PS Risk Reduction on the Ivory Prospect via Geologically Constrained Non-Parametric Inversion and Bayesian Uncertainty Estimation on a Fault-Bounded Reservoir*

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Abstract

In 2014 Centrica Energy operated the Ivory Exploration well (6707/10-3 S) in 1420m of water in the Norwegian Sea within the PL528B license. Gas was found in turbidite sandstones of the uppermost Kvitnos Formation (informal ‘Delfin Member’). The Ivory structure is a fault bounded, three-way dip closure situated on the Nyk High. The well is located about 20km north east of the Aasta Hansteen gas development, which is expected to begin producing in 2018. The Nyk High is located in the north-eastern part of the Vøring Basin, which has been tectonically active in several phases, from Carboniferous to Late Pliocene time, with the main tectonic phases in Late Paleozoic, Late Mid-Jurassic-Early Cretaceous, and Late Cretaceous-Early Tertiary times. The tectonics of the Late Cretaceous and Tertiary periods were controlled by the relative movements along plate boundaries, with the last rift phase ending with continental breakup at ~54Ma followed by seafloor spreading. During the last phase of intra-continental rifting and separation, uplift, erosion and increased clastic input in the Vøring Basin occurred. The present configuration of the Nyk High mostly dates from the Late Cretaceous to Earliest Tertiary and probably involved both extension and compressional/transpressional reactivation. Prior to the formation of synclines and highs the area probably constituted a single broad Early Cretaceous Basin where deposition of Kvitnos and Nise formation turbiditic sandstones took place. The main challenge in mapping the extent of the Ivory discovery has been seismic imaging at the crest of structures bound by major faults (e.g. fault shadow effects), together with depth conversion uncertainty and a poor well to seismic tie. To address the uncertainties associated with these issues, a new prestack depth migration was run using a dataset re-processed with the latest demultiple and deghosting technology. From this final migrated volume, structural uncertainty was then estimated using a Bayesian statistical analysis of the tomographic resolution matrices in conjunction with prior uncertainty estimates.

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Introduction

In 2014 Centrica Energy were operating the Ivory Exploration well (6707/10-3 S) in 1420m of water in the Norwegian Sea within the PL528B license (figure 1). Gas was found in turbidite sandstones of the uppermost Kvitnos formation (informal 'Delfin Member'). The Ivory structure is a fault bounded, three-way dip closure situated on the Nyk High. The well is located about 20km north east of the Aasta Hansteen gas development, which is expected to begin producing in 2018.

The main challenge in mapping the extent of the Ivory discovery has been seismic imaging at the crest of structures bound by major faults (e.g. fault shadow effects), together with depth conversion uncertainty and a poor well to seismic tie. To address the uncertainties associated with these issues, a new pre-stack Depth Migration (preSDM) was run using a dataset re-processed with the latest demultiple and deghosting technology. From this final migrated volume, structural uncertainty was then estimated using a Bayesian statistical analysis of the tomographic resolution matrices in conjunction with prior uncertainty estimates.

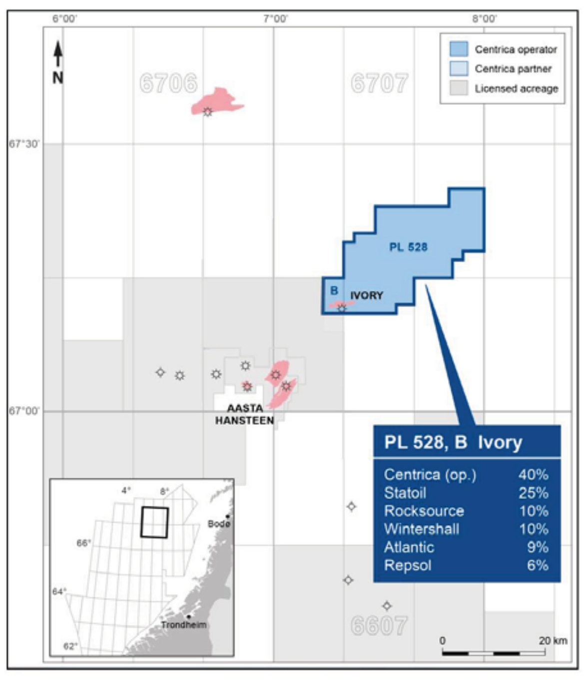

Figure 1: Location of Ivory Discovery.

