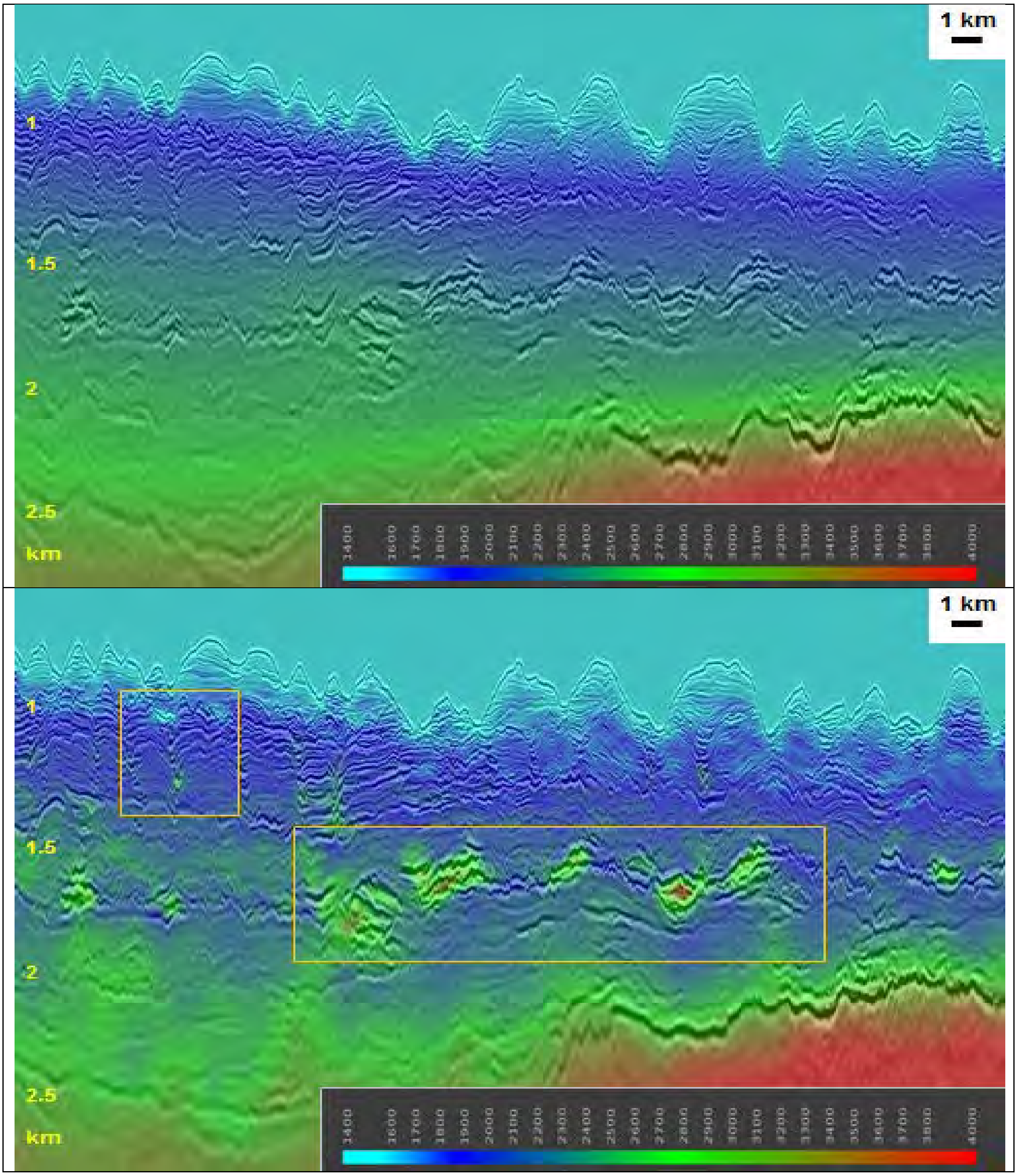

Figure 4 *Top: Final Kirchhoff 3D PreSDM image in the zone below the paleo-canyon complexity after several iterations of parametric picking, with interval velocity overlay. Bottom: Corresponding image after four iterations of non-parametric (generalised) moveout picking. The boxes indicate areas where higher resolution velocity information has been recovered. Overall the image is improved for all deeper major reflectors.*