Input Data Quality and Data Processing

The data were acquired in 2010 using a conventional towed source and streamer configuration, so data quality was good. Pre-migration processing focussed on denoise, in preparation for deghosting and demultiple. A cascaded 3D and 2D SRME demultiple approach was used to target free surface multiples which dominated the target depth and deeper section (figure 2a & 2b). IME was also applied to target multiples generated by the top Palaeocene. Deghosting was applied to suppress side-lobes and increased the useable bandwidth from 5-95 Hz to 2.5-110 Hz (figure 2c). The data also benefitted from the application of 4D regularisation.

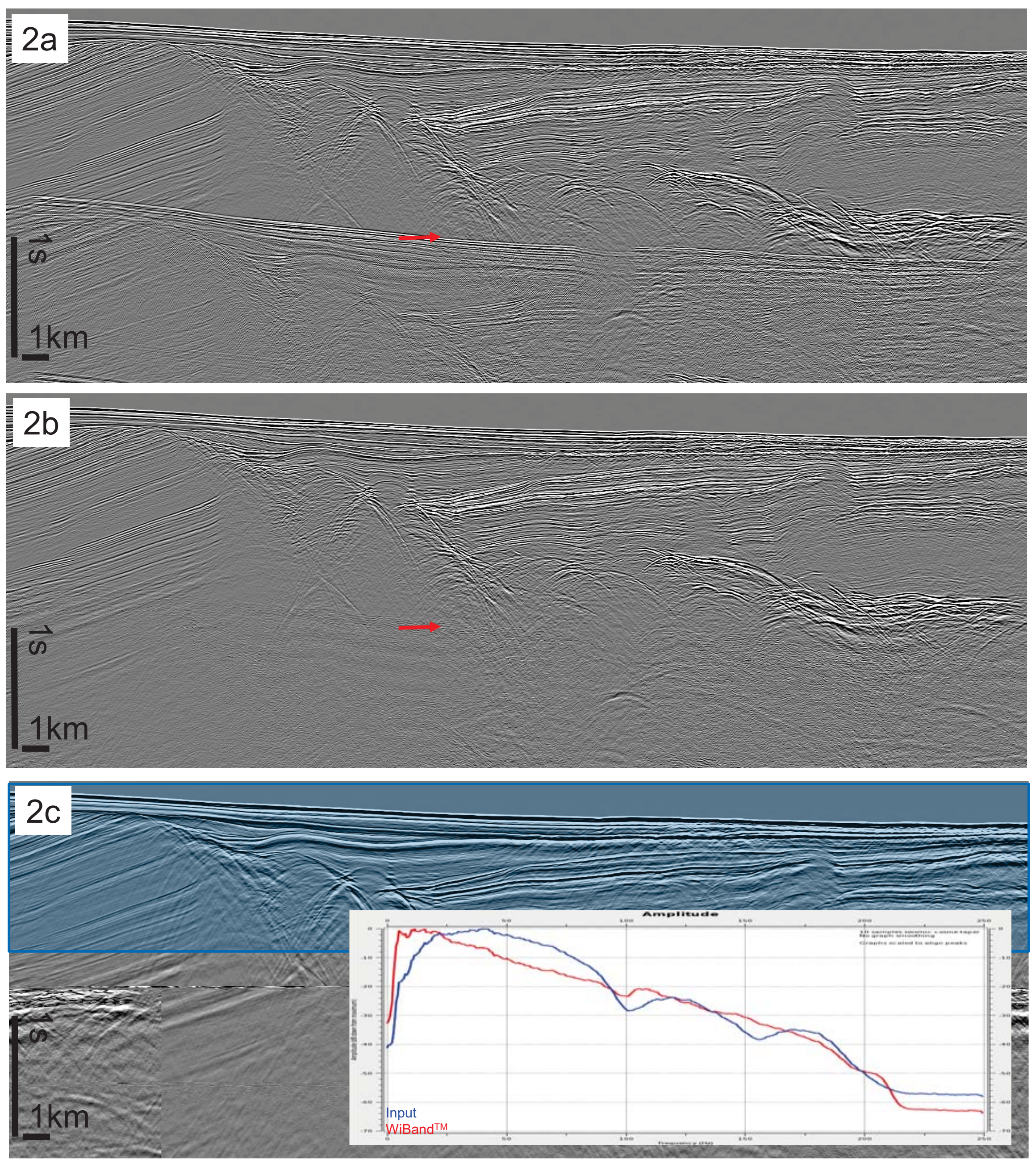

Figure 2: Stack sections showing data (a) before demultiple, (b) after cascaded 3D and 2D SRME and (c) after WiBand™. Note the side lobes have been suppressed and usable bandwidth extended. Further bandwidth extension is achieved following migration using amplitude only inverse-Q compensation.

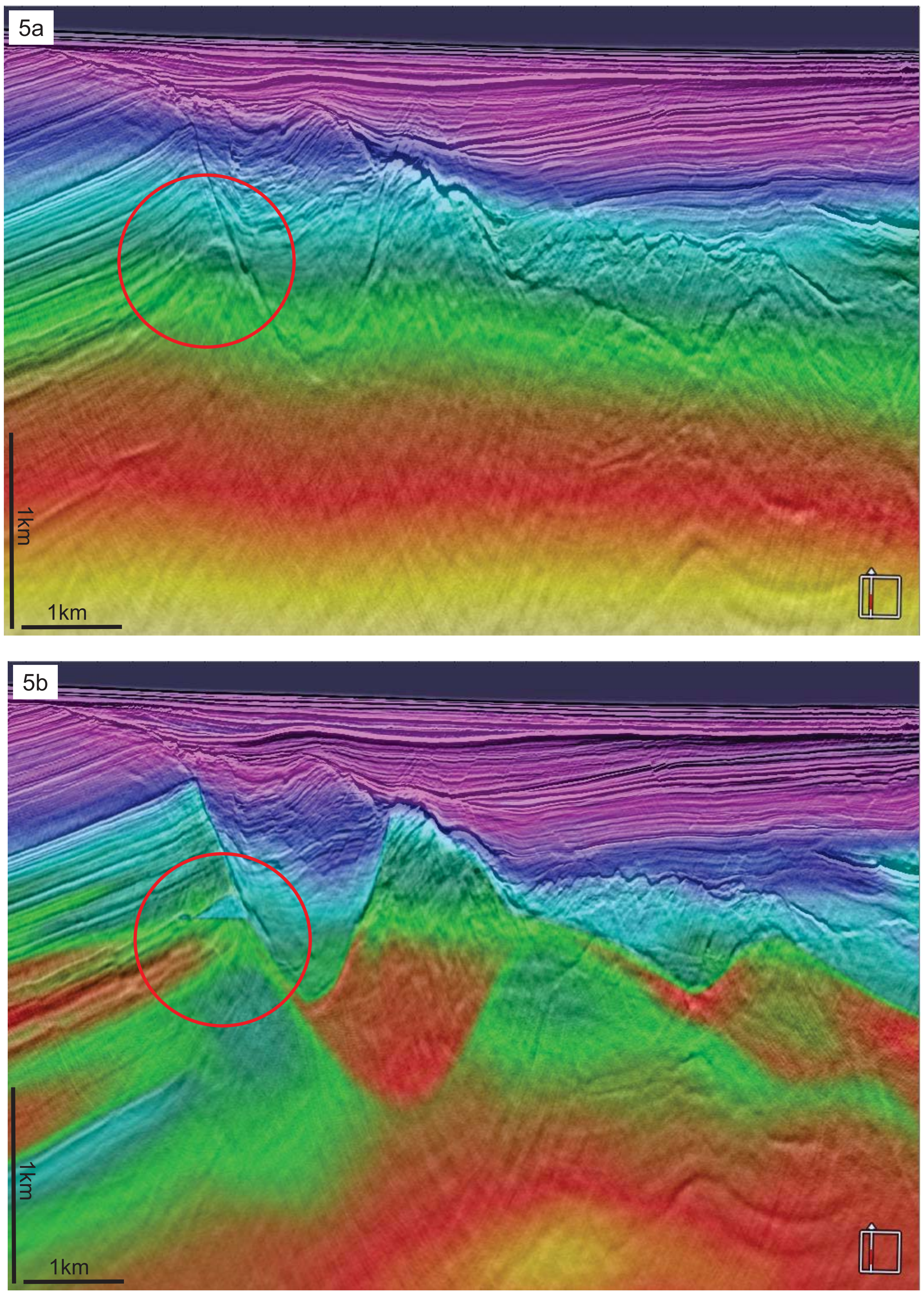

Figure 5: (a) Initial velocity model and (b) final velocity model. Note the manual insertion of shallow gas into the final model has helped flatten reflectors deep down giving a more geologically plausible image

Velocity Model Building

The model evolved through six tomographic model building updates. A non-parametric generalised move-out picker (GMO) was used to resolve fine velocity details in the subsurface (figure 3). The data was pre-conditioned to prevent the influence of residual noise and multiple as well as correctly handling the AVO response of the data. Cell sizes of 150x150x25m in shallow to capture the fine velocity detail and 250x250x50m was used for the deeper section. TTI beam was used to benefit the picker in low S:N areas and well sonics were incorporated to further constrain tomography (figure 4). Final models further benefitted from the introduction of known velocity anomalies (figure 5). Re-processed data benefitted in terms of fine geological structural detail with enhanced continuity and better fault structure resolution (figure 6).