The second example presented here is from shallow water offshore Netherlands (Greenwood et al., 2014). The study area is located in the M-quadrant of the Dutch continental shelf, and displays complex sediment deformation in the Tertiary overburden with respect to the deeper Jurassic and Triassic target levels. Within the Tertiary, at about 800m depth (Figure 5), there is a thin (80m thick) low velocity (water-logged) layer which in places has been deformed into long, narrow, sub-parallel blocks, resembling a submarine slide complex (Figure 6). The velocity effect is pronounced, and as a result, the resolution and amplitude character of the deeper target levels are seriously degraded on conventionally processed PreSDM data. As these features are small (~ 100m), both a conventional parametric autopicker and a ray-based inversion scheme struggle to obtain meaningful results. Conventional 2nd order parametric picking yields the RMO velocity imprint shown in Figure 7.

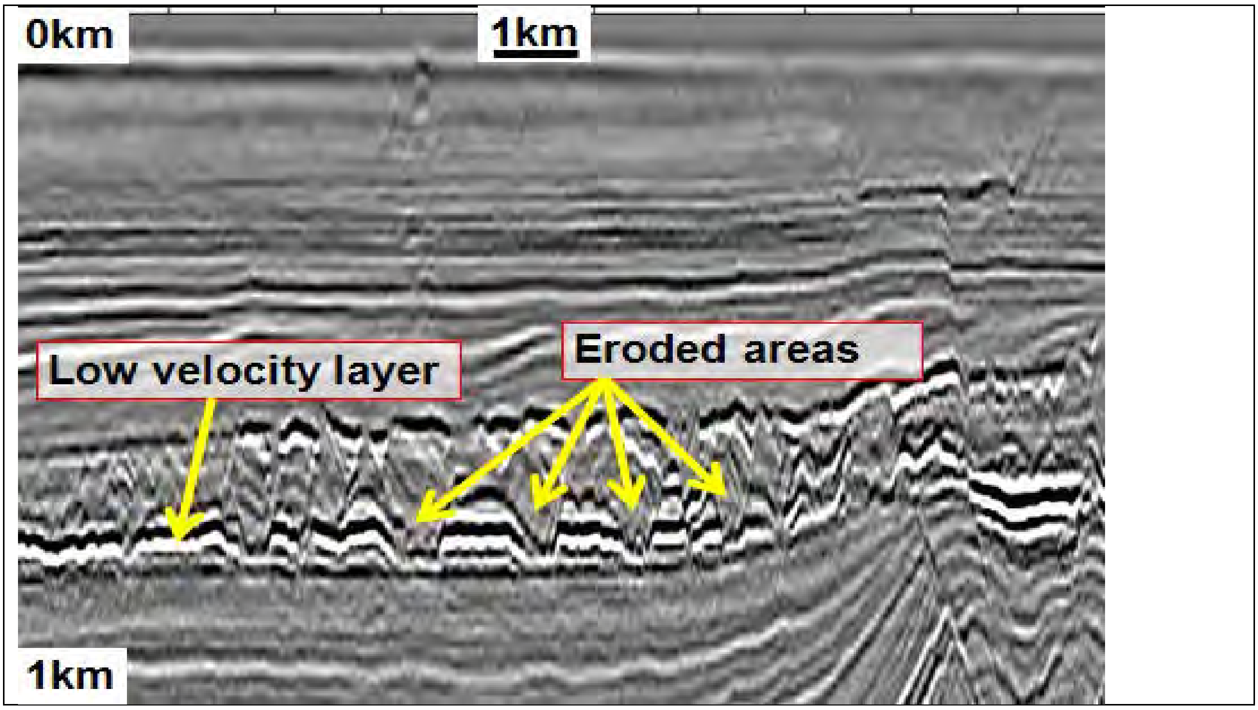

Figure 5 *Vertical section showing eroded layer, with narrow repetitive channels.*