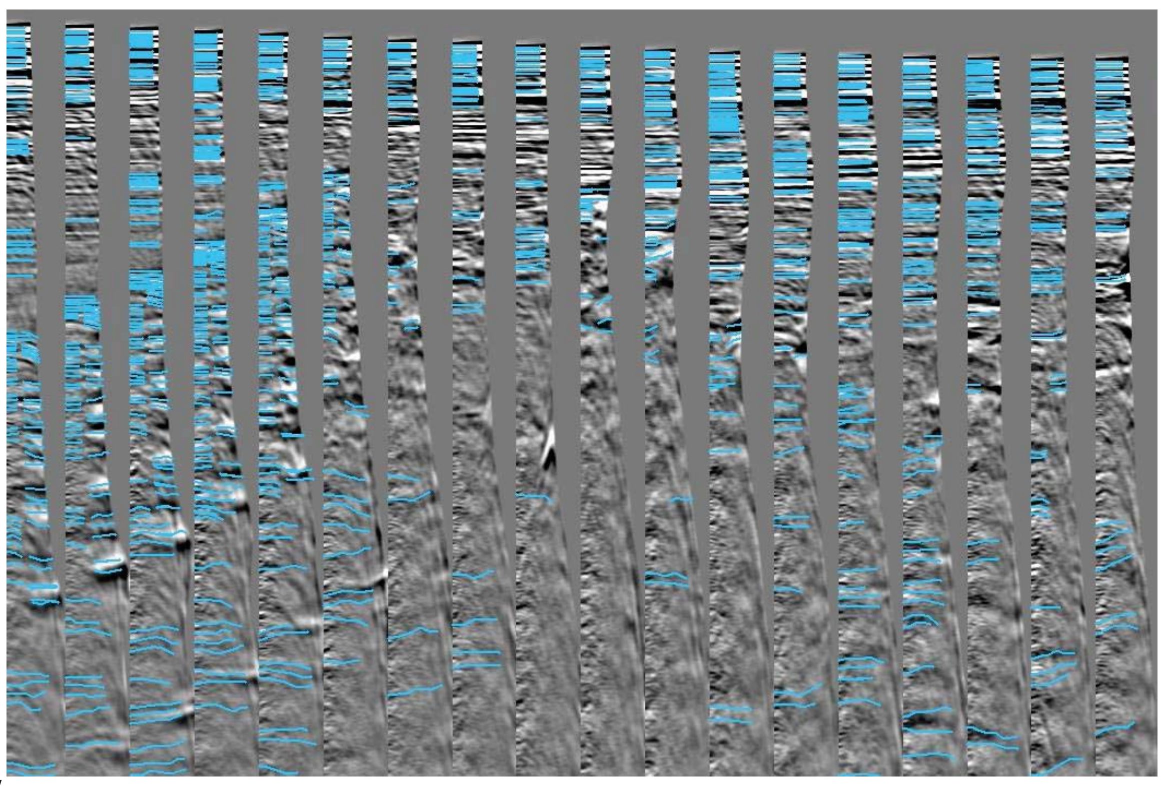

Figure 3: GMO picks. Gathers were conditioned to remove residual noise and multiple. A suitable mute was also applied prior to tomography.

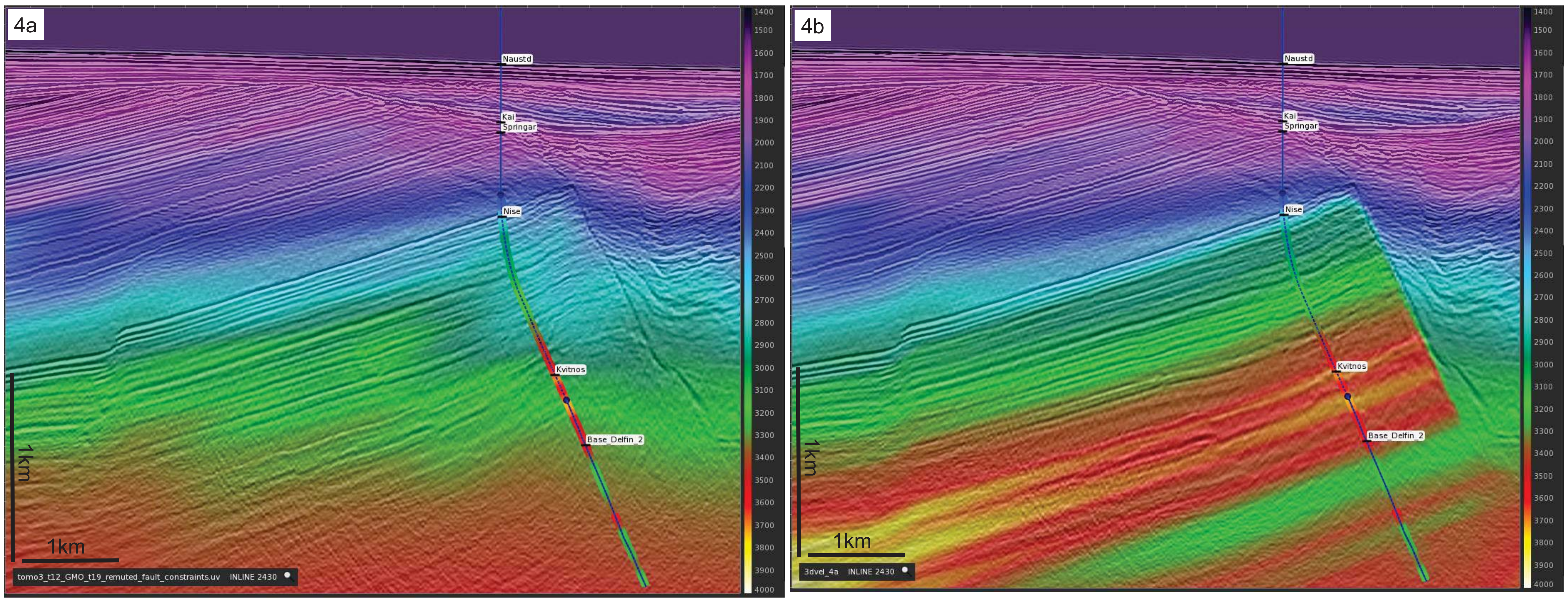

Figure 4: (a) Velocity model after 3 iterations of tomography and (b) after well sonics were introduced to constrain tomography. Note how the velocities within the fault block follow geology as you move away from the well.

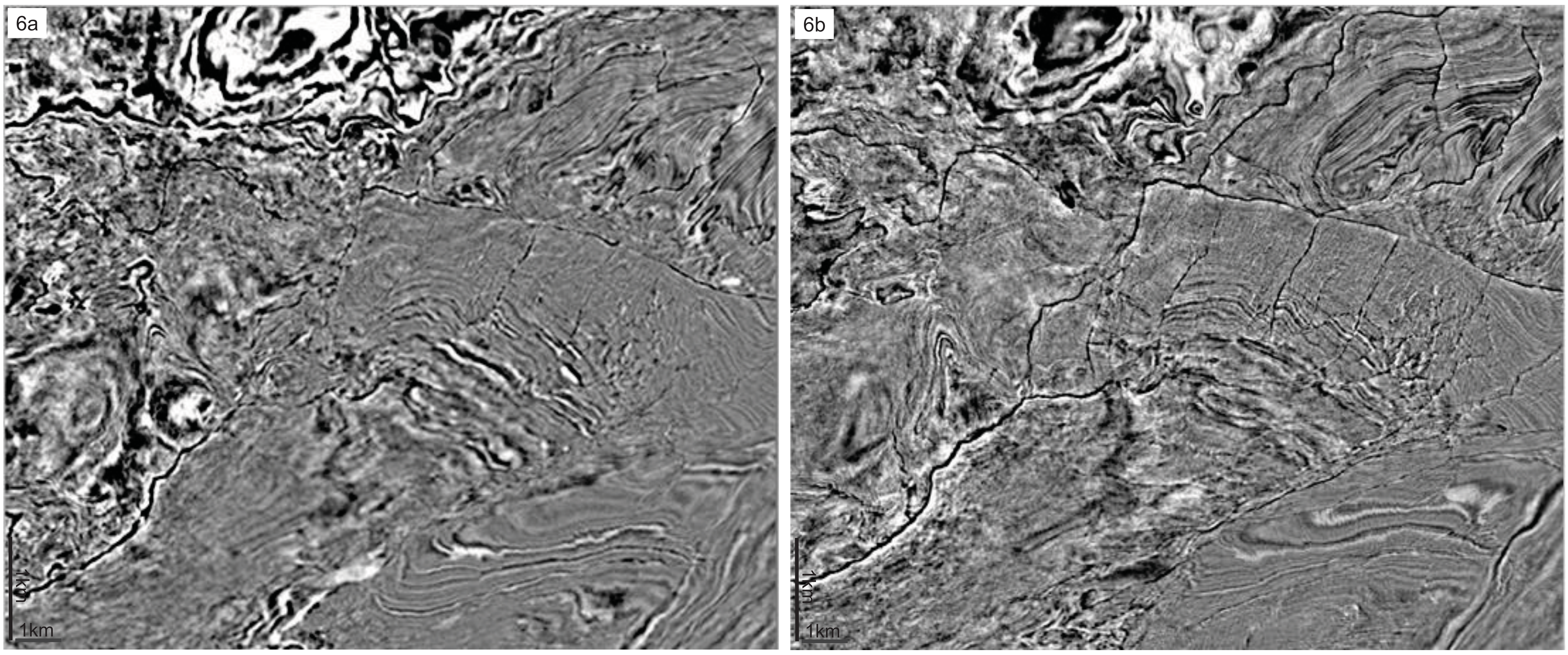

Figure 6: (a) Vintage preSDM depth slice shows less continuity, poor resolution, and limited structural information. (b) The recent processing shows fine detailed geological structure of the bounding faults and better seismic resolution.

Uncertainty Analysis

As depth uncertainty was a concern, the final stage of the project involved uncertainty analysis (workflow shown in figure 7) using Bayesian estimation based on eigenvector decomposition of the tomographic resolution matrices. 200 model realisations were derived and an interpretation of the main bounding fault was map migrated using these realisations. Error corridor overlays and maps were then generated to visualise uncertainty along the fault (figure 8).