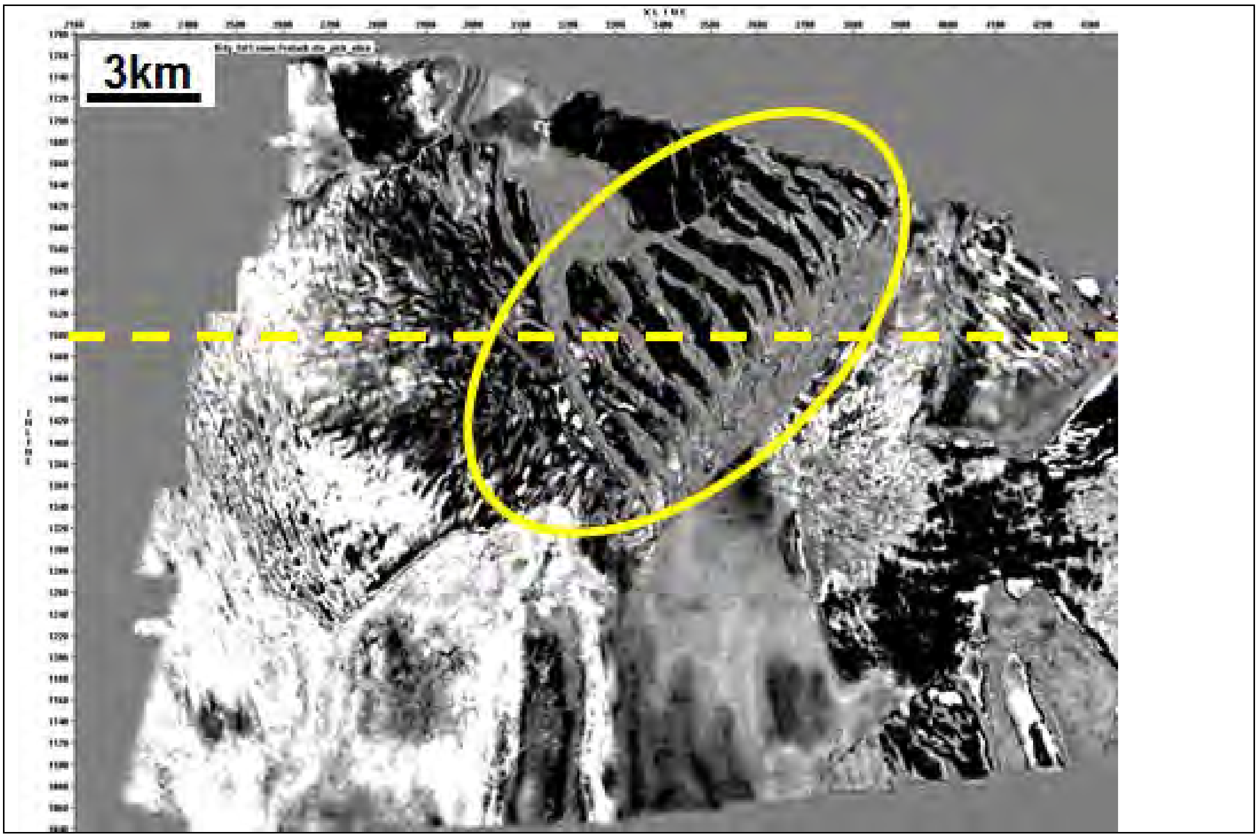

Figure 6 *Slice at 800m through low-velocity eroded layer. The ellipse highlights the eroded region, and the dashed line indicates where Figure 5 intersects the feature.*

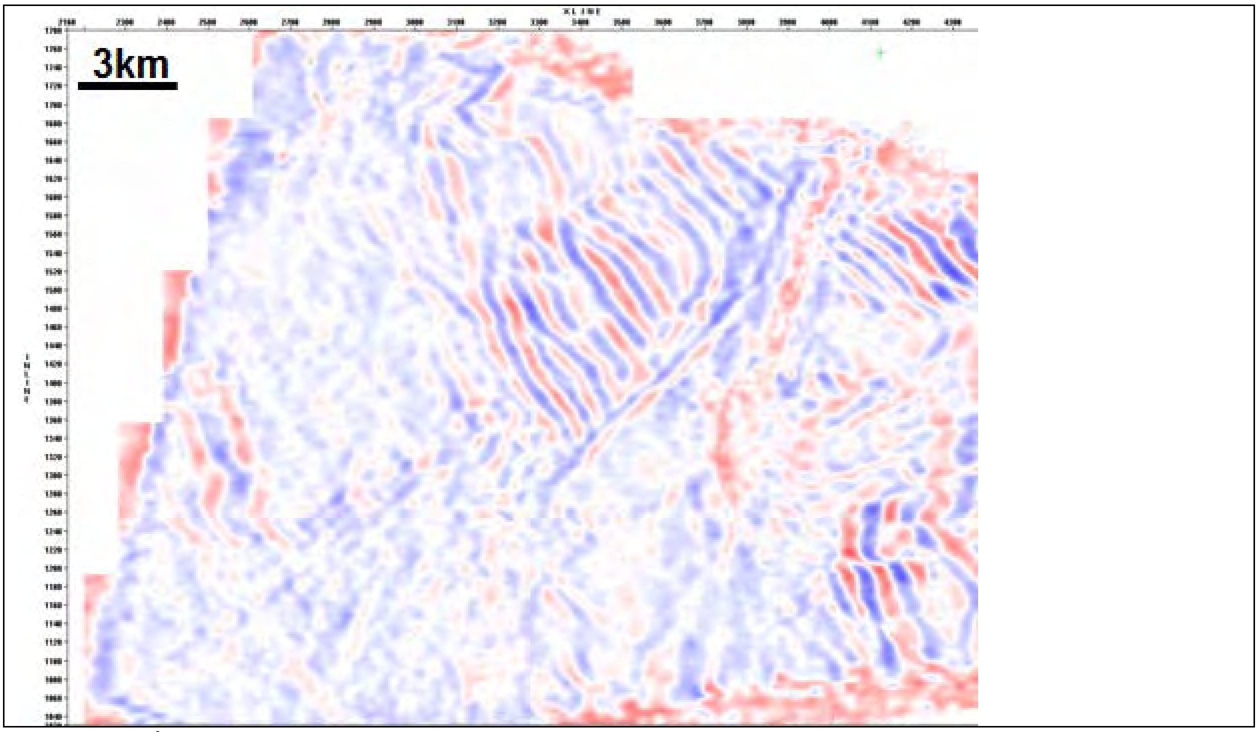

Figure 7 *2nd order parabolic residual velocity error autopicked from muted gathers on a 50m*50m CPR grid.*

In this case, the starting point for the non-parametric picking is a set of gathers migrated with the final results from parametric picking. The difference between 2nd order fitting and non-parametric picking for this set of gathers is displayed in Figure 8. The overlaid red lines indicate the auto-picked RMO trajectories determined by the two methods, clearly indicating how inappropriate the 2nd order fitting is to the irregular shape of the events in the CRP gathers.

The inversion cell, weighting and smoothing constraints within the non-parametric tomography have been carefully optimized to capture the short wavelength of the velocity variations. We were able to reduce the cell-size to 100x100x10m and converge within 100 internal tomographic iterations. Below the low velocity layer, a small amount of structural smoothing was applied after tomography to eliminate some variations that did not conform to the underlying structure. Figure 9 compares the CRP gathers from the parametric and no- parametric approaches. The non-parametric pick tomography update shows short-wavelength variations that correlate very well with the imaged structures at all levels, but particularly at the low velocity layer. Here we see that the water-logged layer is now imbedded into a higher velocity sand that was deposited after the erosion of the low velocity layer. This enhances the lateral velocity contrast sufficiently to absorb the RMO at deeper levels almost entirely.

Figure 10 compares the final migrations with colour velocity overlay for the two approaches. Subtle but important improvements are evident throughout the image produced using non-parametric picking.