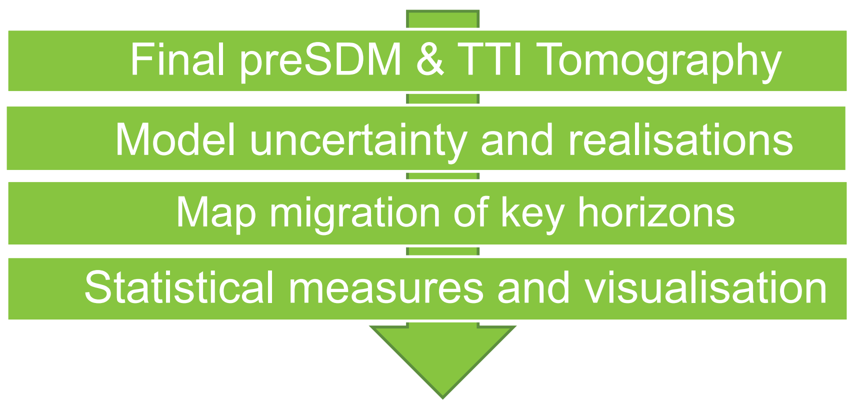

Figure 7: Uncertainty Analysis Workflow

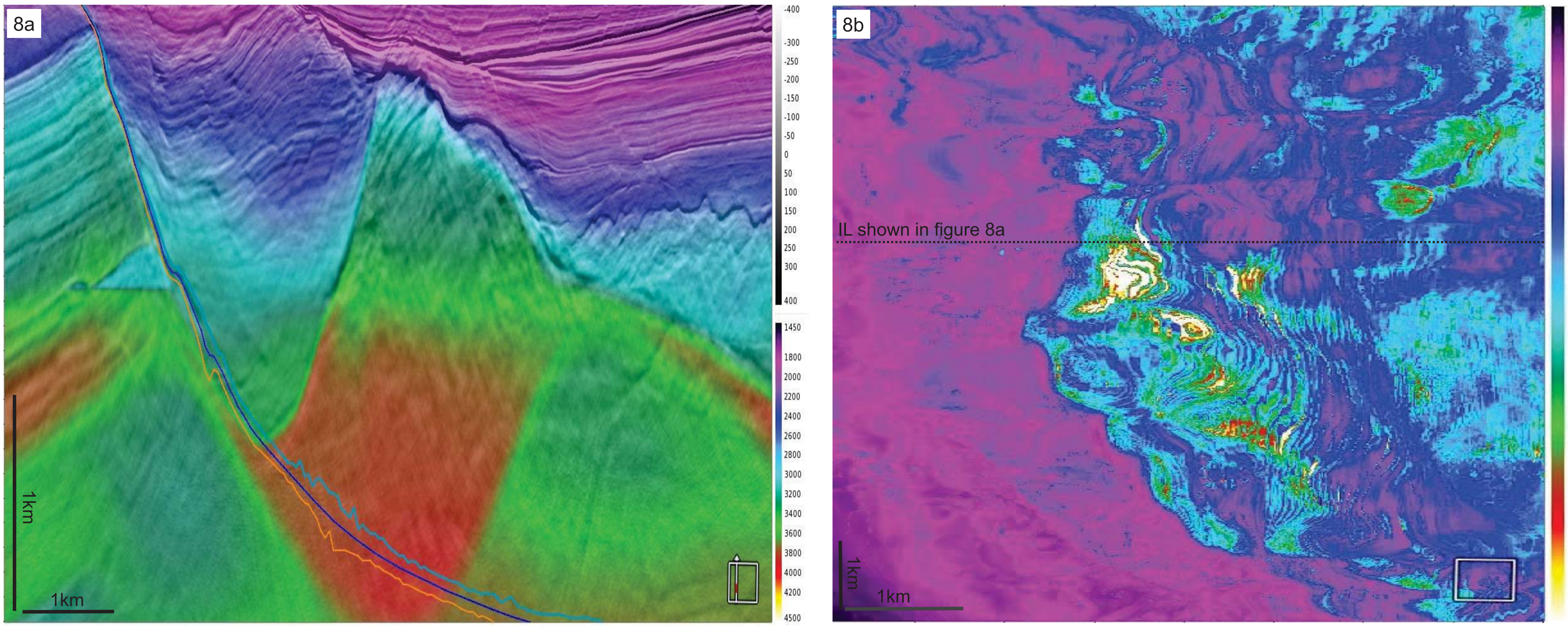

Figure 8: (a) Minimum (cyan) and maximum (orange) uncertainty can be overlaid on stacks to form an error corridor around the horizon (blue). (b) The difference between minimum and maximum uncertainty (i.e. error corridor thickness) can also be plotted as maps - in this case crossline error is shown

Conclusions and Data Examples

Improved, detailed pre-processing and imaging in conjunction with analysis of structural uncertainty in the final preSDM image, has helped to de-risk future development of the Ivory gas discovery.