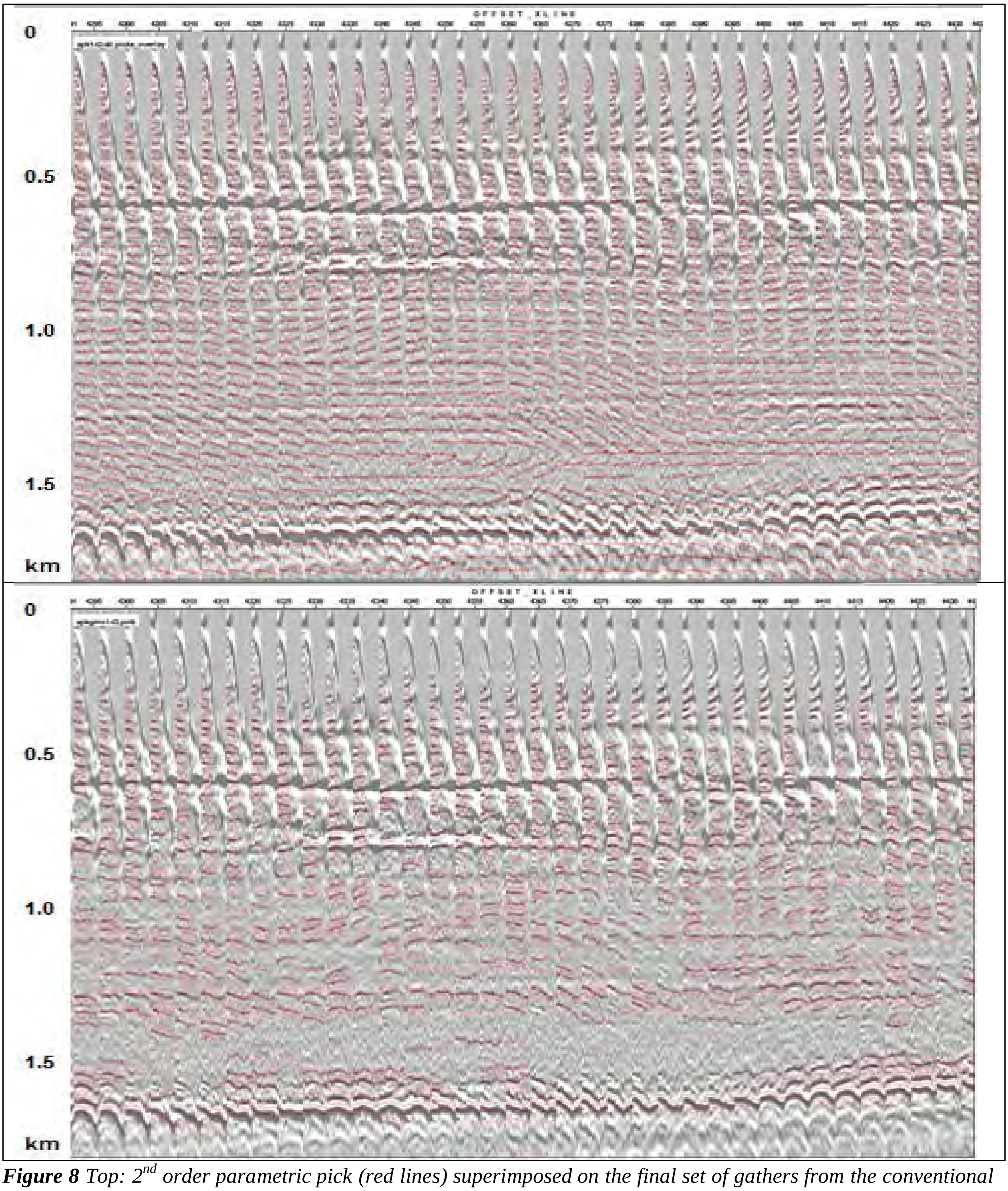

Figure 8 *Top: 2nd order parametric pick (red lines) superimposed on the final set of gathers from the conventional update based on parametric picking. Bottom: Non-parametric picking of the same gathers. The 'V' and 'n' shaped moveout behaviour of the gathers for the deeper reflector are well-tracked by the non-parametric autopicker.*

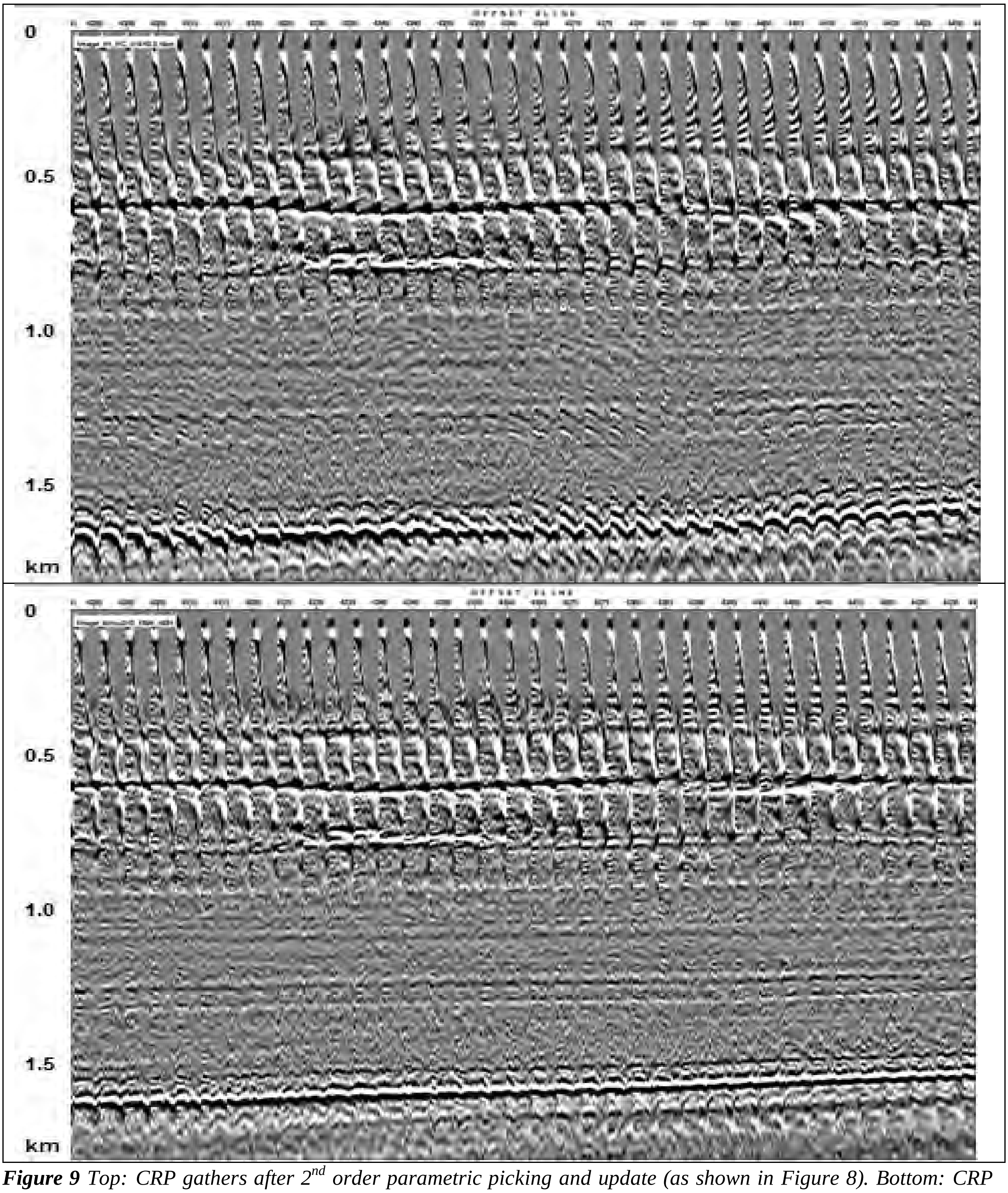

Figure 9 *Top: CRP gathers after 2nd order parametric picking and update (as shown in Figure 8). Bottom: CRP gathers after non-parametric picking and update, showing well-flattened gathers.*