The final preSDM has given the asset team a higher resolution and clearer seismic image, as well as proper depth calibration. The fault shadow effects have been reduced and no sag along the bounding fault can be observed in the Ivory discovery on the reprocessed data. Improved imaging of both small and large scale faults has been achieved through an increased understanding of the velocity field and broad-band processing. The Ivory well shows an excellent well to seismic tie and the container can now be mapped with higher confidence (Figure 9). The area outside the Ivory structure, also covered with reprocessed data, shows improved imaging at both shallow and deeper levels, potentially leading to interesting exploration opportunities in the future.

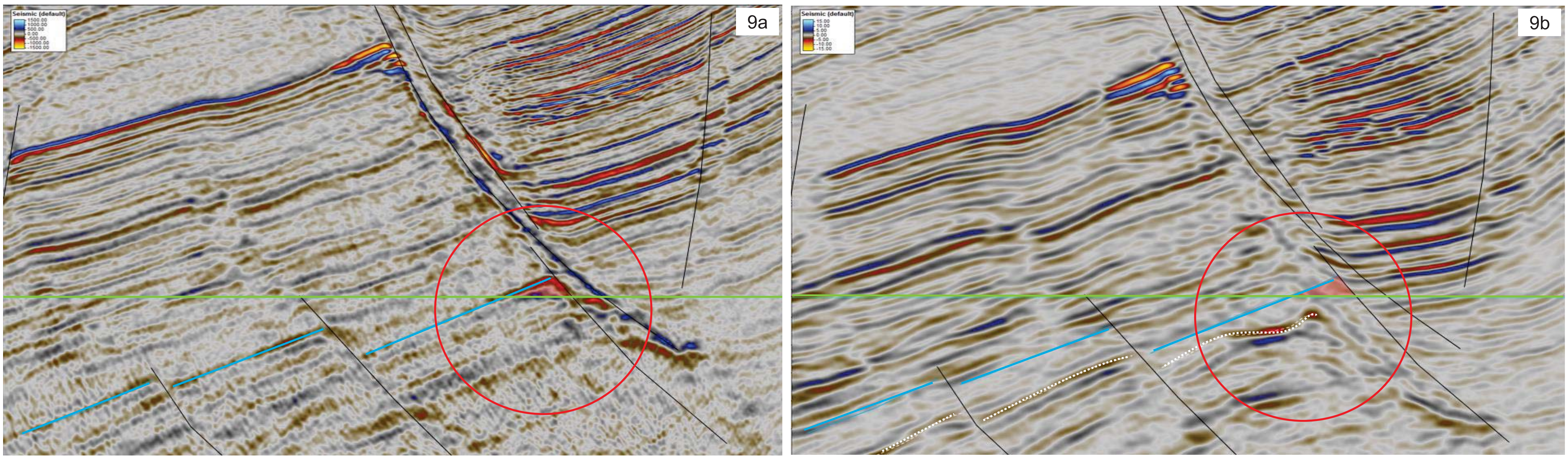

Figure 9: Comparison of (a) new preSDM to (b) vintage preSDM. Top reservoir in blue, vintage Top Reservoir in dotted white, proven GWC in bright green. The Ivory gas discovery is highlighted in red. Notice how the vintage data image top reservoir (and corresponding amplitude anomaly) below the drilled GWC, while the new preSDM lift the structure so the amplitude anomaly fits the proven GWC. This has direct impact on the volumes of the discovery. Also notice the superior imaging of the bounding fault zone in the new data.

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Acknowledgments

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