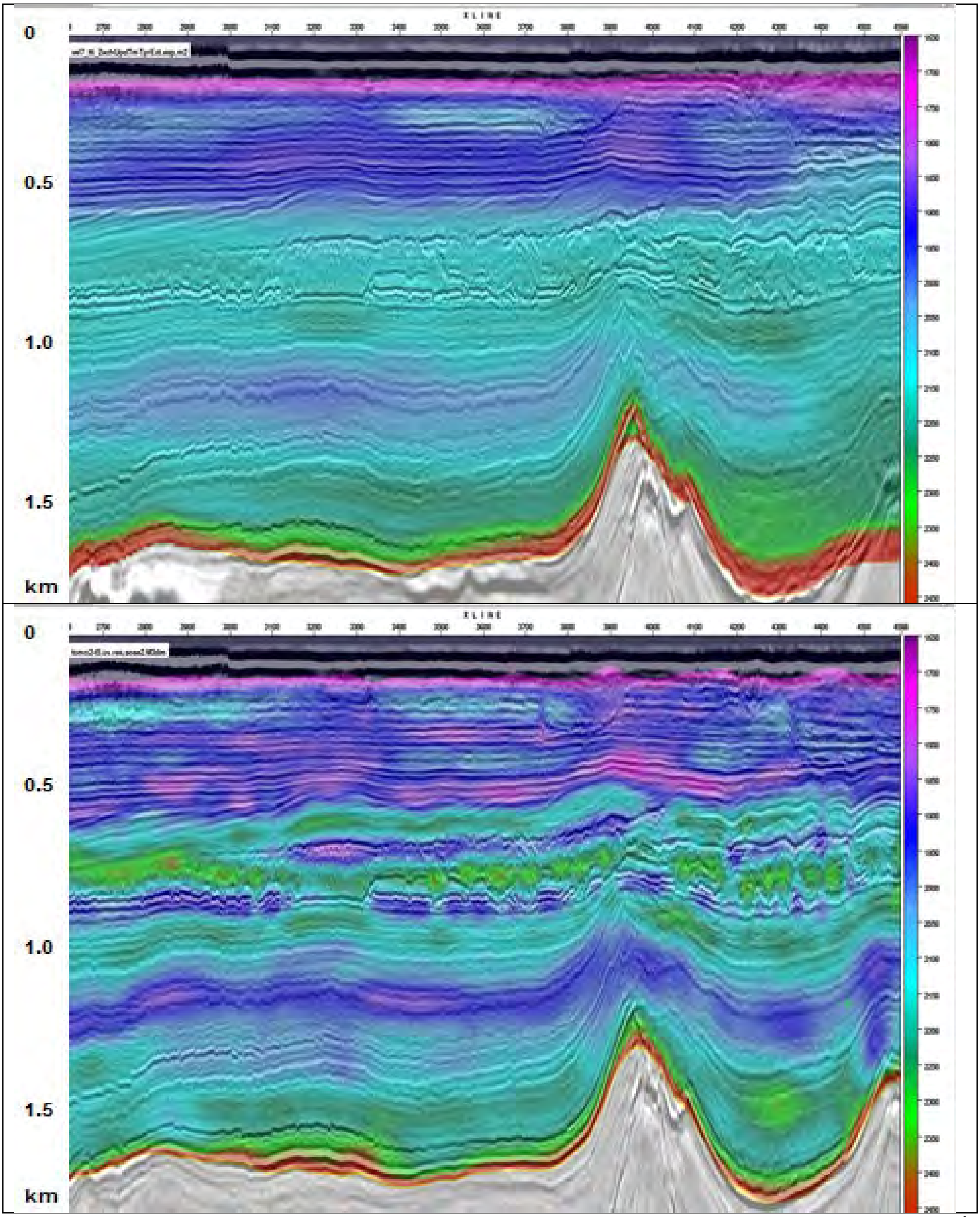

Figure 10. *Final 3D PreSDM images with colour velocity overlay for the gathers shown in Figure 9. Top: After 2nd order parametric picking and update. Bottom: After non-parametric picking and update.*

Conclusions

Anisotropic velocity model building based on parametric 2nd and 4th order RMO picking of CRP gathers will fail to resolve velocity complexity when the scale length of the velocity anomaly is small compared to the cable length of the acquisition. Recent advances in non-parametric picking algorithms have enabled us to successfully resolve additional complexity in the velocity structure using ray-based tomographic inversion of the non-parametric picks.

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